የኢትዮጵያ የአካባቢና የደን ምርምር ኢንስቲትዩት

Ethiopian Environment and Forest Research Institute

Current Information and Technologies on the Environment and Forest:

Proceedings of the 4th Annual Research Outputs Dissemination Workshop

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Addis Ababa, Ethiopia

Ethiopian Environment and Forest Research Institute (EEFRI)

Current Information and Technologies on the Environment and Forest:

Proceedings of the 4th Annual Research Outputs Dissemination Workshop

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PREFACE

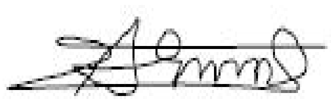
In order to bring about prosperity to the nation, the first thing a leadership should consider is restoring the overwhelmingly degrading natural resource and put the land in productive use. Ethiopia has launched green legacy initiative in this regard since 2019 through its Primier, to restore degraded landscapes and increase its tree cover inorder to improve ecosystem services and agricultural productivity from integrated tree/fruit crops. Billions of ornamental, fodder, fruit, fuel and timber tree species and shrubs have been planted in the last two years. Encouraging is the move as the leadership is taking serious steps to regreening the country. The EFDR Environment, Forest and Climate Change Commission has also taken significant steps in the current year for improving plantated seedlings success in the future plans through establishing model nurseries across the country/ in the regions that accomodate many of the modern nursery essentials. Massive production of bamboo seedlings from seed and tissue culture for restoring the Abbay gorge and reducing the sediment load to the GERD with the endigenous lowland bamboo species is also under way in close cooperation of the EFCCC, EEFRI, Salale and Debre Markos Universities as well as the Wore-Jarso and Dejen Districts. However, serious is the challenge also in the direction of preventing free access to planted sites, protecting young seedlings on communal lands and managing over / free grazing of livestock through providing tree and shrub fodder in a controlled grazing fashion or stall feeding.

In the current information and technologies (4th proceedings) of the Ethiopian Environment and Forest Research Institute, tree-crop integration (agroforestry) outputs, traditional agroforestry land use with soil carbon assessment, sequential agroforestry knowledge from improved fallow like planatation experiences of the *Acacia decurrens* based system at Fageta Lokoma of Awi zone with its contribution to food and nutritional security are presented . Environment pollution management with proper handling of plastic wastes, energy conversion means of the huge water hyacinth biomass. The *Acacia melanoxylon*, rare species in planatation but with good timber values study reports are also included. The energy efficiency test results from fuel saving cookstoves and emission levels from cement factories as well as projections of precipitation and temperature variations in the Omo-Gibe basin research outputs also worth reading.

In the forest products innovation research, the stuied on phenology and fruit yield of rare but very important wild edible tree/shrub species with nutritional and industrial application, the leaf biomass production potentials of the vegetable tree *Moringa stenopetala* at different density planting attract attention. From socio-economic aspects, many more are included to explore in the reading.

I thank presenters of the valuable information and technologies from their original research undertakings, the participants of the annual research review workshop, as well as the reviewers and editors of the present proceedings.

Agena Anjulo Tanga (PhD, Agroforestry)



Deputy Director General, Ethiopian Environment and Forest Research Institute

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The reviewers and editors of the present proceedings, the organizing committee of the annual research outputs dissemination workshop 2020 are well acknowledged for their contribution. EEFRI acknowledge the funding received from EFCCC for the success of the workshop. Paper and poster presenters are also highly acknowledged for presenting and submitting the revised version of their manuscript to editors. All process directors are also acknowledged for collecting manuscripts from authors, submitting to editors. The editors on the other hand sincerely thank all senior researchers for partly reviewing the manuscripts. A big thank goes to the finance, transport and purchase departments for their unreserved support for successful accomplishment of the workshop.

የእንኳን ደህና መጣችሁ ንግግር
በአብዮት ብርሃኑ (ዶ/ር)

ዋና ዳይሬክተር

ዓመታዊ የምርምር ፕሮጀክቶች ግምገማ
የኢትዮጵያ የአካባቢና የደን ምርምር ኢንስቲትዩት

ክቡር አቶ ከበደ ይማም

የአካባቢ፣ የደንና የአየር ንብረት ለውጥ ኮሚሽን ም/ኮሚሽነር

የተከበራችሁ የህዝብ ተወካዮች ምክር ቤት አባላት
ክቡራትና ክቡራን የሥራ ኃላፊዎች
የተከበራችሁ የአውደ ጥናቱ ተሳታፊዎች

ከሁሉ አስቀድሜ ወደ 6ኛው ብሄራዊ የምርምር ፕሮጄክቶች ግምገማ አውደ ጥናት እንኳን በደህና መጣችሁ እላለሁ!

የኢትዮጵያ የአካባቢና የደን ምርምር ኢንስቲትዩት በዋነኛነት የተቋቋመበት ዓላማ አካባቢ፣ ደንና አየር ንብረት ለውጥን የሚመለከቱ መረጃዎችንና ቴክኖሎጂዎችን ማስገባት፣ ማላመድ፣ አዲስ ማፍለቅ እና ለተጠቃሚዎች ማቅረብ ሲሆን፤ ይህንን ለማሳለጥ በ 7 የምርምር ዳይሬክቶሬቶችና በ 2 ማስተባበሪያዎች እንዲሁም በ 7 ማዕከላትና በአንድ ንዑስ ማዕከል በመደራጀት ከፍተኛ ጥረት እያደረገ ይገኛል።

እንደ ኢንስቲትዩት ከተቋቋመበት ከ2007 ዓ.ም ጀምሮ ተቋሙን በልዩ ልዩ ቁሳቁስና የሰው ኃይል ለማሟላት በተደረገው ጥረት መልካም የሚባሉ ውጤቶች ተመዝግበዋል። በአሁኑ ጊዜ በአካባቢ፣ በልውጠ ሕያዋን፣ በደን ጥበቃ፣ በዘርና በደን ውጤቶች ላይ የሚሠሩ ከ5 ያላነሱ ቤተ ሙከራዎች፣ ከ 25 ያላነሱ የዛፍ ዘር ምንጭ ቦታዎች እንዲሁም በርካታ የምርምር የመስክ ሙከራዎችን በመያዝ ምርምሩን ውጤታማ ለማድረግ እየሠራ ይገኛል።

በሰው ሀይል ረገድ ከ700 በላይ ሠራተኞች (ከ280 ያላነሱ ተመራማሪዎች) ያሉን ሲሆን፤ የተመራማሪዎችን እውቀትና ክህሎት ለማሳደግ 69 ያህል ተመራማሪዎች (ኤምኤስሲ 54፣ ፒኤችዲ 15) በረዥም ጊዜ ትምህርት ማለትም በ 2ኛና 3ኛ ዲግሪ በመማር ላይ ይገኛሉ።

ክቡራትና ክቡራን

ባለፉት 4 ዓመታት በመረጃና በቴክኖሎጂ አቅርቦት እንደተቋም የማይናቁ ውጤቶች የተመዘገቡ ቢሆንም፤ ካለብን ከፍተኛ ሀገራዊ ኃላፊነትና ከሥራው ሥፋት አንፃር አሁንም በርካታ ቀሪ ሥራዎች ያሉብን መሆኑን ለመግለጽ እወዳለሁ።

የአካባቢያችን መበከልና መራቆት፣ የአየር ንብረት ለውጥ እያስከተለ ያለው ጉዳት፤ እንዲሁም የብርቅዬ ብዝሀ ሕይወት መገኛ የሆኑ ደኖቻችን ላይ እየደረሰ ያለውን ጥፋት ለመግታት ከምንጊዜውም በላይ የመረጃና የቴክኖሎጂ አቅርቦት እጅግ አስፈላጊ ነው።

መንግስት ይህን በአግባቡ ይገነዘባል። ለተግባራዊነቱም ካለው ውስን ሀብት የአቅሙን ያህል መዋዕለ ነዋይ መድቦ እየሠራ ይገኛል። ነገር ግን ምርምሩ ከሚጠይቀው ዘመናዊ የላብራቶሬ ቁሳቁሶችና ከፍተኛ ገንዘብ አንፃር በቂ ነው ማለት አይደለም።

በምርምር ያልተደገፈ ልማት፣ በምርምር ያልተደገፈ ችግር አፈታት ዘለቄታዊ አይሆንም። በሀገራችን ያሉትን ሁሉንም ችግሮች በአንድ ጊዜ መፍታት እንደማይቻል የሚታመን ቢሆንም፤ ልዩ ትኩረት የሚሹትን በመለየት፤ ባለድርሻ አካላትንና የዘርፉ ባለሙያዎችን በማወያዬትና በመተማመን ወደ ሥራ መግባት ምርምሩ በአስተማማኝ መሠረት ላይ እንዲቆም ወሳኝ ሂደት ነው።

የዚህ አውደ ጥናት ዓላማም ከዚህ የተለየ አይደለም። ከዚህ በፊት ወደ ሙከራ የገቡና የተጠናቀቁ፣ በሂደት ላይ ያሉ እንዲሁም አዲስ የተቀረጹ ፕሮጀክቶች በሥፋትና በጥልቀት ይገመገማሉ። በዚህም ያገኘናቸውን ውጤቶችና ያጋጠሙንን ችግሮች፣ የፕሮጀክቶች አዋጭነትና ፋይዳ ላይ የጋራ መግባባት እንደሚፈጠር ሙሉ እምነት አለኝ።

ይህን አውደጥናት ለማዘጋጀት የደከሙትን ሁሉ፣ በአውደ ጥናቱ ለመካፈል ጊዜያችሁን ሰውታችሁ የተገኛችሁትን በሙሉ፣ እንዲሁም ይህን አውደ ጥናት በገንዘብና በቁሳቁስ የደገፉትን አካላት ከልብ እያመሰገንኩ፤ አውደ ጥናቱን በንግግር እንዲከፍቱልን የአካባቢ፣ የደንና የአየር ንብረት ለውጥ ኮሚሽን ምክትል ከሚሽነር ክቡር አቶ ከበደ ይማምን በአክብሮት ወደ መድረክ እጋብዛለሁ።

ከልብ አመሰግናለሁ!

የመክፈቻ ንግግር

የመክፈቻ ንግግር
በክቡር አቶ ከበደ ይማም
የአካባቢ፣ የደንና የአዬር ንብረት ለውጥ ኮሚሽን ም/ኮሚሽነር

የተከበራችሁ የህዝብ ተወካዮች ምክር ቤት አባላት

የተከበራችሁ የተቋማት ኃላፊዎች፤ የዩኒቨርሲቲ ምሁራንና ተመራማሪዎች፣ ተጋባዥ እንግዶች፤

ክቡራትና ክቡራን

በድጋሚ እንኳን በሠላም መጣችሁ!

ሀገራችን ኢትዮጵያ የብዙ ፀጋዎች ባለቤት መሆኗ ይታወቃል። ከነዚህ ፀጋዎች መካከል አንዱና ዋነኛው የብዝሀ ሕይወት ሀብቷ ነው። ኢትዮጵያ በብዝሀ ሕይወት ሀብት ስብጥር ከአፍሪካ ቀደምት ሀገራት መካከል አንዷ ናት። በውሃ ሀብትም የአፍሪካ የውሃ ማማ በመባል ትታወቃለች። በመልካ ምድሯና በአዬር ንብረቷ ከፍተኛ ተለያይነት የታደለች ሀገር ናት።

በሌላ በኩል ሀገራችን ከላይ የተጠቀሱትን በርካታ የተፈጥሮ ሀብቷን በማልማትና በመጠቀም ረገድ ችግሮች እንዳሉባት ይታወቃል። ምንም እንኳን ባለፉት ሁለት አሥርት ዓመታት ከፍተኛ የሆነ የኢኮኖሚ ዕድገት የተመዘገበ ቢሆንም በተለይ በዘላቂ የተፈጥሮ ሀብት ልማትና ጥበቃ ረገድ አሁንም ያልተፈቱ ችግሮች አሉ። ጥናቶች እንደሚያሳዩት ዛሬም በሀገራችን ከፍተኛ የደን ሀብት ውድመት እየተከሰተ መሆኑን ለመገንዘብ ችለናል።

የደን ሀብት ውድመት የሚያስከትላቸው ችግሮች በርካታ ናቸው። ከነዚህም በደን ውስጥ ያሉ ሰፊ ማህበረ ኢኮኖሚያዊና ሥነ ምህዳራዊ ጠቀሜታ ያላቸው ዕፅዋቶች ይመናመናሉ፣ አሊያም እስከወዲያኛው ይጠፋሉ። የደኖች መመናመን ከፍተኛ የሆነ የሥነ-ምህዳር መናጋት ሊያስከትል ይችላል፣ እያስከተለም ነው። አሁን አሁን በሀገራችን በተለያዩ አካባቢዎች የበረሃማነት መስፋፋት፣ የመሬት መንሸራተት፣ የውሃ አካላት መቀነስ እና ከእነዚህ ጋር ተያይዞ የሚከሰት የተፈጥሮ ሀብት እጥረት እና ግጭቶችን ማየትና መስማት እየተለመደ መጥቷል። በርካታ ሐይቆቻችን፣ ወንዞችና በተለይ የኃይል ማመንጫና የመስኖ ግድቦቻችን በከፍተኛ ደለል እየተሞሉ እንደሆነ ይተወቃል። የመሃከለኛው የስምጥ ሸለቆ አካባቢ በከፍተኛ ፍጥነት ደኑ በመጨፍጨፉና መሬቱም ወደ ሌላ የመሬት አጠቃቀም በመቀየሩ ብርቅዬ ሀይቆቻችንም ለከፍተኛ አደጋ ተጋልጠዋል። ብዙዎች በስፋትም በጥልቀትም እየቀነሱ ከመሆናቸውም ባሻገር በብዙ ዓይነት ኬሚካሎች

እየተበከሉ ነው። የመሬት ኩላሊት በመባል የሚታወቁት ውሃ አዘል (wet lands) አካባቢዎች በፍጥነት ወደ እርሻ፣ ሰፈራና ግጦሽ መሬት እየተቀየሩ ነው።

በሀገራችን ከምን ጊዜም በላይ ከተፈጥሮ ሀብት አጠቃቀም ጋር የተያያዙ ግጭቶች እና ሰብዓዊ ቀውሶች እየተከሰቱ ይገኛሉ። በተለይ በቆላማው የሀገራችን ክፍሎች አርብቶ አደሮቻችን በውሃና በግጦሽ እጥረት ምክንያት እየተቸገሩ እና ቀደም ሲል በስፋት የነበረው መቻቻልም ከጊዜ ወደ ጊዜ እየቀነሰ እየመጣ መሆኑን የሚያሳዩ በርካታ እውነታዎች እየተስተዋሉ ነው።

ከላይ ከተጠቀሱት ከተፈጥሮ ሀብት ዘላቂ ልማትና አጠቃቀም ጋር ከተያያዙት ተግዳሮቶች በተጨማሪ ሀገራችን ለከፋ የአየር ንብረት ለውጥ እና ተያያዥ ጉዳቶች እየተጋለጠች መሆኑ ይታወቃል። ድርቅ ከዛሬ 30 እና 40 ዓመታት በፊት በረጅም ጊዜ አንዴ የሚከሰት መሆኑ ብቻ ሳይሆን በተወሰኑ አካባቢዎች ብቻ የሚታይ ችግር ነበር። ከቅርብ ጊዜ ወዲህ ግን ምልልሱም ሆነ የሚሸፍነው አካባቢ እና የሚያደርሰው ጉዳት ከፍተኛ ሆኗል።

በተለይ ከደን ሃብት መመናመን ጋር ተያየዞ በሃገራችን በርካታ አካባቢዎች የአፈር መሸርሸር እና የምርትና ምርታማነት መቀነስ እየተከሰተ ከመሆኑም በላይ የቆላማ የአየር ንብረት ጠባይ መስፋፋትም ሃገራችን እየገጠሙ ካሉ ችግሮች ዋነኛው እየሆነ ይገኛል። የአየር መበከል እያስከተለ ያለው የጤና ጉዳት ከምናስበው በላይ እየገዘፈ ይገኛል።

ክቡራትና ክቡራን

እነዚህንና ሌሎች ችግሮችን በመቅረፍ ይልቁንም ሃገራችን ኢትዮጵያ ያላትን የተፈጥሮ ፀጋ በዘላቂነት እያለማች እንድትጠቀም ለማድረግ መንግስት በተለይ ለአየር ንብረት ለውጥ የማይበገር አረንጓዴ ኢኮኖሚ ስትራቴጂ ቀይሶ እና ከሁለተኛው የዕድገትና ትራንስፎርሜሽን ዕቅድ ጋር አቀናጅቶ በመተግበር ላይ ይገኛል። በተለይ የደን ሃብታችን ልማትና አጠቃቀም በነዚህ ሃገራዊ ሰነዶች ትኩረት ያገኘ ሲሆን ለምሳሌ ከአራቱ የአረንጓዴ ልማት ስትራቴጂ ምሰሶዎች (Pillars) አንዱ ነው። ሀገራችን በ2030 ከ22 ሚሊዮን ሄክታር በላይ ደን በማልማት የአየር ንብረት ለውጥ ተፅዕኖን ለመቋቋም ግብ ከማስቀመጥ ባሻገር፤ ዘርፉ ለአገር ኢኮኖሚ ግንባታ ላይ ሁነኛ አስተዋፅኦ እንደሚያበረክት ይጠበቃል። ከዚህ ጋር በተያያዘ በቅርቡ በአረንጓዴ አሻራ ቀንና በተለያዩ ጊዜያቶች በተከናወኑ ሥራዎች ከ4 ቢሊዮን ያላነሱ ችግኞችን በመትከልና የተራቆቱ አካባቢዎችን መልሰው እንዲያገግሙ ለማድረግ ከፍተኛ ውጤት ተመዝግቧል። የተተከሉትን ችግኞችን በባለቤትነት የመንከባከብ ሥራውም እየተከናወነ ይገኛል።

ከላይ የተጠቀሱትን መጠነ ሰፊ ሥራዎች ለማረጋገጥ የምርምር ሚና እጅግ ወሳኝ ነው። ዘላቂ የተፈጥሮ ሃብት ልማት እና አጠቃቀም የሚረጋገጠው በመረጃና ቴክኖሎጂ አቅርቦት እንደሆነ ይታወቃል። ይህን የቴክኖሎጂ፣ የዕውቀትና የመረጃ ፍሰትን ለማሳለጥ መንግስት የኢትዮጵያ የአካባቢ እና የደን ምርምር ኢንስቲትዩትን በማቋቋም፤ በአካባቢ በደን እና በአየር ንብረት ለውጥ ዙሪያ ምርምር በማካሄድ ዕውቀትን፣ ቴክኖሎጂና መረጃን በማውጣት ለተጠቃሚዎች በማድረስ ላይ ይገኛል። ይሁንና ሃገራችን እየገጠማት ካለው ውስብስብ ችግሮች አንፃር የቴክኖሎጂና መረጃ አቅርቦቱ ከዚህ በፈጠነ ሁኔታ መሠራት እንዳለበት እንረዳለን። በመሆኑም ለዘላቂ የደን የአካባቢ ልማት ጥበቃና አጠቃቀም እንዲሁም ለአየር ንብረት ለውጥ ያለንን ተጋላጭነት ለመቀነስ እና ዘላቂ እና ፈጣን ልማትን ለማረጋገጥ ከሚመለከታቸው ባለድርሻ አካላት ጋር ጥብቅ ቁርኝት በመፍጠር እንዲሰራ እያሳሰብኩ፤ ኮሚሽን መ/ቤቱም በአካባቢ በደን እና በአየር ንብረት ለውጥ ዙሪያ የሚደረግ ምርምር አቅም ለመገንባት የተቻለውን ሁሉ እንደሚያደርግ በዚሁ አጋጣሚ ለመግለጽ እወዳለሁ።

የተከበራችሁ የአውደ ጥናቱ ተሳታፊዎች

ምርምር ችግር ፈቺ ሊሆን የገባል። ለዚህ ደግሞ ቅንጅታዊ አሰራር ያስፈልጋል። ይህን ስናደርግ ዛሬ ሃገራችን ኢትዮጵያ ወደ ውጭ መላክ ሲኖርባት፤ በዓመት ከ200,000 ዶላር በላይ እያወጣች የምታስገባውን የደን ውጤት መተካት እንችላለን። በየአመቱ በቢሊዮን ቶን የሚለካ አፈር ከተፋሰሶች እየታጠበ ወደ ወንዞች፣ ሃይቆችና ግድቦቻችን እንዳይገባ ማድረግ እንችላለን። ይህን ስናደርግ ነው የአካባቢ እና የደን ዘርፍ በሀገር ኢኮኖሚ ግንባታ ውስጥ ቁልፍ ሚና መጫወት የሚችለው።

በተለይ ገና ብዙ መስራት በሚጠበቅብን የአካባቢና የአየር ንብረት ለውጥ ዙሪያ ምርምሩን ማጠናከር እና አቅም መገንባት ዋና ስራችን ሊሆን የገባል። በዚሁ አጋጣሚ ኮሚሽን መስሪያ ቤታችን ምርምሩን በቅርበት የምንደግፍና በምርምር የተገኙ ውጤቶችን ወደ መሬት ለማውረድ ርብርብ የምናደርግ መሆኑን እያሳወቅሁ፤ የዘንድሮው አመታዊ የምርምር ግምገማ የተሳካ እንዲሆን እየተመኘሁ አውደ ጥናቱ በይፋ የተከፈተ መሆኑን አበስራለሁ።

አመሰግናለሁ።

Section 1: Plantation and Agroforestry Research

The role of *Acacia seyal* on selected soil properties and sorghum growth and yield:a case study of Guba-Lafto District, North Wollo, Ethiopia

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Abstract

Acacia seyal is one of the multipurpose parkland agroforestry tree species in most eastern and southern Africa. It is a common on-farm tree in the rift valley of Ethiopia, but the information is limited on its effect on soil property and sorghum growth and yield. The study was conducted to evaluate its effect on selected soil properties, sorghum growth, and yield at the Guba-Lafto district of northern Ethiopia. Six isolated and closely comparable *Acacia seyal* trees growing on sorghum farms were purposely selected and plots were marked under the canopy of trees with three radial distance (0-2m, 2-4m, and 4-6m) and one outside of the tree canopy (10 meters away from each tree). Soil samples from each distance zone were taken from 0-20 cm and 20-40 cm soil depths for soil property analysis. Four quadrates with 1m*1m at each distance zone in four directions were laid for sorghum growth and yield attribute valuation. Results showed only total nitrogen (TN) was significantly higher ($P<0.05$) at the subsoil layer under the canopy compared to an open area but other selected soil parameters were found not affected by the tree species. Sorghum biomass yield ($p=0.006$) and grain yield ($p=0.025$) were significantly affected due to the shading effect of the tree than in the open area. Generally, *Acacia seyal* had little effect in improving soil properties and showed a negative effect on sorghum yield and growth. Further research on its effect under wide area coverage of parkland system should perform to bring radical shift on the intercropping farming system.

Keywords: *Acacia seyal*, Soil property, parkland, on-farm tree, Yield

Introduction

The human population growth rate in sub-Saharan Africa is increasing rapidly despite the lower rate of food production which needs alternative solutions for parallel growth in food production (Mwangi, 1996). On the other hand, climate change is a major constraint for agricultural production creating a food crisis, particularly for smallholder farmers. It needs climate mitigation action and climate-resilient agricultural strategy (Syed and Jabeen, 2018). High chemical fertilizer input and soil fertility loss are also becoming another causal factor for the decline of agricultural productivity and wide environmental problems (Mwangi, 1996; EEA, 2005; Biala *et al*., 2007). Inorganic or artificial fertilizer applications are also risky for the environment and found to be inhibiting the naturally important nodulation and nitrogen fixation and symbiotic associations which again affect nutrient recycling (NZDL, 1991; Pender and Ehui, 2006).

Agricultural productivity reduction and food crisis challenges call for creating a multifunctional agricultural system that fulfills both intensified crop productivity improvement and a socio-economically valuable farming system (Waldron *et al*., 2017; Garibaldi *et al*, 2017). Improving the current farming system as climate-smart agriculture and sustainable productivity is important for sustainable development and food security via increasing agricultural productivity and enhancing the resilience of livelihoods and ecosystems to climate change (Schaller *et al*., 2017; Lipper, 2014).

Among the different existing options, agroforestry is one of the environmentally friendly approaches that help farmland soils be improved and checked in smallholder farmers (Schaller *et al*., 2017; Fahmi *et al*., 2018). It has many provisional, regulating, and cultural services and considered as a climate-resilient and adaptation mechanism (Udawatta*et al*., 2017; Belay *et al*., 2017; Altieri and Nicholls, 2017; Vermeulen *et al*., 2012). Maintenance and improving existing practices and incorporation of multipurpose trees (MPTs) on farms are recognized as critical interventions to increase agricultural productivity sustainably (Schaller *et al*., 2017; Fahmi *et al*., 2018). Trees are advantageous in protecting environmental degradation and reducing external input costs; generally considered as means for organic farming which assures agricultural sustainability (Jouzi*et al*., 2017). Moreover, nitrogen-fixing legume trees get attention for nitrogen fertilizer enhancement thereby enhance crop productivity and create an opportunity for sustainability (Amanuel*et al*., 2000; Biala *et al*., 2007; Pender and Ehui, 2006).

Acacia seyal is one of the drought-tolerant agroforestry tree species found in most Eastern and Southern Africa and native trees to the Sahelian zone of Africa (Orwa*et al*., 2009; Lal and Stewart, 2014). It has a typical drought avoidance strategy and adaptable to water stress conditions (Merine*et al*., 2015). Unlike other most legume tree species it nodules with both fast-growing (Rhizobium) and slow-growing (Brady rhizobium) bacteria strains which strengthen its role in nitrogen fixation and soil improvement ability (Dreyfus and Dommergues, 1981). Limited research investigations were carried out so far on the *Acacia seyal* effect and its social contribution in various countries at different levels (Abdalla and Fangama, 2015; Woldu*et al*., 1999; Mariod*et al*, 2014). In the study area, different woodlands of Acacia spp. are found in undulating hills and farmlands. The farming communities manage the natural regeneration of *Acacia seyal* in their farmlands. The species seems well adapted to the farming system. However, its contribution to soil fertility and sorghum productivity is the least studied.

Therefore, this study was designed to investigate the effect of *Acacia seyal* on selected soil properties and sorghum growth and yield attributes in farmlands during the main rainy season in the Guba-Lafto district, North Wollo Zone.

Materials and methods

Study area Description

The study area is located in Guba-Lafto woreda (district), North Wollo Zone of Amhara National Regional State, Ethiopia, between $39^0$6'9" to $39^0$45'58" East and $11^0$34'54" to $11^0$58'59" North. The altitude ranges between 1379 to 3200 m.a.s.l. The capital of the woreda is situated 521 km North of Addis Ababa. The soil texture of the area is dominated by sandy clay (46%), clay-loam (39%), and small percentages of sandy soil (8%) and silt soil (7%) (Mengistie and Kidane, 2016). Lithic Leptosols (92.2%) are the dominant soil type in the district followed by EutricCambisols (3.9%) and EutricLeptosols (3.5%) (FAO, 1997). The district is majorly (46%) described with Woina-Dega (temperate highlands) agro-ecological condition The area is semi-arid and characterized by poor rainfall conditions and it has bimodal rainy seasons. Mean annual and monthly rainfall and a temperature range from 800 - 1050 mm and 21 °C to 25 °C respectively (Mengistie and Kidane, 2016). Subsistence agriculture is the main livelihood system of the rural population with commonly mixed, crop and livestock farming systems. Agricultural land is limited (about 36 % of total land) and landholding size per household ranges from 0.4 to 1.93 ha (Lemma, 2010). Among various cereals and pulses, sorghum (*Sorghum bicolor* and *Eragrostistef* were commonly cultivated crops, especially during the summer rainy season.

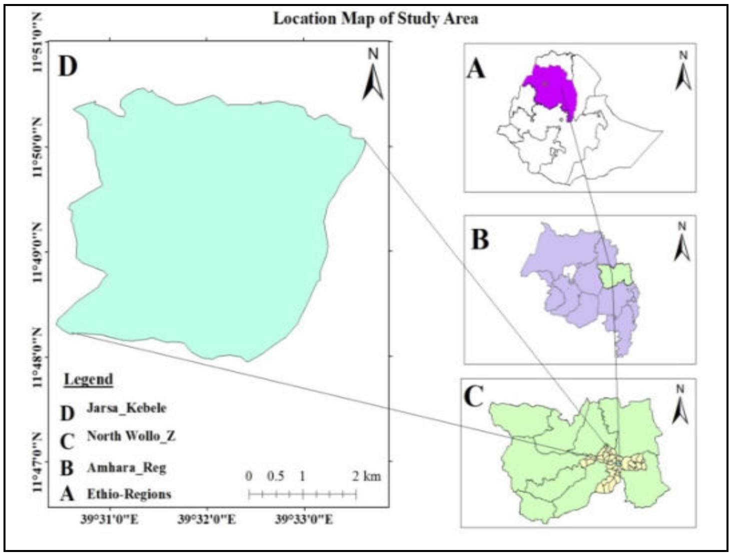

Figure 1: Map showing the location of the study site (Jarsa Kebele) in North Wollo Zone, Amhara region, Ethiopia

Experimental design and treatment

Sorghum (var. *Jamyo*) farmlands with similar crop history and management were systematically selected from farm communities at the household level. Then, six *Acacia seyal* trees were selected randomly from systematically selected trees along with sorghum farms. Tree height, diameter at breast height (DBH), and canopy diameter were measured. Diameter at breast height was measured over bark using caliper; the crown width and length were measured using meter tape, and the height measurement was taken using Suunto clinometers.

Soil sampling and sorghum growth and yield measurements were taken under three concentric radial distances (subplots) of the selected *Acacia seyal* trees.The samples were taken from an open area-near the base (0-2m), under the canopy (2-4m), the edge of the canopy (4-6m), and a control plot 10 m away from the tree base in four directions (Figure 2).

Soil sampling and analysis

The soil sample was taken from each of the three radial distance of the tree (D1, D2, and D3) and the open area (D4) (Figure 2), using a stainless auger (Wilding, 1985) in four directions with two soil depths of 0 – 20cm and 20 - 40 cm (Hartz, 2007; Estefan *et al*., 2013). The samples were collected at the end of the long rainy cropping season. A total of 48 composite soil samples (6 plots x 2 depths x 4 concentric distance zone) were sampled and analyzed at the Sirinka AgriculturalResearch Center soil laboratory. Soil pH was determined by using a pH meter in a 1:2.5 soil: water (i.e. one part soil sample with two and half part of distilled water ratio) suspension. Soil electrical conductivity (EC) was measured using a conductivity meter in saturated paste extract. Total nitrogen (TN) was determined by the Kjeldahl acid digestion method (Jackson, 1958); available phosphorus was determined through absorbance on spectrophotometer following Olsen (1954); Cation exchange capacity (CEC)was determined after extraction of soils with ammonium acetate method at pH 7 following Chapman (1965); soil organic carbon was determined by oxidation method (Walkley and Black, 1934); soil bulk density (BD) estimated by oven-dry method (Brady and Weil, 2002); moisture content (MC) by Gravimetric method (Blake and Hartge, 1986); texture determined by Bouyoucos methods using hydrometer (Bouyoucos, 1962).

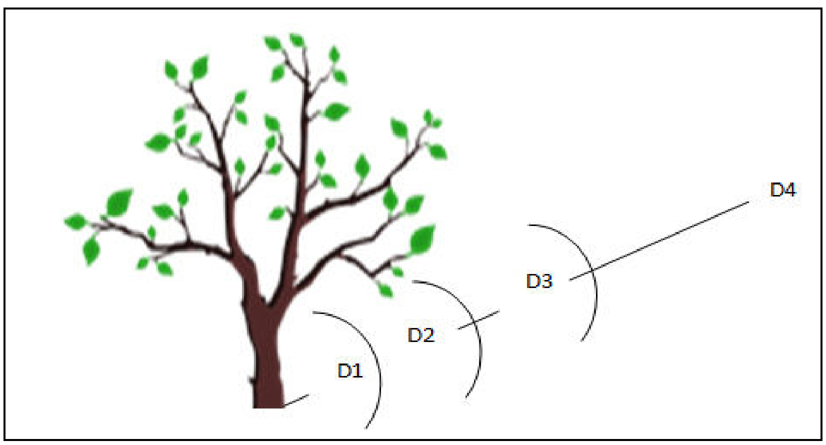

Figure 2: On-farm sample plot design; where D represents the radial distance from tree and sampling repeats in four directions

Growth and yield parameters of sorghum were collected from each subplot of 1 m x 1 m. Sorghum plant stock height and panicle length were recorded using meter tape from 10 randomly selected sorghum plants of the net quadrant at harvest time. Total numbers of sorghum plants counted on each sub-plot were taken and used their average value. Above-ground biomass of sampled sorghum was sun-dried to constant weight and biomass yield was estimated on a kg ha^{-1} basis. The standing sorghum plants' panicles were collected and manually threshed; the grains were cleaned and weighted at 12.5% moisture level and the yield was estimated per hectare basis. One thousand kernels weight in gram (gm) were manually counted and weighted. The sorghum yield (kg/ha) was estimated as a total sum of biomass and grain yield. Harvest index of sorghum was determined as a fraction of grain yield in the unit of measurement to total yield and expressed in percentage (Harvest index (%) = Grain yield / Biological yield (grain + straw) x 100) (Yoshida, 1981).

Statistical analysis

Assumption of normality and homogeneity of variance were first checked via the Shapiro-Wilk test and Levene test, respectively (Zar, 2009) for meaningful interpretation. LSD test was used for mean separation. Characteristics of trees, soil physicochemical properties, and sorghum growth and yield parameters were described by using mean and standard deviation. The effect of the tree on soil properties and sorghum growth and yield were tested by using a one-way analysis of variance. two two-way analysis of variance was employed to check the interaction between radial distance and soil depth treatments by using Wilks' Lambda test (Pallant, 2007). Soil parameters mean value variation along soil depth was also tested by Independent T-test along with each radial distance of tree. SPSS Version- 20 software was used for analysis.

Results and Discussion

Effects of *Acacia seyal* on soil properties

Soil physical properties

Soil particle fractions did not significantly vary ($p>0.05$) with distance from the tree (Table 1). This might be due to less impact of management practices on the soil properties (Gupta, 2006; Miller and Donahue, 1995; White, 1997). Similar findings were reported for the case of different parkland tree species such as *Acacia seyal*, *Ziziphus spina-christi,* and *Acacia senegal* (Tanga *et al*., 2014; Woller*t al*., 2017; Githae*et al*., 2011).

Table 1: Mean values (±SD) of selected soil physical parameters under soils in different distances from trees and two soil depths in *Acacia seyal* parkland system at Guba-lafto woreda

Soil properties	Soil depth	Distance from tree				P-value
		near tree bole	under canopy	edge of canopy	outside canopy	
Clay (%)	1	55.25[a] ±1.73	56.25[a]±4.47	56.17[a]±3.25	55.0[a]±7.86	0.958
	2	56.67[a]±5.79	56.83[a]±6.13	58.58[a]±3.56	55.42[a]±9.44	0.871
Silt (%)	1	22.83[a]±3.02	23.58[a]±1.36	21.42[a]±2.13	23.75[a]±3.45	0.418
	2	23.17[a]±4.86	24.75[a]±2.21	20.83[a]±2.62	23.75[a]±3.45	0.272
Sand (%)	1	21.92[a]±2.94	20.83[a]±3.47	22.42[a]±4.23	21.25[a]±5.9	0.921
	2	20.17[a]±4.6	18.42[a]±5.65	20.08[a]±3.92	20.83[a]±7.3	0.891
MC (%)	1	34.64[a]±1.16	35.06[a]±1.06	35.72[a]±2.02	34.77[a]±1.83	0.649
	2	35.09[a]±1.44	34.90[a]±0.32	35.18[a]±1.04	34.86[a]±0.89	0.937
BD (gm/cm^3)	1	1.06[a]±0.04	1.06[a]±0.03	1.03[a]±0.08	1.07[a]±0.08	0.63
	2	1.05[a]±0.06	1.04[a]±0.03	1.05[a]±0.04	1.06[a]±0.04	0.94

Rows with the same superscript letters are not significantly different at $p < 0.05$; soil depth with 1and 2 represents 0-20 cm and 20-40 cm respectively.

Moisture content was not significantly affected by the species along both soil depths ($p>0.05$) at harvesting season (Table 1). However, the lowest (34.64%) and highest (35.72%) moisture contents were recorded near the tree bole (D1) and the edge of the canopy (D3) respectively for the topsoil layer (Table 1). Normally, tree species are expected to maintain soil moisture, through reducing rain speed and increasing infiltration rate (Kessler and Breman, 1991). However, such was not the case with *Acacia seyal*, and this might be due to the competition effect of roots of the species (Seghieri, 1995). Similar results were found by Kassa*et al*., (2010), Akpo*et al*., (2005), and Woller*t al*., (2017) for *Balanites aegyptiaca*, *Acacia tortilis,* and *Ziziphusspina-christi,* respectively, on crop farm. Bulk density (BD) was statistically in par across distances from tree and soil depths (Table 1). It might be due to low organic carbon availability under the canopy of a tree which directly influences soil aggregate stability which again affects the bulk density of soil.

Soil chemical properties

Soil pH and electrical conductivity (EC) were not significantly influenced by the presence of *Acacia seyal* under both soil layers (Table 2). But, Electrical conductivity (EC) was a bit higher, ranged from 0.053 to 0.077 ds/m at the subsoil layer than surface soil EC which ranges from 0.048 to 0.063 ds/m (Table 2) which means, surface soil looks less saline than the subsurface. Even though the difference in EC was not significant, the EC was also relatively higher around tree bole than an open area. This might be due to microbial association and low leaching problems of base-forming cations around a tree (Manga *et al*., 2017). The result agreed with Kassa*et al*. (2010) and Wolle *et al*. (2017) who reported the non-significant effect of *Balanitesaegyptiaca* and *Zyziphus spina-Christi* over EC, at the arid area of Humera and Hibru district of Ethiopia, respectively.

Table 2: Mean values (±SD) of selected soil chemical parameters under soils in different distances from trees and two soil depths in Acacia seyal parkland system in Guba-lafto woreda.

Soil properties	Soil depth	Distance from tree				P-value
		near tree bole	under canopy	edge of canopy	control	
pH	1	6.3[a] ±0.21	6.27[a] ±0.16	6.25[a] ±0.19	6.25[a] ±0.29	0.99
	2	6.25[a] ±0.19	6.25[a] ±0.21	6.22[a] ±0.25	6.27[a] ±0.24	0.98
EC (ds/m)	1	0.063[a] ±0.018	0.053[a]±0.013	0.048[a]±0.011	0.051[a]±0.013	0.19
	2	0.077[a] ±0.02	0.053[a] ±0.02	0.054[a] ±0.01	0.069[a] ±0.02	0.13
P (ppm)	1	23.81[a] ±2.92	24.52[a]±3.40	24.16[a]±2.56	24.73[a]±4.28	0.66
	2	26.18[a] ±4.72	23.71[a]±3.26	24.84[a]±4.39	25.91[a] ±4.9	0.75
OC (%)	1	0.66[a] ±0.23	0.59[a] ±0.15	0.66[a] ±0.15	0.63[a] ±0.17	0.91
	2	0.59[a] ±0.19	0.65[a] ±0.12	0.5[a] ±0.199	0.66[a] ±0.21	0.4
TN (%)	1	0.15[a] ±0.04	0.13[a] ±0.02	0.11[a] ±0.06	0.10[a] ±0.05	0.26
	2	0.18[a] ±0.09	13[ab] ±0.04	0.14[ab] ±0.029	0.09[b] ±0.032	0.03*
CEC (meq/100 gsoil)	1	39.0[a] ±14.78	49.0[a] ±4.17	42.2[a]±10.22	45.27[a]±3.98	0.33
	2	37.0[a] ±15.9	47.3[a] ±6.92	43.03[a]±4.74	48.27[a]±3.88	0.17

Rows with the same superscript letters are not significantly different at $p < 0.05$; soil depth with 1and 2 represents 0-20 cm and 20-40 cm respectively

Soil organic carbon (SOC) was expected to be significantly higher under the tree canopy, but not for this case, and this might be due to the lower contribution of litter decomposition for soil carbon (Bernhard-Reversat, 2002). This is in line with the finding for an integrated system of *Acacia seyal* with sorghum cropping system in Sudan (Deng *et al*. 2017).

TN was significantly affected by the presence of *Acacia seyal* tree species (p = 0.035) under the sub-soil layer (20-40 cm) with $p \leq 0.05$ (Table 2). *Acacia seyal* showed a positive significant effect (p=0.035) on the available nitrogen of the sub-surface soil (Table 2), and a decreasing trend was observed from the tree base to the open area. The pattern was expected since most legume tree species including *Acacia seyal* have a positive effect on soil total N because of atmospheric nitrogen fixation(Wolde-Meskel*et al*., 2004; Sinare and Gordon, 2015). It may also be associated with under tree organic carbon availability via litter fall and fine root turnover from trees and droppings of animals resting under the tree (Tilahun, 2007). Likewise, higher, (42% more), nitrogen availability under the canopy of *Acacia seyal* compared to the open area was reported in the rift valley of Ethiopia (Tanga *et al*., 2014). Others also revealed similar findings on different agroforestry tree species (Boffa *et al*., 2000; Birhane*et al*., 2016). Available phosphorus was not affected by the species and this might be due to the lower litter accumulation potential of the species which is related to organic phosphorus availability.

Numerically, CEC had a lower mean value around the root zone for both soil depths compared to the open area (Table 2) but was not statistically different. In agreement with this, Deng *et al*. (2017) reported lower but statistically similar CEC values under *Acacia seyal* on the sorghum intercropping system. Different parkland species like *Balanitesaegyptiaca* and *Zyziphusspina-christi* were reported as having a similar effect but other species like *Acacia tortilis* and *Faidherbiaalbida* showed a positive significant effect on CEC (Kassa *et al*., 2010; Wolle *et al*., 2017; Tanga*et al*., 2014). This might be due to the significant effect of those species on SOC that are directly related to CEC (Tilahun, 2007).

Figure 3: Partial view of soil sampling activities under the tree canopy

Effect of *Acacia seyal* on Sorghum growth and yield

Even though local farmers extensively manage *Acacia seyal* on their farms, sorghum above-ground biomass (AGB) (p=0.006) and grain yield (p=0.025) were found affected by the presence of the species ($p<0.05$) (Figure 4). AGB was lower at near tree base (2368.33 kg/ha) compared to an open area (6558.33 kg/ha) with more than two fold (277%). Grain yield was also observed to be higher (142% more) at open area compared to near tree base (Figure 4). The result was unexpected since the symbiotic and nitrogen-fixing ability of *Acacia seyal* is believed to boost yield by enhancing soil fertility (Dreyfus and Dommergues, 1981). However, local farmers grow it for other benefits like fuel wood production and cash generation.

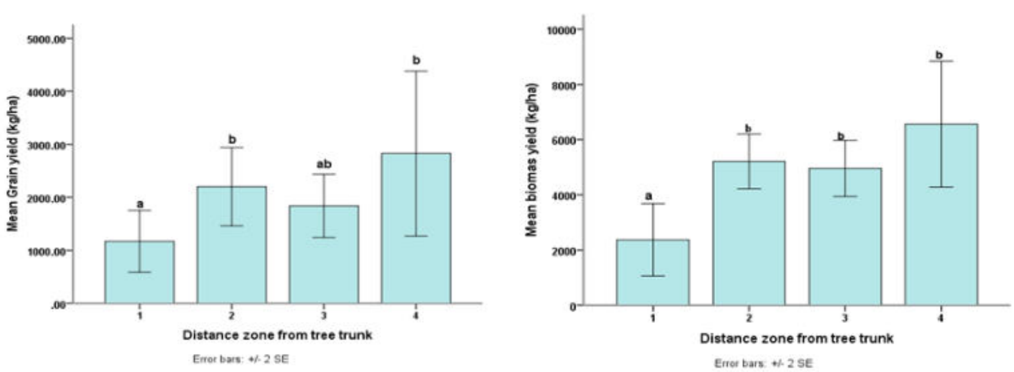

Figure 4: Effect of Acacia seyal on sorghum grain and biomass yield (kg/ha).

Yield reduction might be due to the shading effect of *Acacia seyal* and its allelopathic effect on sorghum survival and growth performance (Hassan *et al*., 2018, Seghieri, 1995). Though pollarding management is practiced in the area, the lower branch tree pruning management activity is more favored by the community and commonly performed at early cropping season. Although pollarding and pruning are conducted by the community, the tree species develops a new canopy in a short period and a shading effect might happen as a result.However, in this study the candidate *Acacia seyal* trees which were not pollarded and with similar growth feature were systematically selected. . Superficial small diameter roots at surface layer and underground root competition of the species also contributes for yield reduction effect (Van Noordwijk *et al*., 2015). Moreover, the shade intolerance character of the sorghum crop (Wilson *et al*., 1998) affected its performance under the canopy (Hassan *et al*., 2018). The result was in line with Deng *et al*. (2017), who reported a negative effect of *Acacia seyal* intercropping on sorghum yield and growth performance in South Sudan (p=0.001). However, other species like *Faidherbia albida* contributed a positive effect on sorghum yield in the case of the "Tahhtay Maichew" district of northern Ethiopia (Birhane*et al*., 2016).

Conclusions and recommendations

The widely grown *Acacia seyal* in the study area had little effect on the selected soil physicochemical properties for both surface and sub-surface soil layers. The positive effect was observed only on the sub surface of the total nitrogen availability. The species had a negative effect on the biomass production and grain yield of sorghum. The negative effect possibly was due to the combined effect of the above-ground canopy and root competition of the species. We recommend further research to the wider area coverage or with a controlled environment to bring radical shift on the species intercropping system. Moreover, research on the determination of optimum tree density and appropriate management for the species is essential.

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Acacia decurrens for food security and land reclamation in Fagita Lekoma woreda, Northwestern Ethiopia

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Abstract

A study on *Acacia decurrens* contribution to food security and land reclamation was conducted in Fagita Lekoma district, Awi Zone, Amahra National Regional State, Ethiopia. Three kebeles in Fagita Lekoma woreda were selected to characterize *Acacia decurrens* plantation practices. Field observation, focused group discussion, and questionnaires were used to collect data. A total of 150 respondents were selected. The study revealed that *A. decurrens* improves the livelihood of the local community such as increased income, better schooling, and housing, reclaims degraded land, improves soil fertility, boosts crop production, and creates job opportunity. Majority of the community allocated > 80% of their land for plating *A. decurrens*. On average the land allocated for *A. decurrens* plantation was 0.74ha per HH. The annual income from the practice is about 30,000 ETB per household. The size of land allocated for *A. decurrens* plantation was significantly affected by the educational status of tree growers. There was a significant difference in charcoal yield among the study Kebeles but not affected by household characteristics. Problems challenging the practice are poor quality of seedlings, planting seedlings with their plastic bags, dense planting, traditional charcoal production, too many brokers along the value chain, lack of diversified use, and disease and pest occurrence. It is important to improve the practice to reap the full potential of the practice. It is also important to scale up the practice to other potential areas of the country.

Keywords: Farmer innovation, income, plantation, profitability, sustainability

Introduction

Deforestation is one of the major environmental challenges in Ethiopia (Bishaw, 2009) escalating (Asfaw and Etefa, 2017) at an estimated rate of 150,000 to 200,000 ha $year^{-1}$ (Zewdie et al., 2010) driven by extensive agricultural production systems, high population pressure, high dependency on biomass energy and free grazing (Gebru, 2016; Nyssen et al., 2004; Wassie et al., 2010). In some areas, the current land-use configuration especially in the north and northwestern Ethiopia has led to a dramatic and detrimental decline in the availability of forest goods and services (Alemu et al., 2017).- In the country, the rural community generates income from the sale of different wood and non-wood products such as timber, charcoal, fuelwood, and other NTFPs informally from the natural forest or plantation forests which in turn aggravated forest degradation (Bekele, 2011).

Following the decline of natural forests (Bishaw, 2009), Ethiopia has embarked on plantation forests development to respond to the huge demand of the society for wood and wood products (Bekele, 2011). This is not unique to Ethiopia but it is common for many developing tropical countries since rural communities in many parts of the tropics depend on forests for their livelihoods and environmental services (Le et al., 2012). In Ethiopia, private, community woodlots and some commercial plantations started in the 1970s and fast-growing non-native tree species have been introduced and planted at a wider scale (Bekele, 2011). The plantation activity in Ethiopia has been carried out under different programs such as food for work, community participation, and individual tree plantation since then. The more recent estimate indicated that the coverage of plantation forest in the country reached to about 1 million ha in 2010 (Tesfaye et al., 2020).

However, the practice of plantation is hindered by many factors such as lack of proper species-site matching, improper planting, poor management after planting, low focus on indigenous tree species, and lack of technical knowledge on plantation establishment and management (Bekele, 2011a; Tadesse et al., 2019).

The most common indicators used for measuring the socio-economic success of reforestation are local income, local employment opportunities, other livelihood opportunities, provision of food and fiber, stability of market prices of locally produced commodities, and local empowerment and capacity building (Le et al., 2012).

In the Amhara region, smallholder tree planting activities have become an important emerging livelihood option(Abiyu et al., 2016). There are some documented farmers' traditional tree plantation and management activities in the region, among which, plantation establishment and management of Eucalyptus, *Acacia deccurens* and bamboo are prominent (Abebe et al., 2020). The best practice with the establishment and management of *A. decurrens* plantation is found in Fagita Lekoma, Awi Zone of the Amhara region.

Acacia decurrens was introduced into the central highlands of Ethiopia in the early 1990s for short-rotation forestry to counter urban firewood shortages arising from deforestation. Around the same time, *A. decurrens* was introduced into state-owned plantations of the northwestern highlands (Kassie et al., 2016).

Planting and management of *A. decurrens* plantation in the district of Fagita Lekoma was started in 1996 and the species currently is planted at a wider scale in all the 27 kebeles of the woreda. In total, about 41,914 ha of *A. decurrens* plantation is planted in the district. The plantation is expanding at an alarming rate at the expense of crop land and other land use types (Berihun et al., 2019). The land cover change from 1995 to 2015 showed a yearly increment of forest cover by 1.2% and loss of cropland by 1% majorly because of *A. decurrens* plantation (Wondie and Mekuria, 2018).

The market value of the charcoal of *A.decurrens* attracted more people to be involved and resulted in the high expansion of the species. Short-term economic benefits, adaptability, and fast growing nature of the tree species are the main driving factors for its expansion (Wondie and Mekuria, 2018).

In the beginning, the government was providing technical and material support. Nurseries were run by the government and seedlings were distributed to farmers free of charge. Under some circumstances, training was also provided. Some persons who have been involved in large scale plantation of the species were given incentives. As the practice became adopted by the local community, the government withdrew from this practice. Now, the plantation is expanding and fully established and managed by the farmers without any external support. Neighboring Kebeles and districts having similar agro-climatic zone with Awi zone for example Sekela district of West Gojjam administrative zone started to expand the species.

Various studies were conducted on *A. decurrens* plantations such as the hydrological response of *A. decurrens* plantation (Berihun et al., 2019), the effect of the practice on soil organic carbon and nitrogen (Abebe et al., 2020), cover change due to *A. decurrens* plantation (Belayneh et al., 2018; Wondie and Mekuria, 2018), and economic and financial sustainability of an *A. decurrens* plantation (Nigussie et al., 2020). Despite all these efforts, gaps exist in characterizing and documenting A.decurrens plantation development and management practices.

The current study was conducted with the main objective of characterizing farmers' practice on *A. deccurens* plantation establishment and management. The specific objectives were to 1) characterize the practice (economical, ecological, and social); 2) identify the major strengths and weakness; 3) forward recommendations for improving and scaling up the innovation to other potential areas of the country. The research output is believed to provide relevant information for the wider application of the practice in other areas of the country with similar agroecological and socio-economic settings-and contribute to food security, land rehabilitation, and narrowing the fuel wood (energy) demand and supply gap.

Materials and methods

Description of the study area

The study was conducted in the Fagita Lekoma district of Awi Zone, Amhara region, Ethiopia. The district is located at $36^{o}40'–37^{o}06^{0}$ E longitude and $10^{o}56'–11^{o}12'$ N latitude (Wondie and Mekuria, 2018) (Figure 5).

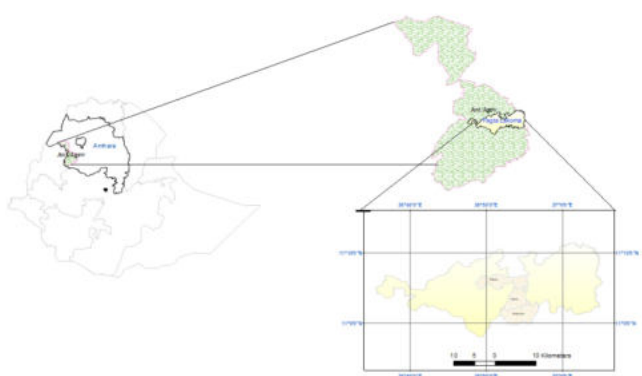

Figure 5: Location of Fagita Lokema woreda in Awi zone, Amhara region

The area coverage of the woreda is about 67,750 ha, and the population is estimated at 149,000. The woreda is part of the northwestern highlands of Ethiopia and is characterized by rugged topography. Elevation ranges from 1888 to 2915 m.a.s.l. The main land cover types are cropland, forestland, grassland, and settlements. The soil, predominantly Acrisols and Nitosols, has been severely eroded (Nigussie et al., 2017a). Subsistence agriculture is the predominant economic activity in the study area (Tesfaye et al., 2014).

The remnant forest patches of Awi Zone in North-western Ethiopia are mainly dominated by *Prunus africana*, *Albizia schimperiana*, *Albizia gumifera,* and *Celtis africana*. In recent years, the previously large and continuous forests of this region have been lost because of continued human exploitation and habitat fragmentation (Alemu et al., 2017). The remnant forest patches are under heavy pressure due to uncontrolled grazing and illegal logging by the local inhabitants. The remnant forest patches are thus highly threatened due to human disturbance and fragmentation(Yineger et al., 2014).

Nigussie et al. (2017b) 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 on small land holdings (Tesfaye et al., 2014). The landscape of the study area has been modified by human activities, mainly by the expansion of *A. decurrens* plantations and settlement areas (Wondie and Mekuria, 2018). In fifteen years (2003-2017), the forest cover increased by 256% because of *A. decurrens* plantation (Belayneh et al., 2018).

The expansion of *A. decurrens* plantation is triggered by low crop productivity due to soil acidity, which causes difficulties for annual crop production because of nutrient fixation. This compels farmers to either grow crops that tolerate acidity, or plant trees that can restore soil fertility and/or generate additional income for the household (Wondie and Mekuria, 2018).

Sampling techniques and data collection

A multi-stage sampling technique was employed to select study sites. First, the study woreda was selected purposively because of the existing *A. decurrens* plantation. As there was no difference in the practice accessibility was taken into consideration in selecting study Kebeles. Accordingly, Gulana, Gafera, and Endewuha Kebeles were selected. The total numbers of HHs of each selected Kebeles were obtained from Kebele offices.

The total sample size was determined by taking 5% of the total number of households of the three selected Kebeles. This resulted in a total of 150 respondents and proportional sample allocation was used to distribute the number of respondents in each Kebele (Table 3). Data were collected through questionnaire and focused group discussion (FGD). The questionnaire containing both open and close-ended questions was pre-tested for its consistency, logical flow, and length and corrected as per the feedback obtained from the test. FGD was also conducted on 8-10 HHs in each study Kebele to substantiate information collected from the questionnaire.

Table 3: Total HHS and a selected number of HHs in three kebeles in Fagita Lekoma woreda

S/N	Kebele	Total HH	No. of selected HH
1	Gulana	1050	53
2	Gafera	874	43
3	Endewuha	1073	54
	Total		150

Data analysis

The responses from closed-ended questions of the questionnaire were coded and entered in an excel spreadsheet for descriptive and inferential statistics. The parameters analyzed were area planted, number of seedlings planted, proportion, and size of farm land allocated to *A. decurrens* plantation. Responses from open-ended questions were summarized. The relation between these parameters and household socio-economic characteristics such as age, educational status, and landholding size were also analyzed. For quantitative data, the *stat* package in R version 4.0.3 (R Core Team, 2020) was used to run ANOVA and correlation analysis. Tukey HSD was used to determine significant differences between means ($P = 0.05$).

Results

Household Socioeconomic Profile

Almost all of the respondents (141, n=150) were married. The average family and landholding sizes were 5.6 and 1 ha, respectively (Table 4). About 50% of the respondents have a family size of 4-6 persons, however, more than half of them (about 57%) have less than 1ha of land on which they produce food crops and plant tree seedlings mainly *Acacia decurrens*. About 34% of the number of tree grower HHs (150) aged 40 to 50 years and 18% of them aged >60 years.

Table 4: Mean value of selected characteristics of HH and *A. decurres* plantations

HH and Plantation characteristics	Mean ± standard deviation
Age of respondents (years)	47.21±13.49
Size of landholding	1.04±0.46
Family size (number)	5.6±0.46
Size of A. *decurens* plantation (ha)	0.74±0.42
Experience in *A. decurrens* plantation (years)	8.9±4.83
Number of *A. decurrens* seedlings planted ha^{-1} yr^{-1}	5296.67±
The spacing used to establish A. decurrens plantation	0.35±2637.84
Rotation age of *A. decurrens* plantation for charcoal	4.79±0.38
The selling price of *A. decurrens* plantation stand	31950±8157.79
Charcoal production per ha of *A. decurrens* plantation (sacks)	2782.67±962.01
The selling price of *A. decurrens* plantation per sack	78.49±8.14

About 54% of the respondents either can read and write or completed elementary school. A few (3) respondents are diploma graduates who were working as employees in government institutions. They resigned from their offices and joined the *A. decurrens* based income generating activities through which their lives improved and they, currently, can support their family in a better situation than before.

Table 5: Category of Household characteristics by number and percent

Household variables and category	Number	Percent
Educational background		
Illiterate	49	32.7
Can read and write	50	33.3
Primary	31	20.7
Secondary	17	11.3
Others (10+, 12+)	3	02
Age		
<30	16	10.7
>=30 and <40	27	18
>=40 and <50	51	34
>=50 and < 60	29	19.3
≥60	27	18
Land-holding size		
< 0.5ha	10	6.7
>=0.5 and <1	53	35.3
>=1and <1.5	52	34.7
>=1.5 and <2ha	25	16.7
>=2ha	10	6.6
Family size		
<=3	23	15.3
4-6	74	49.3
7-9	49	32.7
>=10	4	2.7

Almost all of the respondents (99%) use more than one type of energy source for cooking and heating. All of the respondents use wood as source of energy in addition to other energy sources. About 60% of the HHs use cow dung as an energy source in addition to other energy sources.

Table 6: Energy Sources used by HHs

No.	Energy source*	Number of HHs	Percent
1	1,3,4	3	2.0
2	1,3,4,5	4	2.7
3	1,3,4,5,6	19	12.7
4	1,4	2	1.3
5	1,4,5	4	2.7
6	1,4,5,6	32	21.3
7	1,4,5,6,7	2	1.3
8	1,4,6	13	8.7
9	1,4,6, 7	3	2.0
10	1,4,6,7	3	2.0
11	1,5,6	5	3.3
12	1,6	29	19.3
13	1,6, 7	21	14.0

* 1=Wood, 2= Electricity, 3=Crop residue, 4=Dung, 5= Leaf litter, 6= Charcoal, 7=Solar. Energy source combination with less than 1% is not included

Characteristics of *A. decurrens* plantation establishment and management

Seedling production

About 97% of the respondents produced seedlings of *A. decurrens* for their use or sale by collecting seeds scattered on the ground. About 90% of those who are involved in seedling production cover their seedling demand solely from their nursery. Many people in the surrounding area including students of the Ethiopian Orthodox Church are producing seedlings to generate income (Figure 6).

Labor shortage and lack of water are some challenges faced in seedling production of the species. The majority of private nurseries for seedlings production were found around homesteads where there was no onsite water supply.

Figure 6: Partial view of A. decurrens seedling production around homesteads in Fagita Lekoma woreda

Plantation establishment

The establishment and management of *A. decurrens* was being carried out by the local community without significant support from the government**.** About 77% of the respondents confirmed the absence of support from the government concerning *A.decurrens* plantation establishment and management. The practice is run fully by the farmers. Development agents at the Kebele level take field data to confirm whether the stands are matured enough or not for charcoal production. The remaining respondents mentioned that the government provides technical support on the establishment of the plantation, management, harvesting techniques, marketing, and material support. Experts at the woreda level are expected to make assessment and inventory to confirm the plantation qualifies for harvesting. Experts use intellectual guessing rather than conducting actual inventory because of an increasing number of farmers for the service. As a result, the discrepancy between the estimated and the actual yield of charcoal was mentioned by the respondents.

Our study revealed that all of the respondents were involved in planting *A. decurrens*. Even though the primary objective of the plantation is for charcoal production (n=148), people are also getting other benefits such as fuelwood (128), construction materials (93), and others (4). Some farmers also grow other tree species such as *Eucalyptus* and bamboo to satisfy their wood demands which could not be fulfilled by *A. decurrnes* (Table 7).

Table 7: Variables related with A. decurrens planation by number and percent of respondents

No.	Variable and category	Number of respondents	Percent
1	**Type of tree species planted**		
	A. decurrens	48	32
	A.deccurens and Bamboo	2	1.3
	A.deccurens and *E. globulus*	84	56
	A.deccurens, *E.globulus,* and bamboo	16	10.7
2	**Percent of land allocated for *A. decurrens* plantation**		
	<30%	9	6
	31-50	43	28.7
	51-70	30	20
	71-90	17	11.3
	91-100	41	27.3
3	**The spacing used to plant *A. decurrens* (m**×m**)**		
	0.25 ×0.25 (160000 seedlings ha^{-1})	6	4
	0.3 × 0.3 (111111 seedlings ha^{-1})	17	11
	0.4 × 0.4 (62500 seedlings ha^{-1})	4	2
	0.5 × 0.5 (40000 seedlings ha^{-1})	92	61
	0.6 ×0.5 (33333 seedlings ha^{-1})	1	0.67
	0.75 ×0.75 (17778 seedlings ha^{-1})	4	2.67
	1 ×1 (10000 seedlings ha^{-1})	26	17
4	**The survival rate of *A. decurrens* seedlings**		
	Excellent (>90%)	129	86
	Very good (80-90)	18	12
	Good (50-70)	3	2
	Poor (< 50%)	0	0

The species is established in the form of Taungya, mixed mainly with annual crops. It is also established as monocrop in sloppy and marginal lands where crop production is not possible. Normally, after harvest, the land is used to grow crops until the soil fertility starts to decline.

Then, *A. decurrens* is established and the cycle continues. Different kinds of crops including teff, wheat, and barley are sown immediately after the harvest of the plantation. Particularly, when *Teff* is sown after tree harvest, the crop grows tall and has a massing vegetative growth; however, its productivity is low because the soil is too fertile for the crop.

Planting density/spacing

In the area, the planting spacing between *A. decurens* seedlings ranges from 0.25 m x 0.25 m to 1m x 1m. The majority of the respondents (61%, n=150) have used a planting spacing of 0.5 m x 0.5 m. On the other hand, about 17% and 20% of them used a spacing of less than and > 0.5 m x 0.5 m respectively (Table 7). Almost all of the respondents (147, n=150) mentioned that they were using closer spacing for biomass production since small size trees were required to manage harvesting and processing involving boys and girls for charcoal production (Figure 7) and denser stands were generating better price than widely spaced bigger trees. Moreover, the land shortage was also reported by respondents as one of the most important factors for closer spacing. As a secondary factor, seedlings mortality under some cases such as termite damage is also mentioned for using closer spacing to offset the damage. The respondents also mentioned that closer spacing does not create a problem for them since the rotation age is short, 4 to 5 years.

There was no statistically significant difference in spacing, several seedlings per ha among the studied kebeles (p>0.05).

Figure 7: Picture showing women and youth involved in cutting stems into smaller pieces in Fagita Lekoma woreda

Size and proportion of land allocated for *A. decurrens* plantation

About 71% of farmlands were used for growing *A. decurrens* during the study year and the average household plantation size was about 0.74ha. The land allocated for planting the species ranged from 14% to 100%, and about 65% of the respondents (n=150) allocated >50% of their farmland. Moreover, some respondents converted their total land including crop land, homesteads, and irrigable lands to *A. decurrens* plantation.

Size of plantation was significantly varied with education background of the respondents (F=4.84, p= 0.001), $p_{(\text{Primary – Illiterate})}$ =0.05, $p_{(\text{Secondary-illiterate})}$= 0.01, $p_{(\text{Illiterate- 10+ or more})}$ =0.04 (Figure 8). There was an increasing trend in the area of plantation with increasing educational background. Plantation size didn't show a significant difference with landholding size. Plantation size was not significantly affected by age of the households, family size, and Kebele.

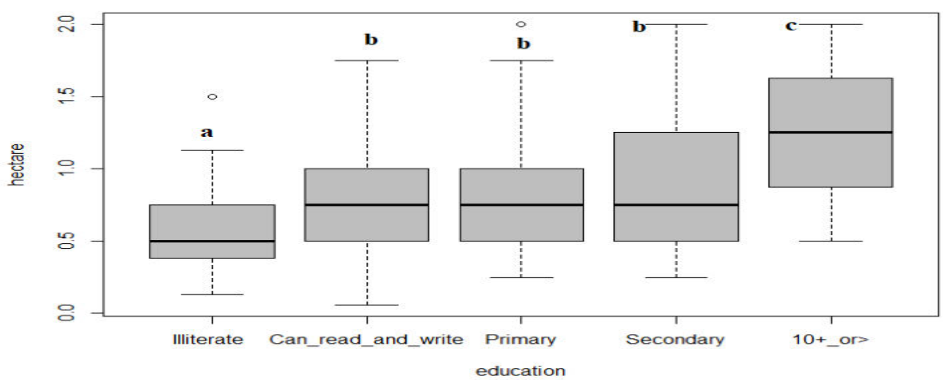

Figure 8: Size of *A. decurens* plantation and educational status of respondents.

From all respondents, ten farmers were leasing land on a contractual basis for planting the *A. decurrens*. In that lease agreement, only one-fourth of the generated income from the sale of the product was paid to the land owners and the lease period was agreed up to 25 years. But, currently, the agreement signed is for 5 years and half of the product/income from the leased land is paid to the land owner. An additional 3000 ETB per quarter of the land was paid to the land owner immediately after signing the lease agreement.

Rotation age

Even though the economic feasibility of the alternative rotation ages is not studied, farmers traditionally were practicing a 5 to 6 years rotation age of *A. decurrens* plantation for charcoal production. Whenever farmers financial needs arise, they even cut a three years old plantation. The respondents also recognized that "production per unit area increases with the age of the plantation, however, for charcoal production it will be difficult to process (shorten) the stem into billets and remove branches when they get bigger. This also leads to an increase in the cost of saw blade for processing. As respondents indicated, a premium price for older plantation is at the rotation age of **7** years. As the age of the plantation increases, from the commonly used 4-5 years to 7 years' charcoal quality and production per unit area increases. But longer rotation age decreases the number of years when the crop can be integrated with the plantation.

There was a marginally significant difference (F=2.82, p=0.05) in the rotation age of plantation between Gulana and Gafera Kebeles where the highest rotation age was recorded in Gafera Kebele. Rotation age was also significantly affected by family size (F=4.07, p =0.05) and the relation was inverse.

Management and other tending operations

The farmers protect planted seedlings of *A. decurrens* from animal damage by fencing them for the first two years when they are young and palatable and then stop further management activities at the sapling stage. Seedlings are susceptible to livestock damage only for the first two years as the plant is palatable at the early growth stage. Therefore, fencing and protection of the plantation against livestock are required only in those years.

Tree harvesting and use

The trees are cut at the ground level, even a little bit lower, to remove the stump to facilitate plowing for crop production. This study also revealed that farmers generated cash from the sale of charcoal and leftovers, smaller branches for fuel wood, and from harvesting of trees. The respondents also mentioned that timber from *A. decurrens* trees was used for house construction even though the wood is not as strong as Eucalyptus.

Yield and income from *A. decurrens*

Table 8: Products and services from A. decurrens plantations

No.	Variable and category	Number of respondents	Percent
1	**Current products from *A. decurrens***		
	Fuel wood	128	85.3
	Charcoal	148	98.7
	Construction Wood	93	62
	Others	4	2.7
2	**Perceived products and services from *A.decurrens***		
	Farm implements	30	20
	Shade	41	27
	Fuelwood	132	88
	Forage	13	8.7
	Soil fertility	148	98.7
	Charcoal	145	96.7
	Controlling soil erosion	147	98
	Seed	123	82
3	**Profitability compared with crop production**		
	1 × (the same)	3	2
	1.5	3	2
	2×	122	81
	3×	18	12
	4×	4	3

Note. For perceived products and services column sum is more than 100% because of multiple responses

Charcoal production per ha is about 3000 sacks. There was a significant difference in charcoal yield among the studied Kebeles (F= 3.8, p= 0.02). A significantly higher yield was obtained in Gulana Kebele than Gafera Kebele (p=0.02) (Table 9). The average selling price of a sack of charcoal is about 90 ETB. Therefore, from a hectare of *A. deccurens* plantation, one can get an income of about 270,000 ETB. If the plantation is sold as a stand without felling and further processing, the selling price is only about 128,000 ETB.

Table 9: Household variables and charcoal yield

No	HH variables	Charcoal yield per ha (Number of sacks) *
1	**Family size**	
	<=4	2717.39±142.9[a]
	four-six	2758.11±118.96[a]
	seven-nine	2840.82±146.27[a]
	>=10	2900±191.49[a]
2	**Kebele**	
	Gulana	3018.87±153.55[b]
	Gafera	2483.72±127.54[a]
	Endewuha	2788 ±113.29[ab]
3	**Landholding**	
	< 0.5ha	2800±252.98[a]
	>=0.5 and <1	2566.04±102.19[a]
	>=1and <1.5	2873.08±153.76[a]
	>=1.5 and <2ha	2952±148.64[a]
	>=2ha	3020±304.7[a]
4	**Educational status**	
	Illiterate	2685.71±145.10[a]
	Can read and write	2810±144.91[a]
	Primary	2925.81±171.89[a]
	Secondary	2623.53±151.35[a]
	Others (=>10$^+$)	3333.33±352.77[a]
5	**Age**	
	<30	2775±152.62[a]
	>=30 and <40	2948.15±202.15[a]
	>=40 and <50	2962.75±158.79[a]
	>=50 and < 60	2451.72±136.69[a]
	≥60	2637.04±160.14[a]

Note. *Similar letters following figures in a column of specific HH variable are not significantly different (p=0.05).

Labor demand and profitability of *A. decurrns* plantation

The demand for labor is high for seedling production (January to June) and planting seedlings (June to July). Additionally, the labor demand for harvesting and processing (cutting stems in smaller billets for charcoal making and charcoal production), is also high. However, the labor demand for harvesting and processing is almost negligible for most of the respondents because they sell their stand on the stump. Whereas, those who are ready to produce charcoal either they produce themselves or give the contract to skilled persons. If they have to give a contract, the owner should harvest and process the trees, and make all the necessary arrangements. The contractor only piles the billets and ignites for proper charcoaling. This costs the owner 2 birr per charcoal sack after charcoal production. The profitability of charcoal varies with market location. Transporting charcoal to Addis Ababa is by far more profitable than selling in the local market (Table 10). The profitability and cost-benefit analysis of the practice was calculated based on information obtained from the respondents (Box 1).

Table 10: Profitability of 0.25 ha A. decurrens plantation at different selling location

No	Activities by year*	Addis Ababa market		At site of production	
		Expense	Income	Expense	Income
	Year 1				
1	Seedling purchase	3000.00	0.00	3000.00	0.00
2	Seedling planting	2000.00	0.00	2000.00	0.00
3	Planting hole preparation	2000.00	0.00	2000.00	0.00
4	Transporting seedlings to site	200.00	0.00	200.00	0.00
	Year 5				
1	Tree felling	13000.00	0.00	13000.00	0.00
2	Removing branches	2000.00	0.00	2000.00	0.00
3	Cutting to pieces	13000.00	0.00	13000.00	0.00
4	Piling	2000.00	0.00	2000.00	0.00
5	Charcoal making	1600.00	0.00	1600.00	0.00
6	Straw/*teff* residue for charcoal making	3900.00	0.00	3900.00	0.00
7	Sack for charcoal	4800.00	0.00	4800.00	0.00
8	Nylon rope	1440.00	0.00	1440.00	0.00
9	Transport to road side	1600.00	0.00	1600.00	0.00
10	Royalty cost	7200.00	0.00	7200.00	0.00
11	Transport cost to Addis Ababa	11200.00	0.00	0.00	0.00
12	Income from sale of charcoal	0.00	120000.00	0.00	72000.00
	Total expense (A)	**68,940.00**	**0.00**	**57,740.00**	**0.00**
	Total income (B)	**0.00**	**120,000.00**	**0.00**	**72,000.00**
	Net income (B-A)		**51,060.00**		**14,260.00**

Note, * years 2-4 are not included as there was no income and expense

Box 1. The assumption used to calculate the profitability of *A. decurrens* plantation. This assumption is based on information from respondents.
About 10,000 seedlings are planted on 0.25 ha of land. The local selling price of seedlings was 0.30 Birr/seedling. Establishment cost is reduced since the plantation is established mixed with annual crops. On such a field one person can plant 500 seedlings per day, prepare 500 planting holes per day. 130 person-days (pds)are required to fell trees grown on 0.25ha. Removing branches require 20 pds. 130 pds is needed to cut trees into billets. Pilling billets require 20 pds. The labor cost during the study period was 100 ETB/person-day. Charcoaling required 2 ETB per sack of charcoal produced. From 0.25ha about 800 sack of charcoal can be produced. About 60 sacks of teff residue /straw that cost 65 Birr each are required per 0.25ha of the plantation. A sack for collecting charcoal costs 6 ETB. 12 roles of nylon roll that cost 120 ETB, 2 Birr per sack of charcoal to transport to the roadside, 9 ETB royalty fee per sack of charcoal, 14 ETB per sack of charcoal for transportation to Addis Ababa. The selling price of one sack of charcoal at a site and in Addis Ababa is 90 and 150ETB respectively.

The profitability of *A. decurrens* plantation compared to crop production

According to the respondents, the productivity and profitability of *A. decurrens* plantation depend on the land quality. They stated that, on degraded lands, the profitability was by far more profitable than crop production. More than 80% of the respondents perceived that planting a hectare of *A. decurrens* could generate a twofold profit in monetary value than crop production. The practice also reduces the application and expense of chemical fertilizer since the *A. decurrens* plantation improves the soil fertility of the planting sites. Thus, the application of chemical fertilizer is in a small amount on the harvested lands as a starter when food crops are sown immediately after harvest. On the other hand, on fertile lands, growing crops may be more profitable than planting *A. decurrens* because farmers grow 2 or 3 times field crops annually and get animal feed.

Environmental services

Planting *A. decurrens* could reclaim degraded lands that are affected by salt in the study area. Before the introduction of *A. decurrens,* respondents perceived that there were several land-related problems in the local area including low soil fertility (148 respondents), high acidity (57 respondents), low crop productivity (141 respondents), and low forage production (44 respondents). In general, the respondents explained that the land was extremely degraded and became out of production. They said that "*thanks to the species, degraded lands are reclaimed and life is secured in the area, without this practice, the inhabitants would have* *been out migrated to other areas or life would be miserable in the area*". According to respondents, in some cases, few farmers that migrated to other less populated areas now returned in the area because of the potential of *A. decurrens* plantation. Nowadays, it is a common practice that farmers spread ash and charcoal leftovers on their farm land to increase soil fertility and boost crop yield (Figure 9).

Figure 9: Pictures showing biochar left after charcoal production (A) mixed and spread on farmland by frequent plowing (B) A. deccurens extremely improves soil fertility of degraded lands and boost the productivity and production of crops

The stand structure and yield of the crops is enormous after harvesting *A. decurrens.* According to the farmers' perception, the type of crops that increased yield in their order was *teff* (136 respondents), wheat (28 respondents), finger millet (27 respondents), and barely (8 respondents). The productivity of *teff*, when sown after harvest of *A. decurrens*, is tremendous. In some cases, vegetative growth of teff increased and faced lodging problems and resulted in reduced yield since the land is too fertile for the crop.

Employment opportunities

The majority of respondents have been generating income from the species. Moreover, farmers have improved their life standard and - livelihood because of the species. A range of age groups of the community is participating in production chains ranging from plantation establishment to marketing. Those activities include, among others, seed collection and sale, planting seedlings, harvesting, processing into manageable sizes for charcoal production, charcoal burning, transporting to the roadside, and brokers' and traders' involvements. -

Challenges in the current production system of *A. decurrens* plantation

Despite its attractive innovation and significant positive impact on farmers' livelihood and land rehabilitation in the area, there are several problems encountered related to the system. The perceived problems by tree growers in order of importance are pests (Figure 10), frost, drying, labor shortage, water shortage for seedling production, free grazing, low seed quality, market fluctuation, bureaucracy, land shortage, and shading. Other problems mentioned related to the establishment and management of *A. decurrens* plantation is planting multiple seedlings per planting hole and planting seedlings with polybags (Figure 11). The field observation shows that about 5 seedlings per polybag were planted without removing the polybag and in some cases, according to tree growers these seedlings found up to 10 in number in one pot and used for planting in one hole and the fittest survives after the severe competition at the early growth stage.

Figure 10: Pictures showing multiple seedlings planted in a single planting-hole (B) without removing the polybags (A)

Figure 11: Pictures showing pest occurrence (A and B) and their effect on A. decurrens plantation (C and D)

Some growers of *A. decurrens* rent -land for a longer period, up to 25 years, because of land shortage for plantation.

Currently, most farmlands are converted to *A. decurrens* plantation, and expenditure for food crops is rising and even becomes difficult for some farmers to cover all household expenses with the generated income from *A. decurrens* plantation. Moreover, most of the farmers do not have sustained yield from their plantations. As it can be concluded from the age distribution of *A. decurrens* plantations owned by the respondents (Table 11), there are some years with no harvest.

Table 11: Age structure of A. decurrens plantation in the study Kebeles

No.	Variable and category	Number of respondents	Percent
1	**Age of plantation (years)**		
	1 year	60	40
	2 years	104	69.3
	3 years	71	47.3
	4 years	59	39.3
	5 years	32	21.3
	6 years	2	1.3
2	**Age composition of plantations owned by individuals**		
	1 type	35	23.3
	2 types	59	39.3
	3 types	51	34
	4 types	4	2.7
	5 types	1	0.7

Note. The percent sum is more than 100% because of multiple responses. HHs own different aged stands of *A. decurrens*

The other vital problem mentioned by farmers was the lack of product diversification in the study area. The majorities of tree growers have concern and fear if the demand and value of charcoal decrease in the future due to the expansion of electrification.

In the study area animal feed is also becoming a critical problem because of the expansion of *A. decurrens* plantation converted from all type of lands including pasture. Crop residue from *teff* that was used for animal feed is now utilized for charcoal burning that could create an additional burden on farmers to practice livestock rising.

The other critical problem observed during the field survey was the palatable nature of seedlings by browsing animals at the early stage of the *A. decurrens* plantation. Thus, to protect the newly planted seedlings of *A. decurrens* from various domestic animals (Figure 12), farmers could incur extra cost for fencing.

Figure 12: Pictures showing browsing problem on A. decurrens by different domestic animals (A, B, C) resulted in the loss of planted seedlings (D)

As farmers practicing mixed livelihoods, the shading effect of the plantation to the neighboring farm crops is distressing. Therefore, the neighbors get forced to plant *A. decurrens*, though it is not in their interest. In many cases, farmers also convert fertile lands (backyards and irrigable lands) to *A. decurrens* plantation compromising the food security condition of farmers. Some suggested such practice to be stopped and supported by law enforcement in this regard.

Discussion

We found rapid expansion of *A. decurrens* plantation at the expense of crop land in the woreda and nearby areas driven by the charcoal value (income generating) of the practice. A study in the area showed that.*A. decurrens* plantations were expanding at the rate of 1.2% due to the high market for charcoal(Wondie and Mekuria, 2018).

The woreda of Fagita Lekoma is one of the best successful *A.decurrens* plantations in Ethiopia. This is because the plantation brings significant contribution to their livelihood improvement and reclaiming degraded lands. According to Holden et al. (2003), unlike the plantation of Eucalyptus, which highly competing with water and nutrients, *A.decurrens* could improve soil fertility and rehabilitate degraded lands. The response from the respondents on the effect of *A. decurrens* on the surrounding environment is consistent with previous research findings such as Berihun et al. (2019) who reported a positive hydrological response to the practice. However, lower soil organic carbon and nitrogen were reported under *A. decurrens* plantation (Abebe et al., 2020). This paradox could be due to the complete removal of plant residues from the woodlots after harvest.

The response from the respondents showed that *A.decurrens* is more profitable than alternative lands. This is in agreement with Nigussie et al. (2020) who reported *A. decurrens* as more profitable than alternative systems.

Despite the high survival rate of *A.decurrens* seedlings in the study area, the production of seedlings is very traditional and the quality of seedlings is poor. The quality of seedlings is a combined function of their genetic quality and physical condition as it leaves the nursery (Wilkinson et al., 2014). Seedling survival is one of the important parameters for the success of plantation, seedling survival *per se* is not enough to measure plantation success (Le et al 2012).

Results revealed that very narrow spacing was used for planting seedlings (160,000 stems/ha). . This is the least planting spacing ever reported in the country. So far, the narrowest spacing for tree planting (50,000 stems per ha) was reported for Eucalyptus plantation in Ethiopia (Bekele, 2011). Therefore, optimum spacing has to be determined through research (Rais et al., 2020; Rocha et al., 2016).

Charcoal production is also one of the concerns that need improvement since the local community in the study area is practicing the traditional way of charcoal burning that emit excessive smoke to the surrounding area. Inconsistentway of charcoal production reduces charcoal yield (Chiteculo et al., 2018) and affects largely human health (Garedew and Simon, 2018). Smoke is reported as one of the major health problems in the country. This health problem could also be more intense since more than half of the respondents use cow dungs as fuel for cooking and heating in addition to wood, charcoal, and other energy supplies(Mekonnen and Köhlin,2009). In addition to creating health problems for people, using dung for fuel resulted in soil nutrient depletion. Therefore, satisfying the energy demand of the community through plantation establishment and management indirectly reduces the land degradation problem and improves soil fertility (Holden et al., 2003).

By tree growers, almost no tending operations are practiced on *A. decurrens* plantation except livestock exclusion during the early age of establishment. Lack of management on plantation development is a common problem in Ethiopia (Bekele, 2011). However, proper management at all stages of the plantation has to be implemented to maximize the profitability of the practice (Chokkalingam et al., 2006; Le et al., 2012).

The rotation age of *A. decurrens* plantation is fixed based on farmers' practice without a scientific background. This is one of the issues that need to be solved through research since it affects the production and productivity of plantations.

It was reported that though *A. decurrens* is highly profitable, the system imposes a risk of liquidity problem on farmers throughout the 5-year investment period, which indicates that those who have enough land or who are financially capable can benefit from the required 5-year investment. But, it will be more difficult for those with limited land and financial resource (Nigussie et al., 2020). This was also more complicated by the age distribution of *A. decurrens*. Most of the respondents have one or two age groups of *A. decurrens* plantation. Therefore, the yearly plantation is required to have a yearly harvest.

The respondents of our study mentioned that shortage of land for tree growers is one of the major limitations to expand further *A. decurrens* plantation and establishment. The same problem was also revealed by Wondie and Mekuria (2018). Thus, several respondents rented land for planting *A. decurrens.* Our study also revealed that labor was one of the major problems for establishing and harvesting *A. decurrens*. There was a decrease in plantation size with decreasing family size which further confirms the labor problem. Previous studies also reported labor as a major problem for such practice (Nigussie et al., 2020).

The monoculture nature of the plantation also draws attention that the occurrence of pests in some specific places could be an indication for the future constraints of the plantation. Wondie and Mekuria (2018), also stated that mono-cropping practice may result in disease and pest occurrence, and this needs due attention.

Conclusions and recommendations

In general, the introduction of *A. decurrens* plantation in the study area significantly improved the livelihood of the local community through job creation, rehabilitation of degraded lands, improving soil fertility, and increasing agricultural crop production.

We did not use econometric models to compare the economic contribution and profitability of various agricultural practices on the same land management unit. We use only tree growers' response to show the comparative profitability. The profitability calculation of the *A. decurrens* itself is very crude and detailed economic analysis is required to provide concrete information on the profitability of the practice.

Despite the successful innovation of small-scale plantation development activities in the area; some important concerns need to be resolved to maximize the profit from the practice. This is especially important when scaling-up and promoting innovation in other similar areas. Therefore, the following recommendations are presented:

- Modernization of all activities ranging from seed procurement to marketing has paramount importance to use the full production potential for income generation and environmental services the innovation.
- There is a need for the creation of forest associations for tree growers and charcoal producers for effective plantation management and marketing to maximize the profitability of the practice.
- It is important to diversify the means of livelihood of the local community as well as diversify products and services from the innovation. The species can be used for dye, gum production, and others.
- Balancing *A. decurrens* plantation development and crop production is important; there is a possibility of decreasing income generation and aggravate food insecurity due to market failure of charcoal value and damage on plantations by disease and pest.
- Incentive mechanisms shall be established for the experts to do the actual inventory of the plantation before harvest.
- Training in charcoal making is important since the majority of the respondents were not involved in charcoal making as they do not have the technical capacity and this incurs additional costs for them.

- Research must be conducted to prevent plantations from pest damage and select appropriate spacing that minimizes cost and maximizes productivity/production of species.
- In areas, where crop production is not feasible due to land degradation and loss of soil fertility, plantation of *A. decurrens* could be promoted as an alternative land use and livelihood means
- The best practices from A.decurrens growing areas should be optimized and scaled-up into areas with similar biophysical and socio-economic conditions
- Wider expansion of *A. decurrens*-based plantation systems could be achieved through improving extension, credit access, and road infrastructure to connect small-scale farmers to markets and finance. Extension service concerning tree planting and management is important for the success of plantation efforts.

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Section 2: Forest Resources Utilization Research

Effect of postharvest handling techniques on the physical, proximate, and anti-nutritional composition of *Ziziphus mauritiana* in Ethiopia

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Abstract

Fruit quality is affected by different factors such as packaging technology, and storage condition. The fruit quality of *Z. mauritiana* depends on the postharvest handling techniques. Thstudy aimed to identify suitable packages for handling and transportation and to characterize the mineral, nutritional and anti-nutritional composition of matured and immatured fresh *Z.mauritiana* fruit collected from Kobo, North Wollo, Ethiopia. *Z.mauritiana* fruits were packed in three types of packages (nestable plastic crate, cold box, and wooden boxes) and transported over a distance of 500 km by road. The fruits packed in a cold box had lesser bruising damage, weight loss, and had better quality in terms of physical injuries, weight loss, and decay as compared to those packed in wooden boxes and a nestable plastic crate. On the other hand, the phytochemical analysis of *Z. mauritiana* showed that it contains acceptable amounts of moisture content (5.72), ash (6.15-6.227), protein (8.75-9.35), fiber (1.63-1.74), fat (5.45-5.7), phytate (310-321) and tannin value (11251-11478). The analysis of minerals for *Z. mauritiana* fruits showed that it has an acceptable amount of potassium (226.6955 mg/100g), calcium (1.977 mg/100g), sodium (0.34609 mg/100g), magnesium (0.22440 mg/100g), iron (0.039 mg/100g) and zinc (0.02059 mg/100g). Therefore, *Z. mauritiana* fruit can be used as a good source of food.

Keywords: *Ziziphus mauritiana*, Post-harvest handling, Cold box, Mineral content

Introduction

The wild edible fruit contributes to the major portion of the human diet that provides essential biochemicals like carbohydrates, proteins, and lipids (Seifu *et al*., 2017). These wild edibles not only contribute to the essential biochemicals and energy requirement but also act as supplementary sources of vitamins and minerals that are the indispensable requirement of the body to maintain the proper physiological homeostasis of the body (Sudeshna *et al.,* 2019). Nutritional qualities of wild edibles are comparable and sometimes superior to the domesticated variety (Ebert, 2014). More recently, several types of research are focused on wild edibles as sources of food (Narzary *et al*., 2015; Abdus Satter*et al*., 2016; Seal *et al*., 2017) and medicine used for the treatment of different diseases like diabetes, jaundice, wounds, and cancer (Mir, 2014).

Almost 100 species of deciduous shrubs and trees belong to genus *Ziziphus*, family Rhamnaceae, which grows well in tropical and subtropical areas of the World. Some species, like *Ziziphus mauritiana* occurs in almost every green continent. *Ziziphus* species survive in extreme drought conditions and are an excellent source for natural vegetation in the deserts of Indo-Pak (Razi et al., 2014). The family has 52 genera and more than 952 species (Tourm *e.t al*., 1992) of which the species *Z. jujuba* Mill (Chinese jujube or Chinese date*), Z. mauritiana* Lamk (Indian jujube or ber), and *Z. Spina* Christi (L.) wild (Christ's thorn) are the most important in terms of distribution and economic significance. Some species, like *Z. mauritiana* and *Z. jujuba,* occur nearly on all continents, whereas other species, like *Z. nummularia, Z. spina-christi,* and *Z. mucronata* are restricted in their distribution to distinct areas (Pareek, 2001). *Ziziphus* is also found in disturbed areas near settlements and along roads in African countries where the fruits are harvested from naturally regenerated populations and sold in local markets. The yield potential varies from 100 to 200 kg per tree per annum. It is considered an underutilized fruit crop in semi-arid regions of the world and can be successfully cultivated in the marginal ecosystem of the subtropics and tropics (Singh, 2016).

Z.mauritiana (Jujube, English) (Kurkura, Amharic) is a spiny tree or shrub 8 - 15 m tree from the Rhamnaceae family with a wide geographical spread. It grows in most semi-arid areas of Africa where rainfall ranges from 200-1200 mm per year. The species is also common in the drier regions of South and Southeast Asia. *Z.mauritiana* is tolerant of drought, water-logging, salinity, and a wide range of soil pH. It is common in Gonder, Gojam, Welo, Shewa, Arsi, IIlubabor, Gamo Gofa, Bale, Sidamo, and Harerge, widely distributed in arid parts of tropical and South Africa, Madagascar, and Arabia (Hooda *et al*., 1990; Anonymous, 2002*). Z. mauritiana* is a multi-purpose tree. It has a long history of usage as vital food and/or traditional medicine. Various parts of the *Z.mauritiana* plant, including roots, stem, leaves, flowers, and fruits used as pharmacological agents (Ahmed *et al.,* 2020).

Ziziphus fruit is generally eaten fresh and is a rich source of ascorbic acid, essential minerals, and carbohydrates. Scientific evidence has shown that jujube fruits contain a high amount of bioactive compounds including ascorbic acid, triterpenic acids, phenolic acids, amino acids, saponins, cerebrosides, flavonoids, polysaccharides, and mineral constituents (Ahmed *et al.,* 2020). It is richer than apple and mango in vitamin C, protein, and minerals and contains higher phosphorus and iron than orange. Postharvest losses of these crops may occur at any point between harvest and consumption in the marketing process. In developing countries, postharvest losses of fresh produce vary between 25-50% of the total production, depending on the commodity. The post-harvest losses of perishable (vegetable and fruits) food crops amounted to be about 30% (Fekadu and Dandena, 2006)

The shelf-life depends mainly on the *Ziziphus* cultivar, storage temperature, packaging method, and stage of harvest. During storage, the fruits lose weight and shrivel, change color and become red, lose acidity and ascorbic acid, but gain in sweetness. The storage life of *Ziziphus* fruits is extremely short and the rapid perishability of the fruits is a problem. At ambient temperature a shelf-life of 2–4 days is common. A cost and returns analysis showed that *Ziziphus* production is highly remunerative but requires proper handling concerning pre-harvest, harvesting, and postharvest treatments, packaging, transportation, storage, postharvest pathology, processing, etc. Profits could be enhanced if efforts to increase production are supplemented with efforts to minimize postharvest losses and enhance shelf life (Singh, 2016).

Freshly harvested fruits can be stored in containers such as gunny; net or polyethylene bags, cloth packs, and boxes for 4-15 days at room temperature (25-35 °C) without loss of organoleptic quality fruits can be stored in a cool chamber for 6-10 days. However, the high humidity, which develops in the cool chamber, is conducive to spoilage. Fruits can retain acceptable organoleptic quality for 3 weeks kept in polythene bags and baskets at 13 °C in an incubator. Kept in polythene bags in cold storage at 10 °C, fruits of some cultivars can be stored for 28-42 days. Fruits can be stored frozen at -18 °C for 6 weeks (Singh, 2016).

Cold storage transportation is the one widely practiced method for bulk handling of the perishables between production and marketing processing. It is one of the methods of reserving perishable commodities in the fresh and whole state for a longer period by controlling temperature and humidity within the storage system. Most fruits and vegetables have a very limited life after harvest if held at normal harvesting temperatures. Postharvest cooling rapidly removes field heat, allowing longer storage periods. Proper postharvest cooling can: Reduce respiratory activity and degradation by enzymes; reduce internal water loss and wilting; Slow or inhibit the growth of decay-producing microorganisms; reduce the production of the natural ripening agent, ethylene. In addition to helping maintain quality, postharvest cooling also provides marketing flexibility by allowing the grower to sell produce at the most appropriate time (FAO, 1984, quoted by Knoth, J., 1993). Therefore, transporting *Z.mauritiana* fruits in refrigerated trucks or vans at midnight may be convenient, also effective in preserving the quality of fruits. Night temperatures can be used to keep stores cool (FAO, 2003).

Consumers are currently demanding more convenient and diversified products, which meet the desired flavor, aroma, and color, not neglecting their nutritional quality. Extensive studies have been carried out using *Ziziphus* fruits to prepare various processed products, such as candy, dehydrated products, juice and wine, jam and jelly, and shreds and powder (Pareek *et al*., 2009). However, jujube fruits have a short shelf-life and can be stored for no more than ten days under non-controlled conditions (Ahmed *et al.,* 2020). Besides, in our knowledge even if there are reports of availability and consumption of *Z.mauritiana* fruit in Ethiopia, there is no information on the postharvest handling and its composition. Therefore, this study was undertaken to identify suitable packages, both from a technical and economic point of view, for handling and transportation. The study also aims at characterizing the mineral, nutritional and anti-nutritional composition of matured and immature fresh *Z.mauritiana* Fruit collected from Kobo, North Wollo, Ethiopia.

Materials and Methods

Samples collection and preparation

The physiologically matured wild edible *Z. mauritiana* fruits were harvested from Kobo in Amhara National Regional State in Ethiopia (12°09′N 39°38′E with an elevation of 1468 meters above sea level). Sorting and grading of fruit were carried out in the field. The homogenous samples of uniform, similar size and an equal weight of fresh, fully ripe fruits with good appearance were placed into the testable plastic crate, wooden box, and cold box, then immediately transported to Addis Ababa, Forest product Innovation, Research, and Traning Center laboratory. The suitability of each package type *Z. mauritiana* fruits was tested and put in the deep freezer for the further experiment (for physical test, proximate, and Anti-nutritional).

Figure 13: *Ziziphus mauritiana* fruit collection and preparation

Physical tests of *Ziziphus mauritiana*

Wight loss in percent

Weight loss percent was calculated using the following formula:

$$Weightloss(\%) = \frac{Initialweight - Recordedweight}{Initialweight} x\ 100$$

Initial weight = After the fruit collected and before it transport

Recorded weight = After the fruit transport

Proximate analysis of *Ziziphus mauritiana*

Sample preparation

The collected *Z.mauritiana* was thoroughly washed with distilled water, and their holdfasts and visible epiphytes were removed. The cleaned fruits were dried in a ventilated oven for 24 hrs with a lower temperature of 40 °C. Then, the pulp of the fruit was separated and ground using mortar and pistil. The pulp was stored under the dried condition for further proximate, anti-nutritional, and mineral analysis (Kumar *et al.,* 2008).

Determination of moisture content

A moisture content determination was carried out for oven-dried fruits. Accordingly, three replications of *Z.mauritiana* fruit pulp samples that weighed accurately 2 grams from each preservation technique was weighed and dried in an oven overnight for 12 hrs at 105°C. The moisture content of the fruit pulp was expressed as follows (AOAC, 2007):

$$Moisture(\%) = \frac{(W1 - W2)}{W1} * 100$$

Where: W1 = weight (g) of the sample before drying

W2 = weight (g) of the sample after drying

Determination of ash content

Three replications of ground *Z.mauritiana* fruit pulp samples (moisture-free) that weighed accurately 2 g and heated on a burner in the air to remove its smoke. Then each fruit pulp sample was burned in a furnace at 550°C for 4 hrs. The ash content was expressed as indicated below:

$$Ash(\%) = \frac{(W1 - W2)}{W1} * 100$$

Where: W1 = weight (g) of the moisture-free sample before burned

W2 = weight (g) of the sample after burned

Determination of total nitrogen and crude protein

The Kjeldahl method was used for nitrogen determination taking 0.5 g of ground *Z.mauritiana* fruit pulp sample was added to digestion flask in three replications from each preservation technique. The percentage of nitrogen content was then calculated (Ibrahim *et al*., 2013). The protein content was calculated using the nitrogen conversion factor of 6.25 as proposed by Greenfield and Southgate (Greenfield *et al*., 2003).

Determination of crude fiber

The crude fiber was determined by acid-base digestion or the Coarse Fiber method taking 2.0 g of *Z. mauritiana* fruit pulp sample (moisture-free). The crude fiber was calculated as the difference between the weight of the residues and ash and converted as a fraction of the sample was expressed as a percentage loss in weight on ignition (AOAC, 1990).

Determination of crude fat

Two grams of the *Z. mauritiana* fruit pulp sample (moisture-free) in triplicate were weighed into a porous thimble and its mouth plugged with cotton. The thimble was placed in a soxhlet apparatus. A dry pre-weighted solvent flask was connected beneath the apparatus, to it was added the required volume of solvent (hexane or petroleum ether), and then was connected to the condenser. An adequate amount of hexane (boiling point of 40-60°C) was added to a pre-weighted solvent flask. The solvent flask was heated on a heating mantle for eight hours to extract the crude fat. After the thimble was removed, the solvent was retained from the apparatus. The excess solvent was evaporated from the solvent flask on a hot water bath and the flask was dried at (40-60°C) an oven. Then it was cooled in a desiccator and weighed (Gali *et al*., 2016).

Tannin Determination

This was determined using the method described by Burns *et.al* (2001). One gram of dried *Z. mauritiana* fruit pulp sample was extracted with 10 ml of 1% HCl in methanol using a mechanical shaker for 24 hr at room temperature and centrifuged for 5 min. 1 ml of the clear supernatant solution was taken and mixed with 5ml of Vanillin HCl reagent and stand for 20 minutes until the reaction was completed. The absorbance of the clear supernatant solution at 500 nm was measured using a UV-VIS spectrophotometer (CECL 1021 model mad in England). Finally, the amount of Tannin was determined by using the SPSS plot's slope; and intercept of the standard curve and following the equation stated below (Latta and Eskin, 1980).

$$\text{Tannin}\ \frac{\text{mg}}{\text{g}} = (\text{As} - \text{Ab}) - \frac{\text{Intercept}}{\text{Slope} * \text{d} * \text{w}}$$

Where: **As** = Sample absorbance,

Ab= Blank absorbance,

d = Density of solution (0.791g/ml) and

w = Weight of sample in gram

Anti-nutritional analysis of *Ziziphus mauritiana*

Phytate determination

The phytate was determined using the method described by Latta and Eskin 1980. Accurately 0.5 g of ground *Z.mauritiana* fruit pulp sample was weighed into a 100 ml conical flask with three replications and 10 ml of 0.2 normal hydrochloric acids was added into a conical flask. The sample was extracted by a soaking method using a mechanical shaker for 1 hr at ambient temperature and filtered. Then 2 ml of wade reagent solution was added into 3 ml of filtered solution. The solution was then homogenized and centrifuged for 10 min at 3000 rpm. The clear mixture solution was taken and the absorbance measured at 500 nm using a UV-VIS spectrophotometer (CECL 1021 Model mad in England).

Mineral Analysis of *Ziziphus mauritiana*

Preparation of acid digests

The acid digestion method of Toth *et al*. (1948) was followed for the analysis of inorganic constituents. The previously prepared *Z. mauritiana* pulp was used for the analysis. 500 mg oven-dried powder of fruits was transferred into a 150 ml clean borosilicate beaker and 10 ml concentrated nitric acid (HNO_3) was added. It was covered with a watch glass and kept for an hour until the primary reactions subsided. Then it was heated on a hot plate until all the material was completely dissolved. After it cooled to room temperature, 10 ml of Perchloric acid (60%) was added to it and mixed thoroughly. The solution was further heated strongly on the hot plate until it became colorless and reduced to about 2-3 ml. After cooling, it was transferred quantitatively to a 100 ml capacity volumetric flask, diluted to 100 ml with distilled water, and kept overnight. The next day the extract was filtered through Whatman No. 44 (Ashless) filter paper. The filtrate was stored properly and used for the analysis of inorganic constituents. The level of Calcium, Magnesium, Sodium, Iron, Manganese, Zinc, and Copper was estimated by using Atomic Absorption Spectrophotometer (Perkin-Elmer, 3030 A). The mineral content was expressed as mg/100g dry plant material.

Result and Discussion

The physical change of *Ziziphus mauritiana*

The physicochemical change (decay, trimming, physical injure, weight loss, and total loss) of *Z.mauritiana* wild fruit were shown in Table 12.

Table 12: Effect of different package material on the cumulative post-harvest loss of *Z.mauritiana* during handling and transportation

Type of fruit	Days in transport	Packaging material	% losses to					
			Decay	Trimming	physical injuries	weight loss	Other	%Total losses
Ziziphus Mauritiana fruit	3	Nestable plastic crates	0.00	NM	0.16	0.44	-	0.60[b]
		Wooden box	0.00	NM	0.39	1.48	-	1.87[a]
		Cold box	0.00	NM	0.075	0.09	-	0.165[c]

Each value represents the mean of twenty-five replicates. Similar letters followed by raw are not significantly different at $p<0.05$.

The selection of suitable package types is necessary to minimize post-harvest losses during the handling and transportation of fruits. A suitable package helps or protects the fruit from mechanical injuries, tampering, and contamination from physical, chemical, and biological sources. Table 1 showed there was a significant difference between packaging materials ($p< 0.05$). According to the results, *Z.mauritiana* fruits showed the highest post-harvest total losses (decay, physical injuries, and weight loss) when packed/handled in a wooden box. The reason for high post-harvest losses is mainly due to vibration, abrasion, and compression damage to fruits when handling and transporting after packaged in wooden boxes. Cold box shows the lowest postharvest loss compared to nestable plastic crates followed by wooden box (Table 12).

Proximate and anti-nutritional content of *Ziziphus mauritiana*

The results of essential nutrient contents in the edible part of fresh fruits (*Z. mauritiana*) are shown in Table 12. The highest moisture content of the fresh *Z. mauritiana* fruit was found in matured (5.72%) and the lowest was ripe (3.55%), however, it is lower than the moisture contents of 9.69% reported by Abubakar *et al.,* 2017 for *Z. mauritiana* of Nigeria. But it shows a highly comparable result (5.16) of wild fruits of *Z. mauritiana* reported by Keta, 2017. This is due to the moisture content in this study was determined in the dry base. Even though water is an essential compound of many foods, the low moisture content of the *Z. mauritiana* is an indication of good storage quality with a minimal fungal or microbial activity that does not permit the growth of molds in the sample or sample product (Hassan and Umar, 2004).

The ash content range between 6.15 and 6.227% for matured and the lowest in 4.75%- 4.84% for ripe *Z.mauritiana* fruit in this study. These results are highly comparable with 5.81% reported by Abubakar *et al.,* 2017 for *Z.mauritiana* in Nigeria and 6.16 for *Z.mauritiana* reported by Keta, 2017. High ash content indicates that the fruit contains nutritionally more important mineral elements (Umar *et al*., 2007).

The protein content in ripe *Z. mauritiana* (between 10.84 and 11.44 %) and matured *Z. mauritiana* (between 8.75 and 9.35 %) was higher than *Z.mauritiana* of Nigeria, which is 4.96% (Abubakar *et al.,* 2017) and 6.16 of *Z.mauritiana* reported by Keta, 2017. Therefore, *Z. mauritiana* of this study shows high protein content than the amount reported in the above-mentioned studies.

The fiber content was in the range between 1.63-1.88% and the matured *Z.mauritiana* had the highest content. This result is very similar to that reported by Keta, 2017 which is 1.67 for crude fiber. However, the result is lower than *Z.mauritiana* of Nigeria (23.34%) reported by Abubakar *et al.,* 2017.

The percentage of fat content in matured fruits ranged from 5.45 to 5.7whereas in ripe fruits the range was from 3.47to 3.93 (Table 2). This is also lower than that reported by Abubakar *et al.,* 2017 for *Z. mauritiana* of Nigeria (15.75%).

According to the result found in this study, the ripe *Z. mauritiana* fruit shows the lowest moisture content, ash, crude fat, and also comparable value of fiber and protein content compared to matured *Z. mauritiana* fruit and from other studies as shown above. This variation is perhaps due to the geographical, environmental, and species type of the compared species. Nevertheless, this indicated that ripe fruits have good storage quality with a minimal fungal or microbial activity that does not permit the growth of molds in the sample or sample product. However, it shows the lowest nutritional and anti-nutritional composition.

Table 13: Characteristics of mature and ripe *Ziziphus mauritiana* fruit

Rep.	Status	MC%	Ash%	CF	F	Nitrogen%	Proteins,%	PHY	TAN
1	Ripe	3.85	4.75	3.47	1.88	1.78	11.14	100	9459
2	Ripe	3.55	4.84	3.93	1.83	2	11.44	103	9257
3	Ripe	3.7	4.76	3.7	1.85	1.5	10.84	101	9358
1	Matured	5.72	6.22	5.45	1.63	1.45	9.05	321	11251
2	Matured	5.42	6.15	5.7	1.74	1.7	9.35	310	11478
3	Matured	5.57	6.19	5.57	1.68	1.2	8.75	316	11364

Ripe: a stage at which the fruit is ready to be harvested, **Matured:** a stage at which the fruit is ready for consumption **MC:** Moisture content, **CF:** Crude fat, **F:** Fiber, **PHY:**Phytate, **TAN:** Tannin

Z. mauritiana showed 100-103 and 310-321 phytate content for ripe and mature respectively. On the other hand, *Z. mauritiana* showed 9257-9459 and 11251-11478 tannin content for ripe and mature. The result in this study was very high compared to the result reported by Umaru*et al.,* 2007 and Parmodini and Uday, 2014 for Indian Jijube.

Mineral content

The macro and micro-elements of the investigated wild fruits are shown in Table 3. The analysis of minerals in matured *Z. mauritiana* fruits indicated that potassium (226.6955 mg per 100 g of edible part) was the most abundant among the macro elements, followed by calcium (1.977 mg per 100g of the edible part) and sodium (0.34609 mg per 100 g of the edible part). The potassium content of Z. *mauritiana* fruits was higher than the rest mineral contents determined in this study. The study shows high potassium content and lowers calcium and sodium content than that of *Z.mauritiana* of Nigeria reported by Abubakar *et al.,* 2017.

Regarding the microelements, the quantification results of the fruits indicated that the fruits contained a large amount of magnesium (0.22440 mg per 100 g of the edible part), followed by iron (0.039 mg per 100 g of the edible part) and zinc (0.02059 mg per 100 g of the edible part. These results are comparable with *Z.mauritiana* of Nigeria that shows 0.018 for Iron and

0.003 for Zinc but it's lower than magnesium 4.20 (Abubakar *et al.,* 2017). Our results in mineral contents (Na, K, Ca, Mg, and P) are comparable with that of the findings of Keta, 2017.

Table 14: Mineral composition of matured Ziziphus mauritiana fruit

Content	Dry weight (mg/100 g)
Zinc	0.02059
Calcium	1.977
Iron	0.039
Potassium	226.6955
Magnesium	0.22440
Sodium	0.34609

Conclusion and Recommendation

The Z. mauritiana packed in a cold box had lesser bruising damage, weight loss and had better quality in terms of physical injuries, weight loss, and decay as compared to those packed in wooden boxes and a nestable plastic crate. The matured *Z. mauritiana* fruit has a high proximate, anti-nutritional and mineral value and bioactive potential. It contains acceptable amounts of moisture content (5.72%), ash content (range between 6.15 and 6.227%), protein content (between 8.75 and 9.35 %), fiber content (between 1.63% and 1.74%), fat content (between 5.45% and 5.7%), phytate content (310 and 321) and tannin value (between 11251 and 11478). The analysis of minerals in matured *Z. mauritiana* fruits indicated that it has an acceptable amount of potassium (226.6955 mg per 100 g of edible part), calcium (1.977 mg per 100g of the edible part), sodium (0.34609 mg per 100 g of the edible part), magnesium (0.22440 mg per 100 g of the edible part), iron (0.039 mg per 100 g of the edible part) and zinc (0.02059 mg per 100 g of the edible part). In conclusion, the results indicate that the *Z.mauritiana* fruit pulp, which is popularly used by the local communities, contained appreciable amounts of nutrients and minerals and can serve as useful food and nutrients deficiency supplements.

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Effectiveness of Used Motor oil and Sawdust Extract as Control Measures on three Lumber Species against Subterranean Termites and Fungal Damage

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Abstract

Damage of biodeterioration agents (Termite and fungi) on forest products including lumber and bamboo-based products in the areas of construction and wood industry sectors in Ethiopia is a serious problem. A research was conducted on the natural durability of *Eucalyptus pilularis, Eucalyptus viminalis,* and *Trichilia dregeana* lumber species, and the effectiveness of control measures against subterranean termites and fungal attack. A total of 165 lumber samples (stakes) having dimensions of 2 x 5 x 50 cm were treated using used motor oil with non-pressure treatment application methods namely hot and cold dipping and brushing. Stakes of *T. dregeana* lumber were treated with their sawdust extract using the hot and cold dipping method. Treated stakes were taken and installed at Bako, Adami Tulu, and Meisso grave-yards research stations. Damage of subterranean termites and fungi varies with lumber species, control measures, graveyard stations, and length of exposure years to biodegrading agents. Mean termites and fungal damage on stakes of *E. pilulalris* treated with used motor oil using hot and cold dipping method was 48% while that of fungi was 20.5% at five and half years. *E viminalis* stakes treated with used motor oil were damaged 55% by termites and 80% by fungi. Brushing with used motor oil and hot and cold dipping with sawdust extract from the *T. dregeana* was not better than the untreated control. *E viminalis* control stakes were more damaged (62.5%) by termites than *E. pilularis* (55%) and *T.dregeana* (60%) stakes. *E.viminalis* stakes were more damaged by fungi while *E. pilularis* and *T. dregeana were* damaged by termites. In general, the non-pressure method using used motor oil treatments increases the service life of lumber stakes up to four times compared to the untreated lumber stakes.

Keywords: Biodeteriorating agents, control measures, fungi, hot and cold dipping, lumber stakes, natural durability

Introduction

Damages caused by biodeteriorating agents (Termites, fungus, beetles, and marine borers) on forest products being utilized by construction and wood industries are serious problems that led to, destruction of valuable indigenous lumber species such as *Juniperus procera*, *Hagenia abyssinica*, *Cordia africana*, *Podocarpus falcatus,* and *Pouteria adolfi-friederici*. Biodeterioration damage is among the overlooked major causes (natural and seasoning defects, mechanical wear, and weathering) of the destruction of forest products in the country.

The potential damage of termites and fungi (families of Basidiomycetes-brown and white rots), (Ascomycetes and Deuteromycetes -soft rots) on forest products (wood and bamboo) is an important economic consideration throughout the tropics both in the selection and growth of plantation species, manufacturing and utilization of the resulting wood products.

Subterranean termites (Macro-and-microtermitinae) have been considered as the major causes for the damage of wooden houses and other constructions in Ethiopia, which led to partial or complete rebuilding in 3-5 years. However, destruction of wood and bamboo-culms-based constructions with soil and moisture contact applications in the different parts of the country have occurred, even within 1-2 years short time, which has been caused by subterranean termites and/or fungal mutual attack (Nicholas, 1985), (Wood, 1986), (Desalegn *et al.*, 2003), (Desalegn *et al.*, 2007), (Tadesse and Desalegn, 2008), (Kebede *et al.*, 2011), (Desalegn *et al.*, 2012), (Desalegn, 2013), (Desalegn *et al*., 2015), (Desalegn, 2015).

In Ethiopia, research activities have been carried out to evaluate termite and fungal damages on lumber and bamboo culms and the effectiveness of control measures against biodegrades. Moreover, these research activities have been conducted in a few agroecological zones and localities of the country and majority for short periods, less than five years (Wood, 1986), (Cowie, 1990), (Tsegay Bekele, 1996), (Desalegn *et al.*, 2003), (Desalegn *et al.*, 2007), (Wubalem Tadesse and Desalegn, 2008), (Kebede *et al.*, 2011), (Desalegn *et al.*, 2012), (Desalegn, 2013), (Desalegn *et al*., 2015), (Desalegn, 2015).

The need for treatments on lumber and bamboo culms is to increase the service life of forest products and their aesthetic values, thereby decreasing frequent harvesting of the available scarce resource. They are also important to replace and maintain the degraded lumber and bamboo culms-based structures and to minimize and keep under the economic threshold. The lumber tree species selected for the study were *E. pilularis* and *E. viminalis*, which are home-grown exotic species, and T. *dregeana* an indigenous tree species. These species are fast-growing, good for plating on large scale, and sustainable utilization in the country. The lumber of *E. viminalis* is non-durable with permeable sapwood and heartwood which is extremely resistant to impregnation (Webb *et al*, 1984), (Brink, 2008b).

There is no adequate information in this regard related to the other species. The odor from *T.dregeana* lumber duringplanning and cross-cutting at Forest Products Innovation Research and Training Center was very irritating, sneezing, and was causing headache to the processors. The basic lumber characteristics of these tree species as alternative construction and industrial materials including natural durability and control measures against subterranean termites and fungal damage were not yet known by the development sectors, construction industry, and end-users in the country.

A research was conducted on the natural durability of lumbers from these species and the effectiveness of control measures against subterranean termites and fungal attack and the objectives of the study were to: (i) investigate natural (graveyard) durability of *E. pilularis, E. viminalis,* and *T. dregeana* sawn lumber species at fields (outdoors), (ii) evaluate the performance of control measures (used motor oil and sawdust extract from *T. dregean*) against biodegrades and application techniques that can improve natural durability and prolonged utilization of the three lumber species in their respective growing areas and similar sites.

Materials and Methods

Descriptions of the study sites

The study sites are compounds of Adami Tulu Agricultural Research Center, Bako Agricultural Research Center, and Miesso research station. The agroecological conditions of Adami Tulu Agricultural Research Center are hot to warm sub-humid (Mid rift valley) and that of Bako Agricultural Research Center is mid-altitude (sub-humid) and Miesso belongs to hot to-warm arid-lowland plains. Locations of the three study sites (hereafter, graveyard research stations) are indicated in figure 14 on the map of Ethiopia.

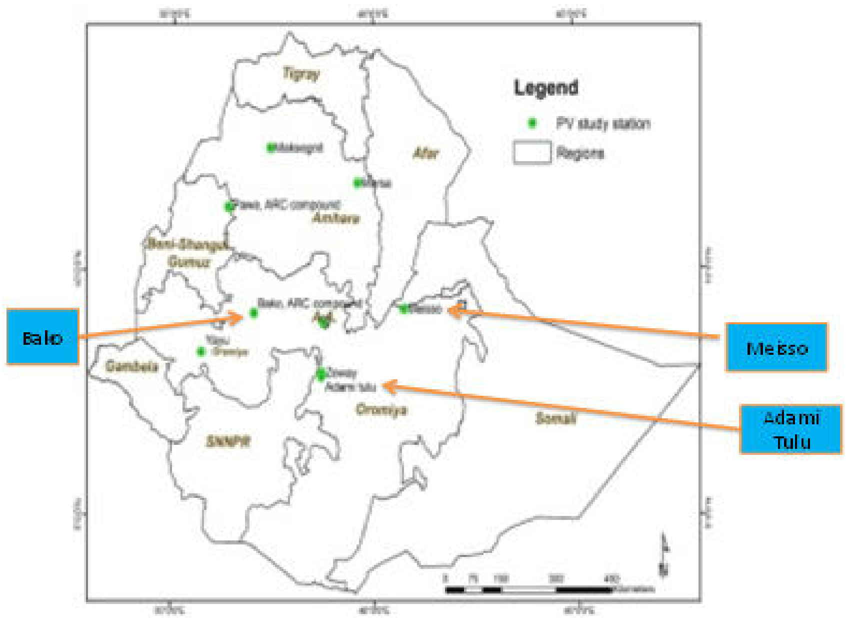

Figure 14: Location of graveyard research stations on the map of Ethiopia

Study species

The study lumber tree species were *Eucalyptus pilularis* Sm. and *Eucalyptus viminalis* Labill. [both belongs to the family Myrtaceae] and *Trichilia dregeana* Sond [Family: Meliaceae] that have fast growth, high yield (*E. viminalis* 10-20 m^3/ha/year), good performance (height, diameter, and clear bole), having versatile lumber and non-timber forest products, socio-economical/ cultural and ecological benefits and services, good site adaptability and coppice ability (*E. pilularis* and *E. viminalis*) in the country.

E. pilularis (blackbutt, pilularis gum) is a tree up to 70 m tall, with bole up to 4.1 m in diameter (Brink, 2008a). In Ethiopia, *E. pilularis* (Figure 15a) is available at the former research trial stations of Central Ethiopia Environment and Forest Research Center (CEE-FRC) namely Suba, Shashemene, Asella, and Belete. *E. Pilularis* has easy regeneration, quick growth, and fire-resistant abilities (http://www.publish. csiro.au/samples/ euclidsample/html/ Eucalyptus_ pilularis.htm), (http://en.wikipedia.org/ wiki/Eucalyptus _pilularis).

E. viminalis is an evergreen tree species up to 50 – 90 m tall, bole up to 120-150 cm in diameter (Brink, 2008b). *E. viminalis* is resistant to fire (Brink, 2008b). In Ethiopia, *E. viminalis* (Figure 15b) was planted at the former CEE-FRC research stations, namely, Suba, Shashemene, Asella and Belete research stations (Mihertu, 2004).

Trichilia dregeana is a tree species that can attain a height of up to 35 m, the tall main stem assuming a relatively straight trunk dividing into large branches and sometimes buttressed up to 1.8 m in diameter (Thirakul, 1993), (Bekele, 2007). *T. dregeana* is an excellent feature plant that is fast-growing and provides great shading for coffee and other perennial crops (http://www.gardeningeden.co.za/plants-trichilia-dregeana.html).

2A 2B 2C

Figure 15: Tree species with the clear bole of E. pilularis, E. viminalis and T. dregeana

Harvesting, log sawing, and lumber stakes preparation for laboratory and field tests

The selected matured sample trees of *E. pilularis, E. viminalis* and *T. dregeana* were harvested from three different sites (Shahemene/ Hamulu, Asella/ Elena, and Dedessa river area, respectively) having 10 m^3 from each species. The harvested logs were representative of merchantable log sizes with good morphological quality, straight and cylindrical stem, relatively free from visible defects. The selected trees were felled, cut into a series of 2.5 m long logs, and up to a top merchantable diameter of 20 cm. The sample trees of *E. pilularis, E. viminalis* and *T. dregeana* had a mean height of 27, 36, and 15 m, respectively, and the mean diameter at breast height (DBH) was 50, 39, and 210 cm, respectively.

Harvested logs of *E. pilularis, E. viminalis* and *T. dregeana* while green (48.25%, 56.1%, and 65.45% moisture content, respectively) were transported to Addis Ababa, Forest Products Innovation Research and Training Center for testing. All the logs received proper handling during storage, transportation, and processing. Logs were sawn to 3 cm thick boards using a mobile circular sawmill by applying the flat (through-and-through) type of sawing method. This sawing method was used to obtain approximately equal proportions of sapwood and heartwood. The lumber was seasoned to about 15% MC to avoid discoloration and deterioration. A total of 165 lumber stakes having dimensions of 2 x 5 x 50 cm were prepared for the study.

Treatments applied on the sample lumber stakes

Two treatments namely used motor oil and sawdust extract was applied using non-pressure methods (hot and cold dipping, and brushing) to treat the lumber stakes against biodegrades.

Hot and cold dipping of lumber stakes

For the treatment of stakes with soil-borne type preventive measure namely used motor oil (UMO) was used. The stakes were treated using the hot and cold dipping (HCD) open tank method or thermal process (FAO, 1994) and brushing. In the case of *T. dregeana* lumber, sawdust extract from *T. dregeana* using hot and cold dipping techniques was applied in addition to UMO using HCD application method. The stakes were submerged in a dipping tank containing 25 litres of cold UMO. The fire was burned under the dipping tank and the oil was heated gradually to about 90°C to reduce the viscosity of the oil and maintained for four hours (FAO, 1994). The treated stakes were withdrawn from the dipping tank after one-day cooling. Finally, the stakes were cleaned from surplus oil using cloth rags and were air-seasoned for a week before installation at grave-yard stations.

Brushing of lumber stakes

UMO brushing was applied to half size of the stakes having a dimension of 2x5x50 cm. The treated stakes were left in the air for a week to dry.

Control lumber stakes

Lumber stakes as untreated controls for testing the natural durability of the lumber species were not treated with UMO and sawdust extracted from *T. dregeana* lumber. The natural durability of lumber species and performance of control measures were expressed from durable to very perishable based on the modified and adapted grades (Eaton and Hale, 1993).

Lumber stakes installation

The stations for the graveyard durability test were demarcated with an area of about 20 x 20 m² and fenced with barbed wire and live vegetation. For the installation of lumber stakes, pits were dug 25 cm deep having a spacing of 25 cm between the stakes and 50 cm between rows. The stakes were labeled and tagged with identification codes and were installed systematically in the prepared pits with half their lengths (25 cm) in the ground and the other half remaining above the ground (Figures 16 and 17).

3A 3B

Figure 16: Pictures showing: E. pilularis stakes (3A) and biodegraded (3B) at Bako Research Station

4A 4B

Figure 17: Pictures showing T. Dregeana stakes installed at Adami Tulu research station

Tests on the natural durability of stakes, performance of control measures, and application methods were conducted simultaneously at the three stations.

Evaluation of lumber stakes deterioration at trial stations

The deterioration rate of each lumber species stake against subterranean termites and fungal attacks were determined using visual inspection/observation supported by sounding and indenting methods. Earthen tunnels, termites mud tubes, and exit holes or galleries on the stakes were used to signify the presence and damage of subterranean termites. Fungal decay was characterized by color changes, softening, brashness, brittleness, and the development of hype growth/decayed external appearance (assessed visually) were used to indicate fungal damage (Nicholas, 1985), (Eaton and Hale, 1993).

The inspection and performance evaluation (data collection) of untreated and treated stakes with control measures was carried out at three, six, and twelve months after installation of the stakes and every year thereafter (Willeitner and Liese, 1992). Grades from one to five (1-5) were adapted and used to determine biodeterioration of lumber research stakes: 1= sound, no decay and/or termite attack (100% resistance), 2 = local, superficial/ moderate (75% resistance), (3= slight, limited (50% resistance), 4= sever and deep (25% resistance), (and 5= failure/complete attack (0% resistance) (Gjovik and Gutzmer, 1986), (Willeitner and Liese, 1992), (Eaton and Hale, 1993), (Highley, 1995), (Desalegn *et al.*, 2003), (Desalegn *et al.*, 2007).

During the inspection, mostly after the rainy season, each stake was carefully removed from its pit and the presence and extent of attack by termites and/ or fungi were assessed, evaluated, and recorded before its re-installation into the pit. Inspection at the trial station was continued until 50% of the underground parts of the untreated stakes were completely degraded and/ or fell to the ground.

Results and Discussion

The appearance of lumber tree species

Heartwood of *E. pilularis* has been yellowish brown to light brown. The heart wood of *E. viminalis* has been pale yellow or pink and was not clearly demarcated from sapwood (Figure 18) (Brink, 2008b). The wood of *T. dregeana* was a pale pink. The odor from *T.dregeana* lumber while planning and cross-cutting has a very irritating odor, sneezing, and headache to the processors.

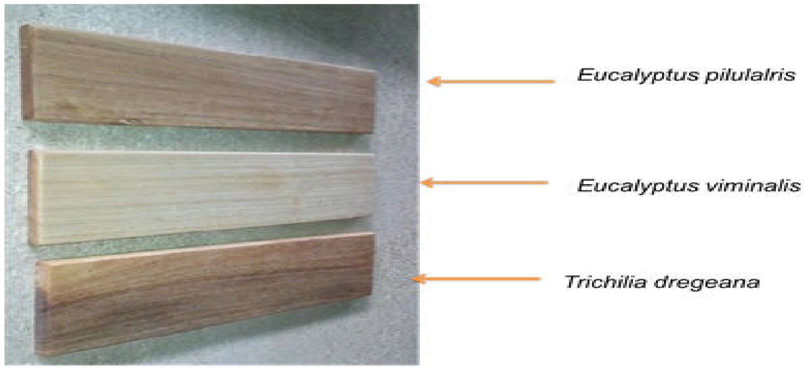

Figure 18: Lumber pictures of the studied tree species

Density of Lumber species

The density of *E. pilulalris* (780 kg/m^3) and that of *E. viminalis* (810 kg/m^3) at 12% moisture content were classified as very heavy (650-800 kg/m^3). The density of *T. dregeana* (530 kg/m^3) at the same 12% moisture content classified as light density (300-450 Kg/m^3) lumber species (Desalegn and Kaba, 2017), (Kaba and Desalegn, 2020).

Biodegrades damage and effectiveness of control measures

Subterranean termites and fungal damage rates vary with lumber species, treatments, trial stations/ locations, and length of exposure years to biodegrading agents (Table 15 and Figure 19). Subterranean termites damage on lumber stakes of *E. pilulalris* treated with used motor oil (using both hot and cold dipping and brushing methods) was 48% while that of fungi was 20.5%, at five and half years. Untreated control stakes were more attacked (60%) by subterranean termites and 27.5% by fungi.

E. viminalis lumber stakes treated with used motor oil were damaged to 55% by subterranean termites and 80% by the fungal attack at four and half years. Subterranean termites and fungal damage of treatments and at all grave-yard research stations (Bako, Adami Tulu, and Meisso) are presented in Table 15 and figure 19.

Table 15: Mean subterranean termites and fungal damage per treatment at Bako, Adami Tulu, and Meisso research stations

Treatments against Controlling damage	Lumber Species	Research station	Duration of graveyard tests (Year)	Mean subterranean termites damage (%)	Fungal damage (%)
B	EP	B	5.5	57.5	7.5
B	EP	AT	5.5	47.5	47.5
B	EP	M	5.5	40	7.5
B	EV	B	4.5	2.5	82.5
B	EV	AT	4.5	75	72.5
B	EV	M	4.5	87.5	87.5
B	TD	B	4	97.5	65
B	TD	AT	4	80	82.5
B	TD	M	4	47.5	52.5
C	EP	B	5.5	70	22.5
C	EP	AT	5.5	52.5	47.5
C	EP	M	5.5	57.5	12.5
C	EV	B	4.5	10	90
C	EV	AT	4.5	80	85
C	EV	M	4.5	100	50
C	TD	B	4	77.5	72.5
C	TD	AT	4	55	42.5
C	TD	M	4	45	2.5
D	EP	B	5.5	47.5	12.5
D	EP	AT	5.5	55	50
D	EP	M	5.5	42.5	-
D	EV	B	4.5	50	82.5
D	EV	AT	4.5	82.5	85
D	EV	M	4.5	92.5	7.5
D	TD	B	4	-	-
D	TD	AT	4	-	-
D	TD	M	4	40.	52.5
E	TD	B	4	92.5	100
E	TD	AT	4	60	40
E	TD	M	4	100	67.5

Note: Intact against fungal damage; Study tree species EP-*Eucalyptus pilularis*, EV-*Eucalyptus viminalis* and *TD-Trichilia dregeana), (*control measure treatments: D- Hot and cold dipping treatment with used motor oil, B- Brushing treatment with used motor oil, C- controls (Untreated stakes) and E- Sawdust extract from *T.dregeana), (* graveyard locations: B- Bako (West Shewa), AT-Adami Tulu (East Shewa) and M-Meisso (Eastern Hararge) as located on the map of Ethiopia (Figure 1)), (duration of lumber stakes at graveyard research stations: *Eucalyptus pilularis*(5.5 years), EV-*Eucalyptus viminalis*(4.5 years)and *TD-Trichilia dregeana*(4 years)

All treatments on *E. viminalis* stakes were less effective in resisting subterranean termites and fungal damages. This could be attributed to the high density (810 kg/m^3) of the species that could lead to less absorption and retention of treatments. Lumber stakes of *T. dregeana* treated with used motor oil using hot and cold dipping treatment method were damaged to 15% by subterranean termites and 17.5% by the fungal attack at year four. *E. viminalis* stakes treated with the same treatment using brushing were damaged to 75% by subterranean termites and 67.5% by fungal attack. Brushing with used motor oil and sawdust extract from the *T. dregeana* was less effective on *T. dregeana* lumber, not better than the untreated stakes.

Subterranean termites at Bako station were Microtermes and *Pseudocanthotermes militaris* while that of Adami Tulu, having the same agroecology as that of Zeway, was dominated by subterranean and mound-building termite species, *Marcotermes bellicosus* (Zewde Berhane and Yusuf, 1974), (Desalegn*et al.*, 2003), (Desalegn*et al.*, 2007). The subterranean termites at Meissio station were Microtermes.

E. viminalis untreated stakes were more damaged (62.5%) by subterranean termites than E. pilularis (55%) and *T.dregeana* (60%) stakes. The treatment using *T. dregeana* sawdust extract was not better than the untreated control of *T. dregeana* lumber.

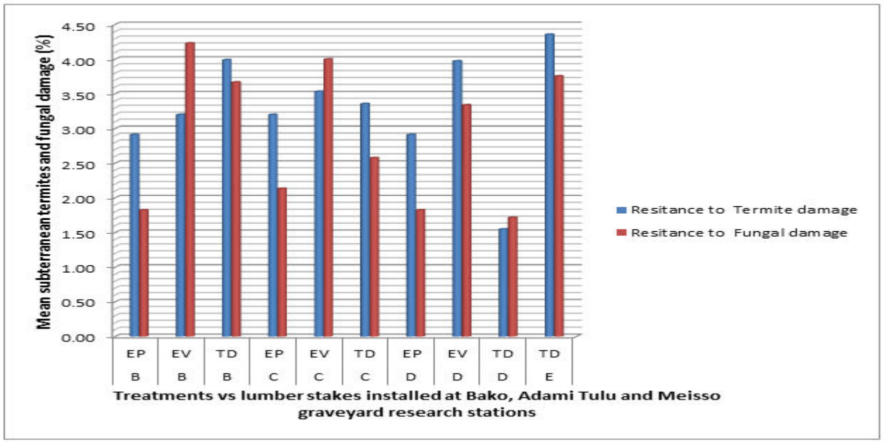

Figure 19: Mean subterranean termites and fungal damage (%) by treatment and locations at Bako, Adami Tulu, and Meisso graveyard research stations D- Hot and cold dipping treatment with used motor oil, B- Brushing treatment with used motor oil, C- Untreated stake

All treatments on *E viminalis* lumber stakes were less effective in resisting subterranean termites and fungal damages.

Conclusion and Recommendation

Used motor oil treatments using hot and cold dipping methods increased the life of the lumber in-ground and moisture contact up to four times compared to the untreated lumber stakes. Further applied research recommended, involving different commercial and traditional alternative controlling measures, at different graveyard research stations and for a prolonged time to fill the information and technological gaps on natural durability of lumber species, effective control measures and application techniques that can promote rational utilization of the resource in the different agroecological zones of Ethiopia where biodegradation and wood-based products utilization have economic relevance.

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Evaluation of the Chemical Composition and Pulp and Paper making Potential of *Acacia melanoxylon* Grownat Chencha woreda in SNNPR, Ethiopia

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Abstract

This study aimed to investigate the chemical composition of *Acacia melanoxylon* and its potential for pulp and paper making. The samples consisted of 6 trees, and sample discs were taken at 10%, 50%, and 90% along the merchantable tree height. Chemical compositions were determined and their change with tree height was evaluated. All chemical analyses were determined following the standards outlined in the American Society for Testing Material (ASTM) except, cellulose and hemicellulose content which was conducted using Kurschner-Hoffer and Alkali extraction method, respectively. Data were analyzed using one-way analysis of variance and Duncan multiple range test for mean comparison at $\alpha = 0.05$. The results of the study showed that the overall average values of chemical composition were 45.02%,21.94%, 23.79%, 5.52%, 3.24%, and 0.48%, for cellulose, hemicellulose, Klason lignin, hot-water soluble extractives, alcohol-benzene extractives, and ash content, respectively. A significant amount of chemical composition variation was observed between the bottom and the top portion of the tree, except, hot-water soluble extractives. Given experimental results, it was observed that tree height had a significant impact on the amount of chemical composition.

Keywords: *Acacia melanoxylon*, Chemical composition, Paper, Pulp, Tree height

Introduction

The worldwide paper consumption is estimated to be 400 million tons per year and is expected to increase to 500 million tons by 2020 (Sharma *et al*., 2013). The global consumption of paper and paperboard products increases continuously due to numerous reasons, which include population growth and industrialization in developing countries (Hurter and Riccio, 1998).

The pulp is produced from hardwood, softwood, and agro-residues. Hardwood and softwood pulping accounts for 95% of the total worldwide pulp production and the rest 5% comes from non-wood raw materials, mainly agro-residues and grasses (Jimenez *et al*., 2005).

The chemical composition of raw materials is the basis for many properties of pulp and paper. Different scholars reported the relationship between chemical composition and pulp and paper properties. For instance, Kiaei *et al.* (2014) reported that cellulose content has a positive relationship with pulp quality and high cellulose content gives high mechanical strength for pulp, especially tensile strength (Madakadze *et al*., 1999). According to Ates *et al*. (2008), high extractive content will be an indicator of low pulp yield as well as higher chemical consumptions both in pulping and bleaching. Moreover, hardness, bleachability, and other pulp properties, such as color, are associated with the lignin content of the raw material (Malik *et al*., 2004).

In Ethiopia, paper demand is growing by 10 percent every year (ERCA, 2015). For instance, in 2003, the average annual domestic production of paper was 7,266 tons, while in the same year, 127,132 tons of paper was imported which means the average total supply of paper during the period under consideration was 134,398 tons per annum, of which only about 5% was locally produced. Hence, the consideration of some fast-growing wood species in Ethiopia as a potential raw material for pulp production is the right step towards meeting the demand for pulp and paper. In this regard, *Acacia melanoxylon* tree is one of the candidate species for pulp and paper production because of its fast growth, ability to coppice, and adaptation to different agro-ecological zones, and wide range of uses.

Acacia melanoxylon which is locally known as ‘’Omedla’’ is one of the most important multipurpose tree species and found in cooler and wetter upland areas, moist and wet Kolla, Weynadega, and Degaagroclimatic zones of Ethiopia. This species has been used mainly for firewood, charcoal, light construction, plywood, flooring, fence posts, shade, ornamental, windbreak, gum, and tannery. It can coppice from damaged stems and grows fastly on a variety of soils (Bekele, 2007).

Ethiopia fully relies on imported pulps for paper production although there are many indigenous and exotic wood species in Ethiopia that can be used for pulp production (Desalegn*et al*., 2012). This is due to a lack of knowledge and information on pulp properties of different tree species and other limitations (Desalegn*et al*., 2012; CCIDI, 2015).

Before recommending any wood species for pulp and paper production, adequate information on chemical composition is vital since it affects the quality of pulp and paper products (Cao *et al*., 2014). Even though *A.melanoxylon*grows in a wide ecological range and has multiple uses, its potential for pulp and paper products were not known in Ethiopia. Therefore, this study aimed to investigate the chemical compositions of *Acacia melanoxylon* and its potential for pulp and paper production.

Material and Methods

Description of the Study Area

The study sample trees were taken from Chencha woreda of Southern Nations, Nationalities and People Region (SNNPR), which is located 37 kilometers North of Arbaminch town/city, and 500 kilometers from Addis Ababa. It is situated at 37^{o} 26’0” - 37^{o} 40’0” E and 6^{o} 8’0”- 6^{o} 26’0” N longitude and latitude, respectively. The annual rainfall distribution of the area varies between 900to 1200mm (Ogato, 2006).

Sample collection and preparation

Wood discs with thicknesses of 25mm were taken systematically from bottom (10%), middle (50%), and top (90%) portions along with the merchantable tree height (Latib *et al*., 2014).

Table 16: Stem diameter (DBH) and merchantable height of sample trees

Tree No.	Stem diameter (cm)	merchantable tree height (m)
1	25	15
2	26.5	16.5
3	24	17.7
4	28.5	18.5
5	26	15
6	27	17

Thereafter, the collected discs were cut into small strips with a knife and dried. The strips were small enough to be placed in a grinding machine and chips were ground in the Wiley mill. Then, the milled material was placed in a shaker with sieves to pass through a number 40 mesh sieve (450 µm) yet retained on a number 60 mesh sieve (250µm). Finally, each chemical composition analysis was carried according to international standards (Table 17).

Table 17: Standard followed for chemical composition analysis

Chemical composition	Replication	Standards
Cellulose	3	Kurschner-Hoffer
Hemicellulose	3	Direct extraction with aqueous alkali
Klason lignin(72% H_2SO_4)*	3	ASTM D 1106-56
Alcohol-benzene solubility	3	ASTM D 1107-56
Hot-water solubility	3	ASTM 1110-56
Ash Content	3	ASTM D 1102-84

*Klason lignin is the residue obtained after total acid hydrolysis of the carbohydrate portion of the wood.

Experimental design

Sample collection for the investigation of chemical compositions was systematically randomized. Six trees were selected for sample collection and three discs were taken from each tree (bottom (10%), middle (50%), and top (90%)) of the merchantable height. Therefore, a total of 18 discs were taken from six trees. Each chemical analysis was repeated three times.

Data analysis

Statistical analysis was conducted using statistical analysis software (SAS). Differences in chemical composition among the tree heights were analyzed using a one-way analysis of variance. Duncan multiple range tests were used to compare mean values for each chemical composition along with tree height levels at $\alpha = 0.05$.

Results and Discussion

The results showed that the studied species had the highest value of cellulose and Klasonlignin at the top portion of the wood. While, the bottom portion gave the higher value of hemicellulose, alcohol-benzene, hot-water solubility, and ash content (Table 18).

Table 18: Mean and standard deviation of chemical composition along with tree height levels

	Height levels (%)		
Chemical composition (%)	Bottom (10%)	Middle (50%)	Top (90%)
Cellulose	$42.93±0.40^{a}$	$45.10±2.87^{ab}$	$47.03±1.46^{b}$
Hemicellulose	$24.73±0.60^{b}$	$21.56±2.48^{ab}$	$19.51±1.42^{a}$
Klason lignin	$23.13±0.25^{a}$	$23.31±0.10^{a}$	$24.93±0.77^{b}$
Alcohol-benzene	$4.06±0.79^{b}$	$3.19±0.06^{ab}$	$2.46±0.39^{a}$
Hot-water solubility	$5.68±0.30^{a}$	$5.45±0.05^{a}$	$5.42±0.49^{a}$
Ash	$0.56±0.05^{b}$	$0.52±0.025^{b}$	$0.37±0.02^{a}$

The mean of the same row with different superscript are significantly different (p<0.05)

Cellulose Content

Table 18 shows that the cellulose content of *A. melanoxylon* increased from the bottom (42.93%) to the top portion (47.03%). Duncan multiple range tests showed that a significant cellulose content variation was observed between the bottom (10%) of the tree height and the top (90%) of the tree height, however, the top and bottom portions showed insignificant cellulose content variation from the middle (50%) of the tree height at $p<0.05$. In this study, an increasing amount of cellulose content was observed from bottom to top which is similar to the result reported by Amini *et al*. (2006) on *A. mangium.* The mean cellulose content (45.02%) is similar to other acacia species such as in *Acacia tortilis* (46.92%), and *Acacia origina* (45.54%) (Nasser and Aref, 2014). However, the results lower than the amount reported for *A.mangium* (48.42%) (Amini *et al*., 2006) and *E.globulus* (50%), *E. urograndis* (48.6%) (Evtuguin and Neto, 2007).

Cellulose content directly affects the physical and mechanical properties of a paper sheet (Ghalehno and Nazerian, 2013). Furthermore, high cellulose content gives a high pulp yield reported by Khoo and Peh (1982). According to Abdul-Khalil *et al*. (2006), cellulose content close to or above 40% was satisfactory for pulp and paper production. Therefore, *A. melanoxylon* having 45% cellulose content is suitable to use as a raw material for pulp and paper production.

Klason Lignin Content

Hardness, bleach ability, and other pulp properties, such as color, are associated with the lignin content (Malik *et al*., 2004). Softwoods contain around 25-33% lignin and in hardwoods, it can vary between 18- 25% (Bowyer *et al*., 2007).

Klason lignin content of *A. melanoxylon* wood increased from the bottom to top of the tree portion. Duncan multiple range tests showed that Klason lignin of both bottom and middle of tree portions significantly varies from the top portion at $p<0.05$.

The mean of Klason lignin in *A. melanoxylon* obtained in this study (23.79%) was higher than the report of Santos *et al*. (2012) (21.10%) and Lourenco *et al*. (2008), (18.6%) on the same species. The difference in Klason lignin may be due to age and growth environment variation since they affect wood chemical properties(Smook, 1992). However, the result obtained was similar to other *Acacia* species which was studied by Marsoem and Irawati, 2016). They found in the range of 21.6-24.3% and 21.6-24.6% for *A. mangium* and *A. auriculiform* is respectively.

Pulpwood requires a low lignin content since lignin content has been negatively correlated with pulp yield and fiber strength (Amidon 1981; Dutt and Tyagi, 2011). Lignin also causes the paper to become fragile, and because of light oxidation, which results in the production of color bands, it gives the paper a dark or yellowish look (Ghalehno and Nazerian, 2013). According to Ververis *et al*. (2004), the raw material with Klason lignin less than 30% has been accepted for pulp and paper production. Therefore, *A.melanoxylon* of the study site were suitable in terms of its Klason lignin for pulp and paper making.

Hemicellulose

According to Bakker and Elbersen (2005), low hemicellulose content in raw material decreases water-absorbing capacity and thus minimizing the duration of the pulping activity. Duncan multiple range tests showed that the bottom and top portions significantly varied in hemicellulose content, however, the bottom and top portions had no significant variation with the middle portion at $p<0.05$. The mean hemicellulose content obtained in this study (21.93%) was similar to *Acacia tortilis* (21.10%) and *Acacia etbaica* (21.37%) (Nasser and Aref, 2014). However, it is lower than in *A. mangium* (35.5%) (Amini *et al*., 2006). The difference in hemicellulose content may be due to species, age, and growth environment difference of sample trees since it affects chemical compositions of wood (Smook, 1992).

Extractive Content

Extractives of raw material are undesirable parts since they can have a negative impact on the pulping and bleaching operations. For example, low extractives content was related to higher pulp yields (Lourenço*et al*., 2008). According to Ates *et al*. (2008), high extractive content is an indicator of low pulp yield as well as higher chemical consumptions both in pulping and bleaching.

Hot -Water Soluble Extractives

The result showed that hot-water extractives of *A.melanoxylon* were higher at the bottom portion (5.68%) and minimum at the top portion (Table 18). However, hot-water extractives were not significantly affected by tree portions at $p<0.05$. The result was similar to tropical pulpwood species: *Gmelina arborea* (5.20%), *Leucaena leucocephala (*5.60%) (Onuorah*et al*., 2015). Therefore, it is suitable for pulp and paper making.

Alcoholbenzene soluble Extractives

Based on Table 18, alcohol-benzene extractives were higher at the bottom (4.06%) than the middle and the top portion. Duncan multiple range tests showed that alcohol-benzene extractive content varied significantly between the bottom and top portions.

The overall mean obtained in the alcohol-benzene extractive (3.24%) was similar to the previous report of Lourenço*et al*. (2008) (3.96%) however, lower than the report of Santos *et al*. (2012) (6.51%) in *A.melanoxylon.* The differences could be due to differences in methods in which the former studies used alcohol-toluene solution instead of the alcohol-benzene solution. The result was higher than *A.mangium* (1.77%) (Amini *et al*., 2006).

Ash Content

According to table 18, the high ash content was observed in the bottom portion (0.56%) while, the lowest value in the top portion (0.37%) of *A.melanoxylon*wood*.* Ash content variation was not significant between the bottom and a middle portion, although the bottom and the middle portions showed a significant variation to top portions at $p<0.05$ (Table 18). The overall mean percentage of ash content obtained in this study (0.48%) is similar to the previous report of Santos *et al*. (2012)(0.43%) on *A.melanoxylon*, however, lower than *Acacia tortilis* (1.94%), *Acacia origina* (1.99%) (Nasser and Aref, 2014) and *E.globulus* (1.0%)(Miranda *et al*., 2012). The difference may be due to species, age, and growth environment difference of sample trees since it affects chemical properties of the wood (Smook, 1992).

The result showed that the portion of wood with higher density contributed to the increase in the percentage of ash content because of the transformation of sapwood into heartwood from the bottom to the top portion of the tree. Panshin and Zeeuw (1980) reported that the bottom portion has more heartwood and higher density, consequently higher ash content compared with a top portion of the tree.

Table 19: Comparison of the chemical composition of Acacia melanoxylon wood with other papermaking raw materials

Species	Chemical composition (%)					
	Cellulose	KL	Hem	AB	HW	Ash
A.melanoxylon(*)	45.02	23.79	21.93	3.24	5.52	0.48
E. globules (a)	56.90	17.80	n.a	1.40	n.a	1.0
A.mangium(b)	48.34	19.78	35.71	1.77	n.a	n.a
Beech wood(c)	45.80	21.90	n.a	n.a	n.a	0.4
Bagasse fiber(d)	42.34	21.70	n.a	1.85	7.42	2.10
Cotton stalk(e)	43.80	17.60	n.a	n.a	n.a	3.50
O.abyssinica(f)	52.06	22.47	16.90	5.60	6.80	5.30

(*) This study: (*): (a) (Miranda *et al*., 2012): (b) (Amini *et al*., 2006): (c) (Demirbas,1998): (d) (Agnihotri *et al*., 2010): (e) (Ververis *et al*., 2004): (f) (Tolessa*et al*., 2017)

Notes:_*KL: Klason lignin, AB: Alcohol-benzene solubility, Hem: Hemicellulose, HW: Hot-water, n .a. not available*

According to Ogunsile *et al*. (2009), high ash content is undesirable for pulping as they affect normal alkali consumption and create problems at waste liquor recovery. The average ash content percentage of *A.melanoxylon* obtained in this study (0.48%) was lower than other tropical pulpwood species; *E.globulus* (1.0%), *Gmelinaarborea* (0.84%), *Leucaena leucocephala* (2.50%) (Onuorah *et al*., 2015) which showed better property for pulp and paper production.

Conclusions and Recommendations

The basic information on the chemical composition of *Acacia melanoxylon* as a source of fibrous raw material for pulp and paper production was examined. All chemical compositions significantly varied between the bottom and a top portion except, hot-water extractives. Compared to the wood properties related to pulp and paper quality with those of Eucalyptus and other Acacia species currently used for commercial pulpwood, *A.melanoxylon* showed better chemical compositions related to pulp and paper. Generally, the result of the study shows that *A. melanoxylon* is found to be a suitable raw material for the pulp and paper industry.

Based on the findings of the study, the following points were recommended:

- Since *A. melanoxylon* grown in Chencha woreda is suitable in terms of its chemical composition for pulp and paper making, attention should be given by tree growers, investors, government, and non-governmental organizations on its plantation expansion.

- In addition to the results obtained in this study, production and testing of its pulp and paper are also needed.
- Research institutes, governments, and non-governmental organizations should give special attention to the evaluation of different raw materials for pulp and paper production.

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Evaluation of Fiber Characteristics and Basic Density of *Acacia melanoxylon* (R.Br.) Grown in Chencha Woreda of Ethiopia for Pulp and Paper Making

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Abstract

In Ethiopia, there are many woody species, however, little is known about their quality for different applications. In this study fiber characteristics and basic density of *Acacia melanoxylon* were investigated as a raw material for pulp and paper making. Six trees from an even-aged stand and similar class diameter were selected randomly. Wood disks were systematically cross-cut from logs along tree height, at the bottom (10%), middle (50%), and top (90%) of the merchantable height and from pith to periphery at near pith (10%), middle (50%) and near bark (90%) of disk radius. Fiber maceration and basic density were determined, by 50% nitric acid solution and water displacement method, respectively. All the data were analyzed using a two-way analysis of variance at $\alpha = 0.05$. The result showed that the overall mean values were 1.04 mm for fiber length, 21.60µm for fiber width, 15.36 µm for lumen diameter, 3.75µm for cell wall thickness, 0.48 for Runkle ratio, 48.05% for slenderness ratio, 71.10% for flexibility ratio 0.34 for wall coverage ratio and 0.56 g/ml for basic density. Generally, *Acacia melanoxylon* wood is suitable for pulp and paper production, due to adequate fiber dimension, derived fiber value, and basic density. Therefore, attention should be given to tree growers, government, and non-governmental organizations on the expansion of *Acacia melanoxylon* plantation.

Keywords: Basic density, Fiber dimension, Derived fiber values, Paper production

Introduction

The global paper consumption is expected to increase to 500 million tons by 2025, which is about 1.6% growth a year (Forestindustries, 2013; FAO, 2014). The consumption of paper and paperboard products increases continuously due to numerous reasons, which include population growth and industrialization in developing countries (Hurter and Riccio, 1998).

This ever-increasing demand for paper, forcing countries of the world to find technically and economically viable fiber sources to supplement forest-based resources for pulp and paper production (Jahan *et al*., 2008).

The pulp is produced from hardwood, softwood, and agro-residues. Hardwood and softwood pulping accounts for 95% of the total worldwide pulp production, and the rest 5% coming from non-wood raw materials, mainly agro-residues and grasses (Jimenez *et al*., 2005). The demand for paper and paperboard products in Ethiopia has grown fast with endless development.

For instance, according to ERCA (2015), the demand is growing by 10 percent every and in 2003 average annual domestic production of paper was 7,266tons while in the same year 127,132 tons of paper have been imported which means the average total supply of paper during the period under consideration was 134,398 tons per annum, of which only about 5% was locally produced. Moreover, FA0 (2017) reported that Ethiopia's paper consumption per capita was 1.7 kg/year/person.

Hence, the consideration of some fast-growing wood species in the Ethiopia forest as a potential fiber source for pulp production is the right step towards meeting the demand for pulp and paper. However, before recommending any wood species for pulp and paper production, adequate information on fiber characteristics and chemical composition is important, since they affect the quality of pulp and pulp products (Cao *et al*., 2014).

Fiber characteristics have been considered to be the most important factor for determining the degree of efficiency of wood species in pulping (Ogunwusi, 2000). The strength property of paper depends on the characteristics of its fiber. It is frequently correlated with the physical and mechanical properties of paper and paperboard (Keays *et al*., 2015). Morphological characteristics of fiber, such as fiber length and width, are important parameters in estimating the qualities of pulp (Marques *et al*., 2010).

Basic density influences end-use properties of the solid wood and those of the corresponding fiber products, such as pulp yield and paper quality (Wimmer *et al*., 2002). It is also an indicator of energy consumption during pulping (Li *et al*., 2011). Previously fiber properties and basic density of *A. melanoxylon* and its variability have been studied by different scholars (Tavares *et al*., 2011, Santos *et al.*, 2018, Isaias *et al*., 2005; Santos *et al*., 2006).

There are many indigenous and exotic woody species grown in Ethiopia, which could be considered for their suitability as raw material for pulp and paper production. The usage of species as raw material for pulp, paper, and cellulose-based industries are minimizing every day and the wood imports are exhaust country's foreign currency (Desalegn*et al*., 2012, CCIDI, 2015). In Ethiopia, only very few plant species have been studied as raw materials for pulp and paper products such as *Yushinia alpine* (Tolessa *et al*., 2017).

Acacia melanoxylon is one of the several Australian Acacia species introduced to Ethiopia. These species have been distributed widely in cooler and wetter upland areas, Moist and wet Kolla Weyna Dega and Dega agroclimatic zones and used mainly for firewood, charcoal, timber (light construction, plywood, flooring, fence posts, shade, ornamental, windbreak, gum, and tannery). It is a very fast-growing tree species to a height of 35m and producing hard and valuable timber (Bekele, 2007). This species reproduces mainly by seed, which is known to germinate prolifically after the fire. It also sprouts profusely from root suckers, particularly when the roots are damaged, and readily coppices from damaged stems.

Even though the wide range of use of this species, fast-growing, ability to coppice, and its adaptation to different parts of Ethiopia, its quality in pulp and paper products were not known. Therefore, this study aimed to investigate fiber characteristics and basic density of *A.melanoxylon*for pulp and paper production.

Materials and Methods

Description of the Study Area

The study sample trees were taken from Chencha Woreda, South Nation Nationality People region, which is located 37 kilometers North of Arbaminch, and 500 kilometers from Addis Ababa. It is located 37^{o} 26'0" - 37^{o} 40'0" E and 6^{o} 8'0"- 6^{o} 26'0" N longitude and latitude respectively. The annual rainfall distribution of the area varies between 900 to 1200mm (Ogato, 2006).

Sample collection and preparation for fiber characteristics

Six trees were randomly selected from even-aged stands of *Acacia melanoxylon* plantation following the procedure of ASTM D143-83 standard (1983). Sample trees with very close diameter classes, straight stem, and clear wood were selected.

Table 20: Stem diameter (DBH) and merchantable height of sample trees

No.	Stem diameter (cm)	merchantable tree height (m)
1	25	15
2	26.5	16.5
3	24	17.7
4	28.5	18.5
5	26	15
6	27	17

Samples disks for the test were systematically cross cut from a log along each tree height levels, at the bottom (10%), middle (50%), and top (90%) of the merchantable height (Latib *et al*., 2014) and from each disk sample were taken from pith to periphery at near pith (10%), middle (50%) and near bark (90%) of disk radius to perceive variations in fiber characteristics and basic density from pith to periphery.

For fiber dimension, matchstick-size (1 cm × 0.2 cm × 0.2 cm) was taken and 50% nitric acid was used for maceration processes since it consumes less time and economical method (Mahesh *et al*., 2015). Matchstick-size samples were taken in test tubes, immersed completely in nitric acid solution, and kept in a water bath at 70ºC for 5 to 6 hrs to get separated white-colored.

After cooling, nitric acid was drained and macerated fibers were washed with distilled water and filtered using Whatman Grade 1 filter paper for separation of fibers (Mahesh *et al*., 2015). Two slides were prepared per sample and images were taken by using a camera attached Motic BA210 microscope. Then the dimensions of 50 fibers were measured (Ishiguri *et al*., 2016) using the Motic software.

For cell measurement, the specimen was softened in warm water below 100^0 c for one hour and slices were cut by using a Leica sliding microtome with a thickness of 20µm (Ishiguri *et al*., 2016). Then the slice was immersed into safranin solution and 25%, 50%, 75% of alcohol concentrations, respectively for one minute to remove excess safranin solution that may cause invisibility of cells (Berhanu *et al*., 2016). Finally, the specimens/slice was immersed into xylene for 1 minute and put on the slide (standard 7.5 cm×2.5 cm). The small amount of Canada balsam was dropped and covered using a slide cover and kept to dry.

Then an image was taken with a camera attached Motic BA210 microscope and 30 cells from each distance from pith lumen diameters and cell wall thickness were measured from each distance from the pith (Ishiguri e*t al*., 2016) by using the Motic software. The equations used for the computation of the derived values: Runkel ratio (Ibrahim and Abdelgadir, 2015), slenderness ratio (Samarih *et al.*, 2011), flexibility coefficient (Santos *et al.*, 2018), and wall coverage ratio (Hudson *et al.,* 1998) are expressed as equations 1 to 4.

$$\text{Runkle ratio} = \frac{\text{2XCell wall thickness}}{\text{Fiber Lumen Diameter}} \quad \text{(1)}$$

$$\text{Slenderness ratio} = \frac{\text{Fiber lenght}}{\text{Fiber Width}} \text{x100} \quad \text{(2)}$$

$$\text{Flexibility coefficient} = \frac{\text{Fiber Lumen DiameterX100}}{\text{Fiber Diametere}} \quad \text{(3)}$$

$$\text{Wall coverage ratio} = \frac{\text{2XFiber Wall thickness}}{\text{Fiber Diameter}} \quad \text{(4)}$$

Sample Preparation and determination of basic density

For basic density the specimens of wood were cut at three distances from the pith (10%, 50%, 90% of the radius length) (Mechado *et al*., 2014) by the dimension of 20mm x 20mm x 20 mm according to ASTM D14394 (2000), to perceive variations in basic density from pith to periphery from each disk.

The volume of each specimen was determined by immersing the sample in water containing beaker and water displaced from the beaker (in milliliter) by the submerged sample was recorded. Then each specimen was dried in an oven drying machine at a temperature of 105ºC for 24 hrs and re-weighed until a constant weight was obtained. The oven-dry weight of each sample was measured and recorded. Finally, basic density was calculated by dividing the oven-dry weight of the sample (gm) by volume of displaced water at green(ml).

Experimental Design

Sample collection for the investigation of fiber characteristics and basic density was systematically randomized. Six trees were selected and three discs were taken along height from each tree. Then from each disk, three samples were taken from pith to periphery, at near pith (10%), middle (50%), and near to the bark (90%). Mean value of each height level were calculated from the mean of all the measured value from pith to the periphery of each disk (Tavares *et al*., 2011).

Statistical Analysis

Statistical analysis was conducted using the SAS program in conjunction with analysis of variance. Duncan multiple range tests were used to compare mean values for each fiber dimension, derived fiber values, and basic density along with height levels and from pith to the periphery at $\alpha = 0.05$.

Results and Discussion

Fiber Characteristics

Variation of Fiber Length along with Tree Height and from Pith to Periphery

This study showed that fiber length ranged from 1.01 to 1.07 mm along with tree height and 0.99 to 1.08 mm from pith to the periphery of the disks. It varied significantly along with tree height levels (Figure 20a) and from pith to the periphery at $p<0.05$.

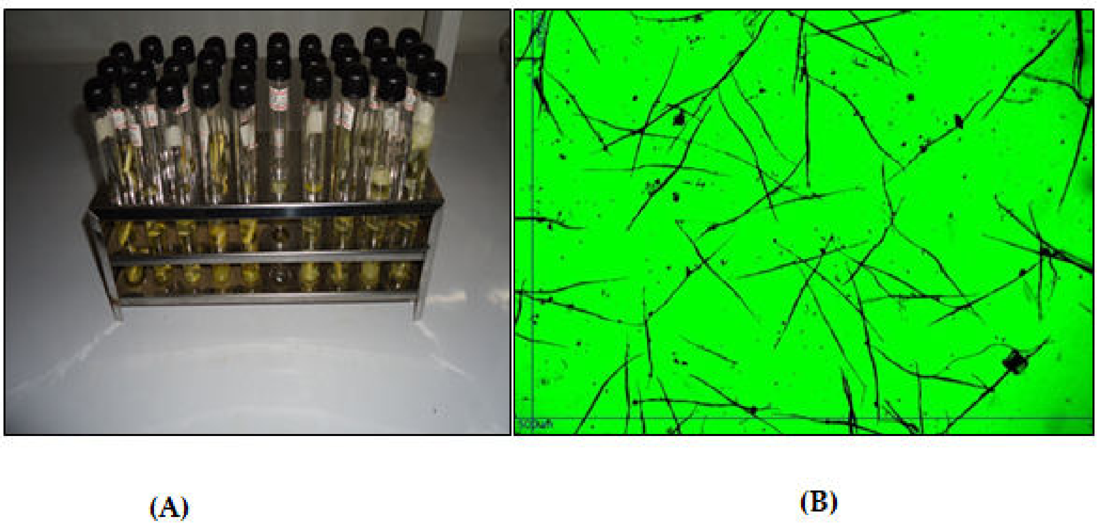


Figure 20: Pictures showing washed fibers by distilled water (A), fiber image (B)

Fiber length decreases from bottom to top portions however, it increases from pith to periphery. A similar pattern of decrease in fiber length from the bottom to the top and its corresponding increase from near pith to the periphery observed in this study had earlier been reported by Tavares *et al*. (2011) on *A. melanoxylon* wood in Portugal. The decreasing trend of fiber length from bottom to the top could be because minimal net photosynthetic activity for cell development at the top is caused by competition for leaf and branch development (Mercy *et al*., 2017). The increase of fiber length from pith to periphery could be explained based on the increase in the length of cambial initials with increasing cambial age and crown formation (Jorge *et al.,* 2000). The cells produced in the primary xylem divide less frequently, thus allowing more time for the fusiform initial section to elongate longitudinally and transversely (Horack *et al*., 1999).

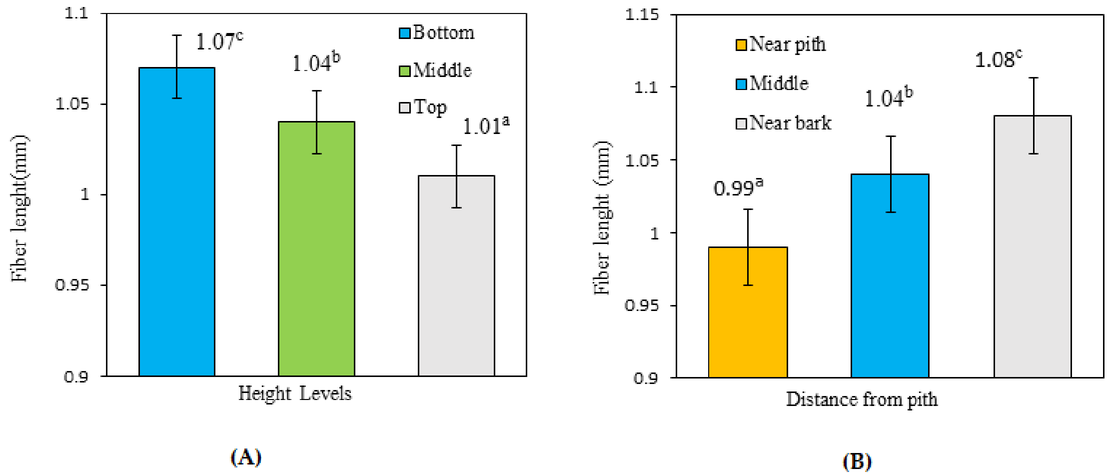


Figure 21: Variation of fiber length along with tree height levels (A), distance from the pith (B)

The mean value in fiber length obtained in this study (1.04 mm) is close to previously reported by Tavares *et al*. (2011) which ranges from 0.91 mm to 0.97 mm, along with tree height levels and 0.75 mm to 1.06 mm from the pith to the periphery of *A.melanoxylon*. But, the result was higher than the report of Santos *et al*. (2006) which ranges from 0.63 to 0.66 mm on the same species. This difference maybe is due to the age variation of sample trees since fiber length increase with the age of the tree (Jorge *et al*., 2000).

The above-mentioned result is also similar with pulpwood species: *Gmelina arborea* (1.03mm), *Leucaena leucocephala* (1.01mm) (Onuorah, 2001), and Eucalyptus species (0.67 – 1.06 mm) (Dutt and Tyagi, 2011; Ververis *et al*., 2004). Moreover, the results were in line with other *Acacia* species, namely; *Acacia mangium* which ranges from 0.96 mm to 1.20 mm (Lim and Gan, 2000), and *Acacia bilimekii* (1.016 -1.201mm) (Isaias*et al*., 2005). Fiber length is an important fiber dimension that affects pulp quality and paper strength (Ek*et al*., 2009). Wimmer *et al*. (2002) also reported that the fiber length of *E. globulus* had a strong effect on pulp yield and freeness, as well as active alkali consumption, besides, to tear index and bending stiffness.

Fiber width, lumen diameter, and cell wall thickness

Variation along with tree height levels

The result obtained in fiber width, lumen diameter, and cell wall thickness along tree height of *A.melanoxylon* were presented in Figure 3. Along with tree height, fiber width ranges from 21.43 to 21.8µm. Duncan multiple range tests showed that fiber width was insignificant along with height levels at $p<0.05$ and it decreases from the bottom to the top of a tree. The mean fiber width obtained in this study (21.60µm) was higher than previously reported by Santos *et al.* (2012) (19.55µm) and Santos *et al*. (2006) (17.6µm) on the same species. This difference may be due to the geographical location and age of sample trees. The result is also higher than pulpwood species such as *E.globulus.* Accordingly, Santos *et al*. (2008) observed values ranges from 18.3 to 19.3 µm, on *A.melanoxylon*and Miranda *et al*. (2001) reported 14.5 to 22.2 µm, of fiber width.

The decreasing trend of fiber width from base to top observed in this study could be because minimal net photosynthetic for cell development at the top caused by competition for leaf and branch development lead to better cell production at the base (Mercy *et al*., 2017).

Lumen diameter of *A.melanoxylon* ranges from 15.08 µm to 15.6µm along with the height levels. Duncan multiple range tests showed a lumen diameter was insignificant along with tree height at levels $p<0.05$. It decreases from bottom to top of tree portions. Lumen diameter affects the pulping process. For instance, the larger lumen diameter gives better pulp beating because of the penetration of liquid into empty spaces of the fibers (Emerhi, 2012).

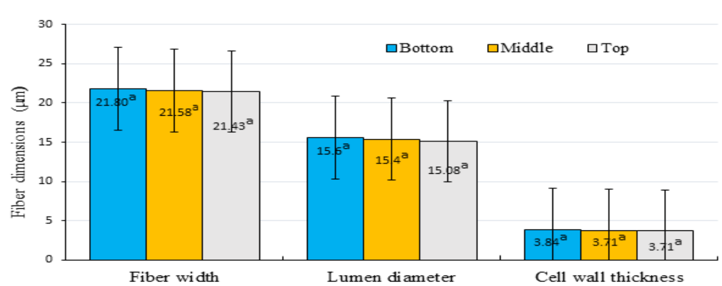


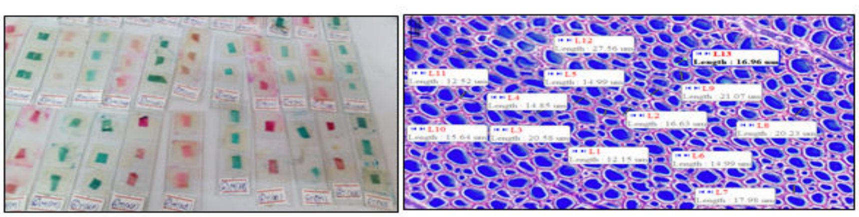
Figure 22: Variation of fiber characteristics along with tree height levels

The cell wall thickness ranged from 3.71 to 3.84 µm along with tree height of *A.melanoxylon.* Analysis of variance carried out at a 5% probability level showed that there was no significant difference in cell wall thickness along with tree height at $p<0.05$ (Figure 22) and it decreases from the bottom to the top of the tree portions. The result obtained was lower than other pulpwood such as *E. globulus* which ranges from 5.4 µm to 7.3 µm along with height levels with a decreasing trend from the bottom to the top of the tree (Quilhó *et al*., 2000).

Wood with thick cell walls tends to produce paper with a poor printing surface and poor burst strength. Thick-walled cells do not bend easily and do not collapse upon pulping, which inhibits chemical bonding. However, thin-walled cells collapse upon pulping, bond well together chemically, and produce a smoother paper surface (Zobel and Buijtenen, 1989). Therefore, *A. melanoxylon* has better than *E.globulus* for pulping in terms of its cell wall thickness.

Variation Across from Pith to Periphery

The fiber dimensions of *A.melanoxylon* wood at different distances from pith to bark are presented in Figure 23. Across the distance from the pith, fiber width ranges from 21.2 µm to 22.1µm. Duncan multiple range tests showed that fiber width was significant between the near pith and at the periphery, although both sections were insignificant varied with the middle section of a disk at $p<0.05$ (Figure 23). Across the distance from the pith, fiber width increased from the pith to periphery. A similar trend was reported by Izekor and Fuwape (2011) on Teak, Ogunsanwo (2000) on *T. scleroxylon*. The reason for this trend was attributed to the influence of the cambium age on the development and maturation of fiber from pith to bark (Mercy *et al*., 2017).



(A) (B)

Figure 23: Pictures showing the prepared slides (a) and cell structures (b)

From the pith to the periphery of *A.melanoxylon*, the mean lumen diameter ranged from 15.08µm to 15.63µm. Analysis of variance carried out at 5% probability level on lumen diameter didn't show significant difference though it increases from pith to periphery (Figure 24). The increase in lumen diameter from the pith to the periphery is attributed to an increase in cell size and active physiological development of the wood as the tree grows in girth (Mercy *et al*., 2017).

The cell wall thickness ranges from 3.5µm to 3.95µm across from pith to the periphery of the disk of *A.melanoxylon wood.* Analysis of variance didn't show significant variation in cell wall thickness between middle and at near bark, however, both the inner section of the disk showed a significant difference to near the pith at $p<0.05$. Cell wall thickness increased from the near pith to the periphery of the disk. The increase of cell wall thickness from pith to periphery was also previously reported by Tavares *et al*. (2011) on *A.melanoxylon* wood.

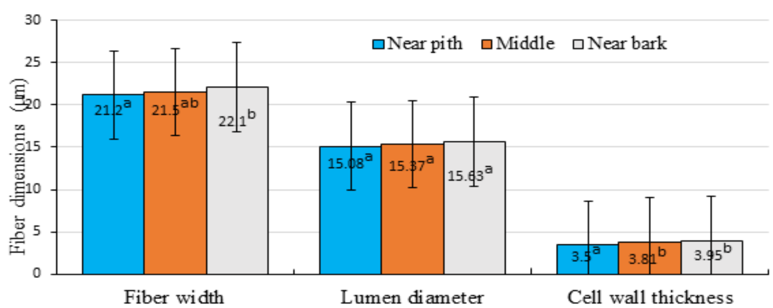


Figure 24: Variation of fiber characteristics across the distance from pith

The result obtained in cell wall thickness was similar to that of Tavares *et al*. (2011), which ranges from 3.45 µm to 3.89 µm. It is also similar to Eucalyptus species (3.29 µm – 3.86 µm) (Dutt and Tyagi, 2011) which is mostly used as a raw material for pulp and paper. However, it was greater than the result reported by Jorge (1994), which ranges from 1.8 µm to 2.5 µm and higher than Santos *et al*.(2018), which has 2.00 µm and 2.40µm in earlywood and latewood respectively, on *A.melanoxylon*. The result was less than that of *Acacia cochliacantha* which increases 5 to 7 µm from pith to bark (QuintanarIsaias*et al*., 2005). This difference may be due to genetic, age and growing environmental differences of sample trees since it affects wood fiber properties (Burdon *et al*., 2004).

Table 21: Summary of Analysis of Variance for fiber characteristics of *Acacia melanoxylon* at Chencha

Source of Variation	DF	FL	FW	LD	CWT
		Mean square and Statistical significance			
Height	2	0.018*	0.611ns	1.267ns	0.096ns
Section	2	0.033*	3.773ns	1.340ns	0.955*
Height x Section	4	0.000ns	0.395ns	0.550ns	0.041ns

*FL: Fiber length, FW: Fiber width, LD: Lumen diameter, CWT: Cell wall thickness, ns: not significant at P>0.05,*Significant at p< 0.05.*

Derived Fiber Values along with Tree Height

Derived values from the fiber dimensions are important to determine the suitability of the material for paper production. As shown in Table 22 the mean values of the Runkle ratio ranged from 0.48 to 0.49. Duncan multiple range tests showed that there was no statistically significant difference in the Runkle ratio along with tree height levels at p< 0.05 (Table 21).

Table 22: Mean and standard deviation of derived fiber values along with the height

Derived fiber values	N	Sampling height (%)		
		Bottom (10%)	Middle (50%)	Top (90%)
Runkle ratio	18	0.49±0.05	0.48±0.05	0.49±0.04
Slenderness ratio	18	49.08±3.12	48.19±3.76	47.13±3.27
Flexibility coefficient	18	71.56±4.66	71.36±4.15	70.36±4.41
Wall coverage ratio	18	0.35±0.03	0.34±0.04	0.34±0.03

The mean values of the slenderness ratio obtained along tree height levels ranged from 47.13% to 49.08% (Table 22). It has higher in the bottom and a minimum at the top portion. Duncan's multiple range test showed that there was no significant variation of slenderness ratio between portions at p<0.05 (Table 22). The slenderness ratio is related to fibre length and width and influences paper sheet density and increases tearing resistance (Agnihotri *et al*., 2010).

The mean values flexibility coefficient along tree height levels of *A.melanoxylon* ranged from 70.36% to 71.56% and it decreases from the bottom to the top of the tree portion. Analysis of variance carried out at a 5% probability level shows that, there is no significant difference in flexibility coefficient along with tree height (Table 22).

The mean values obtained in the wall coverage ratio along tree height ranged from 0.34 to 0.35 and it decreases from the bottom to the top portion of the tree. Duncan multiple range tests show that there was no significant difference in wall coverage ratio between portions at $p<0.05$ (Table 21). The wall coverage ratio is an index for bending resistance (Hudson *et al*., 1998) and is related to fiber flexibility (Amidon, 1981).

Derived Fiber Values from Pith to Periphery

From pith to the periphery of the disk the mean values of the Runkle ratio ranged from 0.46 to 0.50. Analysis of variance showed that Runkle ratio significantly varied between the near pith and at near bark, however, both the inner sections didn't show significant variation to the middle at $p<0.05$.

This value agrees with previously reported results by Santos *et al*. (2012), Anjos *et al*. (2011), and Santos *et al.* (2018) on *A. melanoxylon*. Furthermore, the result of this study is a little less than the Runkle value of *E. globulus* wood which was 0.56 as reported by Patt *et al*. (2006).

According to Kiaei *et al*. (2014), the Runkel ratio is a parameter used to determine the suitability of raw material for pulp. Ona *et al*. (2001) reported that the Runkel ratio significantly relates to pulp yield (positively) and digestibility (negatively). According to some studies, the Runkle ratio of < 1 shows that the fiber is highly appropriate for pulp and paper production, values from 1 to 2 is regular, and above 2 it may not be used for the paper (Santos *et al*., 2018). All Runkle ratio values obtained in this study were less than 1 (Table 22 and 23), suggesting the suitability of *Acacia melanoxylon* for pulp and paper production.

The slenderness ratio from pith to periphery ranged from 46.69% to 48.86% and increased from inner to outer wood. Duncan's multiple range test shows that there was no statistically significant variation in the slenderness ratio from pith to the periphery at $p <0.05$. Ververis *et al*. (2004) reported that, fiber with less than 70 slenderness ratio not appropriate to use as a raw material in the pulp and paper industry.

Hence, in terms of its slenderness ratio, *A. melanoxylon* not suitable for pulp and paper production since the value obtained is less than the accepted standard (70%) both along with tree height and from pith to the periphery. According to Ogunjobi*et al*. (2014a), pulp tear resistance increases with increasing fiber slenderness. This means paper made from *A.melanoxylon* would have low tear strength and therefore may not be suitable for wrapping and packaging purposes.

Table 23: Mean and standard deviation of derived fiber values across the distance from the pith

Derived fiber values	N	Distance from the pith (%)		
		Near pith (10%)	Middle (50%)	Near bark (90%)
Runkle ratio	18	0.46 ±0.04[a]	0.49±0.06[ab]	0.50±0.04[b]
Slenderness ratio	18	46.69±3.79[a]	48.37±2.95[a]	48.86±3.44[a]
Flexibility coefficient	18	71.13±4.76[a]	71.48±4.08[a]	70.72±4.43[a]
Wall coverage ratio	18	0.33±0.02[a]	0.35±0.04[b]	0.35±0.02[b]

The value obtained in the flexibility index ranging from 70.72% to 71.48% from pith to the periphery and it was higher in the middle section of the disk (Table 23). ANOVA test showed that there was no significant difference in flexibility coefficient from near pith to the periphery of the disk at $p<0.05$ (Table 24).

The overall mean value obtained in flexibility coefficient was similar to the previous work of Santos *et al*. (2018) on *A.melanoxylon* wood, which is in the ranges of elastic fiber (50-75%). Additionally, the value is similar to other known pulpwood such as that of *E. globulus* species (72%) and *E. camaldulensis* (70%) (Ona *et al.,* 2001).

According to Hemmasi*et al*. (2011), the flexibility coefficient (FC) can be divided into four classes: fibers with FC over 75 are categorized as highly elastic; fibers with FC between 50 and 75 are elastic; fibers with FC 30 and 50 are rigid and those with FC less than 30 are highly rigid fibers. Furthermore, the values of the flexibility index, ranging from 50% to 75% will produce a good paper with high strength properties (Brindha*et al*., 2012). According to this classification, the flexibility coefficient of *A. melanoxylon* fibers is 71.1, so it is included in the elastic fibers group and satisfies the requirement for its suitability for pulp and paper production.

The mean values obtained in-wall coverage ratio from pith to the periphery of *A. melanoxylon* range from 0.33 to 0.35 and it was higher at the periphery of the disk. ANOVA test shows that there was no significant difference between middle and at near bark, while both sections were significant to a near pith at $p<0.05$ (Table 24). According to Nisgoski*et al*. (2011), a material with a wall coverage ratio value less than 0.4 is considered to be good pulpwood since it is not too rigid. Therefore, *A. melanoxylon* is suitable for pulp and paper production, since the value obtained fulfilled the accepted standard.

Table 24: Summary of Analysis of Variance for derived Fiber properties

Source of Variation	DF	Mean square and statistical significance			
		RR	SR	FC	WCR
Height	2	0.000ns	20.649ns	7.271ns	0.000ns
Section	2	0.009ns	17.594ns	2.582ns	0.004ns
Height x Section	4	0.001ns	4.737ns	18.896ns	0.000ns

RR: Runkle ratio, SR: Slenderness ratio, FC: Flexibility coefficient, WCR: Wall coverage ratio, *ns: not significant at P>0.05, * significant at p< 0.05.*

Basic Density

The overall mean basic density observed in this study was 0.56g/ml which ranged from 0.53 to 0.607 g/ml. Basic density significantly varied between the bottom and the top portion, while both portions didn't show a significant difference to the middle portion along with tree height levels at $p<0.05$ (Figure 25a). From pith to the periphery of the disk, basic density was significantly varied at $p<0.05$ and decreased from bottom to top and increased from pith to periphery.

The continuous reduction in basic density with height in the tree from bottom to the top and its corresponding increase from near pith to periphery observed in this study had earlier been reported in the wood of *A. melanoxylon* (Machado *et al.*, 2014; Nicholas and Brown, 2002) and *E. globulus* (Wimmer *et al.*, 2008). Additionally, its significant variation from pith to periphery was also previously reported by Machado *et al.* (2014).

The mean basic density obtained in this study was similar to the values of previous studies on *A. melanoxylon*. Accordingly, Nicholas and Brown (2002) reported values between 0.465 to 0.670 g/cm^3 for 70 years-old trees and 0.432 to 0.649 g/cm^3 for 40-years-old with significant variation at different height levels (Santos *et al*., 2012) and Ilic (2000) reported from 0.546 to 0.566 g/cm^3 on the same species.

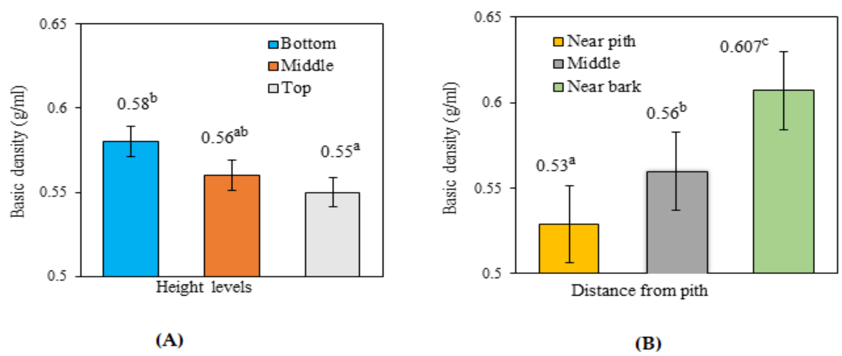


Figure 25: Variation of basic density along with height levels (a) and distance from the pith (b)

The results are comparable to other acacia species and it is similar to *A. auriculiformis* (0.57 g/cm^3) (Chowdhury *et al*., 2009). However, the results were higher than that of *A. mangium* wood with 0.42 and 0.45 g/cm^3 for 5 and 7-years old trees respectively (Makino *et al*., 2012). This higher value may be due to age and genetic and environmental differences as they affect density. The result obtained in this study also comparable with a density of other pulpwood growing in Ethiopia such as *globulus* (0.780 g/cm^3) and *E. camaldulensis* (0.853 g/cm^3) where the value is lower (Desalegn *et al*., 2012; 2015).

The highest values of the basic density at stem base (old) and lowest at the top (young), obtained in this study, may come from a combined effect of cambial age and influence from the root system (Machado *et al.*, 2014). Basic density is an important parameter in pulping properties: wood with a low basic density produces paper with high sheet density; tensile, bursting, and folding strengths; and lower resistance to beating; but with the lower pulp yield and tearing strength (Yahya *et al*., 2010; Santos *et al.*, 2012). It also influences pulp yield and paper quality (Wimmer *et al*., 2002). According to Clark and Hicks (2002), the preferred range for wood density in pulp and paper production is between 0.4 to 0.6 g/cm^3. Therefore, the wood density of *A. melanoxylon* is suitable for pulp and production.

Conclusion and Recommendations

The fiber characteristics and basic density were investigated from the wood of *Acacia melanoxylon* trees growing in Chencha woreda of Ethiopia to determine the usefulness of these trees as fiber resources for pulpwood production. Compared to the wood properties related to pulp and paper quality with those of *Acacia* and *Eucalyptus* species currently used for commercial pulpwood, *A.melanoxylon* showed better properties.

All fiber dimensions decrease from bottom to top portion, however, it increases from the pith to periphery of the disks and only fiber length differences was significant along with the tree height levels at $p<0.05$. Derived fiber values decrease from bottom to top portions and increase from pith to periphery. Since there was no significant variation in all the derived fiber values between tree heights, any part of the tree portion may be utilized for pulp and paper production. Basic density decreases from the bottom to the top and significantly varies between the bottom and a top portion. However, it decreases from pith to periphery and highly significant at $p<0.05$. Generally, *A. melanoxylon* has good fiber properties (adequate fiber dimensions, basic density, and its derived fiber values) as a raw material for the pulp and paper industry except for the slenderness ratio which is lower than the accepted standard.

Based on the findings of the study, the following points were recommended: -

- Since information on fiber characteristics and basic density of *A. melanoxylon* grown in the studied area shows its suitability for pulp and paper production, attention should be given by tree growers, investors, government, and non-governmental organizations on its plantation expansion.
- In addition to information on fiber characteristics and basic density revealed in this study, production and testing of its pulp and paper should be needed.
- Since such types of works are lacking in Ethiopia, government, non-governmental organizations, research institutes, higher learning institutions should give special attention to this area.

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Seasoning Characteristics and Density of *Acacia melanoxylon* Lumber Grown in Chencha, SNNPR, Ethiopia

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Abstract

Seasoning is one of the major factors that determine the quality, utilization, and service life of wood as round and sawn lumber. Seasoning characteristics and density were investigated along with the tree height of *Acacia melanoxylon*. For this study, *A. melanoxylon* trees were selected randomly and harvested from Chencha, SNNPR Ethiopia. Sample logs were collected from the bottom, middle, and top portions, and sample boards were prepared for the determination of seasoning characteristics and density along with the tree height. The basic density and tangential, radial, and volumetric shrinkages were affected by tree height ($p<0.05$), and the highest values were observed at the base and lowest at the top of tree height. The mean values of the basic density were 0.57 g/cm^3. The mean values of the tangential, radial and volumetric shrinkage from green to 12% moisture content (MC) were 3.8%, 1.97%, and 6.19%, respectively and longitudinal shrinkage was negligible. The mean initial and final MC for air and kiln seasoning stacks were 67.36% and 14% and 66.19% and 12.03%, respectively. Air seasoning time to reach 14% MC took 42 days, while kiln seasoning to reach 12.03% MC took 7 days. The species showed low shrinkage and less seasoning defects both on-air and kiln seasoned boards.

Keywords: *Acacia melanoxylon*, Basic density, Kiln, Seasoning, Shrinkage, Stem height

Introduction

In Ethiopia, wood and wood products supplies for industrial, construction including research purposes are mainly from the natural forest (Teketay *et al*., 2010; MEFCC, 2017). To reduce the pressure on the remaining natural forests and endangered indigenous trees, large hectares of plantations of exotic species have been established and several exotic tree species were introduced into the country. *Acacia melanoxylon* was one of the species introduced to Ethiopia to be used as an alternative source of raw material to meet the ever-increasing demand for different forest products. *Acacia melanoxylon* R.Br belongs to the family Leguminosae and subfamily Mimosoideae (Lemmens, 2006). It is a fast-growing species with a tall and straight trunk/bole. It is commonly called Australian Blackwood (Nicholas and Brown, 2002) and locally known as Omedla in Ethiopia (Bekele, 2007). *A. melanoxylon* grows in cool, temperate rainforests, open forests of the tablelands, and coastal escarpments (Nicholas and Brown, 2002). It performs well in altitude ranging from 1500 to 2300 meters above sea level with a mean annual temperature of 6 to 19 ^{0}C, mean annual rainfall is 750 to 2300 mm (Orwa *et al*., 2009).

Acacia melanoxylon timber is a medium density, with excellent drying and finishing properties (Chudnoff, 1980). The timber also has low shrinkage and glues well with most common adhesives (Chudnoff, 1980; Bradbury *et al*., 2010b). It is also easy to work, has even texture, usually straight and it turns and bends well (Nicholas and Brown, 2002). *Acacia melanoxylon* timber is highly used in the world for cabinet-making and furniture (Boland *et al*., 1984). It is also suitable for veneers, turnery, paneling, carving, flooring, boat building, gunstocks, musical instruments, plywood, tennis racquets, and knobs (Chudnoff, 1980; Nicholas and Brown, 2002; Bradbury *et al*., 2010b). The value of *Acacia melanoxylon* wood is mainly given by its heartwood content and its golden-brown color, often containing darker veins or reddish streaks (Searle, 2000).

The use of wood is influenced by the density and seasoning characteristics of the timber. Density, moisture, seasoning and shrinkage characteristics (tangential, radial, longitudinal and volumetric), seasoning rates, and defects are among the major factors that determine the quality, utilization and service life of wood as round and sawn lumber (Simpson, 1991; Deniget *al*., 2000; Desalegn, 2006; FPL, 2010). On the other hand, familiarity with density and seasoning properties are important because they can significantly influence the performance and strength of the wood used in structural applications (Winandy, 1994).

Seasoning aims to dry timber uniformly with minimum deformation in the shortest possible time to a moisture level similar to the surrounding air (equilibrium moisture content). Seasoning of wood increases the most strength properties of lumber and protects lumber against primary decay, fungal stain, and attack by certain kinds of insects. In Ethiopia, wood seasoning research has been carried out on many home has grown and exotic tree species, but no previous drying studies of Ethiopian grown *Acacia melanoxylon* wood was conducted. Seasoning studies on the species conducted in Australia and South Africa reported that *A. melanoxylon* wood seasons well and maybe either air-dried or kiln-dried from green with no major degrade in thickness up to 50 mm thick(Boas 1947; Hartwig 1964).

In Ethiopia, *Acacia melanoxylon* timber is underutilized due to a lack of information on the wood properties of the species. Therefore, estimating density and managing moisture content in wood for the intended purpose and environment of applications will be rational utilization of timber species in Ethiopia. The objective of this study was to investigate the density and seasoning characteristics of *A. melanoxylon* timber grown in Chencha, SNNPR Ethiopia.

Materials and Methods

Study site description

The species grows on an elevation between 1,300 and 3,250 m above sea level with a geographical direction of 6°8'0"-6°26'0''N and 37°22'30"- 37°43'30" E (Figure 26). The mean annual precipitation and temperature of this area are usually about 1353 mm and 14^0C respectively (Yewubdar and Aseffa, 2017).

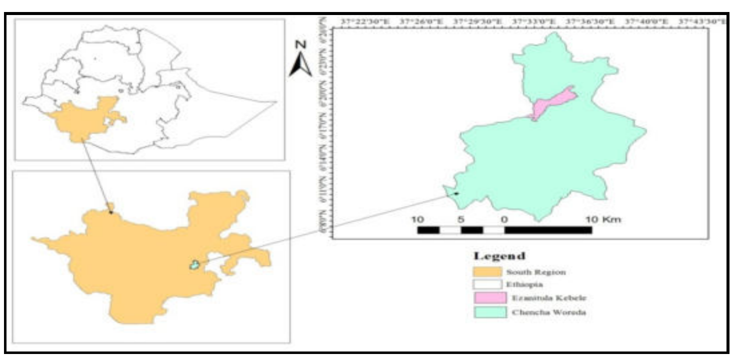

Figure 26: Map of Ethiopia showing the study area

Tree Sampling

A total of ten trees of 30 years old *Acacia melanoxylon* were randomly selected and harvested from the Chencha world community forest. The selected sample trees are straight trunks, normal branching and had no disease or pest symptoms (ISO 3129, 1975; Desalegn*et al*., 2012). The height and diameter at breast height (dbh) of the trees were ranging from 17 to 20 m and 21 to 26 cm, respectively. Each sample tree was cross-cut in to three 2.5 m logs which represent the bottom, middle, and top of the tree height (Desalegn, 2006; Moya *et al*., 2013) and, the end logs were sealed with paint to avoid moisture loss and end check/splitting. Then the sample logs were transported to Addis Ababa, Forest Products Innovation Research and Training Center (FPIRTC) laboratory for further processing.

Sawing and Sampling for Seasoning Characteristics Test

The sample logs were sawn tangentially using circular sawmill produced boards of 3 cm thickness in Forest Products Innovation Research and Training Center, Addis Ababa. Defect-free sawn boards which represent the bottom, middle and top of the trees are selected for the determination of seasoning characteristics for both air and kiln seasoning experiments. From each selected boards, two small sections cross-cut 20 cm inwards from sample board ends having 1.2 cm length and 3 cm thickness were prepared for determination of initial MC along with the tree height for both seasoning methods (Desalegn, 2006) as shown in figure 27. The remained middle parts of the sample boards with dimensions of 100 cm length, 3 cm thickness, and width equal to bolt-diameter were used to determine seasoning characteristics along with the tree height for both air and kiln seasoning experiments.

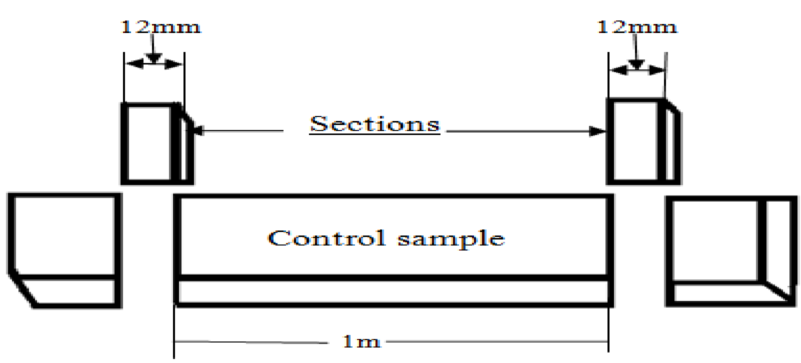

Figure 27: Sample preparation for determination of seasoning characteristics

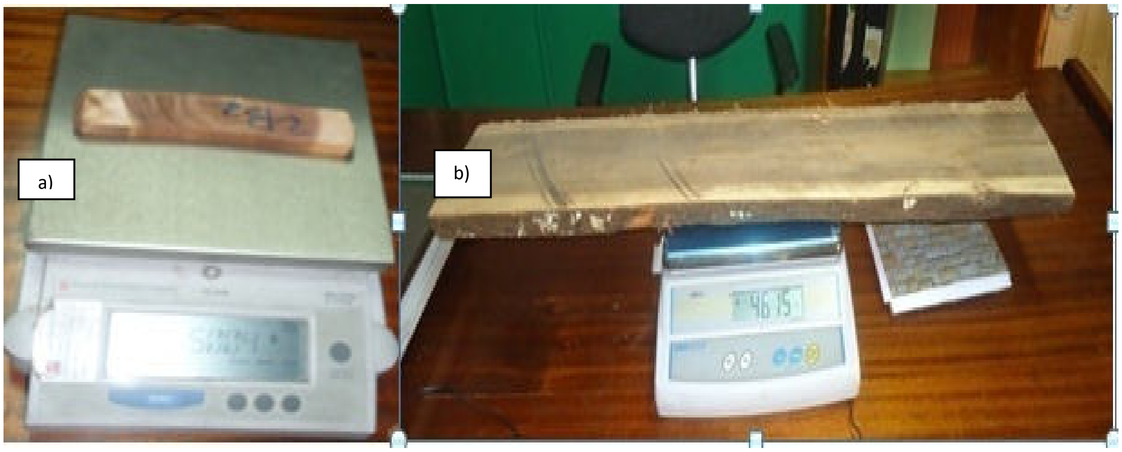

Figure 28: Pictures showing a sample of initial moisture content weighing (a) and sample board weighing (b)

Sample Preparation for Basic density and Shrinkages

Specimens free from visible defects having a cross-section of 20 x 20 mm and length of 30 mm at green state were prepared from the bottom, middle and top boards for determination of basic density and shrinkage characteristics of *A. melanoxylon*. The method used for the determination of basic density and tangential, radial, and volumetric shrinkage based on international standards and procedures (ISO/DIS 4469, 1975; ISO/DIS 4858, 1975; Simpson, 1991; Haygreen and Bowyer, 1996; Denig *et al*., 2000).

Stacking Sawn Boards for Seasoning Characteristics tests

Immediately after sawing, boards were transported to the air seasoning yard and compartment kiln-seasoning chamber areas. Boards were stacked at 3 cm spacing between successive boards to facilitate the circulation of air (Simpson, 1991). They were stacked horizontally in vertical alignments separated by well-seasoned, squared, and standard stickers (Reeb and Brown, 2007).

The sample boards were distributed in each stack to represent the lumber in the stack and the seasoning process at different positions (top-bottom, left-right, and vice-versa). Weighing and replacing the samples into the stack was done repeatedly until the MC reached the desired amount of about 12% moisture content. The control sample boards were properly distributed and positioned in the pockets of the different layers of each stack.

Boards for air seasoning were stacked in an air-seasoning yard under a shed on firm foundations having 45 cm clearance above the ground and a dimension of 1.80x0.45x4 m. The boards were aligned in a north-south direction where the ends were not exposed to the direction of the wind. This was done to facilitate good air circulation and reduce the direct influence of fungi, temperature, wind, and relative humidity. The board for kiln seasoning was stacked out of the kiln on the transfer carriage having a dimension of 2.7x1.6x 0.30 m and placed in the kiln-seasoning chamber.

Figure 29: Pictures showing lumber stacked for air drying (a) and kiln seasoning (b) of *A. melanoxylon* lumber

Air Seasoning

Green weights of all air seasoning sample boards were measured immediately after planning and crosscutting using the sensitive electrical balance. Weighing of samples for initial MC determination was carried out 4 hours interval until the difference between two successive weights of each specimen was between 0.1-0.2 g (Desalegn, 2005), and the final weight was taken as the oven-dry weight (ISO 3130, 1975; Reeb and Brown, 2007; FPL, 2010). The sample boards were weighed (Figure 29b) and replaced into the stacks and re-weighed at a one-week interval. The process was continued until the average final MC of the stack reached about 15-12%, which is the equilibrium moisture content (EMC) for in and outdoor purposes.

Kiln Seasoning

The conventional type of artificial kiln seasoning machine was used for this study. The machine has about 2.5 m^3 wood loading capacity room or chamber. It has controlled air circulation, temperature, and humidity that can be adjusted using psychrometers (dry bulb and wet bulb thermometers) and has been equipped with fans to force air circulation and an air outlet at a temperature range of 40-70ºC. The kiln seasoning schedules were selected based on the species type, initial MC, and density of the lumber species. Kiln schedule Ethiopia number three (Wood Utilization Research Center, 1995), was used for the *Acacia melanoxylon* lumber (Table 25). Kiln seasoning test sample boards were weighed, moisture content was calculated, psychrometers regulated, steaming done, and the direction of the fan changed at 8 hours interval (three times in 24 hours) to allow uniform air circulation, control the seasoning process and quality of the seasoned wood. The process was continuous until the required final 12% MC reached (FPL, 2010; Desalegn *et al*., 2012; Moya *et al*., 2013).

Table 25: Kiln Schedule for hardwoods of Ethiopia

Initial MC (%)	Temperature (°C)		Relative humidity (%)
	Dry-bulb	Wet-bulb	
100-70	38	35	80
70-60	42	37	70
60-50	44	39	65
50-40	50	40	60
40-30	53	42	55
30-20	55	43	50
20-10	60	45	40

Basic Density Determination

The prepared specimen blocks were soaked in distilled water for 72 hours to ensure that their moisture content was above the fiber saturation point. Then the dimensions in all three principal directions (tangential, radial, and longitudinal) were measured with a digital caliper and their weights were taken for green weight. The green volume was calculated based on these green dimensions measurements. Finally, the specimens were oven-dried at 105^0C and relative humidity 65% for 24 hours and again the dimensions and weight measurements were taken. This is continued until constant weights were obtained. Basic density was determined on a green volume, oven-dry weight basis (ISO/DIS 3131, 1975). The formula used to calculate the basic density was:

$$\text{Basic density} = \frac{Wo\ (g)}{Vg\ (mm^3)} \quad (1)$$

Where Wo: is the oven-dried weight in (gm), Vg: is the green volume specimen in (mm^3)

Shrinkage Determination

The radial, tangential and volume dimensions of the basic density specimen blocks were marked and measured using a digital caliper. The blocks were then oven-dried at 105°C for 24 hours. The oven-dried blocks were then weighed and the dimensions were measured again along with the points marked earlier using the same digital caliper. The green to 12% MC shrinkage in tangential and radial and volumetric shrinkage of the same blocks was determined, expressed as a percentage of the saturated dimension to its 12% MC dimension. The different formulas were adapted from ISO/DIS 4469 (1975); ISO/DIS 4858 (1975).

Shrinkage (%) = Decrease in dimension (mm)/green dimension (mm) x100 ---------- (2)

Initial Moisture Content and Rate of Seasoning Determination

Initial and final MCs were determined for both air and kiln seasoning stacks of the lumber. In both seasoning methods, the moisture content (MC) was determined as stated in (ISO 3133, 1975; Denig *et al*., 2000; Reeb and Brown, 2007; FP, 2010). The average MC of the two sections was determined using the specimens prepared. The weight of each sample at the time of cutting was used to estimate the analytically determined oven-dry weight of the stack samples at 12% MC. The moisture content was calculated as follows:

Moisture content (MC %) = (IW-OD/OD) x100 = (IW/OD-1) x100 = (W/OD) x100 ---- (3)
Where, IW= initial weight of wood with water (g), OD = oven dry weight of wood without water (g), W = weight of water alone (IW-OD) (g).

Air and Kiln seasoning rates from green to about 12% MC of each lumber species were estimated from the MC samples of each species (Moya *et al*., 2013). Seasoning rate classification for air and kiln seasoning stacks was done based on the adopted standards from Longwood (1961) and Farmer (1987) respectively.

Seasoning Defects Determination

For this study, sample boards that represent (bottom, middle and top) portions from each air and kiln seasoned experiments were randomly selected and defects were separately measured for each seasoning method. According to Simpson (1991), warp which includes (cup, crook, bow, and twist), and as well as surface splits, end-splits, surface checks, and end-checks were performed on a flat surface with the aid of a measurement wedge. The boards were secured on one end while measurements were taken on the other end. According to Longwood (1961), the severities of seasoning defects were classified based on the magnitude and frequency from green to 12% moisture content. Accordingly, 1= none/defect-free, 2= very slight, 3= slight, 4= moderate, 5= severe and 6= very severe defects.

Statistical Analysis

Statistical Package for the Social Sciences (SPSS) version 20 (IBM Corp. released 2011) was used to analyze the data using Descriptive statistics and analysis of variance (ANOVA) Procedure. A least significant difference (LSD) method was used for mean comparison at $P<0.05$.

Results and Discussion

Basic density and Shrinkage

The basic density and shrinkage percentages are among the main factors that affect the usability of wood as a raw material. The mean and standard deviation values for basic density and shrinkage percentages along the tree height are given in table 26.

Table 26: The mean values of basic density and shrinkage at the bottom, middle, and top of *Acacia melanoxylon* timber

Height	Mean values of basic density and shrinkages				
	n	Basic density (g/cm^3)	Tangential (%)	Radial (%)	Volumetric (%)
Bottom	5	0.604 ± 0.072^b	4.34 ± 0.13^b	2.38 ± 0.35^b	6.97 ± 0.30^b
Middle	5	0.571 ± 0.069^a	3.60 ± 0.19^a	1.93 ± 0.37^b	5.87 ± 0.49^a
Top	5	0.536 ± 0.079^a	3.47 ± 0.55^a	1.60 ± 0.18^a	5.72 ± 0.68^a

Note: Means having the same superscript letter across the columns were not significantly different at $P<0.05$. Where, MC-Moisture content, n-number of specimens

Basic density

The mean basic density of the three portions along with the three tree heights i.e. bottom, middle, and the top is shown in table 27.

Table 27: Summary of ANOVA on basic density and shrinkage of *Acacia melanoxylon* timber

Source of variation	DF	Mean-square and statistical significances			
Shrinkage from green to 12% MC (%)					
		Basic density	Tangential	Radial	Volumetric
Height	2	0.017*	1.755*	1.226*	3.730*

Note: ns-not significant at p<0.05,*-significant at p<0.05 **-highly significant at P<0.01. Where, DF- degree of freedom, MC- moisture content

Statistical Analysis of variance revealed that the tree height had a significant effect on basic density (P< 0.05) (Table 27). The pattern of variation in basic density, as a function of height in the stem, is shown in Table 27. The highest value of basic density was observed at the base and decreased from the base 0.604 g/cm^3 to the top of the tree 0.536 g/cm^3. A similar variation was reported for 10, 15, and 20 years old of *Acacia mangium* (Chowdhury *et al*., 2005) grown in Bangladesh. The same variations to this finding were also noted by different authors (Ali and Uetimane, 2010; Uetimane and Ali, 2010; Hussin *et al*., 2014) for hardwood of *Sterculia appendiculata*, *Pseudolachnostylisma prounaefolia,* and *Albizia falcataria* respectively. In contrast, Santos *et al*. (2013) reported that the basic density of *A. melanoxylon* has an irregular variation that decreases from base to breast height and then increased up to the top of the tree. The variation of basic density from the bottom upwards might have been caused due to the maturity at the base and juvenility at the top of the tree. Juvenility increases from the bottom towards the top, and as juvenility increases basic density decreases (Getahun *et al*., 2014). Haygreen and Bowyer (1996) noted density in the juvenile wood zone is low because there are relatively few latewoods/summerwood cells and a high proportion of cells have thin wall layers.

The result showed that the overall mean basic density of *Acacia melanoxylon* timber was 0.57 g/cm^3 with a standard deviation of 0.077. This finding was in line with the result reported by Nicholas and Brown (2002) that indicated basic density in the ranges of 0.465 to 0.670 g/cm^3 and similarly, Harris and Young (1988) also reported values ranging from 0.312 to 0.681 g/cm^3 for the same species. The mean basic density of *A. melanoxylon* found in this study was greater than the mean basic density (0.531 g/cm^3) reported by Santos *et al*. (2012) for the same species. However, the result of this study was less than 0.607 g/cm^3 as reported by

Tavares *et al*. (2014). These variations may be attributed to genetics and local environmental factors which affect the growth of the trees such as soil characteristics, the density of stand, precipitation, solar radiation, and age of the trees (Panshin and de Zeeuw, 1980).

In comparison with other Acacia species, the mean basic density of this finding was less than *Acacia saligna* (0.637 g/cm^3) reported by Mmolotsi*et al*. (2013) and *Acacia nilotica* (0.61 g/cm^3) reported by Mahmood *et al*. (2016). With commercially known and endangered tree species in Ethiopia, the basic density of *A. melanoxylon* was comparable with density at 12% MC tested of *Hagenia abyssinica* (0.56 g/cm^3) and *Pouteriaadolfi-friederici* (0.60 g/cm^3) and higher than the density at 12% MC of *C. lustanica* (0.430 g/cm^3), *P. patula* (0.450g/cm^3), *Juniperus procera* (0.54 g/cm^3); and lower than those of *E. globulus* (0.780 g/cm^3) and *E. camaldulensis* (0.853 g/cm^3) (Desalegn*et al*., 2012; Desalegn *et al*., 2015).

Shrinkage Characteristics

The mean tangential, radial, and volumetric shrinkage percentages for the three sections along with the three tree heights are shown in table 27. The Analysis of variance revealed that the tree height had significant effects on tangential, radial, and volumetric shrinkage of *A. melanoxylon* ($P<0.05$). The pattern of variation in wood shrinkages, as a function of height in the stem, is shown in table 27. Within the tree, the tangential, radial, and volumetric shrinkages percentages were decreased along with the stem height, from the base upwards. Similar variations were reported for *Sterculiaappendiculata*; (Ali and Uetimane, 2010), for Athel wood (KiaeiandSadegh, 2011), for *Populuseuramericana* (Kord *et al*., 2010), and Oriental beech and Caucasian fir species (Topaloglu and Erisir, 2018). On the other hand, tangential, radial, and volumetric shrinkage increased as wood density increased (Bowyer, *et al*., 2003; Kord*et al*., 2010; FPL, 2010). This finding of shrinkages also linked with the density of the species. The results indicated that the tangential, radial, and volume shrinkage and the basic density show a decreasing trend with increasing tree height of *Acacia melanoxylon* tree.

Despite the tree height, high average shrinkage percentages were observed at the tangential direction (3.80 %) than the radial (1.97%). This variation was comparable with other studies conducted elsewhere for the same species (Nicholas and Brown, 2002) who reported that tangential and radial shrinkage from green to 12% MC was 3.6% and 1.8% respectively. The results depicted that tangential shrinkage was two times greater than the radial direction.

Similar patterns have been reported by different authors for *A. melanoxylon* (Haslett, 1983; Nicholas and Brown, 2002). This indicated that the species is moderate and dimensionally stable.

The results found the mean tangential (3.80%), radial (1.97%), and volumetric (6.19%) were fewer shrinkage percentage than with other *Acacia* species reported by Jusoh*et al*. (2014) for *Acacia mangium* and *Acacia auriculiformis* for tangential (5.12 and 4.72%), radial (3.06 and 2.26%) and volumetric (15.89 and 18.18%), respectively. The variation between tangential and radial shrinkage could be accounted for by combinations of many factors including the presence of ray tissue, which provides a restraining influence in the radial direction, frequent pitting on the radial walls, the domination of latewood in the tangential direction, and differences in the amount of cell-wall material radially and tangentially (Haygreen and Bowyer, 1996). Other factors include the size and shape of the piece, which affects the grain orientation in the piece and the uniformity of the moisture through the thickness (Haygreen and Bowyer 1996; FPL, 2010), and the density of the sample whose shrinkage (%) increases with increasing density.

Based on the classification system adapted from (Chudnoff, 1980), the tangential (3.80%) and radial (1.97%) shrinkage values of *Acacia melanoxylon* lumber from green to 12% MC seasoning were classified as class 1, i.e., very low shrinkage value, indicating that its good stable quality lumber.

Moisture content and Rate of seasoning

Initial moisture content (MC) along with the tree height didn't show a significant difference at $P<0.05$ level (Table 28) with the highest moisture content value was found in the upper part of the stem. This might be attributed to the high proportion of sapwood in the wood close to the upper stem of this species. Similar variations have been reported for *Acacia saligna* (Mmolotsi, 2013) and *Acacia mangium* (Chowdhury *et al*., 2005) grown in Bangladesh. In contrast to this finding reported for *Acacia mangium* was significantly decreased with the increase of tree height (Moya and Muñoz, 2010) grown in Costa Rica.

The results showed that the mean initial moisture content (MC) before air and kiln seasoning of sample boards of each stack was 67.36% and 66.19 (Table 28) respectively. The mean final MC after air and kiln seasoned boards for this species was 14% and 12.03% respectively

(Table 28). The ANOVA table (Table 29) didn't show a significant difference on the final MC of sample lumber along with the tree height at P<0.05 level.

Table 28: Mean values of seasoning characteristics of *Acacia melanoxylon* timber

Seasoning method	Initial MC	Final MC	Rate of seasoning (days)	classification
Air seasoning	67.36	14	42	very rapid
Kiln seasoning	66.19	12.03	7	very rapid

Table 29: Summary of ANOVA table on seasoning characteristics of *A.melanoxylon* timber

Source of variation	Mean-square and statistical significances		
	DF	Initial MC (%)	Final MC (%)
Height	2 91.157ns	3.310ns	
Seasoning method	1 2.030ns	13.261ns	

Note: ns-not significant at p<0.05,*-significant at p<0.05, **-highly significant at P<0.01

The mean value of the rate of air and kiln seasoned lumber of tangentially sawn boards of 3 cm thickness to reach about 14% and 12.03 MC was 42 and 7 days, respectively (Table 28). The result indicated that air seasoning was a faster seasoning rate than with study conducted elsewhere for the same species (Haslett, 1983) who reported that the rate of drying was 69.3 days to reach about 15% MC. This variation might be caused by lumber thickness, location, and the time of year the lumber is stacked (FPL, 2010). This finding was carried out during the dry season in December and January. This result revealed that *A. melanoxylon* lumber took 42 days to reach 14% MC. This noted during the dry period, it is possible to season lumber to less than 20% MC by air seasoning. Since lumber with < 20% MC has no risk of developing stain, decay, or mold (Denig*et al.*, 2000; Wengert, 2006) which could be used for outdoor and above ground construction purposes. Air seasoning alone is not sufficient for lumber intended for most interior use 8-12% is required (FPL, 2010).

Table 30: Kiln schedule developed for *Acacia melanoxlon* lumber

Initial MC (%)	Temperature (°C)		Relative humidity (%)
	Dry-bulb	Wet-bulb	
70-60	38	36	83
60-50	44	40	78
50-40	46	41	74
40-30	50	43	66
30-20	54	45	60
20-10	60	47	50

The average value of kiln-seasoning time obtained in this study was relatively comparable with another study for the same species (Haslett, 1983) who reported that the kiln seasoning time ranges 4-5 and 8-10 days for 25 and 50-mm-thick material respectively. The mean final MC of kiln-seasoned wood based on its purpose may vary from 0 to 25% (Denig *et al*., 2000). Kiln seasoned lumber can have an average specified moisture content of typically 6-8% or an MC suitable for certain use (Denig*et al*., 2000). Based on the rate of seasoning categories (Longwood, 1961; Farmer, 1987), the lumber of *A. melanoxylon* can be classified as a very rapid seasoning rate for both air and kiln seasoning methods.

The air seasoning rate was comparable with the accuracy of ± 5%, and determined with the same method and laboratory, were *Eucalyptus grandis* (37.8 days), *Croton macrostachyus* (44.8 days), and *Pinus Ekebergia capensis* (44.8 days) (Desalegn*et al*., 2012; Desalegn *et al*., 2015). The kiln seasoning rate of *A. melanoxylon* lumber was comparable with *E. deglupta* (7 days) (Desalegn *et al*., 2015). Compared with air seasoning, kiln seasoning gave a better possibility of controlling the relative humidity and temperature, moisture content, rate of seasoning, seasoning defects, appearance, and the quality of seasoned timber besides reducing moisture content (MC) to the desired amount (about 12% MC) in a relatively very short period. The kiln seasoning schedule applied for this timber species was suitable and achieved faster seasoning compared with air seasoning, and not many seasoning defects occurred.

Seasoning Defects

The types and extents of defects are shown in tables 31 and 32. The seasoning defects found on this species were the cup, crook, bow, end-split, surface-split, end check, and surface-checks. The seasoning defects didn't show a significant difference along with the tree height for both air and kiln season ($P<0.05$) as shown in Table 31. However, analysis of variance showed that there was a significant difference between air and kiln seasoned defects except for the cup ($p<0.05$).

Table 31: The mean values of air seasoning defect at the bottom, middle, and top of *A. melanoxylon* tree

Height	n	Mean value of air seasoning defects along with tree height in (mm)						
		Cup	crook	bow	e-split	s-split	e-check	s-check
Bottom	5	1.76 ± 0.67^{a}	1.72 ± 0.41^{a}	3.66 ± 0.59^{a}	31.75 ± 3.50^{a}	81.25 ± 20.16^{a}	0.75 ± 0.5^{a}	0.25 ± 0.5^{a}
Middle	5	1.35 ± 0.46^{a}	2.06 ± 0.83^{a}	2.99 ± 1.86^{a}	30.75 ± 2.99^{a}	46.59 ± 45.99^{a}	0.50 ± 0.58^{a}	00 ± 00^{a}
Top	5	1.37 ± 0.39^{a}	1.46 ± 0.68^{a}	3.50 ± 0.68^{a}	6.25 ± 12.5^{b}	42.50 ± 50.57^{a}	0.50 ± 0.58^{a}	0.25 ± 0.5^{a}

Note: Means having the same superscript letter across the columns are not significantly different at $P < 0.05$. Where, n- number of specimens

Table 32: The mean values of kiln seasoning defect at the bottom, middle, and top of *Acacia melanoxylon* tree

Mean value of kiln seasoning defects along with tree height in (mm)								
Height	n	Cup	crook	bow	e-split	s-split	e-check	s-check
Bottom	5	1.03 ± 0.86^{a}	1.12 ± 0.44^{a}	1.72 ± 0.39^{a}	11.25 ± 8.54^{a}	19.24 ± 29.86^{a}	0.25 ± 0.50^{a}	0.50 ± 0.78^{a}
Middle	5	1.29 ± 0.19^{a}	0.85 ± 0.84^{a}	1.93 ± 1.29^{a}	2.50 ± 5.00^{b}	2.64 ± 10.00^{b}	00 ± 00^{a}	0.750 ± 0.50^{a}
Top	5	0.61 ± 0.52^{a}	0.81 ± 0.50^{a}	1.69 ± 0.75^{a}	15.0 ± 12.91^{a}	12.068 ± 17.07^{c}	0.250 ± 0.5^{b}	0.75 ± 0.5^{a}

Note: Means having the same superscript letter across the columns were not significantly different at $P < 0.05$. Where, n-number of specimens

As depicted in Table 31 and 32 comparatively, air-seasoned boards had more excessive defects than the kiln seasoned boards. This noted that air seasoning depends on the atmospheric conditions, so it is difficult to control the temperature, relative humidity, and air velocity of the surrounding (FPL, 2010). In kiln seasoning, it is possible to control temperature, relative humidity, and air velocity (Keey *et al*., 2000).

Table 33: Summary of ANOVA on seasoning defects of *Acacia melanoxylon* lumber

Source of Variation	DF	Mean-square and statistical significances						
		Seasoning defects in (mm)						
		Cup	crook	bow	e-split	s-split	e-check	s-check
Height	2	0.802ns	0.250ns	0.215ns	237.38ns	2526.59ns	00ns	0.042ns
Drying method	1	0.956ns	4.076*	17.819*	1066.67*	7397.33*	1.042ns	1.50*

Note: ns-not significant at p<0.05,*-significant at p<0.05, **-highly significant at P<0.01 Where, e-split: end-split, s-split: surface split, e-check: end-check, s-check: surface check, and DF: the degree of freedom.

The overall mean values of air-seasoned defects for a cup (1.49 mm), crook (1.75 mm), bow (3.38 mm), end-split (22.92 mm), surface split (56.78 mm), end-check (0.58 mm), and surface check (0.17 mm). On the other hand, the overall mean values of kiln-seasoned defects were cup (0.98 mm), crook (0.67 mm), bow (1.78 mm), end-split (9.58 mm), surface split (11.32 mm), end-check (0.17 mm), and surface split (0.67 mm).

According to Longwood (1961), *A. melanoxylon* lumber defects are categorized under fewer defects in the case of both air and kiln seasoning experiments. The results showed that there was somewhat problem with splits on the lumber. Splits occurred at the pith line and end splitting was a common defect in the air and kiln seasoned boards. This was due to a combination of growth stress, end drying, and lack of fillet restraint in the overhanging ends (Haslett, 1983). The results revealed that warps such as a cup, crook, and bow were a little problem on this species particularly, on the kiln seasoned boards. These types of defects might be caused by poor stacking and natural factors (tension wood and juvenile wood) (Wengert, 2006). Warps that occurred during the seasoning of *Acacia melanoxylon* lumber could be reduced by proper stacking using stickers and top loadings.

Conclusions and Recommendations

From this study, the following conclusions are made.

- Within the stem height of *Acacia melanoxylon*, the basic density and shrinkages (tangential, radial, and volumetric) decreased from the base towards the top of the tree height. The highest values were observed at the base and lowest at the top of the tree height while the green moisture content (MC) of the species was insignificantly increased from the base towards the top.

- *Acacia melanoxylon* lumber is categorized under fast drying rate species in the case of both air and kiln seasoning methods. The species had also low shrinkage and low seasoning defects in the case of both seasoning methods.
- The species was comparable with many indigenous and home-grown exotic timbers in terms of density, seasoning rate, and shrinkage characteristics. Therefore, *Acacia melanoxylon* could substitute the over-harvesting tree species in the country.
- Generally, trees and logs have to be properly harvested, sawn, boards stacked properly, and seasoned to less than fiber saturation point (< 20% MC). Lumber shall be seasoned using the kiln seasoning method to minimize seasoning time, maintain wood quality and suitability for different applications.
- Air seasoning technology needs to shed with a good foundation and air circulation without direct access to moisture and rainfall. The air seasoning technology is not expensive and recommended to small-scale forest products processing industries, construction sectors, and marketing enterprises while the kiln seasoning technology is expensive that could be affordable and recommended to medium and large scale forest products processing industries, construction sectors, and marketing enterprises.

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Variations in Density and Mechanical Properties of *Acacia melanoxylon* Grown in Chencha, SNNPR, Ethiopia

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Abstract

In Ethiopia, the demand for wood has been increasing due to the higher rate of population growth and development of wood industries. This study investigated the density and mechanical properties of *Acacia melanoxylon* along the stem height and radial direction. For this study, representatives of *A. melanoxylon* trees were selected randomly and harvested from Chencha, SNNPR Ethiopia. The sample logs collected from the three portions of stem height and converted into lumber. Specimens were prepared for the determination of density and mechanical properties along with the three stem height and two radial directions (heartwood and sapwood) in green and at 12% moisture content (MC) conditions. The overall mean values of density (0.695 and 0.609g/cm3), modulus of elasticity (9249.7 and 13671.89N/mm^2), modulus of rupture (69.49 and 147.98N/mm^2), maximum crushing strength (33.96 and 62.71N/mm^2), impact bending (9519.60 and 9880.81Nm/m^2), and hardness in tangential (3720.64 and 5373.10N) and radial (3825.8 and 5415.40N) in green and at 12% MC conditions respectively. Forboth moisture conditions, the stem height had significant ($p<0.05$) effects on density and mechanical properties. However, effects didn't show a a significant difference ($p<0.05$) between the heartwood and sapwood both moisture conditions of density and mechanical properties. The interaction effect between tree height and heartwood-sapwood had significant effects on MOE, MCS, and impact bending in case of both moisture conditions. In the case of both moisture conditions, the highest values of density and mechanical properties were observed at the bottom portion and lowest at the top stem of *A. melaxylon*. The tree has the potential as an alternative timber species to supply the wood industry.

Keywords: Blackwood, MOE, MOR, Compression parallel to the grain, Hardness, Stem height, radial direction

Introduction

In Ethiopia, due to higher rate of population growth and development of wood industries coupled with increased demand for wood has caused a dramatic decrease in forest resources. Ministry of Environment, Forest and Climate Change (MEFCC) (2017) report indicated that in 2013, Ethiopia consumed more than 124 million cubic meters of wood each year. With population growth and economic development projections, total wood product demand will increase by about 27% over the next 20 years, reaching an annual consumption of 158 million cubic meters by 2033 (MEFCC, 2017). To satisfy the ever-increasing demands of the consumers, large quantities of lumber, panel, and fiber products are being imported from different countries with hard currency (Kelemwork and Gurmu, 2000; Desalegn *et al*., 2012). Besides the high demand for wood coupled with high deforestation rates of natural forests has led to an increase in the adoption of exotic trees and the introduction of plantation forestry into the country.

Though tree species utilized by the different industries for various wood products are limited in number, for instance, *Cupressus lustanica* (Desalegn *et al*., 2015). According to Teketay*et al*. (2010), there are numerous plantations and potential species whose industrial and other commercial benefits are not yet fully realized. The selective use of the species paired with an inefficient further processing and inappropriate utilization due to lack of information and/or technologies on different wood properties and utilization methods for the alternative timber species. Consequently, it has resulted in the degradation of the existing forests and the selected tree species. Many fast-growing exotic tree species including Eucalyptus species, *Cupressus lustanica*, Acacia species, and other species were introduced to Ethiopia to be used as an alternative source of raw material to meet the ever-increasing demand for different forest products. *Acaciia melanoxylon* was introduced to Ethiopia from Australia and the species was less utilized in the case of Ethiopia. This species has been found or planted in the country is cooler and wetter upland areas, Moist and Wet Kolla, WeynaDega, and Degaagroclimatic zones (Bekele, 2007).

Acacia melanoxylon R.Br belongs to the family Leguminosae and subfamily Mimosoideae. It is a fast-growing species with a tall and straight bole form. It is commonly called Australian Blackwood (Nicholas and Brown, 2002; Lemmens 2006) and locally known as Omedla in Ethiopia (Bekele, 2007). *Acacia melanoxylon* is unusual among the acacias in that it is adapted to moist rather than dry areas (Nicholas and Brown, 2002). It performs well in altitude ranging from 1500 to 2300 meters above sea level with a mean annual temperature of 6 to 19 ^{0}C, mean annual rainfall is 750 to 2300 mm (Orwa *et al*., 2009).

Acacia melanoxylon is a valued timber species since the physical appearance of the wood is considered attractive and has an even texture. It has good strength and machining properties. These properties make the wood suitable for high-quality furniture, cabinet making, fancy veneer, turnery, paneling, carving, flooring, boat building, gunstocks, plywood, tennis racquets, and knobs (Chudnoff, 1980; Boland *et al*., 1984; Nicholas and Brown, 2002; Bradbury *et al*., 2010b). The wood is also used for light construction, tool handles, musical instruments, fence posts, firewood, and charcoal (Lemmens, 2006). The heartwood of *Acacia melanoxylon* tree is a rich brown color and high natural durability (Searle, 2000; Monteoliva*et al*., 2009). Its percentage of heartwood content was about 61%of the total tree volume (Knapic *et al.,*2006).

The use of wood is influenced by the physical and mechanical properties of the timber such as density, moisture, MOE, MOR, compression strength, impact bending, hardness, etc. Density is an important physical property of wood and one of the first to be considered when assessing wood quality, since it correlates with most of the strength properties of wood and conversion processes, including cutting, gluing, finishing, drying, and papermaking (Zobel and van Buijtenen 1989; Desch and Dinwoodie 1996; Searle and Owen, 2005). Mechanical properties of wood indicate the ability of wood to resist various types of external forces, static or dynamic, which may act on it (FPL, 2010). Mechanical properties are very much important in the case of constructional and structural purposes of timber.

The wood properties can vary from species to species, at different site qualities, within species, and individual trees (Haygreen and Bowyer, 1996). Within a single tree can vary along with the tree height and along with radial directions. Nicholas and Brown (2002) noted that the density and mechanical properties of the *A. melanoxylon* are extremely variable within a tree. Also, many scholars (Santos *et al*., 2012; Santos *et al*., 2013) have been reported on the variation of density of the species. However, a few published information on variations of mechanical properties of the species. Machado *et al.* (2014) has reported the variation of density and some mechanical properties along with the tree height and from pith to the bark of *A. melanoxylon* grown in Portugal. Who observed that the density and mechanical properties of the species have irregular variation along with tree height with the value decrease from the base to 5% and then increased from 35% towards 65%. Whereas, he observed an increasing trend from the pith towards the bark of a tree. The variability of all properties is among the main disadvantages of wood as a raw material. So, knowing this is the basis for optimal selection and use of timber for structural purposes. Within a stem variation statistics of mechanical properties is important for the effective use of plantation timbers. Engineers and designers require explicit data on the uniformity of mechanical properties within a tree to estimate its lowest strength. According to Mohd-Jamil and Khairul (2016), within a stem variation of properties affects log during processing into sawn timber and drying procedures. Information on the variation of mechanical properties could also assist in the development of a yield rotation scheme.

Acacia melanoxylon density ranges from (0.465 to 0.670 g/cm3) (Santos *et al*., 2012). The density is directly related to the strength of wood (Nicholas and Brown, 2002). The main reason why density is an index for predicting strength properties is that it is highly affected by cell wall thickness, cell diameter, and the ratio of earlywood to latewood (Dinwoodie, 1981). The species has very good bending properties (TTPB, 2001) and it is highly appreciated due to high crushing strength and resistance to impact, which are all important properties for structural uses (Nicholas and Brown, 2002). *Acacia melanoxylon* is not yet known by the development sectors, manufacturers, and end-users in Ethiopia. It is important to research such economically lesser-known and fast-growing timber species to maintain a sustainable supply of alternative raw materials and increase value addition and select appropriate utilization of technologies for the construction, industry, and furniture manufacturing sectors.

Therefore, the objective of this study was to examine the variations of wood density and mechanical properties along with the three tree height (bottom, middle and top) and along with two radial directions (heartwood and sapwood) of *Acacia melanoxylon* grown in Chencha, SNNPR Ethiopia.

Materials and Methods

Study site description

The species grows on an elevation between 1,300 and 3,250 m above sea level with a geographical direction of 6^{o}8’0”-6^{o}26’0’’N and 37^{o}22’30”- 37^{o}43’30” E (Figure 30). The mean annual precipitation and temperature of this area are usually about 1353 mm and 14^{0}C respectively (Yewubdar and Aseffa, 2017).

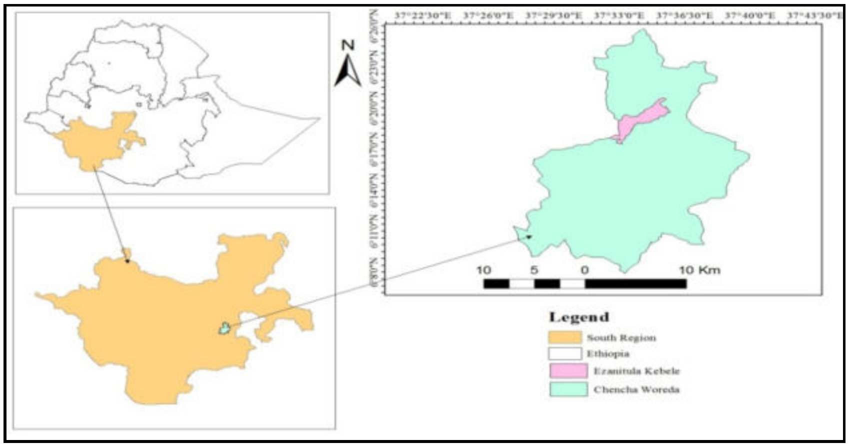

Figure 30: Map of Ethiopia showing the study area

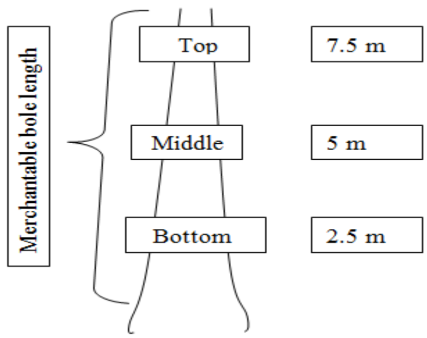

Figure 31: Sample log taken along the three stem height of *Acacia melanoxylon* tree

Tree Sampling

A total of five trees of 30 years old *Acacia melanoxylon* were randomly selected and harvested from the Chencha world community forest. The selected sample trees are straight trunks, normal branching, and had no disease or pest symptoms (ISO 3129, 1975; Desalegn *et al*., 2012). The height and diameter at breast height (dbh) of the trees were ranging from 17 to 20 m and 21 to 26 cm, respectively. Each sample tree was cross-cut in to three 2.5 m logs which represent the bottom, middle, and top of the tree height (Desalegn, 2006; Moya *et al*., 2013) and, the end logs were sealed with paint to avoid moisture loss and end check/splitting. Then the sample logs were transported to Addis Ababa, Forest Products Innovation Research and Training Center (FPIRTC) laboratory for further processing.

Sawing and preparation of wood specimens

The sample logs were sawn tangentially using circular sawmill produced boards of 3 cm thickness in Forest Products Innovation Research and Training Center, Addis Ababa. According to Burley and Wood (1977), the sawn boards for density and mechanical properties were cross-cut into a series of 1.25 m long stringers (Figure 32). These were grouped and coded into odd and even numbers for the green and air-dry tests respectively. Boards for the dry tests were subjected to air seasoning yard under shade up to 12% MC reached. While the green test sample boards were planned, ripped, and cross-cut into a final cross-section of 2x2 cm and 100 cm length and finally, the heartwood and sapwood from each section separately cross-cut into standard length specimens corresponding to each wood properties test. The stringers at air-dry conditions after it reached 12% MC, similar to the green test specimen preparation procedure, the heartwood and sapwood from each section separately cross-cut into standard length specimens corresponding to each wood properties test.

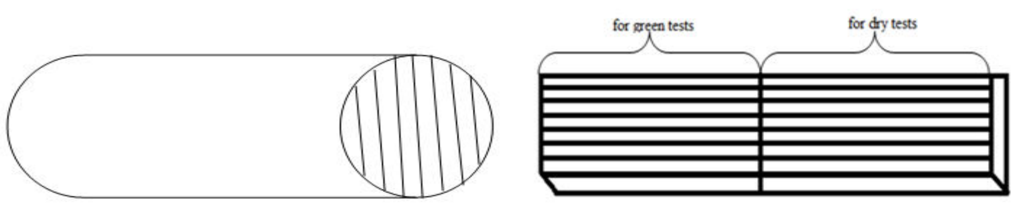

Figure 32: Sawing pattern and specimens preparations from sawn lumber for density and mechanical properties determination in green and air-dry condition tests

Density and mechanical properties test

The specimens were prepared along the three tree heights (bottom, middle and top) and along the radial direction (heartwood and sapwood) from green and at 12% MC conditions for testing of density and mechanical properties.

Table 34: Dimensions, standards, and numbers of test specimen used for density and mechanical properties test

Property	Specimen dimensions (mm)*	Standards	Number of specimens
Density	20 x 20 x 60	ISO 3131	180
Static bending	20 x 20 x 300	ISO 3133	180
Compression// grain	20 x 20 x 60	ISO 3387	180
Impact bending	20 x 20 x 300	ISO 3348	180
Hardness	20 x 20 x 45	ISO 3348	360

(Radial x tangential x longitudinal)*

Density Tests

The density of wood was determined on a green-mass and air-dry-mass basis. A digital caliper was used to measure the dimensions of the samples at the green and air-dried wood at12% moisture content (MC) to determine their volumes. The specimens were then weighed using an electronic balance. Then Densities calculated using the following formulas:

$$\rho g = \frac{Mg}{Vg} \qquad (1)$$

$$\rho 12 = \frac{M12}{V12} \qquad (2)$$

Where ρg is the density at green (g/cm^3), ρ12 is the density at 12% MC, Mg is mass at the green, M12 is mass at 12% MC(g), Vg is the volume at green (cm^3) V12 is the volume at 12% MC.

Mechanical Properties Test

Static Bending

The static bending strength was determined based on ISO 3133, 1975 standard by using the Universal Strength Testing Machine (UTM), type FM2750 with maximum loads of 50 Kilo Newton (KN). The distance between the points of suspension was 280 mm. The load was applied to the center of the specimen, on the radial face at a constant speed of 0.11mm/s. Load of the force plate and corresponding deflection was recorded from the dial gauge manually for each sample. Graph plotting was done for each specimen using Microsoft Excel to calculate MOE and MOR. From each plotted graph, MOE and MOR were calculated using the following formulae:

$$MOE = \frac{p^1L^3}{4d^1bh^3} \text{-----------------------------------} (3)$$

$$MOR = \frac{3PL}{2bh^2} \text{-----------------------------------} (4)$$

Where: MOE=Modulus of elasticity (N/mm^2), MOR=Modulus of rupture (N/mm^2) P^1= Load at the limit of proportionality (N), P= Maximum Load (N) L= Span length (mm), d^1= Deflection at the limit of proportionality (mm), b= Width of the specimen (mm) h= Thickness of the specimen (mm)

Compression Parallel to the Grain

Compression parallel to grain test was done based on ISO 3387, 1975 standard. The specimens were tested using Universal Testing Machine with the speed of loading 0.01 mm/sec. The load was applied through a spherical bearing block, preferably of the suspended self-aligning type, to ensure uniform distribution of stress. On some of the specimens, the load and the deformation in a 15 cm central gage length was read simultaneously until the proportional limit was passed. The test was discontinued when the maximum load is passed and the failure occurs. The Maximum Crushing Strength (MCS) was determined using the following formula:

$$MCS = \frac{C}{bh} \text{-----------------------------------} (5)$$

Where: MCS=Maximum crushing strength (N/mm^2), C=Maximum load (N), b=width of the specimen (mm), h=Thickness of the specimen (mm)

Impact bending

Impact bending or specific impact resistance is the work consumed in causing total failure in impact bending and it is determined based on ISO 3348, 1975. The specimens were tested using a pendulum hammer (Impact Bending Testing Machine, model PW5-S). The specimens were placed on the machine and the load was applied to the center and perpendicular to the radial face of the test specimen. The joule value was read from the force plate of the test machine and the strength was computed using the following formula.

$$Sp.Im.Re. = \frac{P}{bh} \text{---} (6)$$

Where: Sp.Im.Re=Specific impact resistance in (Nm/m^2), P=Joule value (Nm), b=width of the specimen (mm), h=Thickness of the specimen (mm).

Hardness test

Hardness represents the resistance of wood to indentation and marring. Hardness was comparatively measured by force required to embed 11.3 mm ball one-half its diameter into the wood (FPL, 2010). Hardness values were obtained by using the Janka method (ISO 3348, 1975). The specimens were tested using UTM with the rate of loading was 0.11mm/s for both radial and tangential faces.

Statistical analysis

Statistical Package for the Social Sciences (SPSS) version 20 (IBM Corp. released 2011) was used to analyze the data using descriptive statistics and analysis of variance (ANOVA) Procedure. A least significant difference (LSD) method was used for mean comparison at $P<0.05$.

Results and Discussion

Density

The mean values of density along with the three stem height in green and at 12% MC conditions are shown in Table 35 and Table 36. In the case of both moisture conditions, the stem height had a significant effect on the density at $p<0.05$. However, the heartwood and sapwood didn't show a significant effect on density in green and at 12% MC conditions of *A. melanoxylon* timber. The interaction effect between tree height and radial direction didn't have a significant effect in the case of both moisture conditions. From the study, it was found that *A. melanoxylon*at the base had higher density and decreased from the base to top of the tree height in both moisture conditions. Similar variation to this study, a significant decrease in height was found in *Acacia melanoxylon* trees in Argentina (Igartúa and Monteoliva, 2009). The result of the study agrees with the finding on Oriental beech (*Fagusorientalis*) where density decreased from base to top (Topaloglu and Erisir, 2018). Similar patterns were also reported for *Populus euramericana* (Kord *et al*., 2010) and Athel wood (Kiaei and Sadegh, 2011).On the other hand, a significant decrease in specific gravity with increasing stem height was observed in the hardwood of *Acacia mangium*, *Bombacopsis quinata*, *Sweitenia macrophylla*, *Termenalia amazonia* and *Termenalia oblonga* (Moya and Muñoz, 2010) in Costa Rica.

The variation along the stem height might be due to maturity at the base and juvenility at the tip of the tree. Juvenility increases from bottom to top and as juvenility increases density decreases (Getahun *et al*., 2014). Density in the juvenile wood zone is low because there are relatively few late woods/summerwood cells and a high proportion of cells have thin wall layers (Haygreen and Bowyer, 1996). Ishengoma *et al*. (1998) noted that density was the main criterion for the prediction of wood strength properties. Ishengoma *et al*. (1997) also reported that juvenile wood is significantly lower in density than mature wood and hence decreases in density as you move away from the bottom of the stem. This implies that the high-density wood from bottom logs should be used for structural purposes where high strength is required.

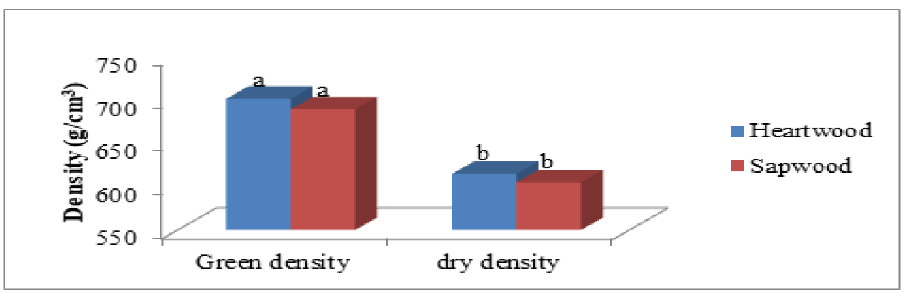

Figure 33: Density variation between heart-sapwood and between green-dry conditions of *Acacia melanoxylon* timber.

In the case of both moisture conditions, the heartwood density was slightly higher than the corresponding sapwood density. A similar variation to this finding was reported for the same species (Aguilera and Zamora, 2009) in Australia. Higher values of heartwood density compared to the corresponding sapwood density were reported for *Acacia burkea* and *Spirostachays africana* (Mmoloti *et al*., 2013) and *Albizzia julibrissin* (Kiaei and Farsi, 2016). The differences may be due to extractives deposited in the heartwood. Aguilera and

Zamora (2009) reported that the phenol extractive content of heartwood was more than double that of sapwood and affected the wood properties of *Acacia melanoxylon*.

The overall mean values of density in green and at 12% MC conditions were 0.695 g/cm^3 and 0.609 g/cm^3 respectively. A similar value of density at 12% MC was reported for *A. melanoxylon* (Igartu´a *et al*., 2009) in Argentina, who found 0.604 g/cm^3 and similarly, in the range of 0.515–0.71 g/cm^3 reported for the same species (Lemmens, 2006). On the other hand, superior values than these findings were reported by Machado *et al*. (2014) with a value of 0.654 g/cm^3 for this species. These variations may be attributed to genetics and local environmental factors that affect the growth of the trees such as soil characteristics, the density of stand, precipitation, solar radiation, and age of the trees (Panshin and de Zeeuw, 1980).

Concerning commercially known and endangered tree species in Ethiopia, the density of *A. melanoxylon* (0.61 g/cm^3) was comparable with density at 12% MC reported for *Hagenia abyssinica* (0.56 g/cm^3) and *Pouteria adolfi-friederici* (0.6 g/cm^3) but higher than that of *Cupressus lustanica* (0.43 g/cm^3), *Pinus patula* (0.45g/cm^3), *Juniperus procera* (0.54 g/cm^3); and lower than those of *E. globulus* (0.78 g/cm^3) and *E. camaldulensis* (0.853 g/cm^3) (Desalegn *et al*., 2012; Desalegn *et al*., 2015). According to Chudnoff (1980), the density tested at 12% moisture content of *A. melanoxylon* was in the interval of medium density species.

Mechanical properties

The results of the mechanical properties of *Acacia melanoxylon* along with the three stem height in green and at 12% moisture content (MC) conditions are presented in Table 35 and Table 36 respectively. Tables 37 and 38 show the statistical analysis of the mechanical properties in green and at 12% MC conditions tested specimens respectively.

Static bending

Modulus of elasticity

The modulus of elasticity is the stress at the elastic limit. The mean values of modulus of elasticity (MOE) along with the three stem height in green and at 12%MC conditions are shown in tables 35 and 36. The Analysis of variance revealed that the tree height and the interaction between tree height and heartwood-sapwood had a significant effect on MOE in the case of both MC conditions at $p<0.05$. However,it didn't show a significant difference between the heartwood and sapwood $p<0.05$. The results showed that in the case of both MC conditions, the highest values of MOE were found at the base of the stem and decreased from the base towards the tip along with the stem. A similar pattern to this finding was reported for *Albizzia julibrissin* species (Kiaei and Farsi, 2016) grown in Iran. This result is similar to the trend of variation of wood density of the species. As reported by different scholars (Panshin and de Zeeuw, 1980; Nicholas and Brown, 2002) density was significantly correlated with the mechanical properties of wood. This noted that the density of the species can predict the values of the mechanical properties of the species.

Table 35: The means and standard deviation values of density and mechanical properties in green basis at the bottom, middle, and top of *A. melanoxylon* tree

Tested properties	n	Bottom	Middle	Top
Density (kg/m^3)	90	727.57 ± 46.05^a	682.28 ± 25.78^b	675.00 ± 45.12^b
MOE (N/mm^2)	90	9655.40 ± 1203.86^b	9129.90 ± 1074.59^{ab}	8963.91 ± 1090.29^a
MOR (N/mm^2)	90	72.73 ± 8.79^b	69.25 ± 8.03^{ab}	66.49 ± 9.57^a
MCS (N/mm^2)	90	35.69 ± 7.13^b	34.44 ± 5.83^b	31.7483 ± 6.56^a
Sp.Im.Re. (Nm/m^2)	90	10055.2 ± 1703.51^b	9450.00 ± 1855.96^b	9054.20 ± 1261.88^a
H. tangential (N)	90	3932.33 ± 605.28^b	3659.3 ± 466.39^a	3570.0 ± 387.51^a
Hardness radial (N)	90	3998.0 ± 611.59^b	3861.7 ± 483.92^b	3617.7 ± 384.59^a

Note: Means having the same Superscript letters across the rows were not significantly different at $P<0.05$.Where, MOE: modulus of elasticity, MOR: modulus of rupture, MCS: Maximum compression strength, Sp.Im.Re: Specific impact resistance, T. hardness: Tangential hardness, R. hardness: Radial hardness, and n: is the number of specimens.

The results show that the bottom portion of *A. melanoxylon* had more stiffness than the mid and top portions. According to Langum *et al*. (2009), the main factors leading to decreasing stiffness are low density, short fibers, thinner cell walls, and higher microfibril angles in juvenile wood and conversely, it is the reverse in matured wood. Desch (1986) reported that the greater the MOE, the stiffer the timber, and conversely, the lower the MOE, the more flexible the timber will be. The mechanical properties are also affected by the presence of knots, spiral grain, relative humidity, and temperature (Huang *et al*., 2003). An important element of wood quality is that of stiffness or its modulus of elasticity (Kollman and Côté, 1968). The end-use of wood material, especially for structural timber is strongly related to the modulus of elasticity.

The modulus of elasticity (MOE) for the heartwood (13863.17 and 9400.50N/mm^2) was slightly higher than the sapwood (13479.62 and 9098.92N/mm^2) for green and at 12% MC conditions, respectively (Fig. 5). According to Machado *et al*. (2014), the value of MOE decreases from 50% (heartwood) to 90% (sapwood) along with radial positions of *A. melanoxylon*. The finding is also in agreement with hardwood such as Oak species (Merela and Cufar, 2013) andSilkwood (*Albizzia julibrissin*) (Kiaei and Farsi, 2016). For example, the heartwood and sapwood of silkwood had MOE values of 5530 and 4800 N/mm^2, respectively. The difference values of MOE of heartwood and sapwood are related to the chemical properties in heartwood and sapwood. A significant amount of extractives are deposited in the heartwood, up to two or three times more than in sapwood (Panshin and de Zeeuw, 1980).

Table 36: The means and standard deviation values of density and mechanical properties at 12% MC from the bottom, middle, and top of *A. melanoxylon* tree

Tested properties	n	Bottom	Middle	Top
Density (g/cm^3)	90	648.64±37.10^a	591.00±32.94^b	590.00±41.71^b
MOE (N/mm^2)	90	14155.30±1524.14^b	13643.20±1395.79^{ab}	13215.50±1507.49^a
MOR (N/mm^2)	90	152.10±13.10^b	147.91±8.35^{ab}	143.94±13.05^a
MCS (N/mm^2)	90	65.41±6.61^b	62.01±7.05^a	60.71±6.50^a
Sp.Im.Re (Nm/m^2)	90	10398.21±1299.11^b	9655.80±1726.71^a	9589.20±1764.32^a
H. tangential (N)	90	5664.70±722.30^b	5333.00±611.15^b	5121.70±866.55^a
H. radial (N)	90	5665.00±536.37^b	321.00±530.49^a	5260.30±661.23^a

Note: Means having the same Superscript letters across the rows were not significantly different at P<0.05. Where, MOE: modulus of elasticity, MOR: modulus of rupture, MCS: Maximum compression strength, Sp.Im.Re: Specific impact resistance, T. hardness: Tangential hardness, R. hardness: Radial hardness, and n: is the number of specimens.

Table 37: Summary of ANOVA at green density and mechanical properties of *A. melanoxylon* timber

Source of	Mean-square and statistical significances						
variation	density (g/cm^3)	MOE (N/mm^2)	MOR (N/mm^2)	MCS (N/mm^2)	Sp. Im. Re (Nm/m^2)	T. hardness (N)	R. hardness (N)
Height (H)	224343.79*	3909024.63*	292.96*	121.80*	6039583.33*	1068974.44*	1113881.11*
Section (S)	13187.06ns	2046989.37ns	118.38ns	132.06ns	3258506.94ns	938401.11ns	693444.44ns
HxS 2	3098.87ns	4345263.35*	616.72*	646.43*	9323000.21*	382987.78ns	32347.33ns

Note: ns-not significant at p<0.05,*-significant at p<0.05, **-highly significant at P<0.01. Where, MOE: modulus of elasticity, MOR: modulus of rupture, MCS: Maximum compression strength, Sp.Im.Re: Specific impact resistance, T. hardness: Tangential hardness, R. hardness: Radial hardness, and DF: the degree of freedom.

Table 38: Summary of ANOVA at 12% MC of density and mechanical properties of *A. melanoxylon*

Source of		Mean square and statistical significances						
Variation	DF	Density (g/cm^3)	MOE (N/mm^2)	MOR (N/mm^2)	MCS (N/mm^2)	Sp. Im. Re (Nm/m^2)	T. hardness (N)	R. hardness (N)
Height (H)		234090.42*	6652744.23*	498.53*	176.414*	7614925.21*	2247567.78*	1428857.78*
Section (S)		12117.70ns	3324087.49ns	161.36ns	39.64ns	7504179.39ns	932284.44ns	646854.44ns
HxS	2	3091.73ns	6585587.32*	312.23ns	144.28*	52659827*	1219687.78ns	695551.11ns

Note: ns-not significant at p<0.05,*-significant at p<0.05, **-highly significant at P<0.01. Where, MOE: modulus of elasticity, MOR: modulus of rupture, MCS: Maximum compression strength, Sp.Im.Re: Specific impact resistance, T. hardness: Tangential hardness, R. hardness: Radial hardness, and DF: the degree of freedom.

The overall mean values of MOE in green and at 12% MC conditions were 9249.70 and 13671.89 N/mm^2, respectively. The analysis of variance showed that MOE was significantly different between the green and at 12% MC condition tested specimens of *A. melanoxylon* timber. The overall mean value of this finding was greater than the mean values of MOE tested at 12% MC (13,000 N/mm^2) and less than in green condition (13,000 N/mm^2) for this species elsewhere (Bootle, 1983). Igartùa *et al*. (2015) reported less value of MOE in 12% MC condition (10,900 N/mm^2). Less value of MOE in green and air-dry conditions (11781.9 and 14124.5 N/mm^2) respectively also reported for this species (Chudnoff, 1980). However, another study on the same species reported higher MOE values (9095 and 14400 N/mm^{2}respectively) in green and air-dry conditions (Haslett, 1986)than the current study.

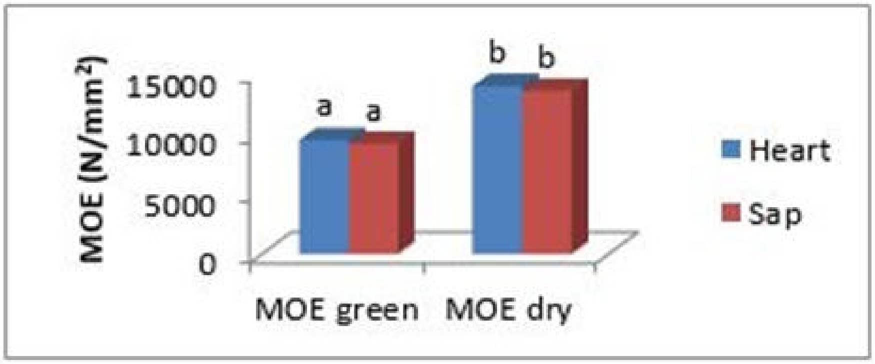

Figure 34: The variation of MOE between heart-sapwood and between green-dry conditions of *A. melanoxylon* timber

In comparison with other Acacia species, the findings were greater than the values of MOE of *Acacia mangium* and *Acacia auriculiformis* tested at 12% MC (9992 and 8214 N/mm^2), respectively (Jusoh *et al*., 2014). However, values greater than this finding were reported for MOE tested in green and air-dry conditions (14300 and 19700 N/mm^2), respectively for *Acacia schafneri* (Machuca-Valesco *et al*., 2017) and also for *Acacia deccurens* tested at 12 % MC (14310 N/mm^2) (Desalegn *et al*., 2012). Concerning commercially known timber species in the country, the MOE of *A. melanoxylon* was greater than *Cordia africana* (6996 N/mm^2), *Cupressus lusitanica* (6145 N/mm^2), *E. globulus* (11655 N/mm^2), and *Prunus africana* (12070 N/mm^2) (Desalegn *et al*., 2012, 2015).

Modulus of Rupture

The mean values of Modulus of rupture (MOR) along the three portions in green and at 12% moisture content conditions are shown in Table 37 and Table 38. The analysis of variance showed that the tree height had significant effects on the modulus of rupture (MOR) along with the stem height ($p< 0.05$) for both MC conditions (Table 4 and Table 5). However, there was no statically significant difference between the heartwood and sapwood for both MC conditions. The results revealed that MOR showed a decreasing trend from the base towards the tip of the tree in both MC conditions and this is similar to the trend of variation of wood density of the species. A similar variation to this finding was reported for Persian wood (*Albizzia julibrissin*) (Kiaei and Farsi, 2016) grown in Iran. The decreasing values of MOR along with the tree height from bottom to the top might be due to maturity at the base and juvenility at the tip of the tree. A higher value for MOR indicates a greater strength (Desch, 1981).

The mean values of modulus of rupture (MOR) of heartwood (70.64 and 149.63N/mm^2) were slightly higher than the corresponding sapwood (68.34 and 146.78N/mm^2)) in both green and at 12% MC conditions of *A. melanoxylon* timber, respectively and this might be influenced by the presence of extractive materials found in the heartwood. According to Machado *et al*. (2014), the MOR decreased from 50% (heartwood) to 90% (sapwood) along the radial direction of *A. melanoxylon* timber. Similar patterns to this finding were also reported for *Pseudolachnostylisma prounaefolia* (Uetimane and Ali, 2010) and Persian Silkwood (Kiaei and Farsi, 2016). According to the report of Haygreen and Bowyer (1996), the heartwood has a higher concentration of extractives and infiltration materials than sapwood; therefore, the density and strength property of heartwood is often slightly higher than that of sapwood.

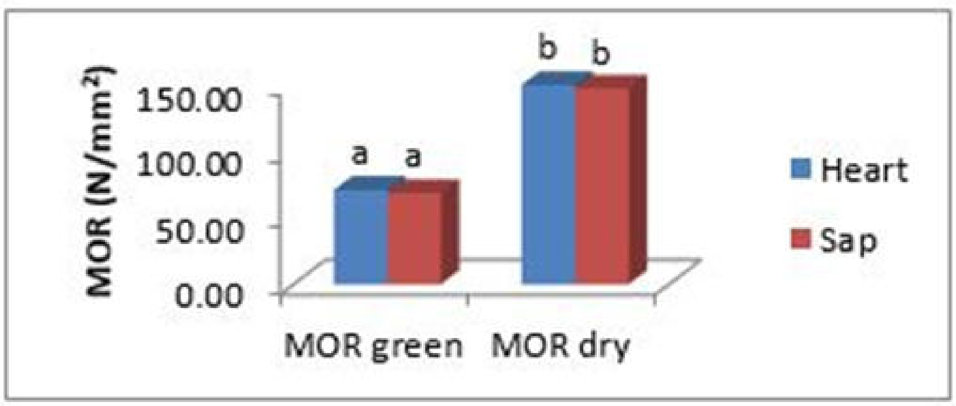

Figure 35: The variation of MOR between heart-sapwood and between green-dry conditions of *A. melanoxylon* timber.

The overall mean values of Modulus of rupture (MOR) in green and at 12% MC conditions were 147.98 N/mm^2 and 69.49 N/mm^2 with a standard deviation of 12.05 N/mm^2 and 9.09 N/mm^2 respectively. Figure 6 depicted that there was a marked difference of MOR between the green and at 12% MC condition tested of *Acacia melanoxylon* tree.

The overall mean values of MOR tested at 12% MC condition were greater than the MOR values reported for the same species: 89.9 N/mm^2 by Igartûa *et al*. (2015), 139 N/mm^2 by Machado *et al*. (2014), and 129.9 N/mm^2 by Haslett (1986). When compared with other

Acacia species this finding was greater than reported by Jusoh *et al*. (2014), for *A. mangium* and *A. auriculiformis* (78 and 89N/mm^2), respectively. About commercially known and endangered tree species in the country, the result was greater than that of *Cordia africana* (64 N/mm^2), *Cupressus lusitanica*(64 N/mm^2), and *Juniperus procera* (87 N/mm^2) tested at 12% MC (Desalegn *et al*., 2015).

Static bending tests, including MOR and MOE, indicated that *A. melanoxylon* can be a useful material for building construction. The MOR and MOE values are used to characterize the strength of beams, joists, rafters, tabletops, chair bottoms, trusses, furniture, and timbers subjected to transverse bending (Desalegn *et al*., 2012).

Compression Parallel to the grain

Compression parallel to grain (crushing strength) determines the load a beam will vertically carry. The mean values of maximum crushing strength (MCS) along with the three stem height tested in green and at 12% MC conditions are shown in tables 35 and 36. The analysis of variance revealed that the stem height had significant effects on MCS in both green and at 12% MC conditions of *A. melanoxylon* timber ($p < 0.05$). However, no significant difference was observed along radial direction i.e. between heartwood and sapwood ($p<0.05$). In the case of both moisture conditions, the MCS showed a decreasing trend from the bottom towards the top of the tree height. This might be due to maturity at the base and juvenility at the tip of the tree height. Similar patterns were reported byIzekor*et al*. (2010)in which a decreasing trend from base to tip in compression parallel to the grain of *Tectona grandis* timber was observed. Similarly results were reported for Oriental beech and Caucasian fir species (Topaloglu and Erisir, 2018).

In contrast to this finding, Machado *et al*. (2014) reported that the compression parallel to the grain of *A. melanoxylon* grown in Portugal increases with tree stem height especially from 35% to 65% of tree height. This indicates that most hardwood species have no common trend variations along with the stem height of the trees.

The maximum crushing strength (MCS) of this finding follows a similar declining trend of the density along with the stem height. Density has usually a significant correlation with compression strength (Gindl and Teischinger, 2002). Desalegn *et al*. (2012) reported that wood with high strength in MCS is suitable for timber used as columns, props, posts, and spokes.

The MCS of heartwood (34.73 and 63.73 N/mm^2) was slightly higher than sapwood (33.26 and 62.23 N/mm^2) in green and at 12% MC conditions respectively. According to Machado *et al*. (2014), the MCS of *A. melanoxylon* timber decreased from 50% (heartwood) to 90% (sapwood) radial direction. This difference between the heartwood and sapwood can be attributed to the higher ethanol extractive content in the heartwood than the sapwood (Aguilera and Zamora, 2009). Also, Haygreen and Bowyer (1996) report indicated that a considerable amount of infiltrated material may somewhat increase the weight of wood and its resistance to crushing.

The overall mean values of MCS in green and at 12% MC conditions were (33.96 and 62.71N/mm^2) with a standard deviation of (6.67 and 6.94 N/mm^2), respectively. There was a significant difference in maximum crushing strength between green and air-dried to 12% MC (Figure 36).

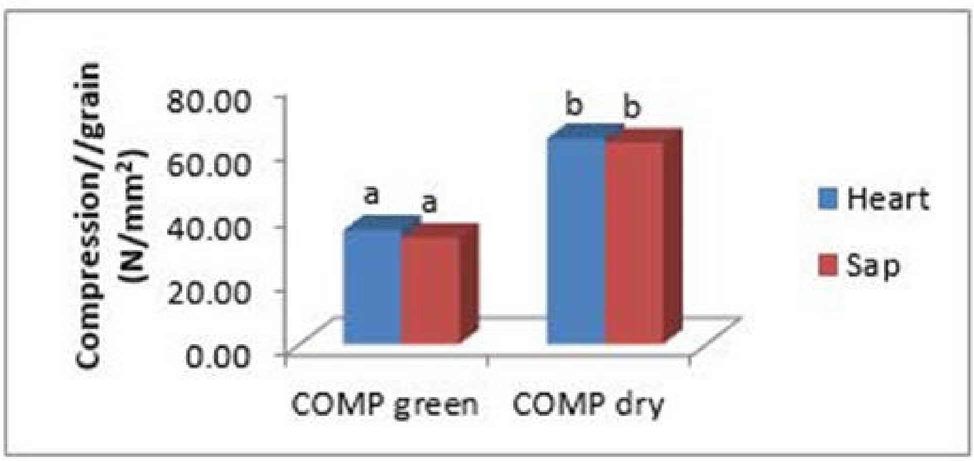

Figure 36: The variation of MCS between heart-sapwood and between green and dry conditions of *A. melanoxylon* timber.

The overall mean values of MCS obtained in this study were comparable with other studies reported by Haslett (1986) for the same species with the values of MCS of 29.4and 62.5N/mm^{2}for green and air-dry conditions, respectively. Similarly, Machado *et al*., (2014) reported that the value for MCS was 61 N/mm^{2}for the same species in 12% MC condition. . However, the findings were greater than the values (33 and 48N/mm^2) reported by Bootle,

(1983) in green and air-dry conditions, respectively. In comparison with other acacia species, the MCS values of *A. melanoxylon* timber in green and air-dry conditions were less than the figures reported (40.8 and 85.8N/mm^2) for *Acacia schaffneri* (Machuca-Velasco *et al*., 2017) and less than that of *A. decurrens* (85 N/mm^2) in air-dry condition (Desalegn *et al*., 2012).

About commercially known and endangered tree species in the country tested an air-dry condition, the MCS(62.71N/mm^2) was higher than that of *Juniperus procera* (38 N/mm^2), *Cordia africana* (29 N/mm^2), *E. globulus* (52 N/mm^2) and *E. grandis* (45 N/mm^2) (Desalegn *et al*., 2012; Desalegn *et al*., 2015). Based on the classification, compression parallel to the grain was in the interval of high maximum crushing strength and used for short columns, trusts, chair legs, blocks, pillars, roof rafters, and pit-props.

Impact bending

Impact bending is the resistance offered by wood specimens to sudden shocks. The mean values of impact bending in green and at 12% MC conditions tested specimens along the three stem heights, respectively. The statistical analysis revealed that the tree height had significant effects on specific impact resistance in both green and at 12% MC conditions. There was no significant difference between heartwood and sapwood in both green and dry conditions. The result showed that the highest value of impact resistance was observed at the base and decreased from the bottom towards the top of the tree height. A similar variation to this finding was reported for Black locust (*Robinia pseudoacacia*) (Adamopoulos *et al*., 2007). This is also similar to other mechanical properties affected by the proportion of earlywood and latewood along with the stem height of the sample species. This variability may also be influenced by a combination of several other factors, including the inherent variability within trees (Harzman and Koch, 1982), growth and environmental conditions, and the presence of high extractive contents (Tsoumis, 1991).

The results revealed that the mean values of specific impact resistance of heartwood (10071.11 and 9808.8 Nm/m^2) were to some extent higher than that of the sapwood (9690.6 and 9230.8 Nm/m^2) for green and at 12% MC conditions, respectively. Aguilera and Zamora (2009), reported that *A. melanoxylon* tree density of heartwood (0.583 to 0.987 g/cm^3) is higher than sapwood (0.494 to 0.740 g/cm^3). This denotes that the heartwood is stronger than sapwood because the density and strength properties of *A. melanoxylon* are significantly correlated (Nicholas and Brown, 2002). The overall mean values of specific impact resistance in green and at 12% MC conditions tested were 9880.81 and 9519.6 Nm/m^2 with standard deviations of 1654.46 and 1660.71 Nm/m^2, respectively. The analysis of variance revealed that there was no significant difference between green and at 12% MC condition tested of specific impact resistance. The impact resistance may be influenced by the moisture content of the specimens. Comparable results were reported for *E. globulus, E. grandis,* and *E. camaladulensis* (Desalegn and Gezahegn, 2010).

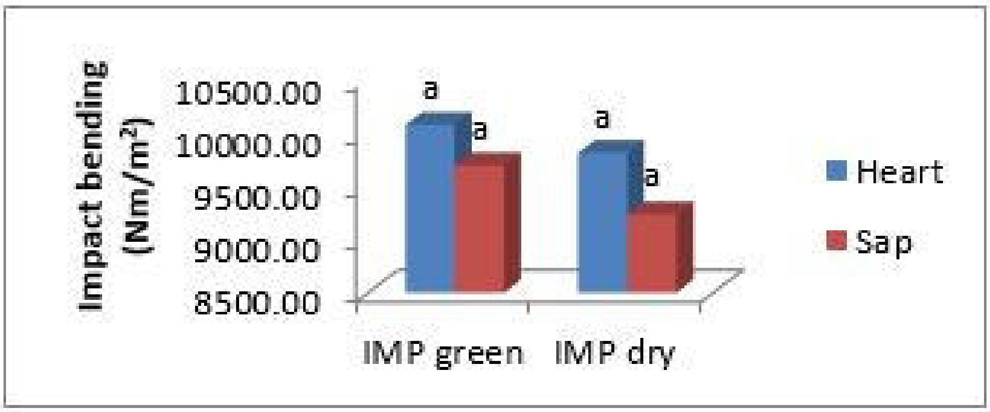

Figure 37: The variation of impact bending between heart-sapwood and between green-dry conditions of *A. melanoxylon* timber. Where IMP is impact bending

The average value obtained in dry conditions was greater than that of *A. decurrens* (7313 Nm/m^2) (Desalegn *et al*., 2012), Cupressus *lustanica* (5888 Nm/m^2), and *Pinus patula* (5187 Nm/m^2) but it was less than values reported for *E. saligna* (12873 Nm/m^2) and *Grevillea robusta* (18094 Nm/m^2) by Desalegn *et al*., (2012 and 2015).

Hardness

The mean values of hardness in the tangential and radial direction in green and at 12% MC conditions along the tree height of the tree were summarized in tables 35 and 36 with other tested mechanical properties of these findings. The ANOVA table (Tables 37 and 38) revealed that the tree height had significant effects on hardness tangential and radial for both in green and at 12% MC conditions ($p<0.05$). However, no significant difference was observed along the radial direction i.e. between heartwood and sapwood for both MC conditions (Table 37 and Table 38). The mean values of hardness tested in both directions showed that a decreasing trend from the base towards the top of the stem height in green and at 12% MC conditions respectively. The variation in the tree height might be because the bottom log of the same tree has more mature-wood than the top log which consists mainly of juvenile wood (Panshin and de Zeeuw, 1980). The overall mean values of hardness were 3720.64N and 5373.10N is tangential) and 3825.80 N and 5415.40N in radial directions in green and at 12% MC conditions, respectively. There was a significant difference observed between green and air-dry conditions for both hardness tested in tangential and radial directions.

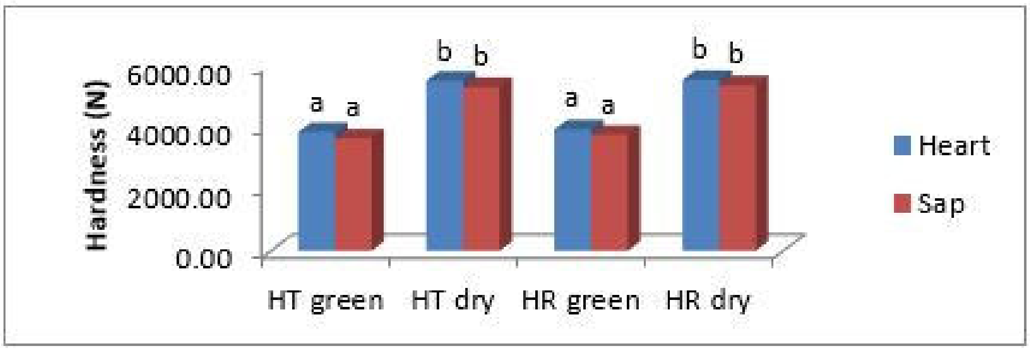

Figure 38: The variation of hardness between heart-sapwood and between green-dry conditions of A. melanoxylon timber. Where HT: hardness in tangential and HR: hardness in the radial direction

The results showed that the mean values of hardness (tangential and radial) in heartwood were slightly higher than sapwood in both green and at 12% MC conditions. Similar patterns were reported for hardwoods of White and Red Oak species at 12% MC conditions (Merela and Cufar, 2013). Mmolotsi and Kejekgabo (2013) reported significant differences in wood density between the heartwood and sapwood found in *Acacia burkea* and *Spirostachys africanum* species.

The overall mean value of hardness in air-dry conditions was less than the value (5900 N) reported by Bootle, (1983) and that of the value (6600 N) reported by Nicholas and Brown (2002) at 12% MC condition for the species. The current value was greater than the value (3600 N) reported for *A. deccurens, Cuprussus lustanica* (2761 N), and *Pinus patula* (2179 N) (Desalegn *et al*., 2015) in air-dry condition.

Conclusions and Recommendations

- Several wood properties of *Acacia melanoxylon* in green and air-dry conditions were investigated for assessing the potential of the species for various utilizations. The density and all tested mechanical properties were affected by tree height in both green and air-dry conditions. However, green and air-dry conditions, the heartwood and sapwood didn't affect the density and mechanical properties of the timber.The interaction effect of tree height and heartwood-sapwood had significant effect on MOE, MCSandimpactbendinginthecaseofbothmoisture conditions.
- In both moisture conditions, the highest values of density and mechanical properties were observed at the base and lowest at the top of *Acacia melanoxylon* timber. This denoted that the bottom portion has strongest than the middle and top portions of the tree.
- The heartwood density and mechanical properties were slightly higher than the sapwood.
- Because the overall mechanical properties get greatly enhanced at 12% MC conditions, the wood materials should be properly seasoned before use.
- *Acacia melanoxylon* timber density and mechanical properties showed that the species belongs to medium to high-density timber species. Therefore, it is suitable for multiple uses that require strength and hardness and can substitute over-utilized native tree species.
- Further studies should be conducted on tensile and shears strength, natural durability, and treatability with preservatives, finishing, and working properties of this lesser-known and lesser utilized of *Acaciamelanoxyon* timber species in Ethiopia.

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Biomass and soil carbon stock assessment of fast growing species in Diksis Woreda, Oromiya Region, Ethiopia: implication of plantation for climate change mitigation

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Abstract

This study estimated the biomass and carbon pools of selected fast-growing tree species in the Diksis Woreda, Oromiya region of Ethiopia. Height and diameter at breast height (DBH) were measured in permanently sampled plots (9mx9m) with three replications. A total of 99 soil samples (0–15 and 15-30 cm) were also collected to determine soil organic carbon (SOC) and bulk density. Above (AGB)and below-ground biomass (BGB)were calculated using the site and species-specific allometric equations while SOC was zanalyzed using appropriate procedures in the laboratory. The results showed that the mean total biomass carbon stocks ranged from 1.2-5.7Mg C ha^{-1}. The highest biomass carbon stock was recorded for *Eucalyptus globules* (5.7Mg C ha^{-1}) and the lowest was recorded for *Eucalyptus grandis* (1.*2*Mg C ha^{-1}). Among the studied tree species, the highest and lowest mean total SOC was recorded for *Casuarinaequisetifolia (*89Mg C ha^{-1}*)*, and *Eucalyptus viminalis* (34Mg C ha^{-1}), respectively. The study also revealed that plantation sites could enhance carbon stocks accumulation both in the biomass and soil. Hence, the plantation can be considered as a potential strategy for climate change mitigation measures in the country.

Key Words: Highland, wood fuel, exotics trees, carbon, plantation

Introduction

Currently, climate change is a great concern for human kind due to its economic, social, and environmental impacts. Climate change mitigation requires the management of terrestrial carbon either by carbon sinks or by preserving existing ones. Carbon sequestration is one such option that can occur in living biomass and in soil. Trees sequester carbon through carbon flux and stocks and carbon sequestration can be enhanced through sustainable management of the existed forest, planting and rehabilitation of degraded forests and conservation. Tree carbon sequestration often proves to be a win-win scenario to contribute to reducing the concentration of CO_2 in the atmosphere by its accumulation in the form of biomass (Mishrh et al., 2013). Among forest management options for carbon sequestration, afforestation is considered to be a cost-effective and environmentally beneficial strategy (IPCC, 2013). Moreover, tree plantation for carbon sequestration has environmental, social and economic values. Forests have a higher carbon density than other ecosystems and land uses (Stinson et al., 2011), and sustainable management, planting, and rehabilitation of forests can conserve or increase forest carbon stocks(IPCC, 2000).

The establishment of tree plantations on cleared land reduces the rate of atmospheric CO_2accumulation. Soils play an important role in the global carbon cycle (Lal *et al.,* 2013) and soil organic carbon contains approximately two-thirds of the carbon stored in forest ecosystems. Soil organic carbon can be determined by the balance between inputs of carbon through litter-fall and roots and loss of carbon. The carbon fluxes are influenced by topography, climate, soil properties, tree species, management regime, previous land use, and stand age (Deluca et al., 2012). Thus, understanding the dynamics of soil organic carbon in forest plantations and estimation of carbon stock potential of different tree species will be an important undertaking that enables to generate knowledge and information. Although this kind of information is very crucial for tree growers, policymakers, development practitioners, and different concerned bodies, available information in this regard is very scanty. Hence, this study aimed to examine biomass and soil carbon stock of selected fast-growing tree species.

Materials and methods

Study site description

The study was conducted in Diksis woreda, East Arsi Zone, Oromiya Regional State, Ethiopia. The mean temperature of the area is ranged from6 to 23°C.and the mean annual precipitation is 1100 mm with peaks in July and August. The soil of the study area is classified as Nitosols.

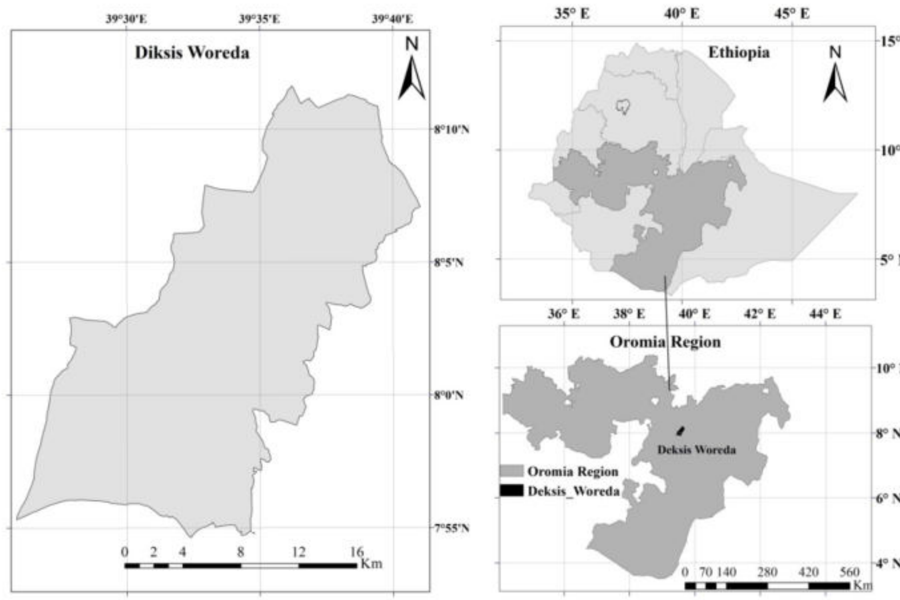

Figure 39: Maps showing the location of the study site

Data collection methods

The data was collected for 10 tree species in a permanent plot with 3 replications. The study aimed to estimate the carbon pool of each species found in the plantation site. Data was measured in different available carbon pools (Biomass and soil organic carbon).

Tree inventory

To determine the biomass of *Cupress lustanica*, *Eucalyptus viminalis, Acacia decurrens*, *Eucalyptus saligna*, *Acacia melanoxylon*, *Eucalyptus camaldulensis, Eucalyptus grandis,* and *Eucalyptus globulus*DBH ≥ 2.5 cm diameter and height ≥1.5 m were measured and recorded.

Soil sampling

A total of 90 composite soil samples for organic carbon estimation and 90 samples for bulk density determination were collected with three soil depths 0-10 cm, 10-20 cm, and 20-30 cm, separately. Soil samples for bulk density analysis were collected separately from each soil depth using a core sampler of 5cm diameter.

Laboratory analysis

The soil samples for bulk density were oven-dried at 105°C for 48 hrs and analyzed following standard procedures. The collected soil samples for organic carbon determination were air-dried and sieved for further analysis and soil organic carbon was determined using the Walkley and Black method (Walkley and Black, 1934). Above ground, biomass was estimated using site-specific allometric equation and belowground biomass was estimated using global average value 26% of AGB (Cairns *et al.,* 1997).

Table 39: Adopted allometric models for biomass estimation of different tree species

Species	Allometric model	Source
Cupress lustanica	$Y= 0.0355 + 0.00003*X^2\times W$	Henery.M et al.,(2000)
Eucalyptus viminalis	$Y=0.0155\times X^{2.5823}$	Hailu (2002)
Acacia decurrens	$Y =3.1582+0.0337x^2 \times W$	Tandon et al.(1989)
Eucalyptus saligna	$Y=0.069413*(X^{2.1472})*(W^{0.3129})$	Henery.M et al.,(2000)
Acacia melanoxylon	$Y =3.1582+0.0337x^2 \times W$	Tandon et al.(1989)
Eucalyptus camaldulensis	$Y=0.0155\times X^{2.5823}$	Hailu (2002)
Eucalyptus grandis	$Y=0.069413*(X^{2.1472})*(W^{0.3129})$	Schubert et al.,(1988)
Eucalyptus globulus	$Y= 0.45*(X)^{2.01}*W^{3.41}$	Zewdi et al.,(2009)

Where Y represents the total dry aboveground biomass of a tree in kg, X is the diameter of the tree in cm and W is the height of the tree in m. The equivalent carbon content in biomass will be estimated assuming 50% of carbon in the biomass as per IPCC,2003.

Total carbon estimation

T_{AGBC}=Biomass carbon stock of trees

T_{BGBC} =Biomass carbon stock of trees

$TBC=T_{AGBC}+T_{BGBC}$Where T_{AGBC}= Total Above ground biomass carbon, MgC $ha^{-1,}$ T_{BGBC}= Total below ground biomass carbon, MgC $ha^{-1}$and $T_{BC=\ Total}$ biomass carbon.

Soil bulk density

Soil bulk density=Dry mass of soil (g)/volume of core sampler (cm^3)

Soil Organic CarbonSOC was calculated as shown below (Pearson *et al.,* 2005)

SOC = BD x %C x depth x 10

Where, SOC = Soil Organic Carbon (Mg ha^{-1}), BD = Bulk Density (g cm^{-3}), Depth of the soil sample (cm), % C = Carbon Concentration

The Total Carbon Stock Estimation

The total carbon stock density from different carbon pools was calculated using the following formula (Pearson *et al.,* 2005).

$C_{Total} = C_{AGTB} + C_{BGTB} + SOC$

Where, C_{Total} = Carbon Stocks (Mg ha^{-1})

C_{AGTB} = Carbon Stock in Above Ground Tree Biomass (Mg ha^{-1})

C_{BGTB} = Carbon Stock in Below Ground Tree Biomass (Mg ha^{-1})

SOC = Soil Organic Carbon (Mg ha^{-1})

Statistical Analysis

The collected data were analyzed using SPSS version20 software. One way Analysis of Variance (ANOVA) was performed to examine the variations in biomass and soil carbon stock among the three species. A post hoc test was used to evaluate the mean differences across the estimated species and mean separation was conducted using Tukey Kramers test.

Result and discussion

Biomass carbon stock

The mean total biomass carbon stocks of selected species were ranged from 1.2-5.7Mg C ha^{-1}. The highest biomass carbon stock was recorded for *Eucalyptus globules* (5.7Mg ha^{-1}). However the lower carbon stock was recorded for *Eucalyptus grandis* (1.*2*Mg ha^{-1}). E*ucalyptus globulus, Acacia melanoxylon* and *Eucalyptus saligna* showed significantly high carbon stock at (α=0.05) level of significance than others.

Table 40: Mean (SD±) carbon stocks by biomass components of selected species (Mg ha-1).

Species	**AGBC (Mg ha $^{-1}$)**	**BGBC(Mg ha $^{-1}$)**	**TBC Mg ha -1)**
*Cupressus lisitanica **	1.3±0.5a	0.4± 0.35a	1.7± 0.75a
Eucalyptus viminalis	1±0.35a	0.4± 0.5a	1.4±1a
Eucalyptus globulus	4.3 ±1.5b	1.4 ±1.2b	5.7±1.5b
Eucalyptus saligna	2.1± 0.65c	0.4± 0.33a	2.5±0.85c
Eucalyptus grandis	1± 0.33a	0.2± 0.5a	1.2 ±0.5a
Acacia decurrens	1.1± 0.35a	0.3 ±0.3a	1.4± 0.56a
Eucalyptus camaldulensis	1.5 ±1.4a	0.2± 0.65a	1.4 ±0.75a
*Acacia melanoxylon**	1.5 ±0.39a	0.5± 0.25a	2±0.49abc

*Note: *.Indicates the mean difference is significant at the α=0.05*

Estimating the carbon pool is crucial for assessing the role of trees in the global carbon cycle and climate change mitigation. The results indicate that *Eucalyptus globuluse*, *Acacia melanoxylon,* and *Eucalyptus saligna* accumulated large amounts of biomass Carbon, both in above and below ground. In the present study, the mean biomass carbon stock of *Eucalyptus globulus* is comparable to the young mixed plantation of fast-growing species having 4.32 Mg ha^{-1} of biomass carbon stock (Singh et *al.,* 2011; Meta *et al*., 2017).

The biomass increase in 3–12-year old stands indicating a fast accumulation of biomass in the younger stand ages. These studies in line with (Bond, 2004). Young forests take up CO_2 at higher rates than others. Our results showed that there is a notable amount of biomass carbon stock. Thus, higher biomass carbon is due to better resource allocation.

Soil organic carbon stock (SOC)

SOC among studied tree species

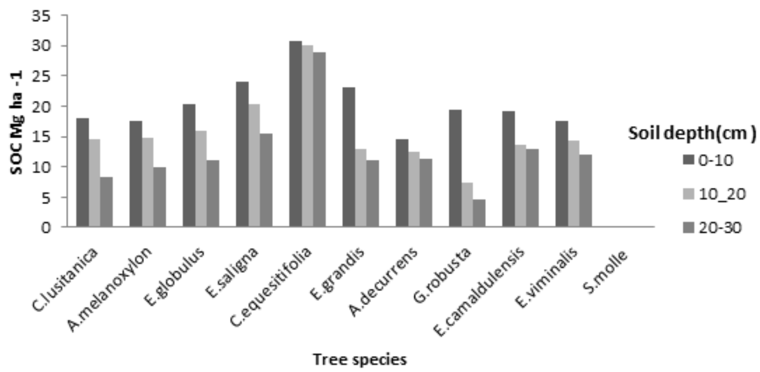

Figure 40: Mean SOC (Mg ha-1) among selected species along three depths (0-10cm, 10-20cm, and 20-30cm).

From figure 40, it can be noted that SOC stocks decreased significantly with increasing soil depth within the same stand. The contribution of the upper topsoil (0-10cm)for soil organic carbon is 40% and the rest was contributed by subsoil (10-20cm) and 20-30cm). The highest SOC was recorded for *Casuarina equisetifolia* (89Mg ha^{-1}) followed by *Eucalyptus saligna* (60±9.8Mg ha^{-1}) while the lowest was recorded for *Eucalyptus viminalis* (34Mg C ha^{-1}). The SOC stock of *Casuarina equisetifolia, Eucalyptus saligna,* and *Eucalyptus camaldulensis* was significantly higher than others at (α=0.05).

The mean total biomass carbon of species estimated in this study was comparable with other studies in Taiwan (Chen-Chi *et. al* 2009; China (Zhou *et al*., 2000). This study reveals that the SOC among selected tree species showed remarkably high stock than another study such asWondo genet, Yirdaw M (2018). Similarly the SOC of *Cupressus lusitanica* was lower than our study results (Hu et al., 2015).

Table 41: Mean SOC (Mg ha-1) among selected species

Species	SOC (0-10cm, Mg ha -1)	SOC(10-20cm,Mg ha -1)	SOC(20-30cm, Mg ha -1)	Total (0-30cm)
Cupressus lisitanica	18±7.6[a]	14±7.7[a]	8±5.8[a]	40±7.4
Eucalyptus viminalis	17±1.1[a]	10±0.5[a]	7±0.8[a]	34±2.9
Eucalyptus globulus	16±9.2[a]	14.5±4.5[a]	11±0.3[a]	41.5±5.6a
Eucalyptus saligna	25±12.5[b]	20±10.9[a]	15±5.3[b]	60±9.8a
Eucalyptus grandis	23±3.4[c]	12±2.6[a]	9±3.8[a]	44±13a
Acacia decurrens	15±5.6[a]	14.8±4.7[a]	14±2.5[a]	43.8±3.9a
Eucalyptus camaldulensis	19±0.5[a]	18±0.5[a]	12±4.4[a]	49±3.9c
Acacia melanoxylon	15.5±2.6[a]	17±2.9[a]	9±1.9[a]	41.5±4.2a
Casuarina equisetifolia	30±0.5[ab]	30±0.1[b]	29±0.1[c]	89±0.8ab
Schinus molle	15.5±1.1[a]	15±0.5[a]	9±5.1[a]	39.5±4a
Grevillea robusta	20.5±1[a]	19±0.5[a]	12±7.5[a]	51.5±6.4abc

*Note: *.Indicates the mean difference is significant at the 0.05 level.*

SOC stock of *Eucalyptus saligna* was found in this study remarkably higher than the result for the same species while it was lower than the reports of (Homann *et al.*1998). This might be due to differences in sample sizes, sample numbers, and analytical methods accurate estimates of SOC distributions are further complicated due to variation in SOC contents, poor spatial coverage, and species types (Cuevas *et al.,* 1991).

The higher soil organic carbon under mixed stands may be attributed to the higher annual litterfall in mixed stands. This study is in line with (Berger et al., 2002; Guckland *et al.,* Dawud *et al.,* 2016).

Furthermore, conifer species allocate more total organic matter than fast-growing tree species (Cuevas *et al.,* 1991). *Casuarina equisetifolia* accumulate more SOC than the other studied tree species types. This could be due to the different strategies of carbon and nutrient allocation potential (Yan liu *et, al* 2017).

Total ecosystem carbon

The highest mean ecosystem carbon stock was recorded for *Eucalyptus saligna* (62.5Mg C ha^{-1}) however; the least was recorded for *Eucalyptus viminalis* (35.4 Mg C ha^{-1}). Table 42 shows the ecosystem carbon stocks of the studied land-use systems.

Table 42: Ecosystem carbon stocks (biomass plus soil) of the studied land-use systems (Mg C ha-1)

Species	Biomass carbon	SOC(0-30cm)	Total Carbon
Cupressus lusitanica	1.7±0.75	40±7.4	41.7±3.9
Eucalyptus viminalis	1.4±1.4	34±2.9	35.4±2.8
Eucalyptus globulus	5.7±1.5	41.5±5.6	47.2±0.7
Eucalyptus saligna	2.5±2.5	60±10*	62.5±1.8*
Eucalyptus grandis	1.2±1.2	44±1.3	45.2±4
Acacia decurrens	1.4±1.4	41.5±3.9	43.5±0.5
Eucalyptus camaldulensis	1.4±1.4	50±3.9*	51.2±1.5*
Acacia melanoxylon	2±0.5	41.5±4.2	43.5±0.9

*Note: *Indicates the mean difference is significant at the α=0.05*

In the present study amongst the selected species the highest mean total ecosystem carbon stock was recorded for eucalyptus this is in line with the reports of (Rizvi *et al.,* 2011). Thus, a considerable amount of carbon could be stored in planting fast-growing species by short-term rotation. On the contrary, our study shows lower carbon stock than the study in India, Kurukshetra (Arora and Chaudhry, 2017).

Tree plantation can significantly promote soil carbon storage with less time as compared to natural vegetation (Houghton *et al*., 1995). Therefore, developing countries' specific information is crucial (Watson *et al.,* 2000). Also, plantations can serve as sources of commercial forest products that alleviate the pressure on native forests and sequester carbon (Curlevski *et al*., 2010).

Conclusion and Recommendations

This study reveals that climate change mitigation can be achieved through properly managing plantation forests. Carbon sequestration by plantation forests could lower the atmospheric concentration of CO_2 and increase carbon stock accumulation. Therefore, there is a great need to implement proper silvicultural practices (site preparation, species-site match, tending operations, etc) in plantation forests to achieve climate change mitigation ambitions. The plantations in the study area stored a significant amount of carbon stock both in biomass and soil carbon pools. The amount of SOC stocks were higher in all studied species than biomass carbon stock. In general, planting fast-growing tree species could result in a significant effect on biomass and SOC stock accumulation apart from the economic benefit that they could provide.

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Population status, distribution, phenological characteristics, and fruit yield potential of *Dobera glabra* Foressk fruit trees in drylands of Ethiopia

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Abstract

Dobera glabra is a wild edible fruit tree which is naturally growing in the north-eastern and south-eastern parts of Ethiopia. This study aimed to generate knowledge on the current stock, phenological characteristics, and fruit yield of *Dobera glabra*. The study was conducted in Amibara and Awash-Fentaleworedas of Afar region, Karat woreda of Southern Nation Nationalities Peoples Region, and Yabelo woreda of Oromia region. A total of 120 sample plots were established with a minimum of 30 sample plots in each land cover type. A sub-sample for regeneration and sapling data collection was used in sub-plots at each corner and center of the major plots. Diameter at breast height (DBH), total height, and crown diameter of the trees were recorded and phenological and fruit yield data were collected every fifteen days intervals for two years. The result revealed that the population status in Yabelo had better reproduction and recruitment as well as regeneration status than Karatand Amibara. Whereas DBH and Height class distribution on cultivated land in Karat showed poor reproductive and recruitment status. The fruit yield in Amibara and Karat/Yabelo areas was found 160.36 kg/25 and 135.02 kg/25 trees respectively.

Keywords: Stock; Phenology; Fruit Yield; DBH; Height

Introduction

Tropical regions of the Earth have more fruit plant species than any other region of the world. They have been endowed with the great diversity of fruit tree species that provide humans with basic food and nourishment for ages since the domestication of beneficial wild plants (crops species) (Rathore, 2003). Tropical continents of the world are bestowed with rich variety of fruit trees with about 1000 species identified in the Americas, 1200 species in Africa, and 500 species in Asia (Paull and Duarte, 2011; Sthapit *et al.,* 2012). Even though, only relatively few fractions of these diversities are marketed worldwide, the diversities are nature's inestimable assets for the livelihoods of local people throughout the tropical regions.

Wild edible fruits have been used as the source of food since ancient times (Özbucak *et al*., 2007). In Ethiopia, the rural populations have a wider knowledge, tradition, and opportunity of using wild edible fruits despite the variation in age, sex, time, and season (Getahun, 1974; Getachew Addis *et al*., 2005). Due to this reason, they are an integral part of the diet of many rural communities and hence have diverse contributions to the livelihoods of communities. Wild edible plants are relevant to household food security and dietary diversification as well as income generation in some rural areas, particularly in the drylands, to supplement the staple food, to fill the gap of seasonal food shortages and as emergency food during the famine, prolonged drought or social unrest (Getahun, 1974; Asfaw and Tadesse, 2001). Moreover, leaves, stems, fruits, flowers, tubers, barks, seeds, roots, and so on, of many wild edible plants are still consumed for their dietary value in many communities around the globe. Wild edible fruits, having nutritional food value provide minerals like sodium, potassium, magnesium, iron, calcium, phosphorus, etc. for human beings (Deshmukuh and Ahilya, 2011). They are also resistant to many plant diseases and provide fibers that prevent constipation. Therefore, wider and sustained promotion of wild fruits as important dietary components should be encouraged.

Wild edible fruits have always been used as emergency, supplementary, or seasonal food sources during periods of crop failure, drought, and famine to avert food insecurity in rural households of Ethiopia (Guinand and Lemessa, 2000; Teketay et al., 2010). Wild edible fruits have also been used as food source diversification (Addis, 2009) since they are rich in nutrients that are absent or limited in locally cultivated crops (Fentahun and Hager, 2009). However, the consumption pattern of Wild edible fruits depends on the availability of normal foods. Wild edible fruits are consumed as supplementary food in normal periods, as food when the volumes of normal household foods start to become insufficient and wild fruits alone used for food only when food reserves or other assets are no longer available (Ocho et al; 2012).

Despite this fact, the role of wild edible fruits in developing countries has been ignored and underestimated for many years (GuinandLemessa, 2001; Teketay *et al.*, 2010). For example, a study conducted in southern Ethiopia by Guinand and Lemessa (2001) and in Afar Region by Gelmesa (2010) indicated that strong traditions, beliefs, and religious taboos still limit people's psychological and mental willingness to domesticate and cultivate wild edible fruits. Although there are indigenous knowledge, practices, and skill with wild edible fruits, the knowledge and practices have not been properly investigated and documented (Getahun, 1974). The available information on wild edible fruits have been used to be transferred to generations being incomplete and scattered in various written documents and oral traditions (Asfaw and Tadesse, 2001). Consequently, depletion of forest resources due to various human and natural factors such as agricultural expansion and human settlement, overgrazing, forest fire, deforestation for construction and energy supply, environmental degradation, and global climatic change are major challenges for cultivating wild edible fruits (Bahru*et al.*, 2013). As a result, much wild fruit tree species are declining from their natural habitats and even some species are endangered and others are near to extinct (IUCN, 2012).

The availability of wild edible fruits in Ethiopia varies with agroecological conditions, food preferences, and indigenous knowledge of diverse cultural groups (Lulekal *et al*., 2011; Teketay *et al*., 2010). The review work of Lulekal *et al*. (2011) indicated that ethnobotanical information was documented on 413 wild edible plants (WEPs)that are found in about 5 percent of the 494 Ethiopian woredas. Teketay *et al*. (2010) has also provided information on 378 WEPs of Ethiopia. Given the highly diverse systems that exist in Ethiopia in terms of geography, ethnicity, and culture, more WEPs are believed to exist. Research findings have indicated that very few WEPs provide most of the wild foods and fruits (Bahru et al. 2013; Tebkew *et al*. 2014)and leaves are the dominant type of edible parts next to fruits (Asfaw and Tadesse 2001; Lulekal *et al*. 2011).

One of the major low land wild fruit tree species in Ethiopia is *D.glabra* which was targeted for the present study. *D.glabra* (Forssk.) Poir. (Salvadoraceae) is distributed in India, Kenya, Saudi Arabia, Sudan, Tanzania, Ethiopia, Djibouti, Uganda, and Yemen. It is an evergreen tree with alternate thick skinny leaves and the flowers are white and the fruits are ovate purple when ripe. *D. glabra* is one of the wild food plants found in the Afar region, Ethiopia, and it is locally known as *Garsa* (Tsegaye *et al*.,2007). The plant grows in dry and moist lowland areas (400 - 1300 ma.s.l.), on saline, heavy, or calcareous loam soils and rocky hillsides). *D. glabra* produces edible fruits and the seed is considered a typical 'famine-food' (Tsegaye *et al*., 2007).

The Afar pastoralists appreciate the drought indicator qualities of *D. glabra* and they reported that new shoots, fruits, and seeds are always produced during the dry season or if rains are delayed or failed. In normal times, when rains are on time or abundant, *D. glabra* does do not produce many fruits and seeds. As such, when the tree blooms and produces fruits abundantly, people think that a drought may very well be underway and hence fear that food may become scarce. Afar people in Aba'alaworeda consider *Garsa* as an important tree for camels. The tree is a good browse and is known as a mineral supplement to camels. Although the importance of *D. glabra* is highly appreciated as a food source and livestock feed and its adaptability to the area, some critical problems are facing the species. Among many other problems, the main one as stated by the local people is that they do not see new regeneration of *D. glabra* and only old trees is available. This was also reported from Yemen where *D. glabra* also doesn't produce any regeneration(Tsegaye *et al*., 2007). Because of the poor regeneration, the more hardy and thorny species such as *Ziziphus* and *Balanites* have taken over *D. glabra* populations (Herzog, 1998). This is an indication to the fact that the plant is highly endangered and that extinction of the plant shortly is inevitable if nothing is done (Tsegaye *et al*., 2007).

Despite its benefits as food and its wide range of adaptation, information on its distribution, population status, phonological characteristics and fruit yield is limited. Therefore, designing different options for development, production, improvement, value addition, and promotion of high-value non-timber forest products is important to generate income for local communities. Thus, the current study was conducted with the objectives of (1) examining the current population status and distribution of *D. glabra* in its natural habitat and farmlands in Amibara, Awah-Fentale, Yabelo, and Karat woredas, (2) to study the phenological characteristics such as flowering and fruiting period and (3) to measure the fruit yield potential of *Dobera glabra.*

Materials and Methods

Description of the study areas

Four *D. glabra* growing areas, namely, Amibara and Awash Fentale woredas of Afar region, Karat woreda of Southern Nation Nationalities Peoples Region (SNNPR), and Yabelo woreda of Oromiya region were selected.

Assessment of populations

This activity was started in assessing information about the better growing areas of *D.glabra* fruit trees and making a quick reconnaissance survey to assess the range and degree of occurrence of the species and representative sites.

For resource assessment, a systematic random sampling method was used based on Woody Biomass Inventory and Strategic Plan Project field manual(WBISPP, 2000). The assessment was conducted in four land cover types; open woodland, dense shrubland, dense woodland, and farmland. Based on land cover types two sampling approaches were used; a 20 m X 100m(2000m^2) for open woodland and farmland and a 20m X 20m (400 m^2) for dense shrubland dense woodland following the procedures in Kent and Coker (1992).

A total of 120 sample plots with a minimum of thirty sample plots in each land cover type were laid along a transect line. The distance between transects ranged from 300m up to 500m depending upon the extent and distribution of the vegetation. A sub-sample for regeneration (<1m height) and sapling (>1m and <5cm DBH) was taken in 5 x 5m sub-plot at each corner and center of the major plots. Within each plot, matured trees were considered to collect different tree parameters, such as DBH, total height, crown diameter and several main branches per tree, and newly regenerated seedlings and saplings were counted.

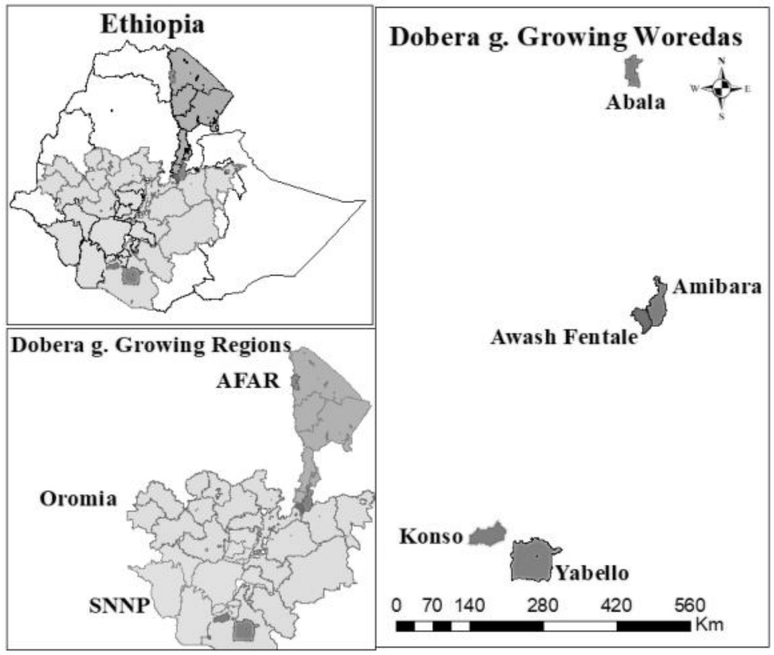

Figure 41: Map of the study areas

Also, twenty-five representative *D.glabra* trees were selected and marked to determine the fruit yield potential of the tree under different diameter classes. The yield traits, namely, number of branches per tree, crown depth, and diameter, number of fruits per tree, and total fruit weight per tree were measured. Also, phenological characteristics were studied to determine the flowering and fruiting time. For this study, 10 reproductively matured and average individual trees with easily visible crowns were selected and marked. Data on flowering and fruiting phenology were recorded at intervals of 15 days for three years.

Data analysis

The quantitative data like DBH, total height, number of branches, and crown diameter was analyzed as well as expressed using micro soft excel. A line graph of *D. glabra* stems versus DBH and height class distribution was also plotted to see the pattern of *D.glabra* stem population density with diameter at breast height and height class distribution on different land use land cover types.

Results and discussion

Tree characteristics

D. glabra was distributed over a wide range in the study areas ranging from 900m to 1500 m a.s.l. Our survey revealed that the number of trees per hectare varies along with different landcover types and geographical locations; i.e. 347, 14, 421, and 44 trees/ha in dense shrubland and open woodland in Amibara and Fentale woredas, open woodland (Yabelo) and in cultivated land (Karat) respectively. In contrast, Tsegaye et al. (2007) reported that the average number of *D. glabra* is 41 trees/ha along the Kulahituriver and in kalah plain of Abealaworeda. The density of the species was 40, 13, and 10 trees/ha in Al Aaarda, Al Aidabi, and Al Shegaig, respectively (Aref et al.,2009). This variation might be the result of geographical, soil, moisture difference and due to high pressure from humans and livestock.

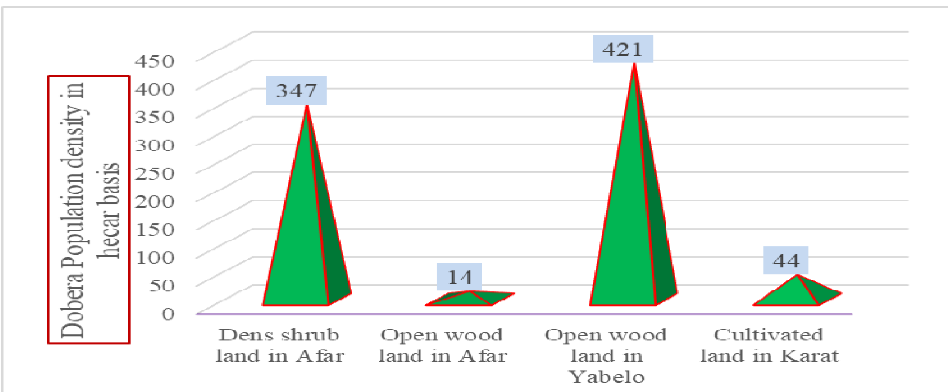

Figure 42: *D. glabra* population density per hectare at Amibara, Awash-Fentale, Yabelo, and Karat

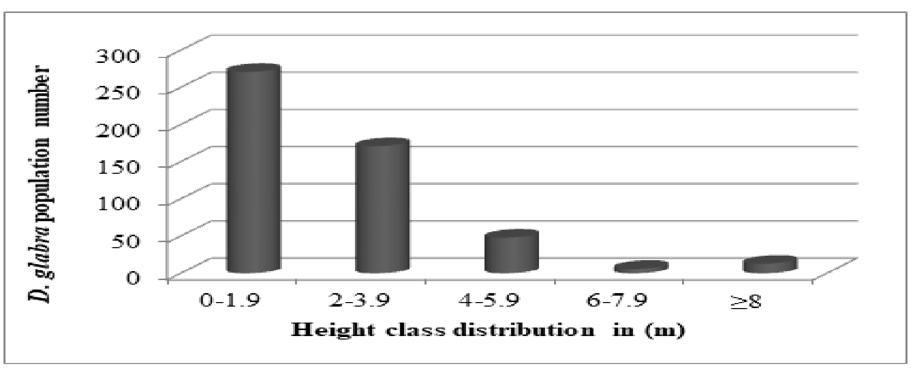

Figure 43: *D.glabra* height class distribution on dense wood land at Yabello

As figure 43 showed, height class distribution of *D.glabra* wild edible fruit trees had an inverted J-shape which was a healthy population distribution having a greater population number of stems under a small size diameter class and decreasing towards the largest height class. Kuma and Shibru (2015) support the above definition that any woody plant structure had an inverted J-shape that shows good reproduction and recruitment potential of the species.

Table 43: Tree characteristics of the three different sites

Region	Woreda	Land use	Mean DBH (cm)	Mean height (m)
Afar	Fentale	Dense shrubland	13.68	4
Afar	Amibara	Open woodland	25.78	5.54
Oromia	Yabello	Dense woodland	7.58	3.24
SNNPR	Karat	Cultivated land	24.75	5.11

Table 43 show that the highest mean DBH was recorded in Afar open woodland (Amibara) and Karat cultivated land 25.78 and 24.75 cm, respectively. This mean DBH variation among those three different sites may be due to age differences, stand density, and site conditions.No regeneration was observed within the two land use land cover types (open woodland and farmland)whereas; abundant regeneration was recorded on dense shrubland and dense woodland.

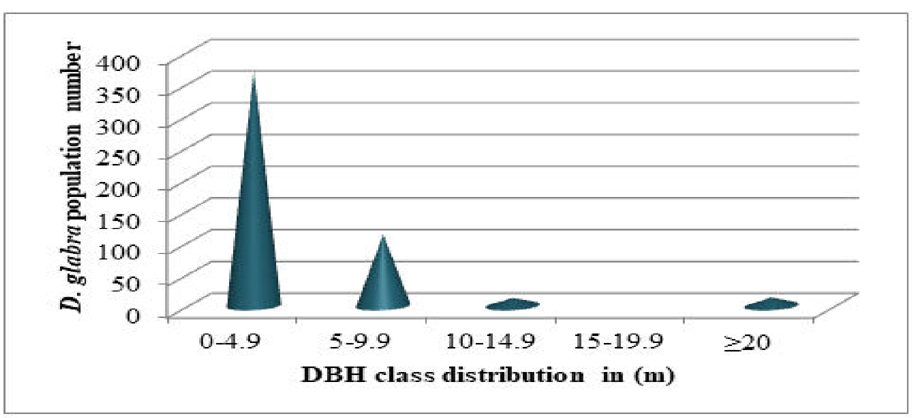

Figure 44: *D. glabra* DBH class distribution on dense woodland at Yabello

D.glabra DBH class distribution showed an inverted J-shape which is an expression of a healthy population distribution where a higher number of individuals was counted under lower-class diameter and where it decreases towards the largest diameter class. According to Dinkissa (2011), irregular diameter class distribution implies that woody plant species in a certain area are under different disturbances either natural or anthropogenic. Generally speaking, both height class and DBH class distribution of *D.glabra* on dense woodland showed a healthy distribution that the sustainability and regeneration status was in a good situation.

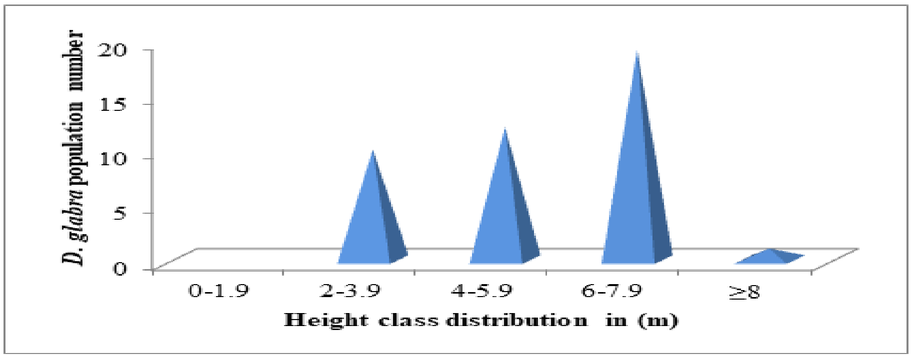

Figure 45: *D.glabra* height class distribution on cultivated land at Konso zone (Karat woreda)

D.glabra wild edible fruit height class distribution on cultivated land showed an unhealthy distribution that a complete absence of individuals was observed on the first (small) height class interval and the fair number of individuals was present on the middle height class interval and somehow the height class distribution pattern seemed a bell-shape.

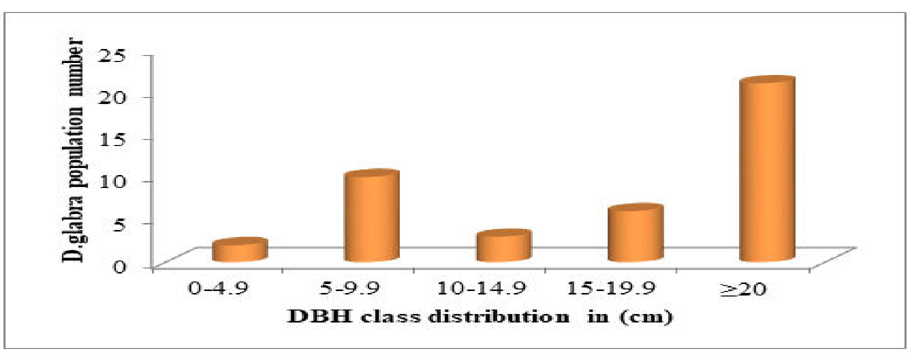

Figure 46: *D.glabra* DBH class distribution on cultivated land at Konso zone (Karat woreda

As shown in figure 47, DBH class distribution of *D.glabra* fruit trees on cultivated land showed that there was an irregular distribution of individuals in different diameter classes implying some levels of disturbance. The source of disturbance could be the removal of regeneration and adult trees during the cultivation of the land hampering the seed bank of the species. According to Mekonen *et. al*. (2015), an irregular-shape indicates a complete absence of individuals in some classes and a fair representation of individuals in other classes.

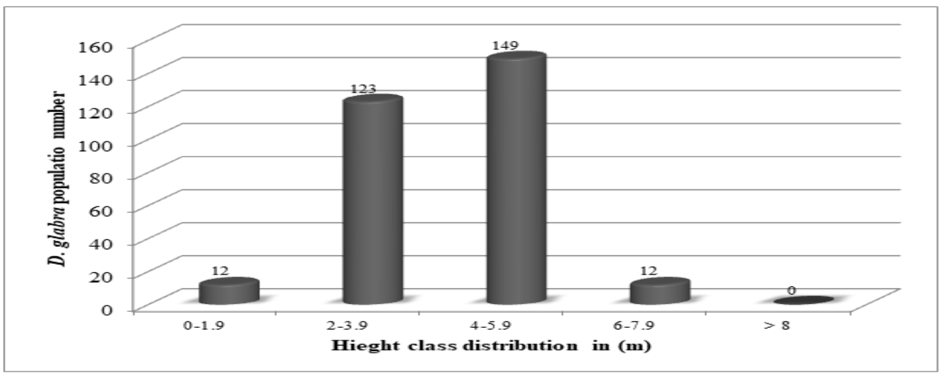

Figure 47: *D.glabra* height class distribution on dense shrub land in Afar region

D.glabra fruit-trees height class distribution on dense shrubland showed unhealthy distribution that a complete absence of individuals was observed on the largest height class interval and relatively high number of individuals was present on the middle height class interval and the height class distribution pattern seemed a bell-shape. A woody plant species having the bell-shaped distribution pattern indicates a poor reproduction and recruitment of species (Feyera *et al*., 2007). The possible reason for decreasing the percentage of the number of individual woody species within the largest diameter class might be due to illegal cutting used by the local people for construction materials and fuelwood consumption (Getaneh, 2007; Tefera *et al*., 2005).

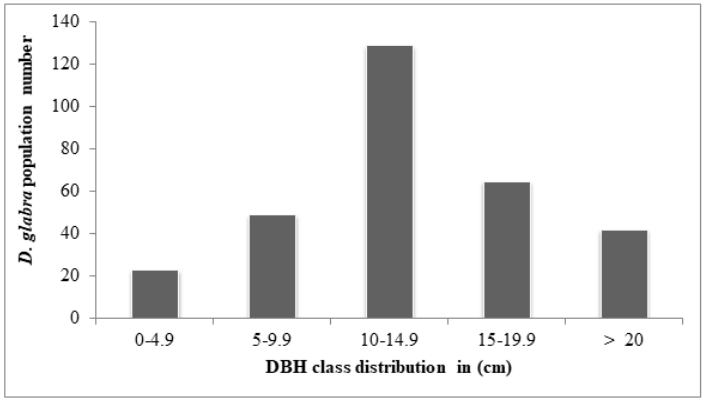

Figure 48: *D.glabra* DBH class distribution on dense shrubland in Afar region

The diameter class distribution of *D.glabra* on dense shrubland in the fentale Woreda of the Afar region showed a bell-shaped distribution. A greater number of individuals counted under the middle DBH class of 10-14.9 and 15-19.9 cm, respectively as presented in figure 48 whereas the small number of individuals were counted towards the left and the right direction of the diameter classes.

A diameter class distribution showed relatively a 'bell-shape', where the number of individuals in the middle diameter classes were high but were low in lower and higher diameter classes. Bell-shaped structure could be associated with intense competition from the surrounding trees and/or other forms of disturbances such as browsing activities (Senbeta, 2006; Gebrehiwot and Hundera, 2014).

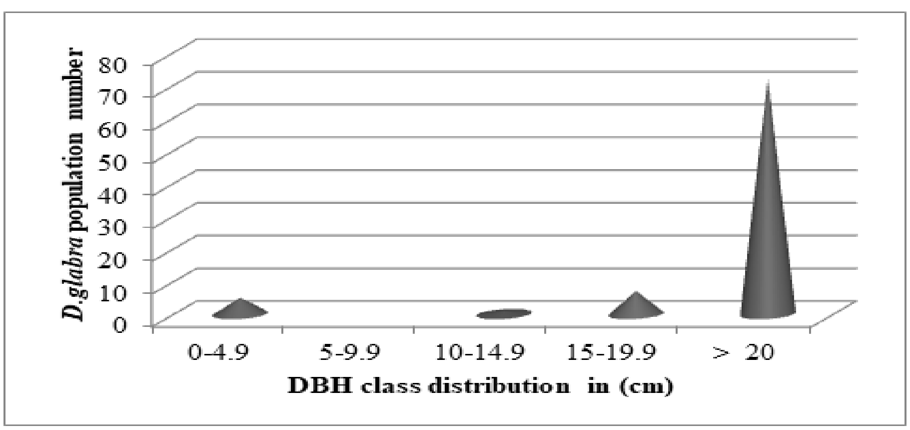

Figure 49: *D. glabra* DBH class distribution on open woodland in Afar region

As figure 49 presented above the diameter class distribution of *D.glabra* on open woodland seemed as normal J -the shape that was the higher number of individuals was counted under the larger diameter classes including the absence of individuals within the second diameter class. Which implied that the population distribution was fewer in the small-diameter class than in the larger diameter classes. When such type of DBH distribution pattern occurred, this indicated that there was selective removal of middle diameter class trees for various purposes by local people like for, fencing, farm tools, house construction, and fuelwood when allowed by the community leaders and there might be browsing, grazing and other disturbance effects in the area Atsbha *et. al.* (2019). According to Beyene, (2010), if any woody plant species showed exactly J-shape diameter distribution the species had poor regeneration condition due to the following factors like 1) over-exploitation of matured trees that might have led to reduced reproduction (that is, flower production, pollination, and seed production); and, 2) livestock browsing activities (uprooting/removal and cropping of fruits) that might have probably inhibited seedling/sapling growth and recruitment.

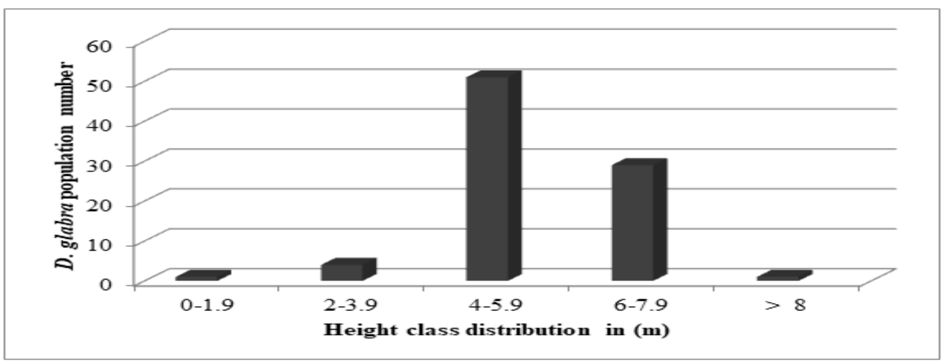

Figure 50: *D. glabra* height class distribution on open woodland in Afar region

Height class distribution of *D. glabra* on open woodland showed that bell-shape distribution which was the higher number of individuals has appeared on third and fourth diameter classes followed by the second diameter class. Whereas the first and the last diameter classes share 0.86% of the total population number of 86 trees which were counted during the data collection time. The most population numbers appeared on diameter classes 3, 4, and 2 that was 43.86%, 24.94%, and 3.44% appeared from the total population under the respective diameter classes.

Phenology and Fruit yield

Table 44: Phenology and Fruit yield of *D.grabla* at three different sites

Region	Land use	Number of days from flower initiation to fruit shading	Fruit yield (kg)
Afar	Open woodland	165	135.02
	Dense shrubland	165	
SNNPR(Konso)	Cultivated land	150	160.85
Oromiya(Yabello)	Dense woodland	150	

As shown in table 44, the period of flower initiation to fruit shading took 165 and 150 days in the study areas. Fruit yield of 135.02 and 160.85 kg was recorded in AfarAmibaraworeda and Karat, respectively. In Karat woreda, *D.glabra* trees were well managed on cultivated lands and the trees are bigger due to their scattered pattern and low nutrient competition; whereas in the case of the Afar region the trees were not managed and there was a high competition of nutrients within the same species and associated species.

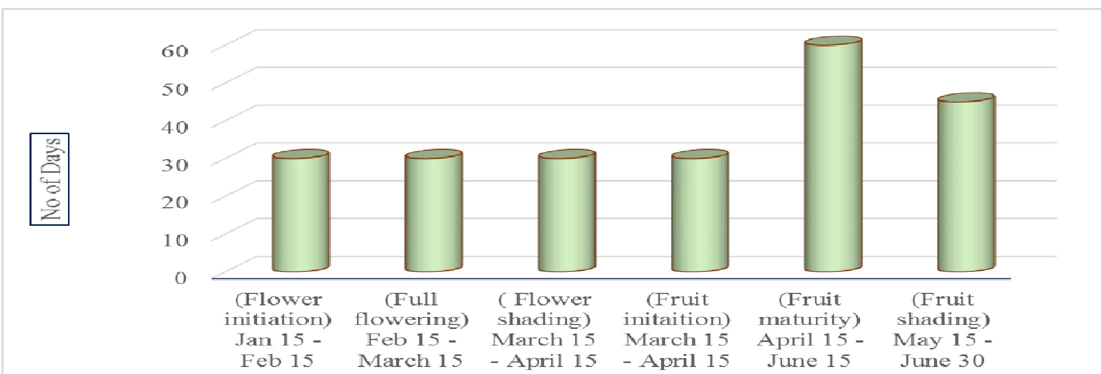

Figure 51: Phenological characteristics of *D. glabra* in Afar region

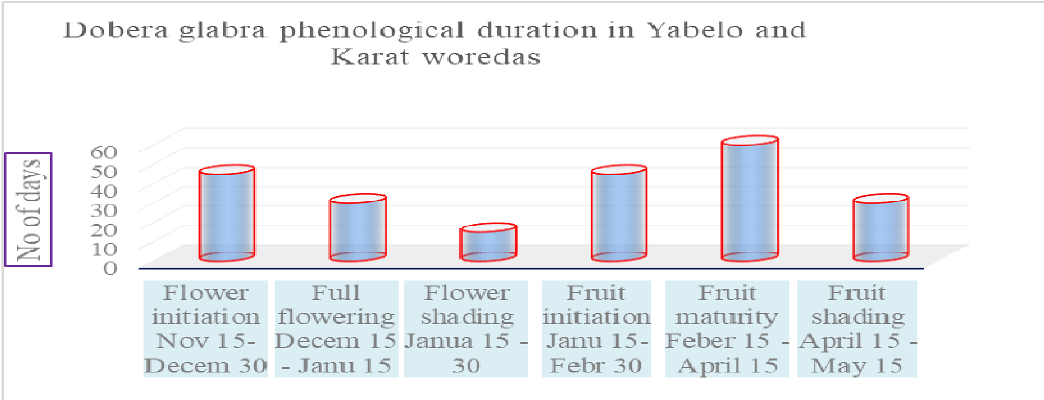

Figure 52: Phenological characteristics of *D. glabra* at Yabelo and Karat woredas

There was a marked phenological difference among study sites. Accordingly, *D.glabra* started flower initiation on mid November and shaded its fruit until May 15 at Yabelo and Karat woredas and whereas in the Afar region flower initiation started on January 15 and complete fruit shading occurred until June 30. This phenological difference among those study sites might be occurred due to the agro-ecological difference of the study sites. However, full flowering, fruit initiation and fruit maturity periods were talking about equal days of 30, 45, and 60 respectively at all study sites. Whereas, flower initiation, flower shading, and fruit shading were taking a different number of days in the study areas.

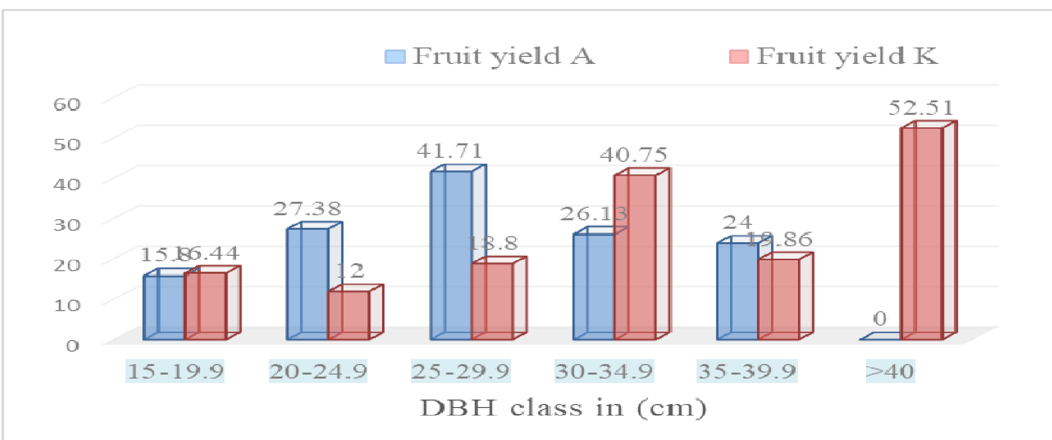

Figure 53: *D. glabra* fruit yield comparison in Afar and Konso

Therefore 135.02 kg and 160.36 kg of fruits was found /25 *D.glabra* trees collected from Afar and Konsorespectively. Figuratively there was a great difference in fruit yield production between Afar and Konso populations. This fruit yield difference from an equal number of *D.glabra* trees in each site might be due to size and performance difference, also due to altitudinal factor, nutrient difference, rainfall distribution, flowering, and fruiting period fluctuation, and other agro-ecological differences.

Conclusion and Recommendation

The resource assessment and yield potential study on *D.glabra* fruit tree was done on different land-use types i.e. on dense woodland, cultivated land inYabello, and Karat woredas respectively, and on open woodland and dense shrubland in the southern Afar region. Therefore, the vertical and horizontal structures (DBH and height class distribution)were inverted J-shape which implied that *D.glabra* population status in Yabello had good reproduction and recruitment as well as regeneration status. Whereas, the *D.glabra* DBH and height class distribution on cultivated land in Konso showed irregular nearly bell-shaped distribution, and this distribution implies poor reproductive and recruitment status. Due to the presence of frequent disturbance during cropping and cultivation on the cultivated land, there is no chance for the emergence of new *D.glabra.*Similar DBH and height class structure distribution was observed in the Afar region both on dense shrubland and open woodland which had poor recruitment and reproduction potential of the targeted species. Although the population density difference was observed in all study sites, all sites had a smallnumber of *D.glabra* population. An especially, very small number of *D.glabra* was counted on open woodland in Afar and on cultivated land at Karat woreda. Fruit yield potential difference was observed between Afar and Karatworedas that were collected from each 25 *D.glabra* trees and about 135.02 and 160.36 kg of *D.glabra* fruit/25 trees respectively. Differences in the phonological calendar were observed between the Afar populations and those ofYabelo and/or Karat woredas. But most of the phenology conditions were taking the same number of days except for some phenological conditions.

- The local community awareness should be improved on the sustainable development and utilization of *D.glabra*fruit trees.
- Proper grazing management strategies should be developed to give chance for seedlings and saplings to perform well; otherwise, the trees will be endangered.
- *Dobera glabra* wild edible fruit trees can be incorporated in agroforestry farming system to sustain the existence of this multi-purpose tree.

Acknowledgments

We would like to acknowledge the Ethiopian Environment and Forest Research Institute (EEFRI) for providing financial support and CEEFRC & HEFRC for facilitating logistic service for our research activity. Sincere thanks also go to Amibara, Konso, Yabeloworedas, and Awash National Park natural resource officials and experts for their support during our fieldwork.

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Effect of Spacing on Growth Performance and Leaf Biomass Yield of *Moringa stenopetala* (Bak.f.) Plantation at Arbaminch

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Abstract

Moringa stenopetala is a multipurpose tree distributed in the lowland areas of the southern part of Ethiopia. This study aimed to determine the effect of plant spacing on plant growth parameters and leaf biomass production of *M. stenopetala*. The study was conducted in Arbaminchworeda. Three planting spacing (0.5 x 0.5 m; 1 X 1 m and 2 X 2 m) were arranged in a randomized complete block design and the treatments were replicated three times. Survival %, root-collar diameter, height, and stem diameter of the trees in each plot were recorded at three-monthly intervals. Data for leaf biomass was collected at the age of 27, 32 and 48 months. The wider spacing produced the largest quantity of dry leaf biomass (119.28 ± 9.02, 143.85 ± 10.29 and 249.8± 24.22 g/tree and 298.2 ± 22.54, 359.62 ± 25.73 and 624.49± 60.59 kg/ha) while the narrow spacing produced the smallest quantity (48.36 ± 5.10, 44.74 ± 3.19 and 88.15 ± 30.28 g/tree and 1934.4 ± 203.89, 1789.56 ± 127.78 and 3526.01± 1211.2 kg/ha) at the 1st, 2nd and 3rd harvest, respectively. This indicates that an increase in the plant spacing led to higher dry leaf biomass production per tree, but the lesser the yields per hectare due to unpronounced competition at early ages of the plantation.

Keywords: Spacing, Plant growth, Leaf Biomass,

Introduction

Ethiopia has diverse physio-geographic features and a very high variation in macro and micro-climatic conditions that contributed to the formation of diverse ecosystems inhabited with a great diversity of life forms of both animals and plants (Teketay *et al*., 2005). Such diverse ecological conditions enabled the country to inhabit about 6000 higher plants of which about 10% are endemic (Hedberg *e t al*., 2009). Friss *et al*. (2010) classified the vegetation resources of Ethiopia into 12 vegetation types. The country is also known as Vavilovcenter of origin and diversity for many food plants and their wild relatives (Edwards, 1991). Despite these rich natural resources and being an agrarian country with over 80% of its population, more than 35% of Ethiopian people are food insecure (FAO, 2010).*M.stenopetala* is one of the edible plants in southern Ethiopia which has been domesticated as a 'cabbage tree'byKonso people from their territory lowland dry forests (Jahn, 1991). *M. stenopetala* is one of the two most common species among the 14 species of the Genus Moringa, in Moringaceaefamily (Beyene, 2005; Jiru *et al*., 2006). It is endemic to East Africa including Kenya and Ethiopia (Jahn, 1991). It is distributed in the lowland dry ecology of the southern part of Ethiopia and cultivated for food, fodder, shade, windbreak and medicinal value around homesteads and in farmlands (Jiru et al., 2006). It has various local names: Shiferaw in Amharic, HalekoinGofa areas, Shelagda in Konso (Jahn 1991; Teketay, *et al*., 2010).

M. stenopetala is a multipurpose tree with vital nutritional, industrial, and medicinal applications (Jahn, 1991; NRC, 2006). The different part of the tree is used for different purposes. The green leaf is consumed as a vegetable, dried leaf for tea, leaves, and pods are used as fodder for animals, seeds are used to purify muddy water, seeds are also a source of cooking oil or for other industrial applications, roots are used to clarify dirty water, and is a medicine to treat different ailments, wood is used for pulp production (Seifu, 2014). The tree is also a drought-resistant that provides shade in arid and semi-arid areas, provide nectars for honeybees, serve as a live fence and ornamental plant and conserve agricultural soils when intercropped farmlands (ICRAF, 2006). The tree is mainly grown as a staple and supplemental food where the leaves are eaten daily together with cereal balls in Konso, Gamo, and Gofa people in southern Ethiopia (Endeshaw, 2003). Almost every household in the areas grow at least four leaves yielding Moringatreesin their homesteads and 10 trees in their farmlands for their daily consumption(Abuye *et al*., 2003; Yisehak *et al*., 2011). The extra production of the leaves and recently the seeds are sold in the market to generate cash income (Jiru *et al*., 2006).

Despite its multitude of benefits and a wide range of adaptation from arid to humid climates with a prospect to be grown in a wide range of land use classes, its distribution is limitedto mainly to southern Ethiopia and its potential has not been taped (Jiru *et al*., 2006). Recently, the production and marketing of the leaves and seeds of *M.stenopetala* have increased in other parts of the country owing to its perceived medicinal and nutritional values (Abay *et al*., 2015) and the tree is now being grown in most lowland and midland parts of the country (Jiru *et al*., 2006, Abay *et al*., 2015). The production is expanding and new businesses are flourishing from time to time where women and youth are benefiting from the growing businesses, creating new jobs and employment, which are believed to reduce poverty (Kaleb and Busha, 2013; Abay *et al*., 2015). *M. stenopetala* can attract more unemployed youth and women to involve in income-generating activities through growing, processing, and marketing of the tree and its products. Recently investors have also shown interest in the establishment of the plantation from *M. stenopetala* for massive production of leaves and seeds and in establishing value-added products (Kaleb and Busha, 2013; Saint Sauveur and Armelle, 2001). Even though the tree has such high value for food security at smallholder farmers' level and industrial value at the national and international level, the tree is being cultivated traditionally without any technical and technological support. Previous studies focused on documenting the use of different plant parts, estimating the number of trees per household per hectare, nutritional contentment of the tree. Generally, there is limited scientific information on the effect of different silvicultural practices on growth performance and leaf biomass yield of *M. stenopetala* (Seifu, 2014). Such scientific studies are important to determine the productivity levels of *M.stenopetala* as a cabbage tree for its leaf biomass in the arid and semi-arid areas of Ethiopia. This study was thus initiated to determine the optimum spacing for better growth performance and leafy biomass yield of *M. stenopetala*. We hypothesized that the decrease in spacing between trees would decrease the stem growth and leaf biomass per tree but increase the leaf biomass yield on a hectare basis.

Materials and Methods

Description of the study area

The experiment was conducted inArbaminchzuriaworeda, Gamozone, SNNPR. Itis found between UTM coordinates of 37N 313305 – 37N 353505 northings and 37N 630585 – 686632 eating at 489km south of Addis Ababa. The woreda has an area of 168,172 hectares, of which 34,137ha is cropland and 15,163ha forest land. There are 14 *M. stenopetala* growing kebeles in the woreda with an average landholding of 1.75ha and with a family size of 6 individuals.

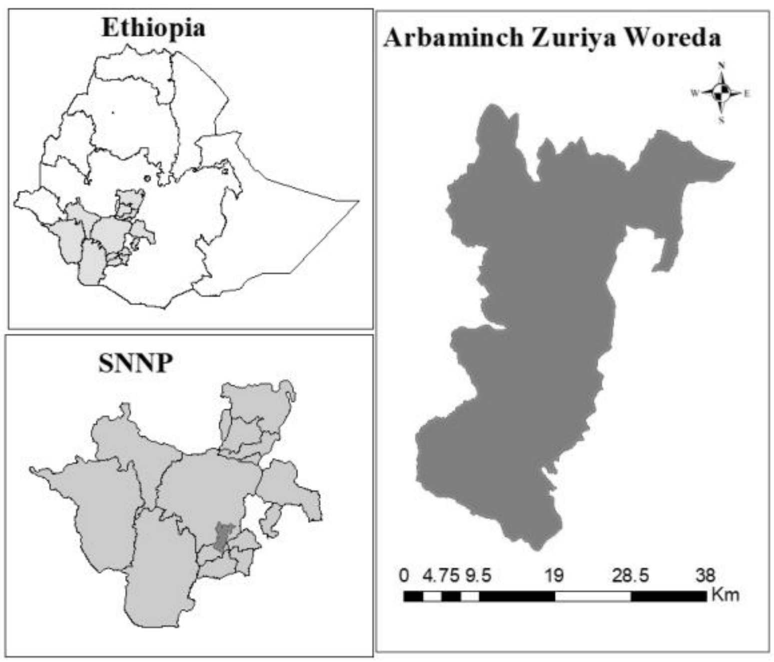

Figure 54: Location of the research site in Arbaminch Zuria woreda, SNNPR, Ethiopia

The altitude of the woreda ranges between 1150 and 2330 metres above sea level. The rainy season is bi-modal with the mean annual rainfall ranging from800 and 1200mm and the mean annual temperature between 16°C and 37°C. The livelihood of more than 92% of the world population is based on farming. The main crops grown in the area are maize, sorghum, and teff. *M. stenopetala* is widely grown in the woreda, almost every rural household plant Moringa trees in home gardens and/or farmlands. The soil type of the study area is ranging between clay and silt loam.

Experimental design and treatment

The experiment was arranged in a randomized complete block design (RCBD) with 3 replications. Land size of 10,000 m^2 was divided into three blocks and 9 experimental plots per block. The treatments consisted of 3 spacing levels namely narrow spacing (0.5mx0.5m), medium spacing (1mx1m), and wider spacing (2 m x 2 m) in three replications. The blocks and plots were separated from each other by 3m and 2m, walkways, respectively with a border of 0.50 x 0.50 m created around the treatment plots.

Establishment and management

The experimental site was cleared and ploughed before planting seedlings. Seeds were collected from KonsoWoreda, SNNPR, which is very close to the experiment site established. Seedlings were raised with 12 cm diameter flat polythene tubes in the nursery at Arbaminchzuriaworeda. The study was conducted under rainfed conditions and planting was done on the site during the rainy season at the end of July 2017. Each seedling was planted in a pit that has a 50 cm depth and across section area of 900cm^2. In each plot, 36 seedlings of *M. stenopetala* were planted in a row and total 972seedlings were used in the experiment. Initial root collar diameter (RCD) and height measurement were done before planting. After planting, a thorough ramming of the fine earth was done to avoid air circulation. During the study, the plots were well maintained by the picking of weeds and cultivated regularly to loosen soils for aeration after the establishment of seedlings. All experimental plots received similar silvicultural practices.

Plant measurement and leaf harvest

The inner 16 seedlings/plot were considered for the required data collection. Survival percent, height, and RCD of the trees in each plot were recorded at three months intervals. Height was measured with a pole graduated in meters and centimeters, and RCD with a digital caliper. Leaves were harvested from the experimental trees at the age of 27, 32, and 48 months after planting. Based on the indigenous leaf harvesting practice of Konso and Derashe people, up to 85% of leaves were harvested per tree per season and 15% leaves were left on each Moringa tree for the enhancement of the photosynthetic process and to sustainably harvest three times.The harvested leaves from each tree were partitioned into leaf, petioles, and stem. Only the leaves were considered for further analysis. The fresh weight of every leaf part of each tree was recorded immediately by using an electronic balance after harvesting. The oven dry weight of sample leaves was measured after drying the leaves at 60˚C for 72 hours (to constant weight) using an electric oven (Amaglo et al. 2006) at the laboratory facility of Ethiopia Environment and Forest Research Institute.

Statistical Analysis

All data were subjected to analysis of variance (ANOVA). The least significant difference at the 5% level was used to identify significant statistical differences between the three spacing levels.

Results and Discussion

Survival

M.stenopetala has shown relatively better mean survival rate in the narrow spacing than the medium and wider spacing at the 3, 6, 9, 12, and 15 months after planting (Table 45). The mean survival rate decreased with time until the 12th month for the narrow and medium spacing while the survival showed a decreasing trend until the 6th month for the wider spacing and was constant then after. The survival rate of the plantation averaged 94%, 89.6%, 88.7%, 87%, and 87% at the age of 3, 6, 9, 12, and 15 months after planting, respectively.

Table 45: The survival rate of *M.stenopetala* over 15 months after planting under three spacing treatments

Spacing	**Survival rate (%)**				
	3rd month	**6th Month**	**9th Month**	**12th Month**	**15th Month**
0.5 x 0.5 m	96.5	94.4	93.1	90.3	90.3
1 x 1 m	91.7	86.1	84.7	82.6	82.6
2 x 2 m	93.8	88.2	88.2	88.2	88.2
Overall	94.0	89.6	88.7	87.0	87.0

Root collar diameter, plant height and stem diameter growth

Growth was slow over the first three months after planting but showed a steady increment in the following months. RCD at3, 6, 9, 12 and 15 months averaged 0.8 cm, 1.3 cm, and 1.5 cm, respectively.

The mean root-collar diameter increments in narrow and medium spacing (0.5 × 0.5 m and 1 × 1 m) resulted in the greatest root-collar diameters (0.51 and 0.55 cm respectively), while the wider spacing (2 × 2 m) recorded the lowest RCD increments (0.4 cm) in the 1st three months (Table 2). In the 6th month, the medium and wider spacing gave significantly higher mean RCD increments than the narrow spacing of 0.5 × 0.5 m. Similar results were also found in the 9th month, where the medium and wider spacing gave greater mean RCD increments than the narrow spacing. In the 12th and 15th months, the wider spacing gave a significantly higher mean RCDincrement than the medium and narrow spacing and the medium spacing gave a significantly higher mean RCD increment than the narrow spacing.

The medium and wide spacing (1× 1 m and 2 × 2 m) resulted in the greatest plant height growth (0.66 and 0.55 m, respectively), while the narrow spacing (0.5 × 0.5 m) recorded the lowest plant height growth (0.35 m) in the 6th month. The medium and wider spacing gave significantly higher mean height growth than the narrow spacing of 0.5 × 0.5 m at 6th month after planting. Similar results were found in the 9, 12, and 15th months after planting where the medium and wider spacing gave greater plant height growth than the narrow spacing.

Stem diameters averaged 1.42 cm 2.0 cm, and 1.96 cm at 9 months for narrow, medium, and wider spacing, respectively; 1.84 cm, 2.7 cm, and 2.99 cm at 12 months for narrow, medium, and wider spacing, respectively; and 2.12 cm, 2.96 cm, and 3.19 cm at 15 months for narrow, medium and wider spacing, respectively. The medium and wide spacing (1× 1 and 2 × 2 m) had a significantly larger stem diameter than the narrow spacing in the 9, 12, and 15th months after planting.

Leaf biomass production

The dry leaf biomass on individual tree level across the densities ranged from 7.8 to 530.4 g/tree, from 9.36 to 608.4 g/tree, and from 6.24 to 1684.8 g/tree for the 1st, 2nd, and 3rd harvests, respectively. A significant difference in the dry leaf biomass production on individual tree level was observed due to spacing. The increase in planting spacing led to an increase in dry leaf biomass at the three harvest seasons. At the first harvest, the wide spacing gave significantly higher dry leaf biomass than the medium and narrow spacing and the medium spacing gave significantly higher dry leaf biomass than the narrow spacing (Table 46). A similar significant difference in the dry leaf biomass production was observed across spacing levels at the second and third harvest.

Table 46: Mean Root-collar diameter increments, plant height growth, and stem diameters of M. stenopetala at 6, 9, 12, and 15 months after planting.

	0.5 x 0.5 m	1 x 1 m	2 x 2 m
Root-collar diameter (cm)			
6 months	$1.67^{a} \pm 0.10$	$3.01^{b} \pm 0.12$	$3.20^{b} \pm 0.13$
9 months	$2.30^{a} \pm 0.13$	$4.61^{b} \pm 0.17$	$5.42^{c} \pm 0.18$
12 months	$2.72^{a} \pm .15$	$5.63^{b} \pm 0.21$	$6.92^{c} \pm 0.20$
15 months	$3.12^{a} \pm 0.16$	$6.14^{b} \pm 0.24$	$7.45^{c} \pm 0.20$
Plant height (m)			
6 months	$0.35^{a} \pm 0.03$	$0.66^{b} \pm 0.04$	$0.55^{b} \pm 0.03$
9 months	$0.81^{a} \pm 0.05$	$1.36^{b} \pm 0.06$	$1.28^{b} \pm 0.05$
12 months	$0.88^{a} \pm 0.06$	$1.54^{b} \pm 0.07$	$1.48^{b} \pm 0.06$
15 months	$1.02^{a} \pm 0.07$	$1.72^{b} \pm 0.08$	$1.69^{b} \pm 0.06$
Stem diameter (cm)			
9 months	$1.42^{a} \pm 0.10$	$2.0^{b} \pm 0.09$	$1.96^{b} \pm 0.08$
12 months	$1.84^{a} \pm 0.11$	$2.70^{b} \pm 0.13$	$2.99^{b} \pm 0.07$
15 months	$2.12^{a} \pm 0.14$	$2.96^{b} \pm 0.13$	$3.19^{b} + 0.11$

Means in the same row followed by the same lowercase letter are not significantly different at $P < 0.05$

The dry leaf biomass on hectare bases across the spacing levels ranged from 31.2 to 8112 kg/ha, from 23.4 to 8736 kg/ha, and from 15.6 to 67392 kg/ha, for the 1st, 2nd, and 3rd harvests, respectively. A significant difference in the dry leaf biomass production on hectare bases was due to the spacing. The increase in planting spacing led to the increase in dry leaf biomass per treeat the three harvest seasons. At the first harvest, the wide spacing (2× 2 m) gave significantly higher dry leaf biomass than the medium and narrow spacing and the medium spacing (1× 1 m) gave significantly higher dry leaf biomass than the narrow spacing (Table 47). A similar significant difference in the dry leaf biomass production was observed across spacing levels at the second harvest. At the third harvest, the wide spacing gave a significantly higher dry leaf biomass than the medium and narrow spacing but there was no significant difference between the medium and narrow spacing in dry leaf biomass production.

Table 47: Mean (± standard error of the mean) leaf biomass production at the 1st, 2nd, and 3rd harvest across the three spacing levels

Leaf biomass Production	0.5 x 0.5 m	1 x 1 m	2 x 2 m
at individual tree level (g/tree)			
1^{st} harvest	$48.36^{a} \pm 5.10$	$90.0^{b} \pm 8.82$	$119.28^{c} \pm 9.02$
2^{nd} harvest	$44.74^{a} \pm 3.19$	$115.08^{b} \pm 9.77$	$143.85^{c} \pm 10.29$
3^{rd} harvest	$88.15^{a} \pm 30.28$	$145.77^{b} \pm 15.87$	$249.8^{c} \pm 24.220$
on hectare bases (kg/ha)			
1^{st} harvest	$1934.40^{a} \pm 203.89$	$900.04^{b} \pm 88.19$	$298.20^{c} \pm 22.54$
2^{nd} harvest	$1789.56^{a} \pm 127.78$	$1150.79^{b} \pm 97.7$	$359.62^{c} \pm 25.73$
3^{rd} harvest	$3526.01^{a} \pm 1211.2$	$1457.67^{a} \pm 158.71$	$624.49^{b} \pm 60.59$

Means in the same row followed by the same lowercase letter are not significantly different at $P < 0.05$

Conclusion and recommendation

The results of the present study showed that the RCD, plant height and stem diameter were maximized at narrower, medium, and wider spacing, respectively.

Planting Moringa at a relatively wider spacing increased leaf biomass production of individual trees. The increase is two to three folds from narrow to wider spacing. However, the species is found to be capable of producing a good leaf biomass yield at a relatively high density of plants on hectare bases. The leaf biomass production per hectare was very high at narrow spacing than the medium and wider spacing. The increase is five to seven folds from wider to narrow spacing. Currently, the population number of Ethiopia is exponentially growing and the land resource became scarce and the need to plant and utilize Moringa trees is growing in different parts of Ethiopia. Our finding shows that Moringa can be planted and produce high biomass in small areas by local communities and investors.

Based on-site condition, Moringa leaves should be harvested at the appropriate cutting height. It will be preferable to collect leaves during the early morning and late afternoon and using clean scissors can help workers to become efficient in collecting more quantity and quality leaves. Planting Moringa trees can create job opportunities for youths and women to earn money by selling Moringa leaves at the local and national markets and improve their livelihoods.

M. stenopetala is one of the few multipurpose trees that can survive in harsh growing conditions. To enhance both plant growth and leaf biomass production, it is desirable to consider fertilizer application and supplementary irrigation under diverse weather conditions and soil types. Such studies are very important for farmers and investors who are willing and able to grow the plant on a larger or commercial scale.

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Population status, Phenological characteristics, and Fruit yield potential of *Adansonia digitata L.* fruit trees in North West lowland area of Ethiopia

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Abstract

Adansonia digitata is one of the wild edible trees that have ecological and socio-economic significance in low land areas. In Ethiopia, Baobab trees are found in a sparsely scattered pattern. Despite its importance, the information on its current status and distribution is scanty. The survey was conducted in the northwestern part of Ethiopia to determine the population structure and density of *A.digitata* in different land-use types. Six plots with a size of 1000m*100m and five plots having a size of 500 m*100 m were established. Sub-plots (25 m X 25 m) and sub-sub plots (5 m X 5 m) were established to record coexisting woody plants and regenerations respectively. Tree diameter, height, and crown diameter data were recorded. The density and structure of *A.digitata* trees were analyzed using SPSS software. The survey result showed that homestead, agricultural, and forest land-use types had 2.24, 1.57, and 0.32$\pm$0.41 trees/ha respectively in Quara woreda. In the homestead, open shrubland and riverine forest land uses of Kafta humera and Maytsebry woredas 0.95, 1.65, and 3 trees/ha were found respectively. However, the density difference among sites was not statistically significant. *A. digitata* had a very low importance value index; therefore, it needs sound management and conservation strategies. According to our result, variability in fruit yield was observed within different diameter classes especially within diameter class of 100 – 199.9 cm and 200 – 299.9 cm. This variability could be due to age, health status, human and animal factors.

Keywords: *Adansonia digitata*, survey, density, distribution, fruit, yield

Introduction

Tropical regions of the Earth have more fruit plant species than any other region of the world. It is endowed with the great diversity of fruit tree species that provide humans with basic food and nourishment for ages since the domestication of beneficial wild plants (Rathore, 2003). Tropical continents of the world possess a rich variety of fruit trees with about 1000 species identified in the Americas, 1200 species in Africa, and 500 species in Asia (Paull and Duarte, 2011; Sthapit *et al.,* 2012). Even though only a relatively few fractions of these diversities are marketed worldwide, the diversities are nature's inestimable assets for the livelihoods of local people throughout the tropical regions.

Like that of Asia and the Americas, the continent of Africa is blessed with a rich tropical flora. Many of the 50,000 or so plants that evolved within its forests and savannas ripen fruits to the many wild creatures into spreading their seeds. Including both indigenous and introduced naturalized ones, tropical Africa has 477 edible fruit and nut species grown across its landscape (Siemonsma *et al.,* 2004).

Ethiopia is endowed with 370 indigenous food plants from 70 families and out of that, 182 species (40 families) are trees/shrubs with edible fruits/seeds (Asfaw and Mesfin, 2001). Out of the above mentioned edible fruits, 25 of the species have marketable fruits/seeds: 21 are marketable in local markets, 2 are reported national and 2 species are internationally marketable (Bashir, 2006).

The rural populations have wide knowledge, tradition, and opportunity of using wild edible plants(Amare Getahun, 1974; Getachew Addis *et al*., 2005). Wild edible plants are relevant to household food security and dietary diversification as well as income generation in some rural areas, particularly in the drylands, to supplement the staple food, to fill the gap of seasonal food shortages and as emergency food during the famine, prolonged drought or social unrest (Amare Getahun, 1974; Zemede Asfaw and Mesfin Tadesse, 2001). Plant parts like leaves, stems, fruits, flowers, tubers, barks, seeds, and roots are consumed in many communities around the globe.

Adansonia digitata (African baobab) is one of the most important wild edible forest products and a key species that have ecological and socio-economic significance in the lowland area (Venter & Witkowski, 2010). It is one of the eight species of baobabs in the genus of

Adansonia (family Malvaceae, subfamily Bombacoideae). Six species occur in Madagascar, one in Australia and one in mainland Africa (Baum, 1995b).

The African baobab is a very long-lived tree and thought that some trees are over 1000 years old (Sidibe and Williams, 2002). It is characterized by swollen trunks and palmately compound leaves. The trunks consist of soft, fibrous wood that can store water. The leaves of juvenile trees are simple and gradually change to 5-7 foliate compound leaves as the tree gets older. Flowers are borne in the axils of leaves and comprise a single, large, odoriferous white flower made up of both male and female reproductive parts. The fruits are large, ovoid, and covered in a yellow/green velvety indumentum. The pericarp is woody and indehiscent. Seeds are reniform, embedded in a soft dry matrix (Baum, 1995b).

African baobabs are indigenous and widely distributed throughout the savannas and woodlands of sub-Saharan Africa where it is found in areas of South Africa, Botswana, Namibia, Mozambique, Zimbabwe and other tropical African countries where suitable habitat occurs (Sidibé& Williams, 2002). It is restricted to hot, dry woodland on Stoney, well-drained soils, and in frost-free areas that receive low rainfall (Curtis &Mannheimer, 2005).

Mostly found in the drier plant communities of the Sudano- Zambesian lowlands where annual rainfall is 200-800 mm annually (Wickens, 1982). In Ethiopia, baobab trees are found in a sparsely scattered pattern in Tigray, Amhara, and Benshangul Gumuz regions and rarely in the Gambela region. *A. digitata* L.trees grow on sandy soil over granite, rocky outcrops, and riverbanks, and its roots are deep-rooted, drought-resistant, and prefer a high water table (Azene Bekele, 2007).

A. digitata L. is mostly regarded as a multipurpose fruit-bearing tree used for medicine, food, fibers, clothing, and soil protection from various plant parts (Sidibe and Williams, 2002; Galizia et al., 2005). It is a typical tree that has been given attention by the local people due to multiple benefits derived from it and important for humans and animals in sub-Sahara and other dry areas of Africa (Galizia et al., 2005). Baobabs have developed structures that can withstand and survive harsh environmental conditions in savannas. Due to human-induced factors, *A.digitata L.* tree species population is declining. Limited works carried out so far on *A.digitata L.* in Eastern Africa (North et al., 2014; Gebauer and Luedeling, 2013; Gebauer et al., 2002; Melkamu et al., 2014) have shown different types of population structures.

Therefore, proper attention needs to be given to manage the remnant populations and develop different schemes to develop plantations, domesticate, and promote the species.

The objective of the study

The overall objective of this study was to generate information on the distribution, abundance, phenological characteristics and fruit yield of *A.digitata L.* Specific objectives include:

- To examine the abundance and population structure of *A.digitata L.* and associated species along with different land use types
- To determine phenological characteristics of the flowering and fruiting period
- To determine the fruit yield potential of *A.digitata L.*

Methodology

Description of the study sites

This study was conducted in the lowland woodlands of Quara woreda of Amhara region and Kafta hummera and Maytsebry woredas of Tigray region. Both are located in the northwestern and northern Ethiopia, respectively as indicated in figure 55. The two regions are adjacent to each other and the three woredas are found in the relatively similar agro-ecological zone with similar altitude, temperature, and rainfall. Quara town is found at about 1049 km from Addis Ababa and Humera town is located at about 1200 km in North West direction from Addis Ababa town.

The vegetation of the study sites is known as the *Combretum-Terminalia* woodland vegetation (Friss et al.,2010; Teketay, 2000; Eshete et al., 2011). Such woodlands are often found in shallow soils and sandy river valleys (Fichtl and Admasu,1994; Teketay, 2000). The rainfall distribution of all study sites ranges from 400 to 1200 mm. The mean annual temperature of Quara woreda ranges from 25 to 42 ^{o}C and that of Kafta humera and Maytsebry ranges from 17.5 - 41.7 ^{o}C. The rainy season of the study areas is from June to September. The remaining 8-9 months between October and May is dry and hot. The temperature reaches its maximum range in the three woredas in April and May, and the minimum temperature is in August and July. Parent materials of the area are dominated by volcanic felsic and metamorphic pre-cambrian basements, and in some parts, limestone. Leptosols and vertisol are the predominant prevailing soil types in the area.

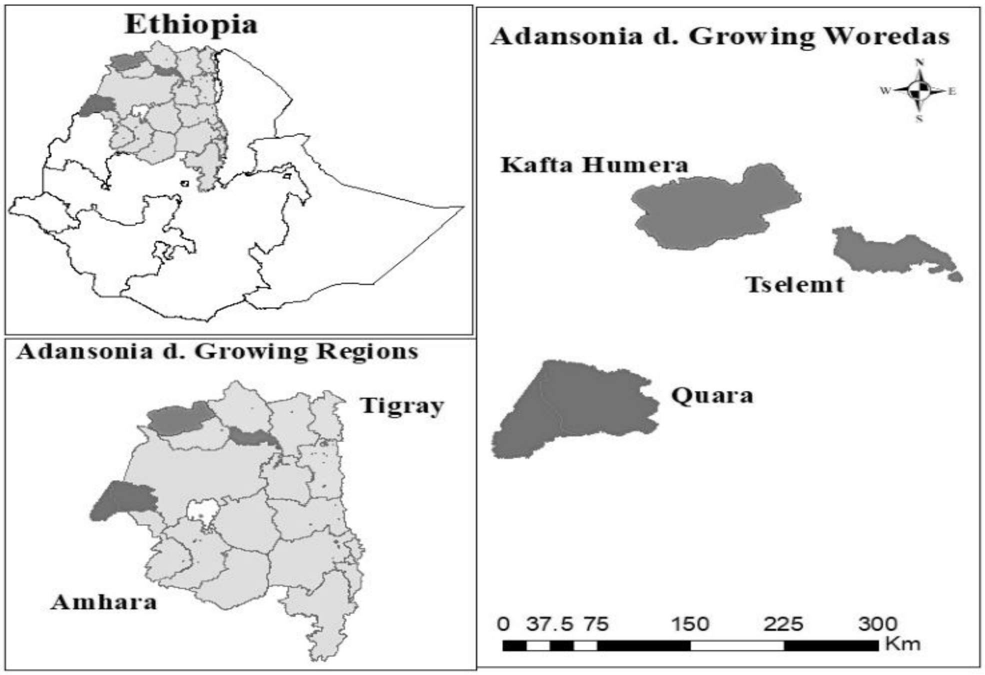

Figure 55: Map showing *A. digitata* study sites in Amhara and Tigray regions

Research design and parameters

This activity was started in assessing information about the location of the potential growing area of *A. digitata L.*tree species. Quick reconnaissance surveys were conducted to assess the range and degree of occurrence of the species and representative sites that harbor the species. The assessments were conducted in Quara woreda at Gelegu kebele, in Kafta Humeraand Maytsebry woreda at Dima and Senasil kebele respectively. Distribution, abundance, and structure of the species were studied in different land-use types such as homestead, agricultural, forest, and open shrub and riverine forestland. The forest, open shrub, agricultural and riverine land-use areas were subdivided into 1 km*100 m main plots, and also homestead land-use or around settlements were sub-divided into 0.5 km*100 m main plots following the methods used by Venter and Witkowski, (2010). Ten percent intensity of the total plots in each land-use type was employed as a sample plot. In each plot, all matured trees including target fruit species and regeneration and saplings were considered to collect different tree parameters, such as diameter at breast height, total height, crown diameter, and a number of main branches per tree. Ten reproductively matured trees with easily visible crowns were selected and marked and a continuous observation and data recording on their flowering and fruiting phenology was recorded based on the observation made at intervals of 15 days for three years. The yield traits: number of branch per tree, crown depth and diameter, number of fruits per branch, number of fruit per tree, and total fruit mass/weight per tree was measured.

Data analysis

Population status of *A.digitata L.* and associated woody plant species were determined by computing density, abundance, frequency, dominance, importance value index (IVI), and population structure.

Density, which refers to the total number of individuals per hectare, in different land-use types was calculated by summing up all the stems across all sample plots (abundance) and translates to hectare base for the species encountered in the study plots (Abeje *et al.,*2011).

Size class distributions of tree species in different land-use types were analyzed and compared using analysis of variance (ANOVA), correlation, and regression analysis.

Heterogeneity of the dry land species in different land-use types was determined using Shannon-Weiner diversity indices. Shannon-Wiener's diversity index (H) was calculated as follows (Adefires, 2006).

$H' = -\sum_{i-1}^{s} pi \ln pi$ Where,

Where, H'=Shannon diversity index; S =the number of species; pi= the proportion of individuals or the abundance of the ith species expressed as a proportion of total cover; ln=natural logarithm.

Evenness which refers to the unique representation of a given species against a hypothetical community in which all species are equally distributed was computed as:

(Evenness) $J = \frac{-\sum_{i=1}^{s} pi \ln pi}{\ln S}$

The composition and structure of the woodland in different land-use types were analyzed as a proportion in the percentage of the various species encountered concerning the total. Thus, the percentage of contributions of targeted species in various measurable entities compare to the associated species was analyzed as follows: The structure of the vegetation was described using frequency distributions of diameter at breast height. Tree or shrub, which is greater than 1.5cm diameter at breast height, and basal area values were computed on a hectare basis. Importance value indices (IVI) were computed to know the dominant woody species based on their relative density (RD), relative dominance (RDO), and relative frequency (RF) to determine their dominance. Finally, the regeneration status of *A. digitata L.*and other associated species in different land-use types were summarized based on the total count of regeneration (seedling and sapling) of species across all sample plots following (Adefires, 2006).

Results and Discussions

The density of *A. digitata L.* in different land-use types

Average densities of *A.digitata L.* in the three-study area of different land-use types are described in table 1. The species generally had very low densities in all the study sites. The result showed that the highest *A. digitata L.* tree density was counted in the riverine forest land of Maytsebry (3trees /ha) and the second-highest density was recorded in Quara homesteads. A study on the species in South Africa by Venter and Witkowski (2010) also revealed very low density and indicated that villages and fields had higher densities of trees (2.16±0.44 and 1.13±0.52 plants/ha) than plains and rocky outcrops (0.96±0.25 and 0.83±0.24 plants/ha).

Figure 56: Sampled *A.digitata* L. trees in four land-use types (farmland, homestead, forest land & riverine forest. From left to right)

The distribution of *A.digitata L.*in the study area varied across the different land use types and the data indicated that the population is not evenly distributed. This could be related to the solitary nature of the species and lack of protection. In some areas, the population of *A.digitata L.* was found in the clustered manner and whereas in the other areas it was distributed more sparsely as indicated in figure 56. Based on the vegetation survey, the population of the species in adjacent river vegetation and abandoned village and church areas were distributed in the clustered pattern. Similarly, Lisao, (2015) that *A.digitata L.* population were mainly observed in settlements in the Omusati region in Northern Namibia.

Table 48: Density of *A. digitata* L. in three land-use types and study areas

Study area	Land-use type	Density (plants/ha)
Quara	Homestead	2.24
Quara	Agricultural land	1.57
Quara	Forest land	0.32
Kafta humera	Homestead	0.95
Kafta humera	Open shrubland	1.65
Maytsebry	Riverine forest	3

Population structure of *A. digitata L.* in different land-use types

Population structures of *A.digitata L.* in the three study areas are presented in Figures 57 and 58. The largest *A. digitata L.* tree (360 cm wide girth) was recorded at a homestead in Quara woreda. About 373 cm and 340 cm largest trees were recorded in Kafta humera open shrubland and Maytsebry riverine forestland use type respectively. Relatively many trees with DBH <50 cm were encountered in different land uses: 15.8% in forest land-use types, the second 10.60% in agricultural land-use type, and the lowest 3.57% in homestead land-use types of Quara woreda. In Maytsebry woreda higher proportion of trees with <50 cm DBH were recorded than in Kafta humera woreda. In Kafta humera relatively higher numbers of sub-adult trees were recorded in open shrubland (17.14%) than homestead land (10.53%). In all land-use types of Quara woreda, many *A.digitata L.*trees were recorded at 101-150 cm and 51-100 cm diameter size classes.

The survey showed that a high number of *A.digitata L.*trees was recorded at 14.1-16 m height size class in Quara woreda as shown in figure 57 A and about 26% of the trees belonged to this size class category. In Kafta humera and Maytsebry, woredas higher numbers of *A.digitata L.* trees were recorded at 12.1-14 height size class categories as indicated in figure 5 B&C. The tallest trees (about 1%) were observed in the agricultural land-use type of Quara woreda that was recorded in the size class of 22.1-24 m. In Kafta humera, the tallest trees (2.86%) were recorded in open shrub land-use type. In general, the majority of trees were laid in the middle height size class category of all study woredas.

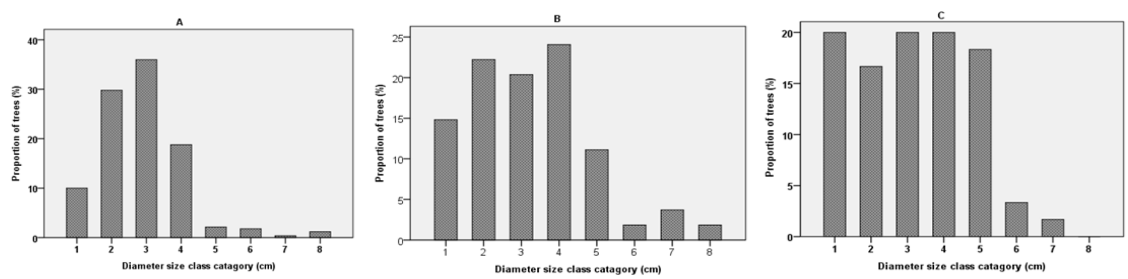

Figure 57: Proportion of A.digitata L.trees in the different diameter size classes-Quara woreda (A), Kafta humera woreda (B), Maytsebry woreda (C). Diameter size class(DSH) in cm; 1=1-50, 2=51-1

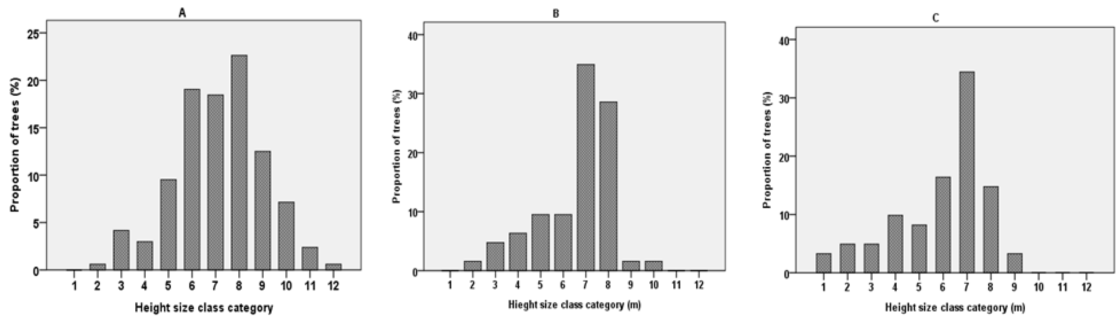

Figure 58: Proportion of *A.digitata* L. trees in the different height size classes- Quara woreda (A), Kafta humera woreda (B), Maystebryworeda (C).Height size class (m); 1= 0-2, 2=2.1-4, 3=4.1-6, 4

Diversity, evenness, and richness of woody species in forest and agricultural land use type

Forest land-use types had higher diversity and evenness than agricultural land-use type in Quara woreda. Species richness in forest and agricultural land-use types was recorded 30 and 21 types of species were encountered. The diversity and evenness of woody species in forest land-use types were 2.37 and 0.70, and in agricultural land-use types 1.98 and 0.65 respectively. All individual species in forest land use type are more equally distributed than agricultural land use type species.

In western Tigray woredas (Kafta humera and Maytsebry) higher number of species richness was recorded in open shrub land-use types (11 species type) than riverine forest land (10 species type) and homestead land use type (7 species type). The diversity and evenness of woody species in open shrub land-use type were 1.80 and 0.75, in homestead land 1.53 and 0.79, and in riverine forest land-use type 0.97 and 0.42 respectively. The distribution of species in riverine forest land-use type is more equally distributed than open shrubland and homestead land-use types. According to the result of two woredas species characteristics, a higher number of species richness and diversity were recorded in Quara woreda than Kafta humera and Maytsebry woredas. The variation of woody species characteristics between woredas and land use types may be due to differences of anthropogenic disturbance levels like continuous cultivation (plow), free grazing, fire, pesticide and herbicide chemicals.

In agricultural land use type, local people had practiced extreme clear cultivation in Quara woreda and this practice reduced the species distribution and composition in croplands. As a result, it is only some trees with high coppicing and resistance ability like *Ziziphus mucronata* and *Acacia polycantha* that were existed. A similar study in Metema woreda (Abeje *et al.,*2011), reveals that superior competitor species in low levels of disturbance monopolize resources and exclude other species whereas at high disturbance levels only the most resistant species survive. Additionally, the study suggested that the wet season length and soil variability were contributed to the variation of species richness. Another study (Haileab *et al.,* 2011), argued that species diversity in each forest ecosystem might be varying, due to altitudinal difference, habitat diversity and low human disturbances.

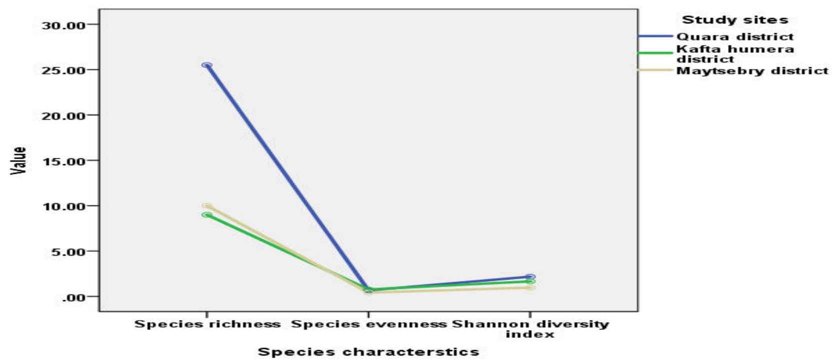

Figure 59: Species characteristics along study woredas

Density, frequency, dominance, and importance value index of species in different land-use types of three study woredas, categories based on the degree of disturbances. The density of woody species in forest and agricultural land-use types of Quara woreda were recorded higher number of stems per hectare rather than different land-use types of Kafta Humera and Maytsebry woredas.

A few species of saplings and seedlings were found to pre-dominate the density of vegetation in the study areas. Five species, namely *Terminalia laxiflora, Combretum adenogonium, Acacia brevispica, Terminalia brownii,* and *Combretum molle* were contributed 74% of the total density at forestland use type of Quara woreda. Similarly, in agricultural land-use type five species such as *Ziziphus mucronata, Acacia polyacantha, Cluttalanceolata, Piliostigma thonningii* and *Acacia brevispica* were contributed to 82% of the total density of woody plant species. In the homestead land use type of Kafta humera woreda, Acacia *senegal, Balanites aegyptica, A.digitata L.* and *Lannea fruticosa* contributed to 92.86% of the total density of woody plant species as indicated in annex 3. In open shrub land use type, *A. digitata L., Dalbergia melanoxylon, Acacia mellifera* and *Dicrostachyus cinerea* contributed to 82.80% of the total density. Also in riverine forestland use of Maytsebry woreda, *A.digitata L., Tamarindus indica, Terminalia brownie* and *Acacia polycantha* species contributed 92.31% of the total densities of woody plant species.

The major species associated with *A.digitata L.* were *Anogeissus leiocarpus, Pterocarpus lucense, Combretum molle,* and *Terminalia laxiflora* in forest land-use type of Quara woreda in order of dominance. *A.digitata L.* is the second dominant tree species in forest land-use type. In the homestead land-use type of Kafta humera woreda, *Lannea fruticosa, Steruculia setigera, Balanites aegyptica* and *Acacia senegal* species were associated with *A. digitata L.* species in order of dominance. In open shrub land-use type, *A. digitata L.*species were associated with *Terminalia brownie, Anogeissus leiocarpus,* and *Balanites aegyptica* species. *Tamarindus indica, Terminalia brownie,* and *Acacia polycantha* species are also associated with the riverine forest land use type of Maytsebry woreda.

Also, *Terminalia laxiflora, Combretum molle, Anogeissus leiocarpus, Pterocarpus lucense,* and *Acacia brevispica* were the highest five ecological important species in order of importance in forest land-use type of Quara woreda. On the other hand, *Ziziphus mucronata* and *Acacia polycantha* were more ecologically important tree species in agricultural land-use types. In the homestead and open shrub land-use types of Kafta humera, *A.digitata L., Acacia senegal, Balanites aegyptica, Dalbergia melanoxylon,* and *Acacia mellifera* were with the highest ecological importance value species in order of importance. Also, *A.digitata L., Terminalia brownie,* and *Ficus vasta* were the three highest ecological importance value tree species in riverine land-use type of Maytsebry woreda in order of importance.

Regeneration status of a woody species

Regeneration status of all species found in forest and agricultural land-use types of Quara woreda are shown in figure 6 and accordingly, *Terminalia laxiflora, Acacia brevispica, Terminalia brownie, Combretum adenogonium,* and *Combretum molle* had better regeneration status of species in forest land-use type. Whereas in agricultural land-use type, *Ziziphus mucronata*, *Acacia polycantha, Clutta lanceolata, Piliostigma thonningii,* and *Acacia brevispica* species had better regeneration status (figure 60). However, in forest and agricultural land-use types, there were no *A. digitata L.* recruitments**.**

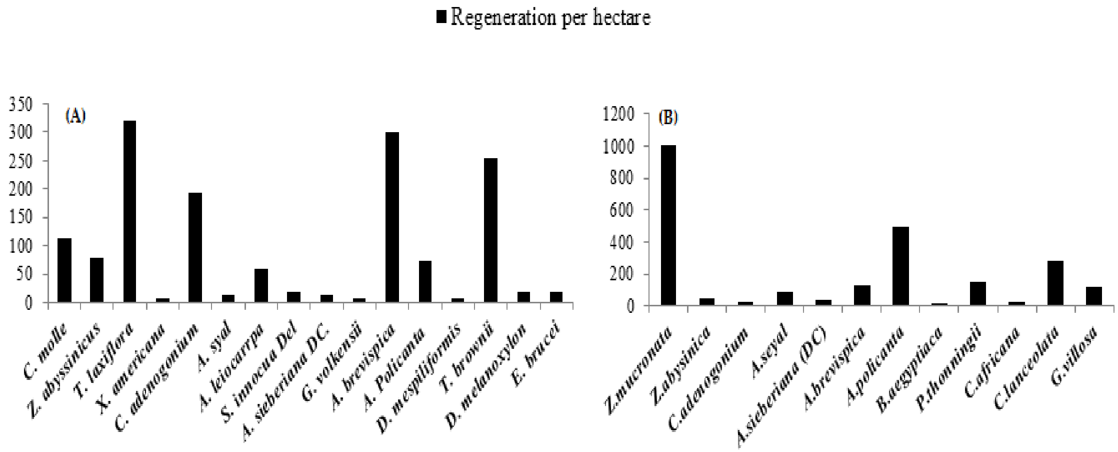

Figure 60: Regeneration status of woody species in Quara woreda of forest land-use type (a) and (b)

Correlation coefficients between different variables

The Pearson correlation of diameter at breast height with height, crown diameter, and diameter at stamp height was described in table 49. The correlation between diameter at breast height and crown diameter (r=0.876**) was strong and positively correlated. It was significant at 0.05 level (p=0.000) (Table 49). The correlation coefficient between dbh and height (r=0.382); height and crown diameter (r=0.331) were weak and were not significant, p=0.18 and p=0.25 respectively. Unlike other tree species, the stem form of *A. digitata L.* is irregular, and therefore there is a need for further investigation on the correlation of diameter at breast height with a diameter at stamp height. According to the current results, the correlation of diameter at breast height with a diameter at stamp height was strongly and positively correlated (r=0.926**). The relations of diameter at breast height and stamp height are also significant at 0.01 level (p=0.00). Further regression analysis was performed to determine the predicted value of the crown diameter by measuring the only diameter at breast height. The result of predicting equation is presented as follows:

$$\text{Crown diameter} = 7,537+0.038 \text{ dbh}$$

Table 49: Pearson correlation coefficients diameter at breast height with height, crown diameter, and diameter at stamp height

Variables	Diameter at breast height(cm)	Height (m)	Crown diameter (m)	Diameter at stamp height
Diameter at breast height (cm)	1	0.382, (P=0.18)	0.876**,(P=0.00)	0.926**, (P=0.00)
Height (m)	0.382, (P=0.18)	1	0.331, (P=0.25)	-
Crown diameter (m)	0.876**, (P=0.00)	0.331, (P=0.25)	1	-
Diameter at stamp height	0.926**,(P=0.00)	-	-	1

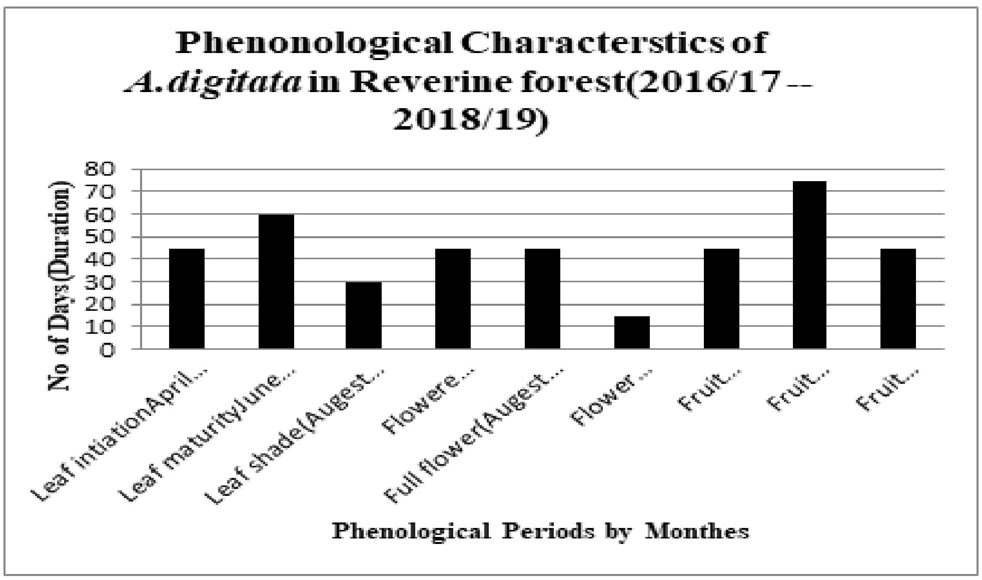

Figure 61: Phenological period of *A.digitata*

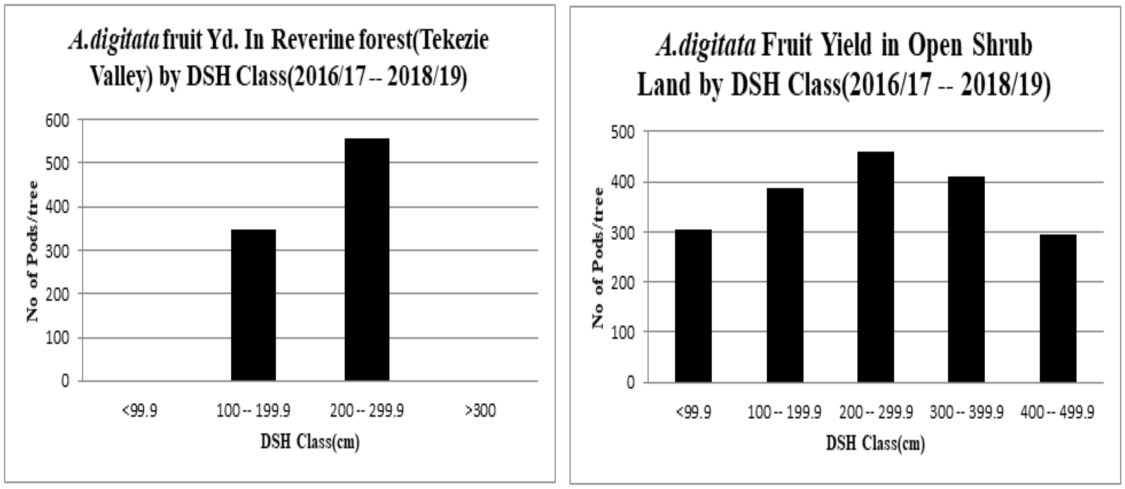

Figure 62: Fruit yield of *A. digitata* in two land cover types

The fruit yield study on *A.digitata* was conducted in riverine forest and open shrub land in western Tigray region. As shown in the above graphs, some variation in pod yield was observed and this might be due to the nature of soil and less presence of baboons in the open shrub land cover type. The sub-adult *A.digitata* trees that are found in diameter at stamp height (DSH) class of 200 cm – 299.9 cm gave better fruit pod yield than the other smaller and bigger DSH classes. The practices of the collection, utilization and selling of *A.digitata* fruits in local markets are poor in the woredas of north-western part of Ethiopia and local communities prefer to sell the Baobab fruits to the neighbouring country (Sudan) in cheap prices. Baobab fruit are harvested once in a year in the study areas.

Sampling and yield collection

A fruit yield potential study on *A.digitata* was conducted in open shrubland and riverine land cover types of western Tigray for two consecutive years (2017 – 2019). For the current fruit yield study, representative *Adansonia digitata* fruit trees from different DSH classes were selected in two land cover types i.e. riverine and open shrubland, and was used to determine the fruit yield potential of the target tree.

A study was conducted on representative trees from different DSH classes and systematic fruit count and collection was done on each tree. The total number of branches that can hold fruit pods was counted to determine the average number of pods per branch and tree.

According to the result of the study, variability in fruit production was observed within different diameter classes and the number of pods per tree was found to be similar in two land cover types, especially within diameter class of 100 – 199.9 cm and 200 – 299.9 cm. This might be due to the youngness and similar age of tress. More number of pods per tree was observed on the trees that are found in the open shrubland within diameter class of 200 cm and 300 cm. This indicated that trees growing on open shrubland with deep soil are more productive than that of riverine which is dominated by shallow soil and rock outcrop.

The result of the study showed some similarity with (Chapman et al., 1992; Botelle et al., 2002; Shackleton et al., 2002; Killmann et al., 2003). They suggested that stem diameters can reliably be used to distinguish between sub-adult and adult trees. Tree with a lower diameter class produced a smaller number of fruits than trees with a bigger diameter class, thus, focusing on trees >100cm DSH would help in harvesting better biomass of pods and pulps per tree.

Fruit production figures from other parts of Africa are limited or not widely published. However, Ibiyemi et al. (1988) quoted an unsubstantiated figure of 250 fruit per mature plant. In contrast, Swanepoel (1993) reported that, over four years, baobabs in the Mana Pools area of the Zambezi River valley did not produce any mature fruit. Assogbadjo et al. (2005) reported that mean fruit production in Benin varied between 57.1 and 157.4 fruit per tree in different climatic zones. Fruit production in communal land in South Africa of 77.1±13.9 (SE) thus falls within the levels found in Benin. Site characteristics can influence fruit production (Peters, 1996) and Assogbadjo et al. (2005) found that variability in site conditions across three climatic zones in Benin significantly influenced baobab fruit productivity.

Conclusions and Recommendations

Relatively higher numbers of *A.digitata L.* tree species per hectare were recorded in the riverine land-use type of Maytsebry woreda. Statistically, there are no significant differences of *A.digitata L.* density between land-use types. The majority of a species population was distributed in the middle diameter size class and height size classes. There was no *A. digitata L. sp*ecies regeneration in all land-use types and this situation will challenge the future population dynamics of *A.digitata L.*

A. digitata L. was highly associated with *Combretum-Terminalia, Ziziphus* and *Acacia* tree species in forest and agricultural land-use types. This species is dominant and has key ecological importance in the woodland vegetation; however, *A.digitata L.* has a very low importance value index.

Some local communities in the study areas have an experience of total harvesting of pods and fruits and using the young shoots and the kidney-shaped seeds of Baobab trees as food and medicine. Due to this reason, Baobab trees have faced a high risk of sustainability and extinction.

- In-situ and ex-situ conservation strategies should be considered for the sustainable development and utilization of this endangered and economically important tree species.
- There is no regeneration of *A.digitata L.* species and the population dynamics of the species is in a declining trend. Therefore, before the extinction of the species, domestication and protection will be crucial.
- The socio-economic importance and attitudes of different ethnic groups towardsBaobab trees should be studied in Benshangul Gumuz, Amhara, and Tigray regions.
- The people living nearby the neighboring country of Sudan buy Baobab fruits cheaply from Ethiopians and make juice from it and in turn sell the juice to Ethiopians.
- Total harvesting of Baobab tree fruits/pods should be controlled and minimized through awareness creation and training.
- Local people especially the youth should be encouraged and organized in making juice from pulps/fruits of Baobab trees.

Further research is required in the following areas:

- Adaptation and domestication trail on *A.digitata* in similar agro-ecological zones
- GIS-based research on population dynamics, temporal, spatial factors that influence the distribution and fruit production of *A.digitata* trees
- The socio-economic importance of Baobab trees
- The nutritional and medicinal value study on Baobab fruits, leaf, and flower parts

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Section 3: Climate Science Research

Status of emission level of cement factories in Central Ethiopia

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Abstract

The assessment covered one governmental and three private cement factories around Addis Ababa, namely; Mugher, Dangote, Habesha, and Derba. Secondary data of clinker, substituted material, and energy consumption was collected from cement factories and the Ministry of Industry in 2018. The assessment covers five production years from 2014-2018. The analysis of the status of GHG emission was made based on the IPCC 2006 software. The emission level of the assessed cement factories depends on the amount of clinker production, efficient use of energy, the use of low carbon content of the fuel, the low carbon content of substituted material, and use of improved technologies. The clinker production process and energy use were the major sources of CO_2 emission from the cement factories in Ethiopia. In this regard, the highest clinker production and GHG emission were recorded in the 2015 production year. In the past five years, 7.6 Mt of $CO_2$was emitted from the assessed cement factories. The cement factories have substituted5,657,310 tonnes of clinker by pumice, gypsum, and other materials that helped to reduce 825,062 tonnes of CO_2 emission. The results indicated that the substituted materials have enabled to reduction of GHG from cement factories. In this perspective, the use of alternative fuels, the choice of the dry process instead of the wet process, improving energy efficiency, and substituting high carbon content materials with low carbon content materials are the most recommended technologies to reduce GHG emissions.

Keywords: Cement, Clinker, Greenhouse gases, Substitution

Introduction

Cement production is a significant source of global carbon dioxide (CO_2) emissions, accounting for approximately 5% of the global CO_2 emissions from industrial and energy sources (Marland et al., 1989). There are two aspects of cement production that result in emissions of greenhouse gases (GHGs). The first is a chemical reaction involved in the production of clinker (the main component of cement) as carbonates are decomposed into oxides and CO_2 by the addition of heat. The second is the combustion of fossil fuels to generate the significant energy required to heat the raw ingredients to well over 1000^{o}C.

The CO_2 emissions depend partially on the type of process used (wet or dry) for clinker making, specifically due to the fuel used for pyro-processing, and the carbon intensity of the fuel inputs used by cement industries. Worrell and Galitsky (2001) estimated that the wet process has yielded an average of 249 kg/st CO_2 intensity as compared to 224.2 kgC/st for the dry process. Cement production is a highly energy-intensive production process. The energy consumption (e. g. coal) by the cement industry is estimated at 2% of the global primary energy consumption, or almost 5% of the total global industrial energy consumption (WEC, 1995).

Due to the rise in concrete construction in Ethiopia, the demand for cement has been growing rapidly. There were four cement plants in 2008 with a combined production capacity of about 2.85 million metric tonnes per year (Getaneh, 2010), while in 2019 there were 26 functional cement factories with a total production capacity of 26.21 million tonnes. Correspondingly, it contributed the highest emission share compared to other industries in the country (CRGE 2011). Consequently, the Climate Resilient Green Economy (CRGE) strategy indicated that around 70% of industry abatement potential should be from the cement industry. This goal will be achieved through clinker substitution and the use of more energy-efficient technologies (MoI, 2015). CRGE strategies (CRGE, 2011) indicated the potential of reducing around 14 Mt CO_2e in 2030 if alternative fuels, production process, energy-efficient materials, and carbon capture technologies are used. Therefore, assessing the GHG emission levels from cement factories helps to recommend greener ways of cement production in Ethiopia towards Nationally Determined Contribution (NDC) initiatives.

Materials and methods

Four cement factories were purposively selected based on their production capacity and proximity to Addis Ababa. Secondary data of clinker production and materials used to substitute clinker were collected from cement factories and the Ministry of Industry in 2018. In this study, the input method was used based on IPCC (2006) inventory software. The input method calculates the calcination of CO_2 emissions based on the volume and carbonate content of the raw materials consumed for cement production (CSI, 2005; 2011). Since there is no country-level specific emission factor, IPCC default value or Tier 1 methods of data analysis were applied. For the substituted materials of which IPCC didn't incorporate into the software, carbonate content of the substituted raw material was used to calculate the CO_2emission.

Results and Discussion

The materials used in cement production and products at different steps of the cement production process emit GHG. Clinkers, substituted materials, calcination, bypass dust, organic carbons in raw materials were found to emit a different amount of GHG.

Figure 63 shows the amount of clinker produced in five consecutive years from 2014 to 2018 in tonnes (MoI, 2018). The highest clinker production was registered in 2015 (4,000,000 tonnes), while the lowest clinker production was registered in 2014 (900,000 tonnes).

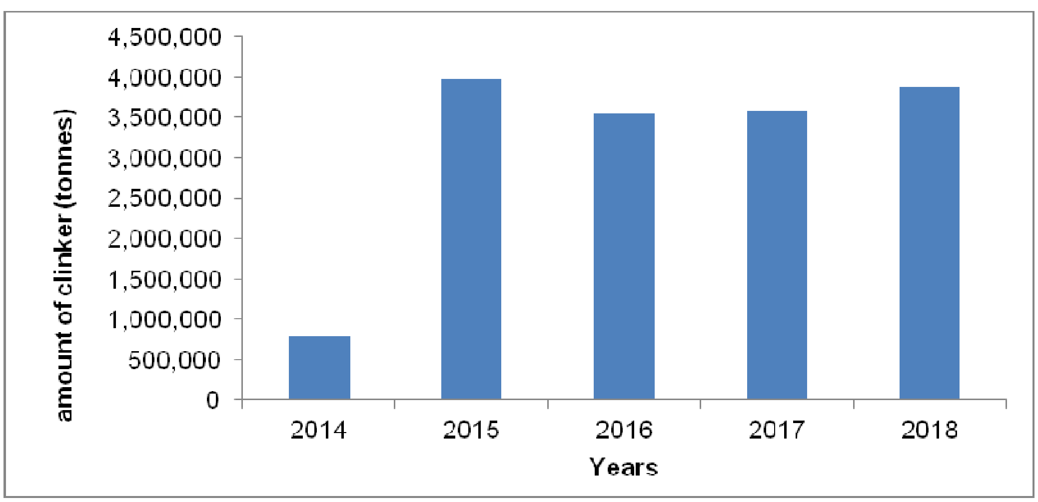

Figure 63: Amount of clinker production in 2014-2018

CO_2 from raw material Calcination

The results showed that there was high CO_2 emission from the four cement factories in 2015 and lower in 2014 from the calcination of raw materials. In the period 2016-2018, the amount of CO_2 emissions has been more or less consistent with a slight increase in 2018.

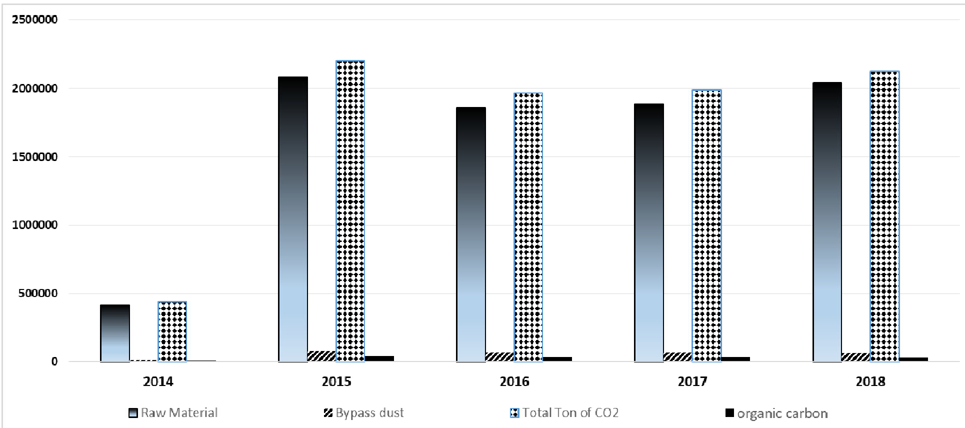

Figure 64 : Emission of CO2 (tonnes) from clinker production

CO_2emisiion from Bypass Dust

Cement bypass dust (CBPD) or cement kiln dust is a by-product of the manufacture of Portland cement. It is generated during the calcining process in the kiln. As we know, Lime (CaO) is a primary source of clinker in cement factories and around 60% of the composition of this material is CBPD (Saad et al. 2015). The result of this assessment shows, around 2,125,457.9 tonnes of CO_2 were emitted in 2015 as indicated in figure 64.

CO_2 emission from organic Carbon in raw materials

In addition to inorganic carbonates, the raw materials used for clinker production usually contain a small fraction of organic carbon which is mostly converted to CO_2 during pyro-processing of the raw meal. The total organic carbon (TOC) contents of raw materials can vary substantially between locations, and between the types of materials used. The result shows i(figure 64), there was a high CO_2 emission from organic carbon in 2015 (41,667.4 tonnes) and 2018 (40,760.9tonnes) production year.

Figure 65: GHG from calcination and cement making

GHG Emission from Energy Source

Due to the very high temperatures reached in cement kilns, a large variety of fuel sources can be used to provide energy. Local and South African Coal, heavy fuel oil (HFO), Automotive gas oil-diesel are the common energy sources of cement factories in Ethiopia. Figure 66 shows CO_2 emission trends from the four cement factories around Addis Ababa in the past five years.

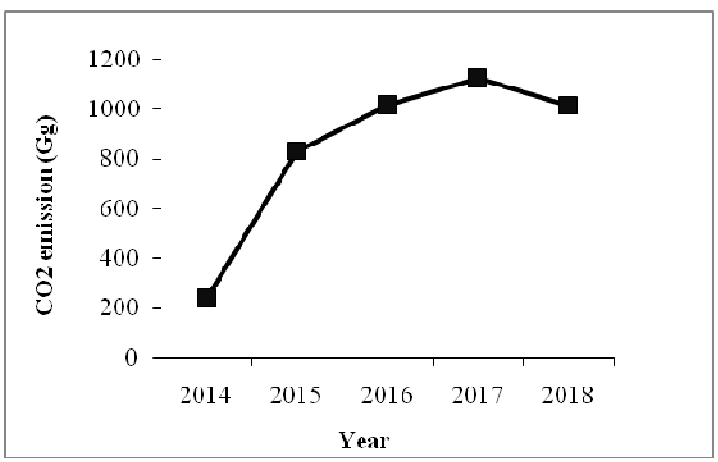

Figure 66: CO_2 emission from energy sources in cement industries

Methane and nitrous oxides are other greenhouse gasses that emitted in cement making processes. Those gasses are relatively small in size as compared to carbon dioxide. Additives have an important role in energy use minimization and emission reductions from calcination because they are light in weight and easy to crush. While some estimate that energy efficiency improvements could achieve emission reductions of up to 40 percent. The trend of Methane emission in the past 5 years showed a decreasing trend, this is because the assessed factories substituted high energy consuming materials (clinker) with low energy consuming materials (e.g. pumice, gypsum).

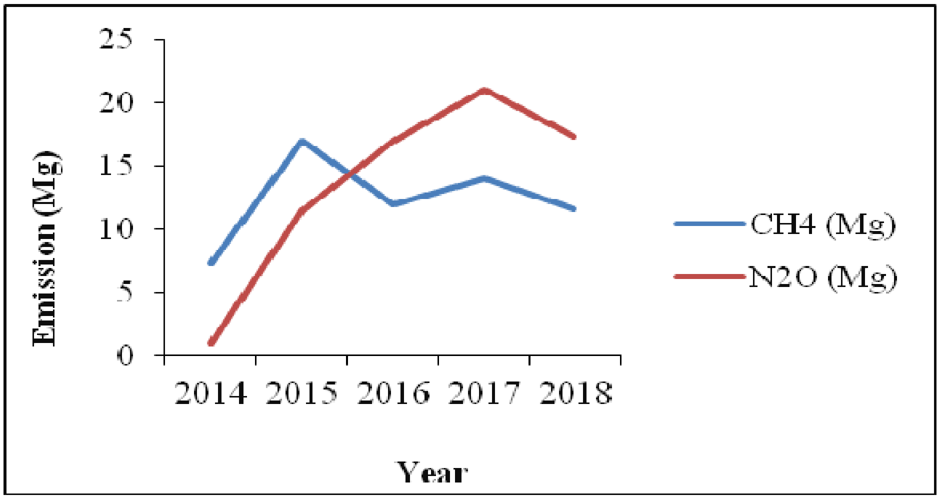

Figure 67: CH_4 and N_2O Emission from energy sources

Substituted Material Utilization of the selected Cement Factories

Additives have an important role in energy use minimization and emission reduction and the Ethiopian cement industries widely use different kinds of additives for the manufacturing of cement. The most common additives that are currently in use are pumice and gypsum. According to the CRGE strategy document, 70% of the industry abatement potential is concentrated in the cement industry. The main lever, clinker substitution, would increase the share of additives in cement; particularly pumice (5 Mt CO_2e of abatement). The upgrade to more energy-efficient technologies and waste heat recovery can reduce up to 6 Mt CO_2e in 2030, while the usage of biomass (mainly agri-residues) will help to reduce GHG emissions by 4 Mt CO_2e (CRGE, 2011).

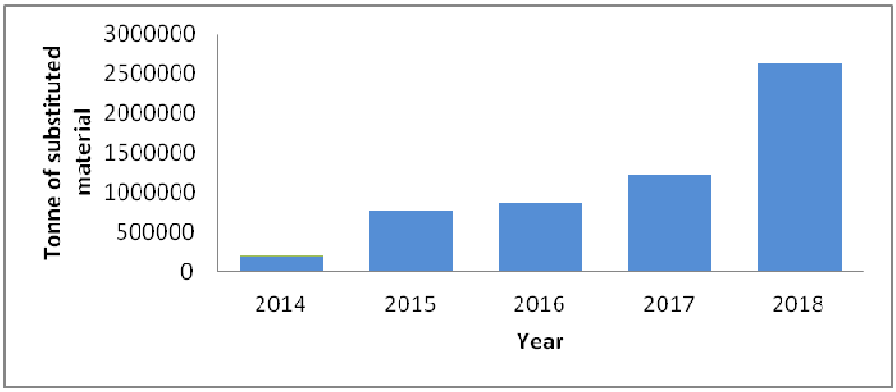

Figure 68: Substituted material used in selected cement factories

Possible reduction of GHG emission from substituted materials

It has been recognized that cement industries release different greenhouse gases to the atmosphere including Dioxin, NO_2, and SO_2. It is a fact that 0.9 ton of CO_2 is emitted per ton of cement (EU, 2010). However, there are strategies for the reduction of carbon dioxide emissions in cement production, even though there is inherent emission of carbon dioxide during chemical breakdown of the limestone in cement kilns during the production of Portland cement clinker. One of the strategies for decreasing CO_2 emission is blending limestone with Portland cement which offers key advantages in reduction of CO_2 emissions, climate change, economic and technical benefits (Bulut, 2010). Blended cement could reduce CO_2 emissions by as much as 20 percent (Tatiana et al. 2014), but its widespread use is limited by other environmental regulations because the substitutes may contain toxic heavy metals; the limited availability of substitute material; and some building code restrictions (blended cement can take longer to set). In this regard, the assessed cement factories are trying to substitute 5,657,310 tons of clinker with pumice, gypsum, and other materials and this helped to reduce 825,062 tons of CO_2 in the past 5 production years (Figure 69).

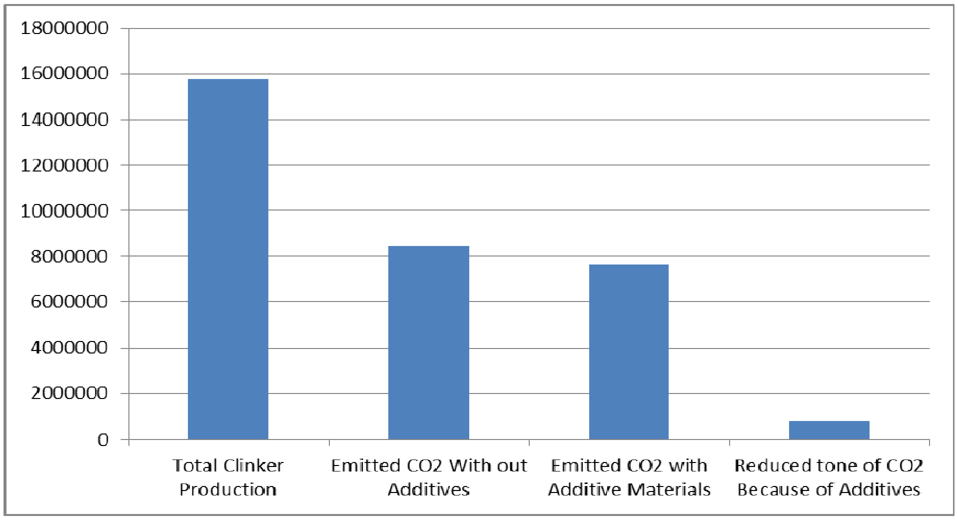

Figure 69 : Potential reduction of CO_2 from substituted materials

Conclusion and recommendation

Ethiopian Climate Resilient Green Economy (CRGE) strategy identified that cement industries are the most GHG emitters of industry sectors. Clinker production process and energy use were the major CO_2 emission sources of the assessed cement factories in Ethiopia. The highest CO_2 emission was recorded in the 2015 production year, around 2 Mt of CO_2. Around 1,760,000 Gg of GHG was emitted in 2018 from energy sources. In total, around 7.6 Mt of CO_2 were emitted in the past five years from those selected cement factories. The emission level from both sources showed a decreasing result, due to measures taken to reduce emission by cement factories. The use of alternative fuels, more efficient kiln process, and substituting clinker by low carbon content materials like pumice, gypsum, etc. were the most important measures taken to reduce emission in the assessed cement factories. The assessed cement factories tried to substitute 5,657,310 tons of clinker with pumice, gypsum, and other materials and this saved 825,062 tons of CO_2 in the past 5 production years.

Cement production is one of the fastest-growing industries resulting in GHG emissions contributing to climate change. Therefore, to reduce emissions from the cement factories there is a need to improve energy efficiency, shift to more energy-efficient processes (wet process to dry process), substitute high carbon fuel by lower-carbon fuel e.g. shifting from coal to natural gas, shift to lower clinker/cement ratio (substitute clinker by other materials), capture and storage of CO_2 from the flue gases, and develop short and long term mitigation plan.

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Contribution of dry forests for climate change adaptation in Tigray Region, Ethiopia

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Abstract

In Ethiopia, there has been little information about the contribution of dry forests to manage the impacts of climate change. This study explores the socio-economic contribution of dry forests and forest products to climate change adaptation. The study was conducted in selected areas in the Tigray region, Ethiopia. A multistage sampling technique was employed to select study villages and the sample respondents. A total of 170 households from the three randomly selected districts (vegetation types) as well as 15 key informants and one focus group (6 members) were purposely selected for an in-depth case study and discussion. An integrated qualitative and quantitative data analysis method was employed to summarize the findings. Results show that more than 94% of the surveyed households visited at least once a month to access the forest and forest products. Dry forests contributed about 16.8% of the total household income. Dry forest income reduced the gap between the line of equality and the Lorenz curve, and the Gini-Coefficient by 21% in dry-evergreen Afromontane forests, by 3.02% in Combretum-Terminalia woodland, and by 3% in Acacia-Commiphora woodland vegetation types. Gender, occupation, wealth status, and distance of the forest from villages significantly affected the income level of the Combretum-Terminalia forest users group. The age of respondents in Acacia-Commiphora woodlands users and family size in dry-evergreen Afromontane forest users influenced dry forest income level. The overall findings showed that relying on dry forest income has become a crucial livelihood strategy in response to the changing climate in the study areas.

Keywords: Adaptation, Climate Change, Dry forest income, Livelihood resilience, Vulnerability

Introduction

Currently, climate change is one of the serious environmental, social, and economical threats facing the world. Adaptation and mitigation are the two broad strategies for tackling this problem. Sustainable forest management has been promoted as a key strategy to reduce the negative impact of climate change (CIFOR, 2005). Forests contribute to the sustained provision of ecosystem goods and services which can help people to adapt to local vagaries due to changing climate, while carbon storage on the above and belowground can contribute as climate change mitigation (Robledo et al., 2012).

Dry forests are Africa's largest vegetation formation and are an integral part of the ecology and socio-economy of smallholder farmers and pastoral communities (FAO, 2010). Ethiopia owns one of the largest dry forests in the continent, rich in biodiversity of high-value tree species that bear commercial gums and resins. Recent professional discourses show that strategic integration of dry forests in Ethiopia and sub-Saharan Africa at large would profoundly contribute to poverty alleviation, climate change adaptation and mitigation, biodiversity conservation and combating desertification (Mulugeta and Habtemariam, 2011; Adefires et al., 2014). Despite its diverse social and ecological contributions, various factors undermine mainstreaming dry forests in the overall dry zone development plan in Ethiopia and many other African countries. Among others, few empirical evidences are demonstrating the actual and potential contribution of these versatile resources to climate change adaptation and mitigation. Therefore, this study was initiated to assess the socio-economic contribution of dry forests to climate change adaptation.

Methodology

The study was conducted in the semi-arid dry land of western, eastern, and northern zones of Tigray Regional State (Figure 70). The study areas were geographically bounded between 12°15' and 14°57' N latitude and 36°27' and 39°59'longitude of northern Ethiopia. The mean annual rainfall varies from 500 to 900 mm and temperature ranges from 15^{o}C to 25^{o}C. The topography of the region ranges from a massif highland of 3,900 m a.s.l to the north-western lowlands where the elevation is as low as 500 m a.s.l.

A multistage sampling technique was employed to select study villages and the sample respondents. Three study villages were selected from Kafta Humera, Atsibi Womberta and Raya Azebo districts which were characterized by Combretum-Terminalia vegetation formation, by dry evergreen Afromontane forest and Acacia-Commiphora woodlands, respectively.

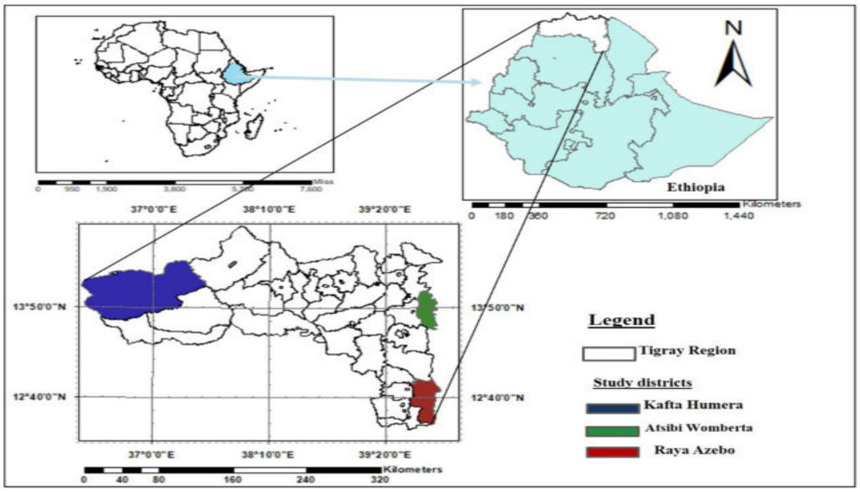

Figure 70: Location of the study area in the different agroecology of Tigray Region

A total of 170 households (51 from Kafta Humera, 58 from Atsibi Womberta, and 61 from Raya Azebo), were randomly selected for the household surveys. Also, from each district, 15 key informants and one focus group (6 members) were purposely selected for an in-depth case study and discussion. The key informants include a representative of local administration, religious leaders, youth representatives, and doing so facilitated a better understanding of existing livelihood systems, variations among households in terms of wealth, and identification of locally relevant wealth indicators (Worku et al., 2014).

Primary data were collected through semi-structured questionnaires, key informant interviews, and focus group discussions. The survey questionnaire had different variables including household characteristics, livelihood strategies, household asset, and income composition, expenditure, dry forest products collected, push and pull factors conditioning dry forest income dependence, perception on climate change, major threats, drought years, climate change coping and adaptation strategies (Worku et al., 2014; Tadesse et al., 2017). Wealth status was categorized into, poor, medium, and rich based on information obtained from the key informants and focus group discussions. Data on the price of forest products and crops was recorded in local currency during a household survey in 2019.

Data was compiled and analyzed using Statistical Package for Social Sciences (SPSS) version 20. Descriptive statistics in the form of frequencies, the output of forest dependency was regressed against selected explanatory variables such as age, family size, landholding size, educational level, occupation, sex, marital status, and distance from the forest and wealth status. The dry forest income was measured as a binary indicator of forest income were 0 if no forest income, and 1 if otherwise. The binary logistic regression model was used (Hosmer et al., 2013) to determine the socioeconomic factors influencing households' forest dependency. The variables were chosen mainly because they cut across the social and economic domains; hence, they will provide a comprehensive insight into the pattern of household forest dependency. Total household income was calculated as the sum of household subsistence income and household cash income from all income sources, including income from dry forests. Cash income includes income from the sale of forest products, while subsistence income was calculated as the value of products being directly consumed by the household or given away to friends and relatives as gifts, multiplied by their local price per unit volume. Costs such as purchased feed for animal and farm inputs were subtracted from the total. Various descriptive and statistical tests, including ANOVA and t-tests, were employed to examine variation in dry forest income levels of households with different socio-economic characteristics. Both Lorentz curve and Gini coefficient were computed to assess the income equalizing effect of dry forests income (Deaton, 1997). Below is the description of the model used to determine the socioeconomic factors influencing forest dependency:

$$\text{Logit (Y)} = \ln\left(\frac{\Pi}{1-\Pi}\right) = \alpha + \beta X_1 + \beta X_2$$

Therefore,

$$\Pi = \text{probability } (Y = \text{outcome} / X_1 = x1, X_2 = x_2)$$

$$\frac{e^{\alpha+\beta 1X1+\beta 2X2}}{1 + e^{\alpha+\beta 1X1+\beta 2X2}}$$

Where π denotes the probability of an outcome, α is the Y-intercept, β's are the regression coefficients, X's are the set of explanatory variables, and e = 2.71828 (natural logarithms base). In this study, the variables age, family size, landholding size, educational level, occupation, sex, marital status, and wealth were used to explain households' forest dependency (Table 50).

Table 50: Explanatory variables included in the logistic regression model

Variable	Description	Measurement
Age	Age of the respondent	Years
Gender (dummy)	Sex of the respondents	1 if male, 0 if otherwise
Family size	Family size of the respondents	Numbers
Wealth	Wealth status of the respondents	0 Poor; 1 Medium 2 Rich
Landholding size	Landholding size of the respondent	Ha
Educational level	Educational status of the respondents	0 if no formal education, 1 primary 2 otherwise
Marital status	Marital status of the respondent	1 if marred 0 if not
Distance from the forest	Distance from the forest on foot	In minute
Dry forest income		In birr

Results

Contribution of dry forests to the household's climate change adaptation

Overall, four major sources of income: crop, livestock, forest, and off-farm-activities (casual work and petty trade) were identified. There was a significant association between the districts (X^2 (10) = 21.27 $p< 0.05$) among income source type. The higher source of household's total income in Kafta Humera (425,932.94 ETB) and Raya Azebo (43,435.42 ETB) was from crop production followed by the livestock. Whereas in AtsibiWomberta (298,434.51 ETB) it was from off-farm activates and dry forests combined. Likely there is a significant difference in terms of dry forest income for the households ($p < 0.05$) between districts. About 94% of the total household visited at least once a month to access the forest and forest products. About 43.5% and 35.5% of the households collected forest and forest products once a month and a week, respectively. The contribution of dry forest for the household income was about 24.4% in Atsibi Womberta, 22.15% in Kafta Humera, and 4.93% in Raya Azebo. In the study districts, dry forest income is used as means of risk reduction such as income gap, diversification of income sources, and saving before the onset of drought. Similarly, several respondents mentioned that dry forests also help the livestock asset as they provide different types of fodders and by way of protecting the remaining livestock from being sold to generate cash. In general, the dependency of households on dry forest income has been increasing.

Table 51: Measures of forest income among households of the three districts (n=170)

Variable	Description	Kafta Humera	Atsibi Womberta	Raya Azebo	Overall
Cash forest income	Total annual household income from sales of forest products (In ETB)	97.94	20.68	105.10	74.15
Subsistence forest income	The total imputed annual value of forest products used by household (in ETB)	1067.54	3953.84	1201.80	2100.45
Total forest income	Combination of cash and subsistence income (in ETB)	1165.49	3974.53	1306.90	2174.61
Share of forest income	Total forest income divided by total income (share)	22.15	24.40	4.93	16.75%
Dry forest income	Binary indicator of forest income: 0 if forest income = 0 1 If forest income> 0	0.67	0.93	0.98	0.81

More than 51% and 34.7% of the households collect forest and forest products from the state forests and community forests, respectively. The major forest products from the dry forests were timber and firewood (Figure 71). *Combretum-Terminalia* woodland contributes about 51% of the major wall construction material and 10.2% of the roof construction materials in the Kafta Humera district. Dry evergreen Afromontane forests also contributed 3.4% of the roof construction materials of the households in the Atsibi Womberta district, while *Acacia-Commiphora* woodland contributed about 73% of the wall construction material and 2% of the major roof material in Raya Azebo districts.

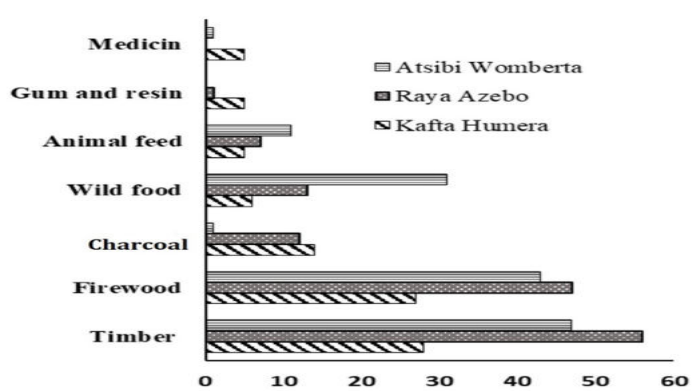

Figure 71: Proportion of households collecting forest products from dry forests

A total of 48 major species of dry forests was used for timber, firewood, charcoal, wild edible fruits, animal feed, and gum and incense. Dry forests contributed to minimization of variation in total households' income. The contribution of dry forest income reduced the gap between the line of equality and the Lorenz curve (Figure 72), and the Gini- Coefficient by 21 % in Atsibi Womberta, 3.02% in Kafta Humera, and 3% Raya Azebo, showing income equalizing of dry forests.

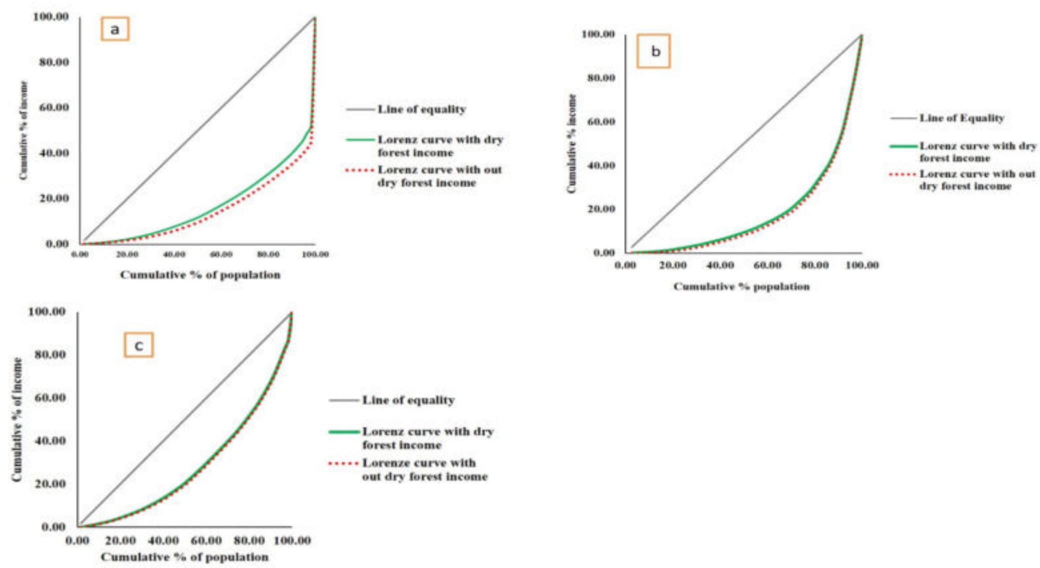

Figure 72: Schematic presentation of the Lorenz curve showing income equalizing effect of dry forests in Atsibi Womberta (a) Kafta Humera (b) and Raya Azebo districts

Generally, this study showed that income from the dry forests for the selected households contributed to 53% of the medium wealth group followed by 41% of the poor wealth group However, the Afromontane dry forest contributed to 62% of the poor wealth group inAtsibi Womberta district.

Socio-economic factors influencing household dry forest income

Spearman bivariant correlation analysis showed that the level of dry evergreen afromontane forest income is positively and significantly correlated with income from livestock ($p < 0.01$) and crop productions ($p < 0.05$) in Atsibi Womberta district but not significantly associated with off-farm activities (casual and pity trade), remittance, direct aid and food for work program. The income from *Acacia-Commiphora* woodlands has a positive and significant correlation with income from livestock production ($p < 0.05$) but a negative and significant correlation with income from direct aid and food for work program ($p < 0.05$) in the Raya Azebo district. Moreover, the income from *Combretum-Terminalia* woodland was not significantly associated with the other sources of income. However, this has a positive relation with livestock, remittance and off-farm activate, and a negative correlation with crop production and food for work program.

Gender, occupation, wealth status, and distance of the forest from their house are variables that significantly affected the income levels from *Combretum-Terminalia* woodlands in Kafta Humera districts. The age of the respondents in Raya Azebo, and the family size of the household in Atsibi Womberta district were influenced by dry forest income level (Table 52).

Table 52: Correlations between different variables with dry forest income level

Explanatory variables	Kafta Humera, $R^2 = 0.59$			Raya Azebo, $R^2 = 0.19$			A/ Wonberta, $R^2 = 0.30$		
	Coef.	t-value	p-value	Coef.	t-value	p-value	Coef.	t-value	p-value
(Constant)	N/A	2.859	0.008	N/A	0.973	0.336		-0.813	0.422
Sex	-0.518	2.859	0.008**	N/A	N/A	N/A	N/A	N/A	N/A
Occupation	0.053	-3.552	0.001**	N/A	N/A	N/A	0.285	1.810	0.079
Age	-0.063	.349	0.730	0.323	2.349	0.023*	-.141	-0.723	0.475
Educational level	-0.045	-.402	0.690	N/A	N/A	N/A	N/A	N/A	N/A
Marital status	-0.135	-.257	0.799	N/A	N/A	N/A	N/A	N/A	N/A
Land holding size	0.322	-1.023	0.315	N/A	N/A	0.099	0.467	0.647	0.643
Wealth status	-0.294	2.529	0.017*	-0.180	-1.235	0.223	-0.153	-0.953	0.347
Distance from the forest	-0.165	-2.056	0.049*	-0.136	-0.987	0.239	0.225	1.520	0.138
Family size	-0.096	-1.162	0.255	-0.194	-1.324	0.192	0.364	2.453	0.019*

Conclusions

This study revealed that dry forest plays a critical role on improving the adaptive capacity of the drought-prone households and reduced the income inequality in between households. There is also the relation between the income from the semi-arid dry forests, poverty reduction, and coping with the negative effect of droughts. Besides the provision of ecosystem services to the local community, dry forests contributed in to providing feed for livestock during the drought season. The contribution of dry forests for the household income is 24.4% in Afromontane evergreen dry forest, 22.15% in *Combretum-Terminalia* woodland, and 4.93% in *Acacia-Commiphora* woodland. Therefore, since the dry forests have a crucial role in climate change adaptation strategies, policymakers, program managers, extension workers, and the local community as well as other stakeholders should give attention to the sustainable management of the dry forests and forest products for better resilience of communities and ecosystems.

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Kitchen Performance Test for *Mirt* and Improved *Gonzie* Cook stoves in Ethiopia

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Abstract

In Ethiopia, over 90% of the total energy supply is obtained from biomass. Firewood is used in inefficient traditional stoves. To improve the efficiency of the traditional stoves, improved stoves were developed and disseminated by government and non-governmental organizations. However, the performance of the stoves at household level cooking conditions was not tested. Accordingly, the present study was aimed at testing *Mirt* and improved *Gonzie* cook stoves kitchen performance by interviewing households and measuring the amount of wood consumed in four woredas (districts) in Ethiopia; Asgede Tsimbla, Bure, Ameya, and Dallocha woredas. In all the study woredas, it was recognized that women using *Mirt*, and improved *Gonzie* stoves had improved their safety from a fire burn. However, there was size unfitness of stoves with pots and lack of chimney. The improved injera baking stoves reduced wood consumption by 34% in Asgede Tsimbla, 37.4% in Bure, 42% in Ameya, and 20.2% in Dallocha woreda as compared to the traditional stoves. The use of improved stoves in using firewood for baking injera emitted 291.03 to 380.58 kg CO_2 per capita and the use of traditional stoves emitted a greater amount. Therefore, wider dissemination of improved stoves should be taken as a solution to reduce wood wastage.

Keywords: Cookstove, Energy, Emission, Firewood

Introduction

In Ethiopia, over 90% of the total energy supply is obtained from biomass sources like firewood, crop residue, and dung. Rural households in Ethiopia consumed over 86% of the biomass fuel (Guta, 2012). The efficiency of three-stone open fire stoves are very low and resulted in the wastage of energy. Then improved stoves were developed in the 1980s to improve the efficiency of the traditional open three-stone stoves (Peters-Stanley and Yin, 2013). Enhancing a cookstoves fuel efficiency reduces the amount of fuel required and can lessen the amount of time spent for gathering biomass fuel, and reduces forest loss (Kedir et al., 2019).

The total national consumption of wood fuel (round wood, branch, leaves, and twigs (BLT) and charcoal as wood) in Ethiopia was 105 million tonnes yr^{-1} (Geissler et al., 2013). From the total wood consumption, 193 million tCO_2e had been emitted annually based on IPCC conversion of wood weight to CO_2^{e}(Penman et al., 2003). The emission has created indoor pollution (L'evesque et al., 2001; GACCS, 2014). Household fuelwood consumption in Ethiopia has doubled from 41million m^3 in 1990 to 82 million m^3 in 2017. Then to reduce fuelwood demand, it is important to disseminate and use fuel-efficient stoves and/or alternative-fuel cooking and baking techniques. Therefore, various types of improved cookstove products that exist in the Ethiopian rural energy workshops and market like Awuramba, improved *Gonzie,* Tikikil, Lacketch, Mirt, Mirchaye etc. are potential wood saving stoves that are prevailing in Ethiopia.

The national improved cookstoves program (NICSP) of Ethiopia was designed to support the implementation of 34 million improved cookstove distribution targets set by the Ethiopian government up to the year 2030. In the growth and transformation plan, GTPI (2010 to 2015) and GTP II (2015 to 2020) about 20.45million improved stoves were planned to be distributed. The program was launched in 2013 to disseminate the 9 million improved cookstoves (ICS) for 4.5 million households (CRGE, 2011). Barr foundation assisted the distribution of improved stoves to 50 woredas in four regions, Tigray, Amhara, Oromia, and Southern Nations and Nationalities People (SNNP).

Communities, NGOs, and entrepreneurs entered into the market of cookstove in the manufacturing, promotion, and distribution of cookstoves. Therefore, cookstove testing is crucial for the cooking sector to identify what the existing problems are. Laboratory tests are usually done to check the performance and fuel consumption of improved cookstoves before distribution. Kitchen Performance Test (KPT) is designed to assess actual impacts on household fuel consumption and is typically conducted in the course of an actual dissemination effort with real populations cooking or baking and gives the best indication of kitchen performance. Then, the objective of the present study was to conduct a kitchen performance test for stoves under use at the household level.

Material and methods

Description of the study area

The KPT case study was conducted in four woredas of Ethiopia; Asgede-Tsimbla woreda (Tigray Region), Bure woreda (Amhara Region), Ameya woreda (Oromia Region), and Dallocha Woreda (SNNPRS). The geophysical condition is shown in table 53 with annual temperature ranging from 12 to 35°C, and annual precipitation 550 to 1750 mm. There are considerable numbers of human and livestock populations in the study areas.

Table 53: Geophysical condition of the study woredas in four regions

Woreda	Region	Annual Precipitation (mm)	Mean Annual Temperature (°C)	Geographic coordinate		
				Latitude	Longitude	Altitude(m)
Asgede Tsimbla	Tigray	550-900	20-35	14°00'00"	38°00'43"	900-1800
Bure	Amhara	1750	17-27	10°42'15"	37°03'33"	700–2750
Ameya	Oromia	1310	12-32	8°35'25"	37°44'59"	1946-2026
Dallocha	SNNP	1025	19-29	7°47'6.33"	38°14'302"	1921-1982

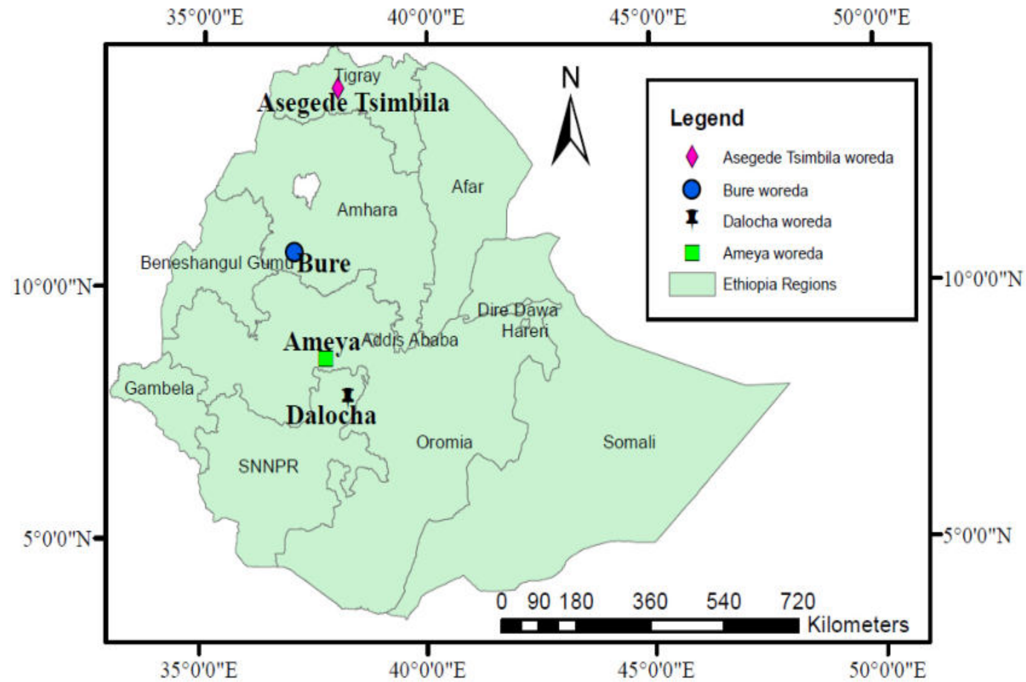

Figure 73: Map of the study areas within Ethiopia

Description of improved cookstoves

The improved stoves, namely *Mirt* and improved *Gonzie*, had specified materials and dimensions (GIZ ECO, 2011). *Mirt* stove is produced with mortar using a mixture of scoria (red ash) or pumice or river sand with cement and serve for more than five years. *Mirt* stove has six parts that are joined together, four parts fit to make a cylindrically shaped enclosure and two other parts joined one on top of the other, and are fitted with the cylindrical enclosure from behind. The two parts serve as a smoke outlet and rest for the cooking pot (GIZ ECO, 2014)

Improved *Gonzie* is made from ceramic clay. It has four parts which when assembled form its basic circular enclosure. Improved *Gonzie* stove has 60 cm diameter; 18 cm height, fuel, and air inlet center 12 cm height, 18 cm width, and 3.5 to 4 cm wall thickness (Dresen, 2014, GIZ ECO, 2014).

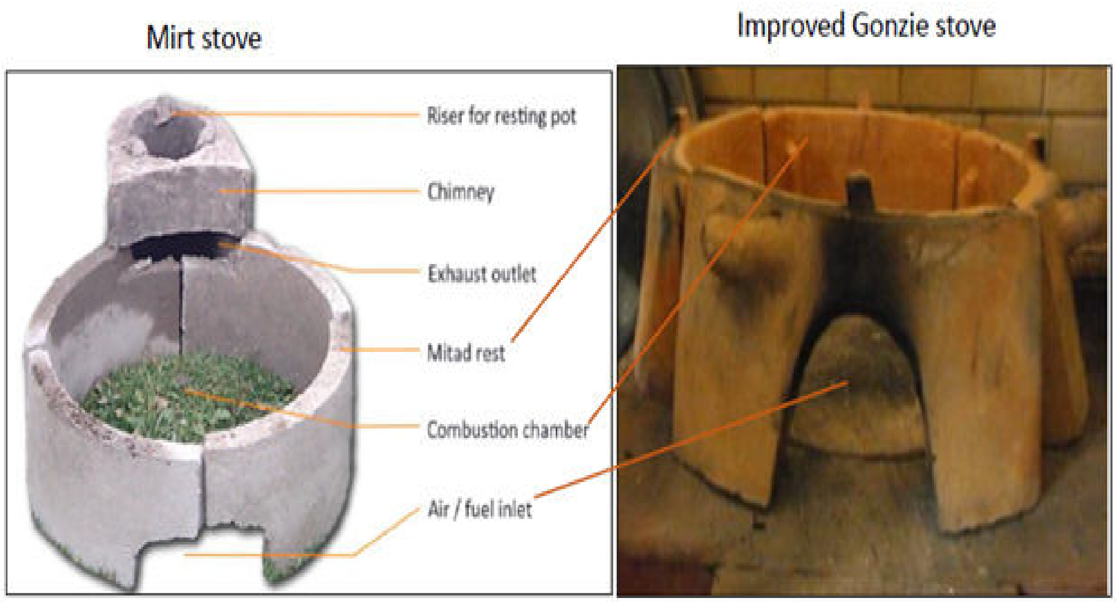

Figure 74: The different parts of Mirt and improved Gonzie stoves

Methods of data collection

In the case of Asgede Tsimbla woreda, households (HH) were selected by cross-sectional and longitudinal methods. The former is that monitors kitchen performance of the two cookstove types on different families. The latter is that monitors kitchen performance of the cookstoves on the same family. Both types of methods are compared using the adult equivalent factor conversion of the household family in number and gender. In those households that hadn't improved and traditional baking stove altogether, the cross-sectional method was applied. Then, a total of 86 households have participated of which 43 HHs each from the improved baking stove "*Mirt*" and traditional baking stove (TBS) users. In the case of Ameya and Bure woredas, one hundred households each, who were using improved *Mirt* baking stoves, were purposely selected for longitudinal assessments of KPT. In Dallocha woreda, the KPT was done with 100 households with improved *Gonzie* stoves and its control of another 100 households with traditional open three-stone fire, as a cross sectional method. Of the 200 households, 190 were from the urban part of Dallocha woreda and ten from the rural part. Although the longitudinal method of KPT for cookstoves was preferable, the mere use of baking in the improved *Gonzie* and the fixed use of plate on the improved *Gonzie* stove, different households were tested for kitchen performance.

In the first step, the selected households were interviewed to give the general overview of the perception on the use of improved cookstove, the management and evaluation of the stoves, the woody species most dominantly used for firewood for cooking and baking, and the general source of heat and light energy in the households using a questionnaire. In the next step, the kitchen was observed by the field assessment crew and firewood was supplied to the selected households sufficient to prepare three rounds of injera baking in improved *Mirt* or *Gonzie* stoves and three rounds in traditional open three-stone stoves, with normal enjera baking interval. Household in rural towns use crop residues and other types of biomass for baking and cooking. However, the present study monitored only the consumption of wood at the moisture content registered during baking injera using mirt stoves, improved *Gonzie* and traditional stoves. Then the weight of wood used during each baking session was measured using hanging balance. For moisture content, three pieces of wood sample were taken randomly and measured using a moisture meter at the top, middle and bottom parts. The adult equivalent for meals in a household was also calculated for each baking day. Constant values were used for gender and age to adult equivalent: a child with age 0 to 14 years as 0.5; female over 14 years 0.8; male with 15 to 59 years as 1 and male over 59 years age as 0.8. The calorific value of the common woody species was considered as 18MJ/kg **(**Shell Foundation, 1984).

Data analysis

Excel-based software developed by Shell foundation (1984) was used to calculate the sessional fuel and energy consumption by a household. Wood consumption per year was calculated using the amount of dry wood used per session, the moisture content of the wood, the 52 weeks per year, and the twice cooking per week as Equation 1. The amount of energy of the wood was calculated by using the mean 18MJ/kg of calorific value as Equation 2 and the amount of wood saved due to improved stove for baking the same amount of injera was calculated by deduction as Equation 3.

Wood consumption per year = (Weight of wood per session)*(moisture content of wood)*(52 weeks)*(2days per week)….Equation 1

Energy consumption= 18MJ/kg*Wood consumption per year……….. Equation 2

$$\frac{\text{Wood saved} = (AWCOst) - (AWIst)}{AWCOst} * 100\%$$ ………Equation 3

Where:

AWCOst =Amount of wood consumed in open three-stone stove

AWIst =Amount of wood consumed in the improved stove

CO_2 emission of stoves in burning wood calculated by considering carbon as half of the total firewood dried biomass (Penman et al., 2003) consumed and then multiplying by 3.67 as Equation 4.

Amount of CO_2 emitted= Amount of biomass*0.5*3.67 -----------Equation 4

1. An independent sample t-test was used to compare the consumption rate of wood and energy when households were using improved cookstove and traditional ones. Analysis of variance was used to know whether there is a significant difference in the consumption of wood and energy by using the two different cookstoves by a household. The social data were encoded in SPSS version 20 software and descriptive results were produced for interpretation and description.

Results and discussion

Household characteristics

The household survey showed that the families selected for the KPT were different in family size that range 4.8 in Amhara to 6.1 in Asgede Tsimbla (Table 54). As can be seen in Table 3, Asgede Tsimbla woreda was the highest in mean family size (5.7) then followed by Dallocha (5.65).

Table 54: The number of household members in different woredas using different stoves

Stove types by woreda	Number by age category (Mean ± Std.er.)					Adult equivalent
	Children 0 - 14	Women 14+	Men 15-59	Men 59+	Total	
Asgede Tsimbla improved *Mirt* stove (n=43)	2.4±0.2	1.6±0.2	1.3±0.2	0.2±0.1	5.6±0.3	3.9
Asgede Tsimbla traditional baking stove (TBS) (n=43)	2.3±0.2	1.9±0.2	1.6±0.2	0.3±0.1	6.1±0.3	4.5
Bure improved and traditional stove (n=100)	1.5±0.1	1.7±0.1	1.4±0.1	0.2±0.1	4.7±0.2	3.7
Ameya improved and traditional stove (n=100)	1.9±0.1	1.5±0.1	1.3±0.1	0.1±0.1	4.8±0.2	3.5
Dallocha-improved stove (n=100)	2.4±0.1	1.7±0.1	1.5±0.1	0.1±0.0	5.65±0.2	4.1
Dallocha-traditional stove (n=100)	2.45±0.15	1.57±0.09	1.56±0.07	0.07±0.03	5.65±0.2	4.1

Evaluation and management of improved injera baking cookstoves

In all studied woredas, the women reported that using improved *Mirt* and *Gonzie* stoves had shortened the time to prepare meals, improved the health condition of a household by reducing smoke, and protected their hands from fire burns, also save fuel. However, they also reported some problems associated with using improved *Mirt* and *Gonzie* stoves such as the size unfitness of pots/ plates with improved stoves, longer time taken to set and start-up fire (absence of air holes to allow air for fast combustion of the fuel), the stove did not heat the room in cold seasons, blocked light for visibility in rooms and lack of a smoke outlet. The evaluation of improved stoves also revealed different responses from respondents; 35%, 31%, 31%, and 97% of the interviewed households inAsged Tsimbela, Bure, Ameya, and Dallocha, respectively, responded that improved stoves have not reduced the amount of smoke to the required level, while 65.1%, 69%, 69% and 3% of the households, respectively, responded that the stoves could reduce smoke to the required level (Table 55). That is, some of the responses were dependent on the specific households' management of the improved stoves.

Table 55: Baking cookstove evaluation and management as responded 'yes' by the households

Opinions	Households in selected woreda (%)			
	A/ Tsimbla (n=43)	Bure (n=100)	Ameya (n=100)	Dallocha (n=100)
Taking longer time to set fire inside the stove	100	100	100	100
The stove causes burns to the cook	53.5	16	27	0
The pots and plates do not fit the stoves	28	23	1	97
Stove makes a lot of smoke and indoor pollution	34.9	31	31	97
Stove takes long to get hot	11.6	41	9	96
Stove does not heat the room in cold seasons	62.8	4	60	100
Stove does not provide light	46.5	3	48	100
Stove breaks easily	27.9	4	9	100
Highly satisfied in the use of the improved cookstove with respect to efficiency and design	100	75	49	100
Is there an improvement in your health condition by using improved stove	74.4	69	71	97
Possesstion of Mirt stoves	97.7	100	99	0
Possesstion of Improved Gonzie and traditional open stoves	2.3	0	1	100
There are ashes inside	46.5	54	43	57
There cracks in the stove	67.4	28	16	30
Rate of family use of the stove-everyday	7	5	10	20
Rate of family use of the stove- with 2-6 days/week	93	91	89	77
Stove installation-elevated	43	95	52	50
Stove installation-earth floor	0	5	48	50

Wood consumption in cookstoves during baking and cooking

The wood consumption in baking and cooking varies with households' family size and types of stoves used. The improved injera baking *Mirt* stoves had saved wood by 34% as compared with the traditional baking stove in Asgede Tsimbla woreda, and by 37.4% and 42% as compared with the three-stone open fire in Bure and Ameya, respectively. In Dallocha woreda, *Gonzie* stoves saved the wood consumption by 20.2% as compared with the three-stone open fire. That is, the improved stoves can reduce deforestation and forest degradation as stated in CRGE (2011) by 20.2 to 42% in comparison to the traditional stoves (Peters-Stanley and Yin, 2013). The reduction in deforestation due to firewood and its smoke has a role in climate change mitigation (USDOE, 2011). In the KPT conducted in Dallocha woreda, the amount of wood saved was less than the savings done by other woredas and other studies of improved stoves in Rana (2013), KPT which is about 65% and in Kedir et al. (2019) controlled cooking test up to 58%. This is due to the opening created by the poor mold design and the wide fuel inlet of the improved *Gonzie* stoves. Moreover, the household used only three of the stove parts by removing the fourth part for the wood inlet and smoke outlet.

The one-way analysis of variance showed a highly significant difference ($p < 0.001$) in sessions fuel and energy used by a household for baking injera in the two stove types (Table 56).

Table 56: Wood consumption of improved stoves compared to traditional open stoves for baking injera

Region-woreda	Wood and energy consumption by household per session in cookstoves	Mean±Std.er.	95% CI		Min.	Max.
			LB	UB		
Tigray Region-Asgede-Tsimbla woreda	Wood used (kg)-*Mirt* stove (n=43)	4.5±2.8	3.8	5.5	1.3	13.2
	Wood used (kg) -traditional baking stove(n=43)	6.8±2.3	6.2	7.5	3.5	12.5
	Energy used (MJ)-in *Mirt* stove (n=43)	85.0±7.8	69.2	100.9	24	240
	Energy used (MJ) – traditional baking stove (n=43)	124.9±6.0	112.8	136.9	66	228
	Wood used (kg) -traditional cooking stove (n=49)	2.8±0.1	2.6	3.1	1.2	5
	Energy used (MJ) – traditional cooking stove (n=49)	51.0±2.1	46.8	55.1	21	90
Amhara Region-Bure woreda	Wood used (kg)-in *Mirt* stove (n=100)	8.2±0.3	7.6	8.7	3.6	21.2
	Wood used (kg) -open stove (n=100)	13.1±0.5	12.1	14.1	6.8	31.4
	Energy used (MJ)-*Mirt* stove (n=100)	150.3±4.9	140.6	159.9	66.0	390.0
	Energy used (MJ) -open stove (n=100)	243.9±9.3	225.6	262.2	126.0	582.0
Oromia Region-Ameya woreda	Wood used (kg)-in *Mirt* stove (n=100)	6.1±0.2	5.6	6.5	2.2	14.0
	Wood used (kg) -open stove (n=100)	10.5±0.4	9.7	11.3	4.7	30.7
	Energy used (MJ)-*Mirt* stove (n=100)	113.6±3.9	105.8	121.3	42.0	258.0
	Energy used (MJ) -open stove (n=100)	197.2±7.6	182.1	212.3	90.0	564.0
Southern Region-Dallocha woreda	Wood used (kg)-in *Gonzie* stove (n=100)	7.8±0.1	7.5	8.1	3.3	10.1
	Wood used (kg) - open stove (n=100)	9.8±0.2	9.4	10.2	5.2	18.1
	Energy used (MJ)-in *Gonzie* stove (n=100)	144.3±2.8	138.8	149.8	60.0	192.0
	Energy used (MJ) - open stove (n=100)	180.9±3.8	173.3	188.4	96.0	330.0

Figure 75: Traditional open stoves and improved Gonzie stoves

Table 57: ANOVA for improved cookstoves wood consumption

Region-woreda	Average values used per household	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Tigray-Asgede-Tsimbla	Sessional wood use (kg)	Between Groups	79.9	1	79.9	13.6	0.000
		Within Groups	1094.9	186	5.9		
	Sessional energy use (MJ)	Between Groups	26472.3	1	26472.3	13.5	0.000
		Within Groups	363840.8	186	1956.1		
Amhara-Bure	Sessional wood use(kg)	Between Groups	1239.6	1	1239.6	77.0	0.000
		Within Groups	3187.9	198	16.1		
	Sessional energy use (MJ)	Between Groups	438553.6	1	438553.6	80.4	0.000
		Within Groups	1079531.7	198	5452.2		
Oromia-Ameya	Sessional wood use(kg)	Between Groups	995.0	1	995.0	93.5	0.000
		Within Groups	2107.0	198	10.6		
	Sessional energy use (MJ)	Between Groups	349782.5	1	349782.5	95.8	0.000
		Within Groups	723334.1	198	3653.2		
SNNP-Dallocha	Sessional wood use (kg)	Between Groups	195.6	1	195.6	59.9	0.000
		Within Groups	647.0	198	3.3		
	Sessional energy use (MJ)	Between Groups	66978.0	1	66978.0	60.0	0.000
		Within Groups	220867.0	198	1115.5		

Per capita wood consumption during baking injera

The per capita firewood consumption of different household naturally varies with the type of food item cooked or baked. On average, the highest wood consumption was observed in Bure woreda using traditional open three-stone stoves and *Mirt* stoves than the other woredas'.

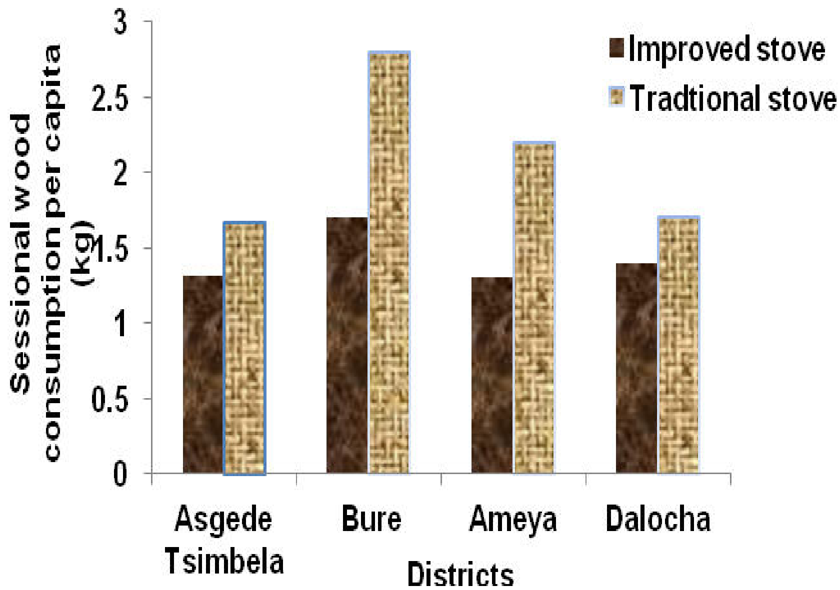

Figure 76: Per capita wood consumption in improved stoves and traditional stoves

Major woody plant species used as firewood

Different types of woody plant species were used as firewood. The most frequently used species for firewood were *Eucalyptus* species in Bure, Ameya, and Dallocha. *Ziziphus spina-christi* and *Acacia spp.* are mostly used in the Aseged Tsimbla woreda of the Tigray region followed by *Ficus spp*. (Table 58).

Table 58: Frequently used species for firewood by respondents in the studied woredas

Species name	Frequencies of households using a species per woreda				
	Local name	Aseged Tsimbla	Bure	Ameya	Dallocha
Acacia spp.	Laftoo (Orm)	32		13	29
Albizia spp.	Kiltu (Orm)	2	2	3	
Anogeissus leiocarpa	Qinchib (Tig.)	13			
Balanites aegyptiaca	Mekie (Tig.)	1			
Calpurnia aurea	Cheka (Orm) Hitsawuts (Tig.)	4		9	
Carisa edulis	Agamssa (Orm)			3	20
Combretum spp.	Akuma (Tig.)	2			
Cordia africana	Awhi (Tig.), Wedessa (Orm)	19	1	12	11
Croton macrostachyus	Tambuk (Tig.), Mekenisa (Orm)	8	8	14	
Dalbergia melanoxylon	Zibe (Tig.)	1			
Dichrostachys cinerea	Gonque (Tig.)	1			
Diospyros mespiliformis	Aye (Tig.)	2			
Dodonea angustifolia	Tahses (Tig.)	1			
Eucalyptus spp.	Bargamo (Orm)		81	76	28
Euclea schimperi	Kliaw (Tig.), Miessa (Orm)	1		28	6
Ficus spp.	Muka Arba (Orm),Sagla(Tig.)	23		3	1
Flueggia virosa	Harmazo (Tig.)	2			
Grevillea robusta	Girevilla (Orm)			2	
Juniperus procera			7		
Olea europea					2
Pettosporum viridifolium	Sole			1	
Rhus natalensis	Tetalo (Tig.)	1			
Schinus mole					1
Vernonia amygdalina			1		
Ziziphus spina-christi	Geba	33			

Carbon dioxide emission reduction potential of improved injera baking stoves

Improved cookstoves reduce the amount of wood consumption by reducing the amount of energy loss. The use of improved stoves in using firewood for baking injera emit 1007.42 to 1,835.73 kg CO_2 from *Mirt* and 1,746.19 from improved *Gonzie* per household as compared to the traditional stoves that emitted 1,522.32 to 2,932.7 kg CO_2 per household. This is in line with Geissler et al. (2013). Such improved baking stoves reduced emission from 21 to 41% of the carbon dioxide that is created by traditional open stoves but 33.8% in the case of Asgede Tsimbla traditional stoves (Table 59).

Table 59: Carbon emission of improved and traditional baking stoves in selected woredas of Ethiopia

Region-woreda	Sessional consumption in stoves	Total amount carbon dioxide emission per household (kg)	Emission reduction in percent
Tigray Region-Asgede-Tsimbla woreda	average amount of wood used by family per session (kg)-in Mirt improved stove	1007.42	33.8
	average amount of wood used by family (kg) per session-traditional baking stove	1522.32	
Amhara Region-Bure woreda	average amount of wood used by family per session (kg)-in Mirt improved stove	1835.73	37.4
	average amount of wood used by family (kg) per session-open stove	2932.70	
Oromia Region-Ameya woreda	average amount of wood used by family per session (kg)-in Mirt improved stove	1365.61	41.9
	average amount of wood used by family (kg) per session-open stove	2350.64	
Southern Region-Dallocha woreda	average amount of wood used by family per session (kg)-in Gonzie improved stove	1746.19	20.4
	average amount of wood used by family (kg) per session-traditional open stove	2193.93	

Conclusion and recommendations

Mirt and improved *Gonzie* stoves were highly accepted and appreciated by the local people because their firewood saving and ability to protect fire burn was better than the local cookstoves. A similar type of *Mirt* cookstoves was used in Asgede Tsimbla, Bure, and Amaya woreda but in the KPT, fuel consumption was varied from 30 to 40%. These differences might be attributed to the differences in cooking culture and width of firewood inlet. In Asgede Tsimbla, the majority of the respondents were using traditional stoves. Thus, to reduce emissions from deforestation and forest degradation and to protect indoor smoke pollution of the community, the government and NGO should make awareness to the community.

There is size variation in the pots and plates based on the cooking culture of communities and across different agro-ecologies. This should be considered in the molding design. In Bure woreda, it is important to monitor the stove and plate producers, to adjust the design of mirt stove by inserting edge in the place where the plates are placed. In Ameya woreda, fire leakage between the junction of pot placement due to improper installation and then deficiencies in the molding equipment should be improved and standardized. There is a need to create a market link and provision of credit for the women organized on improved cook stove production. In Dallocha woreda improved *gonzie* stoves saved lower amount of wood when compared with traditional open stoves because of the wide opening created for firewood inlet and only three parts were used instead of four by the households, which should be corrected by proper monitoring.

Acknowledgments

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Productive and climate-resilient traditional agroforestry systems in Silte district, Southern Ethiopia

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Abstract

Agroforestry is recognized as one of the strategies for climate change mitigation and adaptation option under the Kyoto protocol. The system has been practiced in Ethiopia for millennia by smallholder farmers by incorporating crops with trees providing extensive socio-economic and environmental benefits. These unaccounted benefits of the system need further and specific study. Thus, this study aimed to examine the resilience of three traditional agroforestry systems on the basis of biomass carbon accumulation and socio-economic characteristics in the Silite district, Southern Ethiopia. Systematic random sampling was employed to collect social and biological data. Height and diameter at breast hight of shrubs and trees were measured to determine biomass carbon stock, and a questionnaire was performed for the socio-economic data. The variations in biomass carbon stock among the selected agroforestry systems were performed using analysis of variance. The mean differences across the system were analyzed using a Post hoc test. Socioeconomic data were analyzed using descriptive statistics and Chi-square test. The aboveground and total biomass carbon was varied among agroforestry practices and the mean total biomass carbon aboveground was estimated to be 7, 3.11, and 2.01 Mg C ha^{-1} for parklands, home garden, and woodlots, respectively. In the socio-economic analysis, half of the respondents perceived the occurrence of climate change and the need for adaptation. They also claimed that drought and flood were the natural hazards that widely occurred in the study areas. The study showed that traditional agroforestry systems are capable of building climate change resilience through socio-economic and environmental benefits.

Keywords: Adaptation, Biomass Carbon, Climate change, Mitigation

Introduction

Agroforestry is a long-standing land-use system that incorporates woody perennials, trees, crops, herbaceous plants, and/or animals either in a spatial and/or temporal basis (Doyle *et al.,* 1989). Agroforestry is used in greenhouse gases (GHGs) mitigation and adaptation strategies. The use of agroforestry should not create leakage that would result in the conversion of forest land into agricultural land. Additionally, in agroforestry agricultural land use will remain the landowner's primary intent (Dixon, 1995).

Ethiopia has a good home garden agroforestry system as compared to other tropical African countries. Grain-based cultivation and enset-based mixed cultivation are the major agricultural systems in Ethiopia. The latter system occurs in the southern part while the former is found in the Northern and Northwestern parts of the country (Negash *et al.,* 2013).

Agroforestry can play a vital role in enhancing productivity and sustainability. More recently, agroforestry systems are believed to have a high potential to contribute to climate change adaptation and mitigation. Integration of trees on farmlands minimizes environmental degradation and enhances productivity. Other than the economic contribution, carbon stock estimation in agroforestry systems (AFS) ensure the significance of the system for global carbon balance and enhances the potential of farmers in AFS expansion (Nair, 2012). Smallholder farmers are the most vulnerable to the effect of climate change and variability. Environmental degradation and deforestation through poor land-use system and high demand for fuelwood is the major cause for the changing climate.

Socioeconomic characteristics and perception of farmers played a vital role in technology adaptation and decision making. Adoption is influenced by farmers' perception and their socioeconomic characteristics (Adesina and Baidu - Forsen, 1995). Site district was selected since it is widely known for its agroforestry systems, dominantly: woodlots, home garden, and parkland agroforestry systems. Home garden agroforestry system provides year-round production of food and salable products. *Eucalyptus* dominated woodlot agroforestry is the most dominant system in the study area with high wood product provision for market and domestic consumption as a source of fuelwood and construction materials.

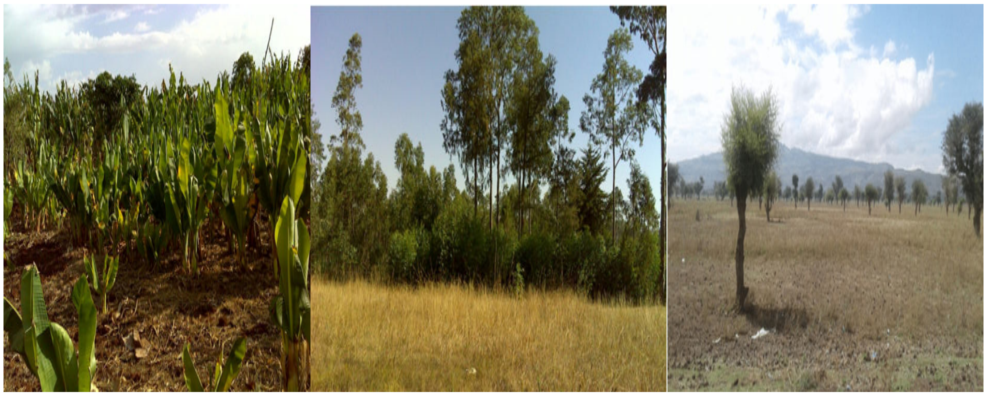

Figure 77: Enset based home garden (left), Eucalyptus woodlots (center) and Parkland (right) agroforestry systems in the study area

Parkland agroforestry system is defined as areas where scattered multipurpose trees occur on farmlands as a result of farmer selection and protection. *Faidherbiaalbida* is the most common tree species that is incorporated in parkland AFS. This species undertakes a physiological dormancy and sheds its nitrogen-rich leaves during the early rainy season. The species mostly takes over inverted phenology with physiological dormancy and sheds its nitrogen-rich leaves during the early rainy season (ICRAF, 1989; ICRAF, 2000). Furthermore, the shaded leaves improve the soil fertility (Dangasuk*et al.,* 2006).

Thus this study was aimed to evaluate the unaccounted socio-economic and environmental contributions of agroforestry systems including carbon stock assessment in the three selected AFS in Silite district.

Materials and Methods

Site description

The study was conducted in two selected rural *kebeles*, namely, Balokeriso and Welay-6 of Silite district, Southern Nations, Nationalities and Peoples Region (SNNPR). It has a total area of 3047.83 $km^2$and geographically located between 7°43' to 8°10'N latitude and 37°86' to 38°86'E longitudes with mean annual temperature ranged from 10.1 to 22.5°C while the annual precipitation ranged from 650 to1818 mm. The targeted woredas had altitude ranging from 1501 to 3500 m.a. s.l. (CSA, 2007) (Figure 78).

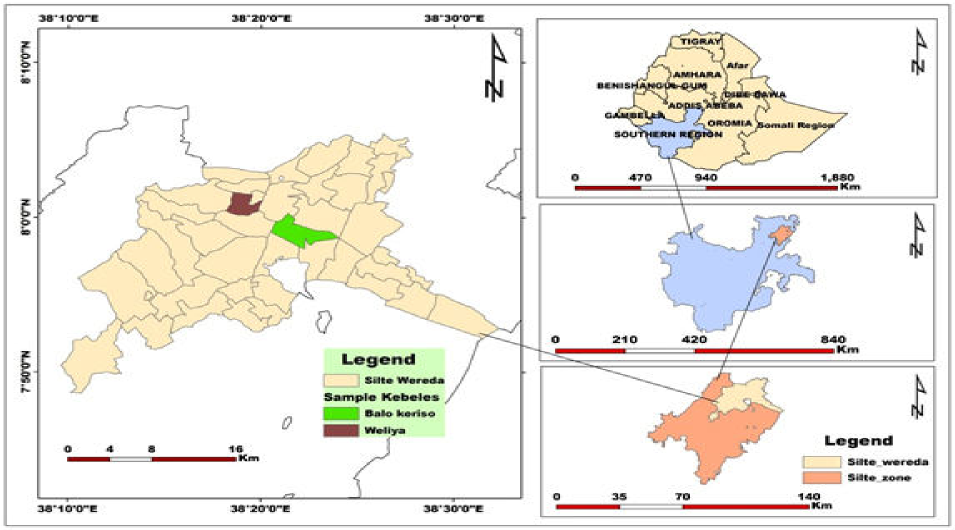

Figure 78: Map of the Silte district showing the study area

Landscape characteristics

The selected AFS were composed of components like staple foods, crops, fruit trees, coffee, and other woody species such as *Faidherbia albida* and *Eucalyptus viminalis* for parkland and home garden AFS, respectively. Coffee, enset, fruit trees, and other woody species are incorporated in home garden AFS.

Selection of study sites and sampling

Before further studies, a reconnaissance survey was done to identify suitable study sites and agroforestry systems. The survey was conducted through a collection of information about agroforestry types of the targeted zone in spatial distribution, and in a temporal basis. Then Silite district in Silite Zone was selected based on the aforementioned parameters. Accordingly, home garden, parkland, and woodlot AFS were identified. Two potential *kebeles*, Welay-6 and Balokeriso, were selected. Twenty households for each AFS were selected randomly. A total of 60 farms consisting of 20 farms from each AFS were randomly selected.

Data collection

Socioeconomic data were collected using systematic random sampling. And the sample households were selected following the procedures of Kothari (2004).

$$n = \frac{(Z^2)(N)\sigma^2}{(N-1)e^2+(z^2)\sigma^2} \ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

Where: N is the size of the population, n size of the sample, e acceptable error (the precision), δ^2 standard deviation of a population, z standard variant at a given confidence level. And for the sake of uniformity the following values were used for calculation, e = 0.5, $\sigma^2 = 3$ and z = 1.96 (95% confidence level).

For woody biomass inventory, sample plots were randomly laid down at 20 mx20 m for home gardens (Abiot and Gonfa, 2015), 50 mx100 m for parklands, and 10 mx10 m for woodlots (Bajigo*et al*. 2015). Each tree within the plot was identified and recorded. All trees in the sample plot with a diameter at breast height (DBH) at 1.3 m ≥ 5 cm, and total tree height (TH) ≥ 1.5 m were measured and recorded (MacDicken, 1997).

For coffee plants, stem diameter at stump height (40 cm, d_{40}) was measured twice perpendicular to each other. For the enset-based home garden agroforestry system, the basal diameter of all enset plants, one-year-old or older, at 10 cm height (d_{10}), was measured and recorded (Negash *et al.,* 2013).

In the case of multistemmed woody species, each stem was measured separately and DBH was squared (Snowdon *et al*., 2002).

$$d_e = \sqrt{\sum_i^n di^2} \ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

Where: d_e is diameter equivalent (at breast or stump height), d_i is the diameter of the i^{th} stem at the breast or stump height (cm).

In the case of trees, coffee, and enset plants, the biomasses were estimated using the plot inventory data and allometric biomass equations (Negash *et al.*, 2013).

Woody species and fruit trees incorporated within home garden agroforestry, aboveground biomass (AGB) was estimated using an allometric equation developed by Kuyah *et al.* (2012) and 50% were used for carbon stock conversion.

$$AGB = 0.091 \times d^{2.472} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

Where: d is the diameter of each woody species and fruit tree.

Belowground biomass (BGB) was estimated using the global average value of 26% of aboveground biomass (Cairns *et al*., 1997), and 50% (default values) was used for carbon stock conversion (MacDicken, 1997). The total carbon stored in the system was estimated by equation 4.

TBC=TAGBC+TBGBC…………………… 4

Where: TAGBC is total aboveground biomass carbon, TBGBCis total belowground biomass carbon, and TBC is total biomass carbon in Mg C ha^{-1}.

Table 60: Adopted allometric models for biomass estimation of different tree species

Species	Allometric model -AGB	BGB	Carbon equivalent (%)
Faidherbia albida	AGB=7.985(W)32.277 (Larwanou 2010)	26% of AGB (Cairns *et al*. 1997)	50% (MacDicken 1997)
Eucalyptus viminalis	$AGB=0.45(X^{3.41})$ (Zewdi*et al*., 2009)	26% of AGB (Cairns et al., 1997)	50% (MacDicken, 1997)
Coffeaarabica	$AGB=0.147d^2_{40}$ (Negash*et al*., 2013)	$BGB=0.490AGB^{0.923}$ (Kuyah*et al*., 2012)	49% Negash*et al.,*2013)
Ensete venticosum	$\ln(AGB_{enset}) = -6.57 + 2.316\ln(d_{10}) + 0.124\ln(h)$ (Negash*et al*., 2013)	$BGB=7\times10^{-6}\times d_{10}^{4.083}$ (Negash*et al*., 2013)	47% Negash*et al*., 2013)

Data Analysis

The collected data was analyzed using SPSS version 20 software. The variations in biomass carbon stock among the selected agroforestry systems were evaluated using one-way Analysis of Variance (ANOVA). The mean differences across the three agroforestry practices were analyzed using a Post hoc test. Socioeconomic data were analyzed using descriptive statistics and Chi-square test.

Results

Socio-economic characteristics of respondents

The average age of the respondents was 40 and 42 in Balokeriso and Welay-6 kebeles, respectively. The average landholding size was 0.65 and 0.55 ha, respectively. About 35% of the respondents were illiterate while the rest were first and second cycle complete. The most popular income source of the respondents was crop production, which accounted for about 58% of the total income. The average income of the respondents was 80,457 birr and 36,253 birr in the aforementioned kebeles, respectively. Forty percent of the respondents got their farming materials from natural forests and 25% from their farmlands.

Topologies of traditional agroforestry system

Home garden, parkland, and woodlot agroforestry systems are the most dominant and preferred agroforestry systems in the study site. In both kebeles, the home garden agroforestry system was the most dominant traditional agroforestry system followed by parkland (Figure 79).

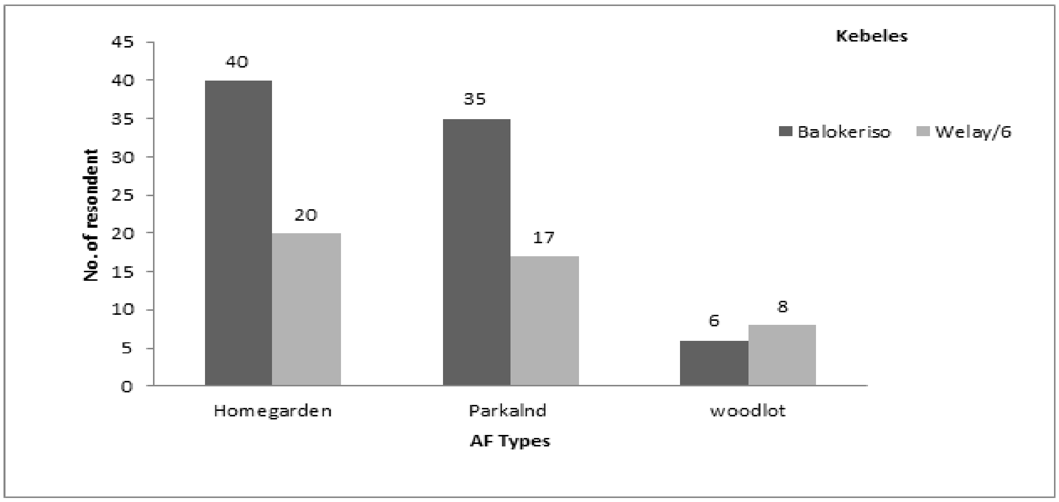

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Figure 79: Types of traditional agroforestry systems in selected Kebeles of the study area

Importance of trees in agroforestry system

The study showed that the contributions of products from trees were significantly different ($p < 0.05$) between the two kebeles. In both kebeles, fuelwood and fruit trees were the main products of agroforestry for income sources and household consumption, accounting for about 42% and 32% in Balokeriso kebele, and 25% and 20% in Welay-6 kebele, respectively (Figure 80).

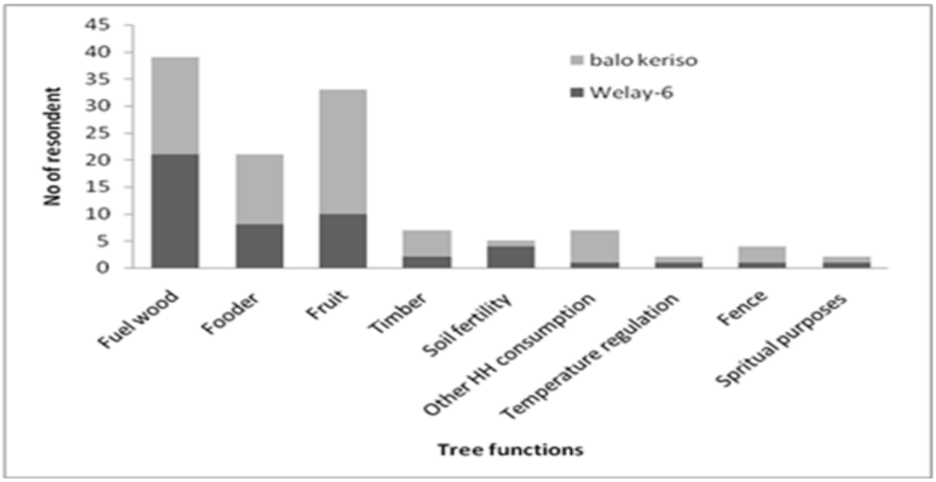

Figure 80: Importance of trees in agroforestry systems for livelihood in the study area

The farmers practiced about 8 major adaptation options including livestock sale, additional work (off farm activities), government and non-government support in additional products to sustain their livelihood for climate change adaptation (Figure 81). Livestock sale was the highest income source followed by off-farm activities and government aid. The respondents replied that drought and flood were the natural hazards widely occurred in the study areas. About 62% and 93 % of the respondents, in the above-mentioned kebeles, respectively, had perceived the prevalence of climate change (χ^2 =15.7, $p < 0.001$). In line with this, 56% and 83% of the respondents replied that agroforestry could increase crop productivity and cope up with climate change effect (χ^2 = 9.1, $p < 0.01$).

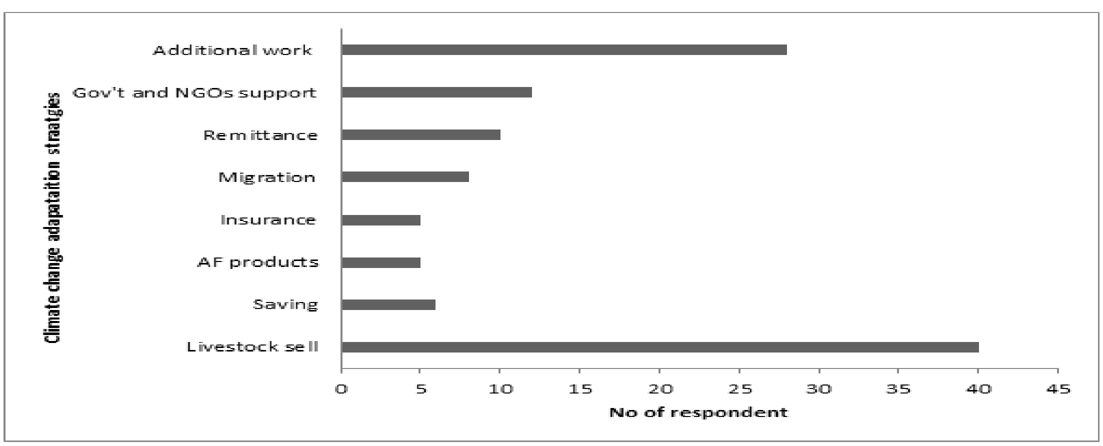

Figure 81: Climate change adaptation strategies of farmers in Silte district, Ethiopia

Biomass carbon stock

The results showed that the AFS in AGBC and TBC was significantly different ($p<0.05$). The mean aboveground biomass carbon stocks in parkland, home garden and woodlot AFS was 5.4,2.14 and 1.28 Mg ha^{-1}, respectively (Table 61).

Table 61: The mean (±SD) carbon stock (Mg ha-1) in different AFSs

Biomass components	Land use system		
	Woodlot	Home garden	Parkland
AGBC	$1.28±1^{a}$	$2.14±0.85^{b}$	$5.4±1.24^{c}$
BGBC	$0.73±0.8^{a}$	$0.97±1.74^{a}$	$1.5±0.78^{b}$
TBC	$2.01±2.1^{a}$	$3.11±2.4^{b}$	$7.01±1.4^{c}$

Home garden AFS consists of trees, coffee plants and enset. The tree component (including fruit trees such as papaya, avocado, and mango) has taken the highest share of the carbon stock.

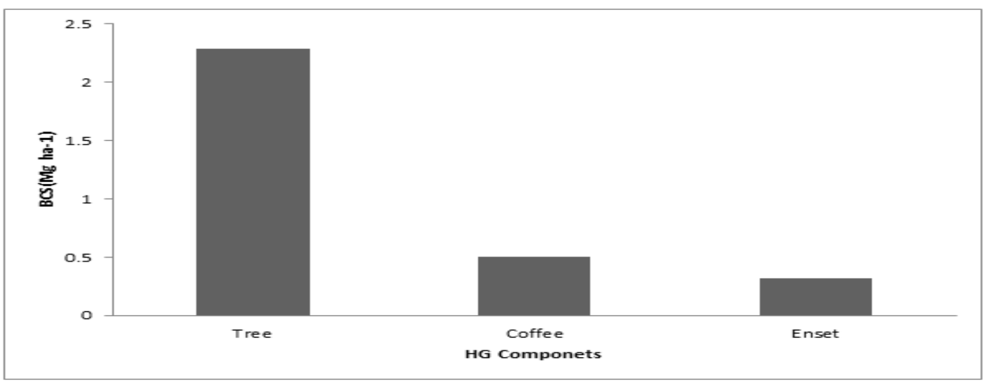

Figure 82: Home garden AFS components carbon stock in the study area

Discussion

A climate resilient land-use system is crucial in conserving the environment and providing socio-economic benefits. The agroforestry system, in this case, has been very crucial and this study shows how the system contributes to managing the changing climate in both aspects.

The present study showed that the above-ground biomass carbon stock was less in woodlot and home garden AFS than parkland AFS. The mean total biomass carbon stock of the three AFS obtained in this study was in line with the results reported for Vietnam, Gununo Watershed Wolayita Zone, and African tropical dry forest which is 10-34 Mg C ha^{-1}, (Pham *et al.* 2018; Bajigo*et al.* 2015; Henry 2010). The biomass carbon of this study was lower than fruit-based agroforestry (60 Mg ha^{-1} C) in Costa Rica and fruit-based agroforestry systems in northwestern Himalaya (51.85 Mg C ha^{-1}) (Senneh, 2007). The aboveground tree carbon of the study area was also less than the smallholders' farms of Vihiga district (36.9 Mg C ha^{-1}) and Siaya district (115.9 Mg Cha^{-1}) in Western Kenya (De Stefano *et al.* 2017). Studies in Gedio Zone in Ethiopia (Bishaw*et al.* 2013), Burkina Faso (Callo-Conch 2018), Tropical Africa (Paeth 2018), and Africa (Sanchez 2002) have revealed similar findings. Increasing tree density within the AFS could enable to build climate change and variability resilience. Moreover, the inclusion of trees for timber or wood production could increase revenue and carbon sequestration potential.

The result of this study also showed farmers had well perceived the occurrence of climate change. They recognized that drought, flood, and other related hazards indicate variation in climate. Even though the impact of changing climate has an adverse impact on the livelihood of the farmers, they came up with different adaptation strategies. Livestock sales, support from government and non-governmental bodies, and saving are amongst the main adaptation options. Also, agroforestry products and services were good strategies in managing the effects of climate variability. Different studies have also supported livestock sale was as one of the options used by the farmers (Copestake, 2008 and Femi et al., 2016). Trees are also becoming more important as a form of indemnification and are increasingly being used by farmers especially during massive loss due to climate change hazards (Pandey, 2007; Chavan et al., 2016). It is, therefore, expected that trees are the most important AF products in managing climate change.

Conclusion

The present study showed that parkland AFS accounted significantly higher amount of biomass carbon stock compared to woodlot and home garden AFS. The study proved that well managed traditional AFS (TAFS) could have high carbon sink potential. Though the local societies are the legatees from TAFS products and proved they perceived climate change, they are less aware of the environmental benefit of the system. Thus, awaking the community about its environmental uses and giving credit for the system by different concerned bodies help in future climate change mitigation and adaptation options. It is also important to note that socio-economic benefit of the system is very crucial and different motivational factor from concerned bodies is required in adapting TAFS products in the events of climate change crises.

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Temperature and precipitation Projections for the Highlands of Omo-Gibe Basin, Ethiopia

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Abstract

Anthropogenic and natural climate changes have upset the local and global climate resulting in the vulnerability of communities and ecosystems. This study aimed to project Temperature and precipitation for specific point locations using different representative concentration pathways of climate emission scenarios for the near term, midterm, and end of the century. The statistical downscaling technique was used to solve the scale problems of resolutions of Global Circulation Models by empirical relationships between large-scale circulation patterns and regional climate drivers. Three future emission scenarios: low, intermediate and high emissions were considered for three periods for the near term (2020-2039), mid-term (2040-2059), and end of the century (2080-2099)**.** The model projected that the mean annual maximum temperature under lower and higher emission scenarios ranges from1.01 °C to 6.32 °Cand 2.0°c to 3.6°c, respectively. Similarly, the mean annual minimum temperature ranges from1.83°c to 3.27°c and 2.32°c to 5.58°c for all time horizons. The ensemble models projected that annual precipitation for all emission scenarios will increase by 5% to 8.1% compared to the 1974– 2005 baseline for the highland Omo_Gibe basin. However, in the main rainy season, the mean monthly rainfall indicates a decreasing trend in the beginning of the rainy season and an increasing trend towards the end of the rainy season for all scenarios in all future time horizons.

Keywords: Climate, RCP, Temperature, Precipitation, Projection, Scenario

Introduction

Climate change projections are important in the generation of reliable climate information and data, and synthesize and disseminate information useful for designing measures to address adaptation to climate variability and change, as well as mitigation (ACPC, 2013). Climate information and services can play a crucial role in national development planning, in managing climate opportunities and risks, and in designing mitigation and adaptation strategies (UNECA, 2011). However, climate change projections are uncertain due to natural variability in the climate system, an imperfect ability to model the atmosphere's response to any given emissions scenario, lack of sufficient data, and lack of tools and models at spatial and temporal scales appropriate for decision-making (ACPC, 2013).

Ethiopia presents a particularly difficult test for climate models. The central part of Ethiopia is dominated by the East African Highlands, which split the country climatically. To the south and east, the land is semi-arid and the rainfall appears in two short spells, to the north and west, there is one major rainy season, *Kremt*. This split in the geographical distribution of rainfall and the different seasonal cycles in different regions of the country make the task of simulating Ethiopian rainfall extremely challenging (Gisila et al., 2015). Drought, rainfall delay, fire damage, and heavy and unexpected rainfall are climate-related hazards that mainly faced resulting in total crop loss, reduced yield, reduced seeding quality, delayed maturity, and increased crop pest/disease (Molla 2016 a).

At recent decades, the problem of climate variability and climate change, due to anthropogenic as well as natural processes are increasing (Molla, 2016b). Developing countries like Ethiopia are more vulnerable to the adverse impacts of climate variability and change. Due to Ethiopia's location in the tropics and dependence on natural recourses (water, forest, and soil), it has the low adaptive capacity and highly sensitive to climate variability, and change which are associated with extreme events. Sensitivity and adaptive capacity also vary between sectors and geographic locations, and time, social, economic and environmental considerations within the country. Current climate variability and extreme events are already imposing a significant challenge to Ethiopia by affecting food security, water and energy supply, poverty reduction and sustainable development efforts, as well as by causing natural resource degradation and natural disasters.

Besides the negative effects of climate change, it also presents the necessity and opportunity to switch to a new, sustainable development model. If Ethiopia were to pursue a conventional economic development path to achieve its ambition of reaching middle-income status before 2025, the resulting greenhouse gas (GHG) emissions would be more than double from 150 Mt CO_2e in 2010 to 400 Mt CO_2e in 2030 (CRGE, 2011). The Ethiopian government has, therefore, initiated the Climate-Resilient Green Economy (CRGE) strategy to transform the country from the adverse effects of climate change and to build a green economy that will help realize its ambitious goals.

Climate change modeling should take into account the spatial and temporal variability of climate in the specific region or location attributed to various factors which include the topographic variations across the region or location and different regional and local weather systems at large and mesoscale.

There is the confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above depending on the models' foundation on accepted physical principles and the model's ability to reproduce observed features of current and past climates (Dawit, 2010).

Finally, achieving Ethiopia's development goals would unquestionably require scientific information and technology regarding the characteristics of climate change in the past and future whereby the spatial and temporal variability of precipitation and temperature are high. Therefore, large-scale trends do not necessarily reflect local conditions. To fill this gap and to improve climate information services on specific point location, projection using different representative concentration pathway emission scenarios for the near term, midterm, and end of the century are necessary. Therefore, the objective of this study was to develop a climate change scenario for Omo-Gibe basins under high, medium and low representative concentration pathways (RCPs**).**

Materials and Methods

Description of the study area

Omo-Gibe River Basin is about 79,000 km^2 and is situated in the southwestern part of Ethiopia, between 4°30' and 9°30' N and 35° and 38° E with an average altitude of 2800 masl. It flows from the northern highlands of the basin through the lowland zone to discharge into Lake Turkana at the Ethiopia/ Kenya border in the south (Figure 83) and is nourished along its course by some important tributaries. The basin is divided sharply into the highlands in the northern half of the area and lowlands in the southern half. The northern highlands are strongly dissected with steep slopes and drained by the Gibe and Gojeb systems which merge to form the Omo in a deeply entrenched gorge that slices into the highlands.

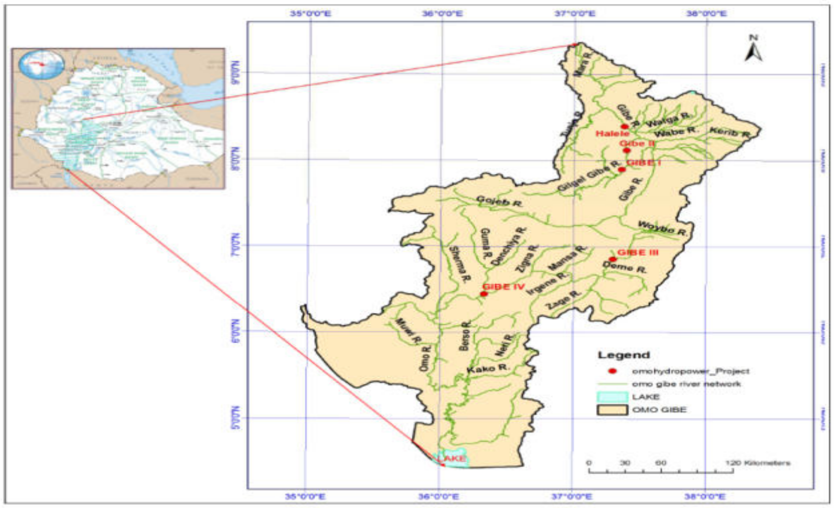

Figure 83: Map of the study area

Data collection and data sources

The observed temperature and precipitation data of the Omo-Gibe Basin was obtained from National Meteorology Agency (NMA). NMA has provided a statistical dataset of daily and/ or monthly precipitation and temperature. This data was from 1988 to 2018. After collecting the necessary data, filling of missed data and quality checking was made**.** The first step before model calibration was quality control using SDSM through the identification of gross data errors, missing data codes, and outliers to get the appropriate quality data. National Centre for Environmental Prediction (NCEP) data was generated for missing data filling and GCM-derived predictors were generated from global database.

Atmospheric large scale variables (CanESM2 Predictors) was downloaded from IPCC's Fifth Assessment Report (AR5) CMIP5/ Coupled Model Inter-comparison Project, Phase 5 (CMIP5)/ a collaborative climate modeling process coordinated by the World Climate Research Programme (WCRP) (http://climate-scenarios.canada.ca/? page=pred-canesm2).

Data Analysis

The screening predictor variables were done by trial and error procedure for model calibration. Using the partial correlations statistics, predictors that showed the strongest association with the predictand were selected. Assembly and calibration of the statistical downscaling model(s) - the large-scale predictor variables identified were used in the determination of multiple linear regression relationships between these variables and the local station data. Then SDSM manual procedure was followed to generate a climate scenario for the basins. The calibration was carried out from 1988-2003 for sixteen years and the withheld data from 2004-2018 were used for model verification.

Climate data downscaled using SDSM was analyzed for trend. Trend analysis of projected rainfall and temperature data was analyzed using Man Kandell trend analysis using TREND software.

Results and Discussion

Calibration and Validation

The model used in this study resulted in a multiple regression equation that can better predict the maximum and minimum temperature than the precipitation. This result is mainly due to the conditional nature of precipitation.

Minimum Temperature

The monthly minimum temperature downscaled for NCEP in the baseline period NCEP-NCAR_1961_2005for Jimma meteorological station is shown in figure 84.

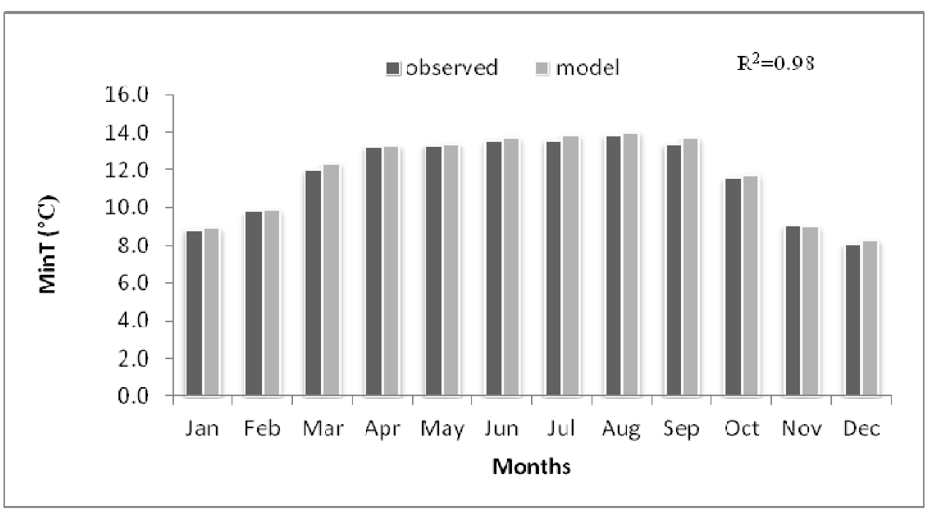

Figure 84: Comparison of observed and modeled minimum monthly temperatures

The result of downscaling minimum temperature indicates that there is very good agreement between observed and simulated minimum temperature. As shown in figure 85, it was also found that, during January, February and April the model error indicates over estimation and underestimation for November. However, during March and September, the model error is 0.35°C and 0.341°C in addition to that during November the model underestimates the minimum temperature.

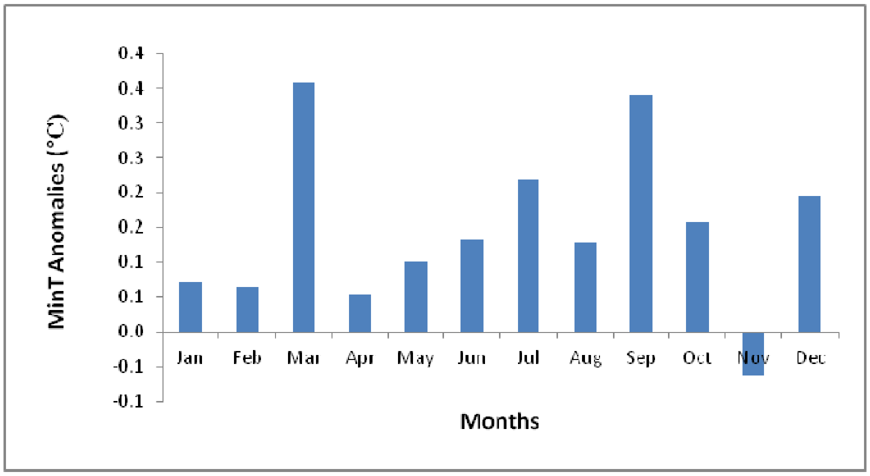

Figure 85: Absolute model errors in the estimate of monthly minimum temperature for Jimma station

Maximum temperature

The monthly maximum temperature downscaled for NCEP in the baseline period is shown in figure 86. The result of downscaling maximum temperature indicated that there is an excellent agreement between observed and simulated maximum temperature.

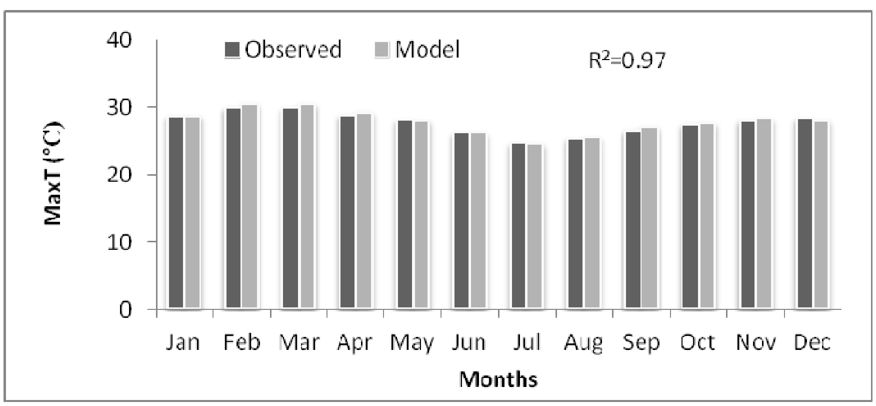

Figure 86: Observed and downscaled monthly mean maximum temperature

As shown in figure 87, the model underestimates maximum temperature for December and overestimates forthe February, March, April, September, and November. However, for the remaining months, the model error is negligible.

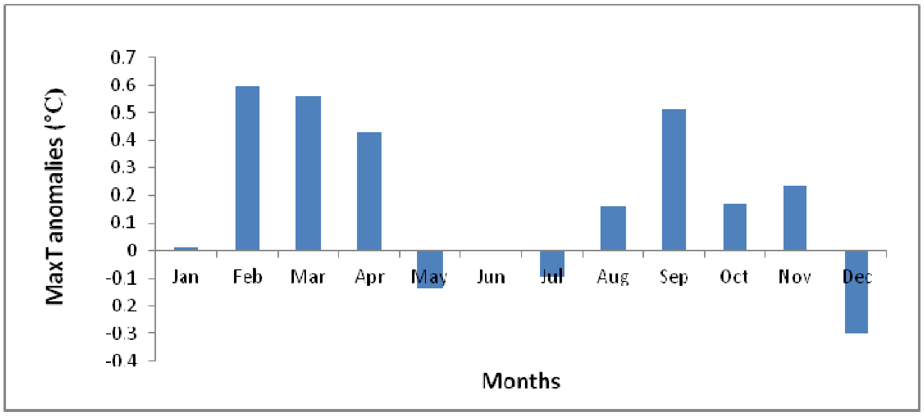

Figure 87: Absolute model error in the estimate of monthly maximum temperature

Precipitation

The model did not sufficiently replicate the historical (observed) precipitation (R^2 = 0.84) data compared to the minimum (R^2 = 0.98) and maximum temperatures (R^2= 0.97). This is due to the complicated nature of precipitation processes and their distribution in space and time. Climate model simulation of precipitation has improved over time but is uncertain. Rainfall editions have a larger degree of uncertainty than that of temperature Moreover the relatively coarse spatial resolution of the current generation of climate models is not adequate to fully capture precipitation variability.

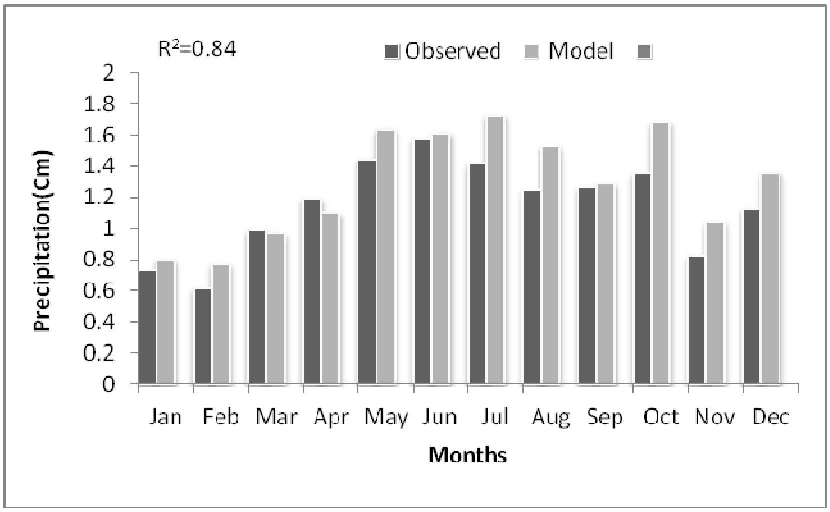

Figure 88: Downscaled and observed mean monthly precipitation

The downscaled precipitation showed an average absolute model error of 0.31mm and 0.33 mm for July and October, respectively indicating that the highest positive increase. Indeed, the error is negligible close to zero for March, June, and September, respectively (figure 89).

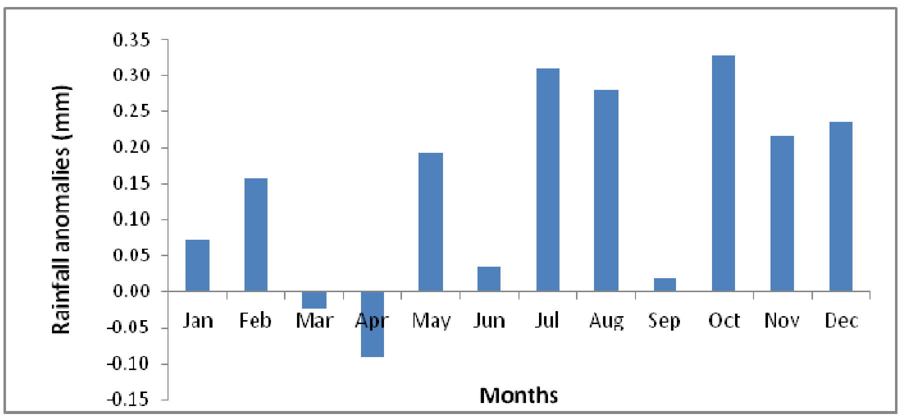

Figure 89: Absolute model errors for the downscaled precipitation

Projection of future climate

The projection generates20 ensembles of daily climate variables, which are equally plausible. Hence, these ensembles were averaged out to consider their characteristics. The analysis results developed for 2020-2039, 2040-2079, and 2080-2099under RCP2.6, RCP4.5 and RCP8.5 were shown in Figures 8-10. As shown in Figure 8, the downscaled maximum temperature shows an increasing trend in all the future time horizons for RCP2.6, RCP4.5, and RCP8.5 scenarios.

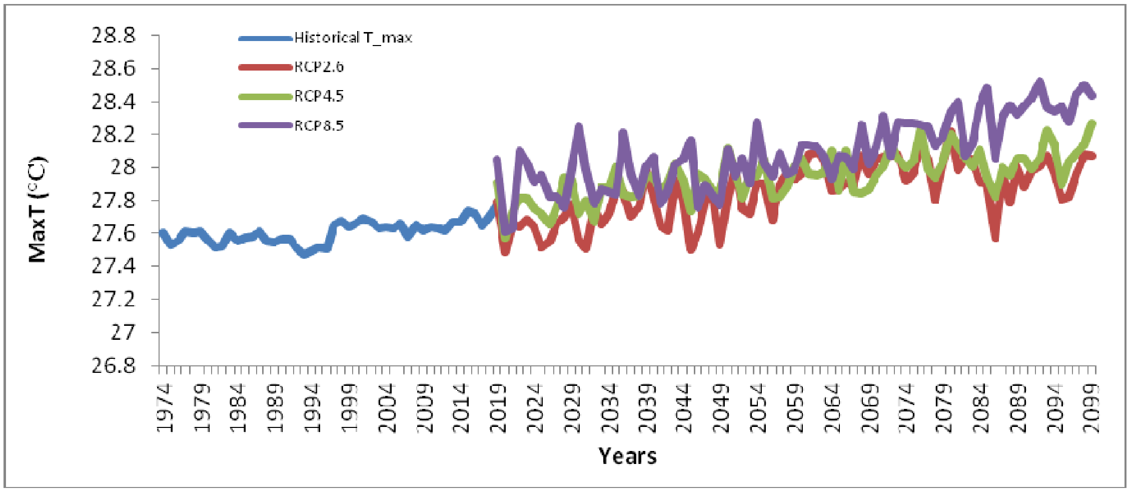

Figure 90: Projection of maximum temperature of area average

As shown in figure 91, the basin's minimum average temperature was increased by 1.83^{0}C, 2.95^{0}C and 3.27^{0}Cunder RCP2.6 scenarios for the near term, mid-term, and end of the century, respectively. For the same time horizon under RCP4.5 scenario,the minimum temperature will rise by 2.19 ^{0}C, 3.30^{0}C and 4.37^{0}C.

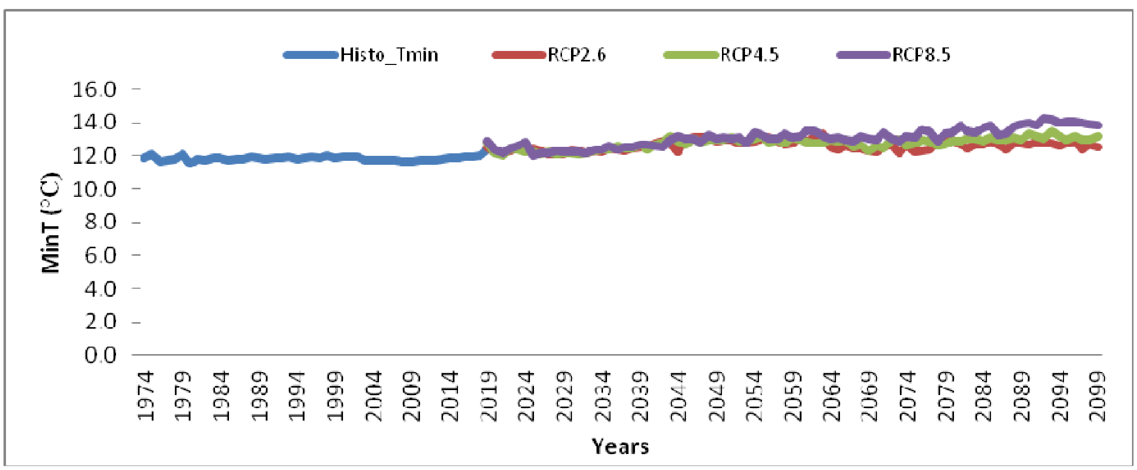

Figure 91: Projection of minimum temperature of Omo-Gibe basin

The results showed that climate model simulation of precipitation has improved over time but still a problematic and has a larger degree of uncertainty than temperature (Figure 92).

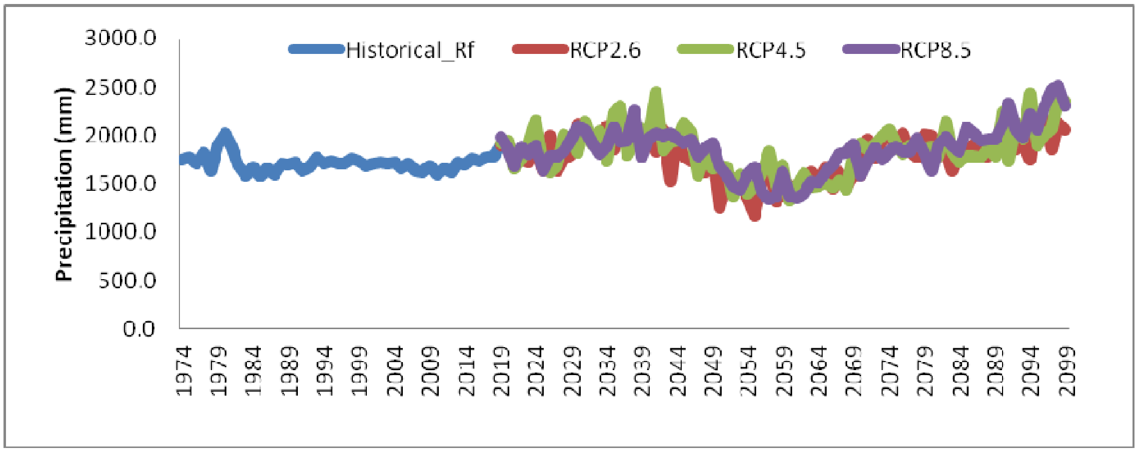

Figure 92: Projection of precipitation of Omo-Gibe basin

Conclusion and recommendation

Both the maximum and minimum temperatures showed an increasing trend in all future time horizons for all RCPs scenarios, but the change varied from station to station with-in the basin. The model projected for lower and intermediate scenarios showed that the mean annual *maximum* temperature change ranges fro 1.01°C to 6.32°Cand for mean annual minimum temperature change ranged from 1.83°C to 5.58°C for the point of location downscaled. The projected change in annual mean maximum temperature for Wolikite station showed a slight difference from other stations under all RCPs scenarios in (2080-2099) and similarly for Sokoru at the midterm (2040-2050).

Finally, there is the low percentage of precipitation change and or increasing depending on RCPs but there will be significantly increase with in different time horizon of 2020's, 2050's and 2080s but for mainly rainy months there will be the decreasing of rf happened on near term and end of the century under RCP2.6 and RCP 8.5. These will guide t to harvest and collect the water from unseasonal rainfall months to for main rainy months.

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Section 4: Environment Pollution Management Research

Social and Environmental Concerns of Flower Farms in Central Ethiopia

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Abstract

The extensive use of fertilizers and pesticides in the flower farming industries has been linked to negative environmental and social impacts. The cross-sectional study was conducted to assess social and environmental concerns of flower farms in Central Ethiopia using questionnaires, focus group discussion, and field visits. This study revealed that 317 (52.75%) of respondents reported that flower farms have been disposing of their flower residue of in the open field. The findings of this study showed that 216(36%) of inhabitants buy or receive empty chemical bags and containers that had been disposed of by the flower farms. Focus Group Discussion participants perceived the decrease in volume and quality of groundwater, a decrease in productivity, land degradation, and increased emerging diseases due to the existence of flower farms in the area. Also, they reported abuse of employee rights, displacement of farmers from fertile land, death of cattle and fish, loss of acceptance for their agricultural and fish products. In conclusion, this study revealed that there are poor waste management and unsustainable activities by the flower farms. The government should closely monitor these farms and undergo a holistic study to quantify environmental and local inhabitant's opportunity costs of flower farming activity.

Keywords: Flower farm, Waste management, Environmental pollution, Pesticides, Fertilizer, Human health

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Analysis of Physicochemical Parameters in Wastewater and Heavy Metals in Soils of Five Flower Farms in Ethiopia

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Abstract

Floriculture is a young and fast-growing industry in Ethiopia. The sector has created employment opportunities and contributed to our country's economic development. But it is blamed for causing environmental pollution. Therefore, this study aims to determine the concentration of environmental pollutants in wastewater and soils of five flower farms located in Central Ethiopia which were selected using purposive sampling. Wastewater and soil samples required for the determination of Physico-chemical parameters and heavy metal concentrations were collected from the flower farms from April 1 to May 25, 2019. Physicochemical parameters including pH, electrical conductivity, total dissolved solids, phosphate, sulfate, and chemical oxygen demand in wastewater, and concentrations of lead, cobalt, and zinc in soil were determined. Accordingly, the pH values of the four flower farms (Farm 1, Farm 2, Farm 4, and Farm 5) were slightly acidic and below minimum pH value (6) allowed for wastewater effluent set by the Ethiopian Environmental Protection Authority. Electrical conductivity at all farms, total dissolved solid at Farm 4, chemical oxygen demand at Farm 3, and 4, sulphate at Farm 4, and phosphate at Farm 2 and 4 were above the provisional standard set by EPA. This study revealed that the wastewater sample collected from Farm 4 doesn't comply with EPA standards in all study parameters. While, the mean concentrations of cobalt and zinc in soil samples varied from 2.8 to 46.6 mg/kg and 54.4 to 111.1 mg/kg, respectively which are not above the EPA permissible limit. Conclusively, the wastewater quality discharged from flower farms is not at a level it cannot cause a harmful effect. Therefore, there is a need to ensure that wastewater is properly treated before discharged into the environment. Also, the authors recommend that further holistic investigation should be carried out on the socio-economic and soil pollution of the floriculture industry in Ethiopia.

Keywords: Floriculture, Heavy metal, Physicochemical, Soil, Wastewater

Introduction

Floriculture is a discipline of horticulture concerned with the cultivation of flowering and ornamental plants for gardens and floristry, comprising the floral industry. It can also be defined as "The segment of horticulture concerned with commercial production, marketing, and sale of bedding plants, cut flowers, potted flowering plants, foliage plants, flower arrangements, and noncommercial home gardening" (Getu, 2009; Tilahun, 2013).

Floriculture is a young and fast-growing industry in Ethiopia. Since the industry is export-oriented, it serves to generate foreign exchange. According to Arefaynie (2009), the major factors that have contributed to the development of the horticulture industry in Ethiopia include suitable climate, altitude, and availability of land, low labor costs, and other favorable conditions. In 2002, there were only five floriculture farms in the country; however, by 2008, this number rose to more than a hundred (EHPEA, 2014).

The study conducted by Kassa (2017) stated that Ethiopian floriculture industries currently produce several flower species, including roses, gypsophila, hypericum, limonium, carnations, and chrysanthemum. Currently, Ethiopia is benefiting from this development by creating employment opportunities for unemployed citizens. Also, the floriculture industry has given the country's export sector an alternative export commodity to the traditional predominant export of coffee.

However, there are several challenges that must be resolved to continue the development of the sector with the present rapid pace. Among the challenges is the high consumption of different chemicals by the sector which can damage the environment through its discharge. According to Tamiru (2007), the production of flowers uses more than 300 chemicals such as pesticides and growth regulators, which can kill useful organisms in the soil and disturb the biodiversity surrounding the flower farms. It is known that soil pollution can lead to water pollution if toxic chemicals leach into groundwater, or if contaminated runoff reaches streams, lakes, or oceans (Bolo and Brachet, 2010;FAO, 2017). Phosphorus fertilizers are among the sources of heavy metal inputs; and superphosphate fertilizers contain, in addition to nutrient elements, trace metal impurities like cadmium (Cd) and lead (Pb). Malidareh and his colleagues (2014) showed that fertilizers might contain heavy metals that can cause serious problems in water and soil. Therefore, the objective of this study was to assess the status of environmental pollutants in five flower farms located in Central Ethiopia by analyzing Physico-chemical parameters in wastewater and selected heavy metals in soils.

Materials and Methods

Study area

The study area consists of five flower farms which were coded as Farm1, Farm 2, Farm 3, Farm 4, and Farm 5 (Figure 93) for the sake of confidentiality. The flower farms were purposely selected based on the magnitude of the social complaint reported by Oromia Environment, Forest, and Climate Change Authority. Farm 1 and Farm 2 are found in Woliso and Bacho Woreda, respectively, of the Southwest Shewa zone. Farm 3 and Farm 4 are both found in Walmera Woreda of West Shewa Zone and Farm 5 is located in Adami Tulu Jido Kombolcha Woreda of East Shewa Zone.

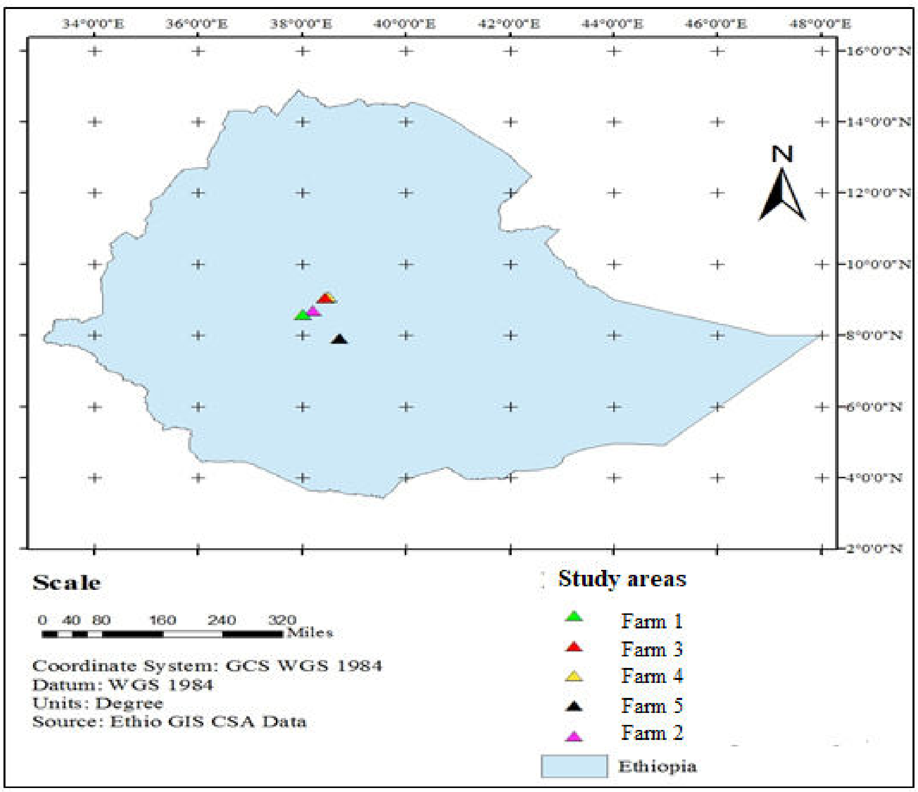

Figure 93: Map showing specific locations of the five flower farms

Sampling, sample handling, preparation, and analysis

Wastewater sampling, handling, preparation, and analysis

Wastewater samples were collected from five flower farms from April 1 to May 25, 2019. All samples were collected at the outlet in triplicate by using sealed plastic bottles which were thoroughly cleaned with detergent, rinsed with distilled water, soaked in 5% $HNO^-_3$for 24 hours, and finally rinsed with distilled water. For each wastewater sample, pH, total dissolved solids (TDS), and electrical conductivity (EC) were measured at a site using a portable multi-meter (Jenway, model 3305). The remaining samples were labeled, preserved, and transported to the laboratory in icebox. In the laboratory, the other parameters were analyzed using standard methods (APHA 1998), i.e. sulphate (SO_4^{2-}) by Turbidimetric, phosphate (PO_4^{3-}) by Vanadomolybdo phosphoric acid colorimetric, and chemical oxygen demand (COD) by the Open Reflux methods.

Soil sampling, handling, preparation, and analysis

First, ten soil samples were collected from the top 30 cm depth of each farm using Auger, spade, and spoon, and applying random sampling technique. Then, ten samples of each flower farm were mixed, homogenized, placed into clean polyethylene bags in triplicate, labeled, and transported to JIJE Analytical testing service laboratory P.L.C. in an icebox to avoid cross-contamination and change of composition by weather conditions. In the laboratory, the samples were air-dried and sieved to pass through 2 mm sieve, digested by a microwave system, and finally Pb, Co, and Zn were analyzed by Flame Atomic Absorption Spectrophotometer (FAAS).

Statistical analysis

The data were analyzed by using Microsoft Excel 2010. Descriptive statistics were used to analyze the data obtained from Physico-chemical analysis of wastewater and heavy metal concentrations of the soil samples.

Results and Discussion

Physicochemical parameters for the wastewater

The mean pH value for each flower farm is shown in Table 62. The results indicated that the mean pH values of the four farms (Farm 1, Farm 2, Farm 4, and Farm 5) were slightly acidic and below minimum pH 7 which is allowed for wastewater effluent by the Ethiopian Environmental Protection Authority (EPA, 2003). As stated by Tamiru and Leta (2017), flower farms add nitric acid and sulfuric acid to decrease the pH of dripping water of a raised pH that arises from the use of fertilizers. The decrease in pH values affects the solubility of nutritive chemicals; it increases the availability of chemicals to aquatic organisms which in turn creates an unfavorable environment for fish and other aquatic organisms (Tadele, 2009).

Wastewater with a high amount of dissolved inorganic substances in ionized form could originate from fertilizers and pesticides used in flower farms. The mean EC values of wastewater were in the range 1,489.7- 17,546.6 μScm^{-1}(Table 62). The results obtained in this study were all higher than the optimum EC value of 1000 μS/cm for wastewater discharges by EPAin 2003. High values of EC show high inorganic ions in the wastewater (Aniyikaiye et al., 2019; Benit and Roslin, 2015). On other hand, the measured mean value of TDS in the wastewater samples of the flower farms varied from 1117.5 to 13160 mg/L. The TDS values of the selected farms were within the limit of provisional standard 3000 mg/L set by EPA except farm 4. The measured mean COD values of the studied flower farms' wastewater varied from 11.2 to 339.2 mg/L). The COD concentration was above the permissible limit for Farm 3 and Farm 4 which could be attributed to excessive organic and inorganic chemical use in the flower farms. In this present study, the measured values of sulphate concentration are below the provisional standard set by EPA (200 mg/L) except at Farm 4 (716.0 mg/L) which is above the limit. Similarly, the maximum phosphate concentration was detected at Farm 4 which was by far above EPA recommended value of 10mg/L.The obtained maximum concentration of phosphate recorded might be due to the flower farm's high application of phosphate-based fertilizers like ammonium phosphate. The result was shown in table 62.

Table 62: Physicochemical parameters in wastewater samples

	Mean values of parameters					
Flower farms	**pH**	**EC(μScm^{-1})**	**TDS(mg/L)**	**COD(mg/L)**	**SO_4^{2-}(mg/L)**	**PO_4^{3-}(mg/L)**
Farm 1	5.7	3116.9	2337.7	12.8	40	2.1
Farm 2	5.8	3120	2340.3	11.2	66	11.5
Farm 3	6.5	2683.6	2012.7	339.2	125.4	7.5
Farm 4	5.9	17546.6	13160	320	716	309
Farm 5	5.4	1489.7	1117.5	16	35.1	1
*EPA permisible limit	6-9	<1000	3000	250	200	10

*Ethiopian Environment protection Ahtourity (2003).

Heavy metal concentration of Soil samples

In this study, except for Farm 2 (12.4 mg/kg), the concentration of lead was below the detection limit for all analyzed soil samples. The obtained result was within the EPA recommended value of 40 mg/kg (EPA, 2003). The mean concentrations of cobalt in soil samples taken from the flower farms were between 2.8-46.6 mg/kg (Table 63). The results revealed that the concentration of zinc was highest among the heavy metals analyzed from all the sample sites. The obtained values were below the provisional standard of 500 mg/L set by EPA. The low concentration level detected for soil analysis might be attributed to the washing of the soil by runoff, dispersion by air, and infiltration below soil sampling depth.

Table 63: Heavy metal concentration in soil samples

Flower farms	**Mean value of heavy metals in mg/L**		
	Pb(mg/L)	**Co(mg/L)**	**Zn(mg/L)**
Farm 1	12.4	37.1	105.2
Farm 2	ND	22.2	106.4
Farm 3	ND	46.6	111.1
Farm 4	ND	23.8	91.6
Farm 5	ND	2.8	54.4
EPA standard	40	-	500

ND= Not detected

Limitation of the study

Wastewater discharges and soil samples were taken only once and analyzed for a few main physicochemical and heavy metal parameters. Hence, it cannot be generalized for broader flower farm pollution status. The parameters that were found to be above the standard limits could have been justified in a better way had there been additional information on the use of fertilizer and other chemicals, wastewater treatment employed, and efficiency.

Conclusions and Recommendations

This study revealed that wastewater discharged from most study flower farms has contaminant concentration not following the permissible level. Among the physicochemical parameters investigated: pH (for Farm 1, 2, 4, and 5), electrical conductivity (for Farm 1 to 5), chemical oxygen demand (for Farm 3 and 4), and phosphate (for Farm 4)not comply with the levels recommended for wastewater discharge set by EPA. Conclusively, the wastewater quality discharged from flower farms is not at a level it cannot cause harmful effects on the environment.

Some amount of pesticides from flowerfarms can inevitably reach our primary concern i.e. human beings and cause undesired impacts. Hence, the flower farms should shift to organic farming which relies on natural methods to control pests and diseases such as crop rotations, composting, encouraging the natural predators of common pests, and developing healthy flowers that have a natural resistance to pests and diseases, so that the related risk can be reduced. And also there is a need to ensure that wastewater is properly treated before discharge into the environment. Adding to this, the authors recommend that further holistic investigation should be carried out on the socio-economic and soil pollution status of the floriculture industry in Ethiopia.

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Design and Fabrication of a Manually Operated Biomass Briquetting Machine and Charring kiln

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Abstract

The major problem associated with briquetting in developing countries like Ethiopia, is the development of appropriate biomass briquetting technology that suits the local condition in terms of production cost, and domestic uses. In this study, a carbonized and manually operated biomass briquetting machine has been designed and fabricated using locally available materials. The briquetting machine consists of 49 welded together molds and each mold has a piston at the bottom and a closing metal plate at the top. The other ends of the piston were welded on a flat metal plate of which places on a 10-ton capacity hydraulic jack. The jack drives the pistons in and out of the molds during operation. The machine can produce 49briquettes at a time having a cube size of 3cm× 3cm × 3cm The manually operated briquetting machine and carbonized is technically feasible, so it can be useful to small and medium scale briquette manufacturers.

Keywords: Briquette, Carbonizer, Hydrolic jack, Mold

Introduction

Briquetting biomass is a densification process which can produce a compact material with higher energy per unit volume (Faizal *et al.*, 2016). Additionally, densification improves the handling and reduces transportation costs, producing a uniform, clean and stable fuel (Granada *et al.*, 2002). The briquetting is a simple and economical proposition to produce solid fuels from the energy-rich locally available resources which replace many of the conventional fuels, such as coal, kerosene, firewood, etc. (Srivastava *et al*., 2014). Briquettes production results a product that has a greater volumetric energy density which is easy for storage and transportation (Debdoubi *et al.,* 2005), require a low cost of production (Wessapan *et al.,* 2010), and generate income through entrepreneurship (Bogale, 2009).

Briquettecan burns with a small flame and with less smoke, and cook with even heat and is long-lasting. It does not require chopping. It is clean, smokeless, odorless, sparkles, and thus more suitable for slow cooking. It has less crack and better strength. It will help in generatin gjob opportunity in rural areas of developing countries. This technology is comparatively pollution-free and eco-friendly. Indirectly it is a way to utilize the total energy available on a farm to generate electricity/thermal heat. Therefore, briquetting of biomass after carbonization would be a promising option (Khobragade, 2015).

The thermally insulated chamber, commonly known as a kiln or carbonized, is necessary to heat the biomass such as agricultural waste. The kiln creates the necessary low-oxygen, high-temperature environment, driving water, and other particulates out of the biomass and leaving charcoal behind. Carbonizer typically requires regulated airflow in the chamber to be adjusted at specified times because the biomass usually serves both as a fuel to heat the kiln and the material being carbonized (Etienne,2007).

The constraint in the advancement of biomass briquetting in developing countries is the development of appropriate briquetting technology that suits the local condition, both in terms of operation and usage of the produced briquette.

The failure of these machines has been attributed to some factors which include inappropriate or mismatch of technology, technical difficulty and lack of knowledge to adapt the technology to suit local conditions, excessive initial and operating cost of the machines, and the low local prices of wood fuel and charcoal (Obi *et al.*,2013).

The more replicable, appropriate, cost-effective, locally available, easy to make, environmentally friendly, and culturally fitting technology is the higher its chance of success (Hood, 2010).

In Ethiopia, briquetting is not yet matured compared to the other countries. Few manually operated briquette machines are found in some parts of the country. Some of the existing briquetting machines in the country have the weak production capacity and are not easily fabricated and accessible. Moreover, the currently available briquette machines are labor-intensive to operate and use. The carbonization process takes much time and the mold design produces a large briquette which is not suitable for the local domestic stove. Overcoming the operational problems associated with this technology and ensuring the quality of the briquettes are crucial factors in determining the growth of briquetting technology.

At the moment, the need for the densification of biomass in Ethiopia is the development of an appropriate briquetting machine suitable to rural communities. For biomass to make a significant impact as fuel for rural communities, it is crucial to develop an efficient, easy to operate, cost-effective, and easy to scale up the technology. Therefore, this study was conducted to yield an improved design of biomass carbonizer and manually operated biomass briquette machine that can overcome the problems and concerns observed in the old prototype.

The general objective of the study was to develop a carbonized and a biomass briquetting machine which is appropriate for rural communities in Ethiopia with the following s specific objectives: to design and fabricate manually operated biomass briquetting machine, design and construct a carbonized and test its performance, and evaluate the performance of briquetting machine.

Materials and Methods

The assumption features of biomass briquetting machine were produced was that it should be portable and cost-effective, easy to fabricate and duplicate the technology, appropriate for rural communities, and suitable to the domestic stove in size.

Table 64: Technical specifications of the biomass briquetting machine

S. No.	Item	Description	Unit	Quantity
1.	Pipe	0.75 mx 1m	No.	1
2.	Screw	22 m x 5 m	No.	2
3.	Automotive Jack	10 tonnes	No.	1
4	RHS	40 mm x 40 mm x 3mm	No.	1
5	RHS	35 mm x 35 mm x 2mm	No.	1
6	Sheet metal	2 mm x 1 mm x 3mm	No.	1
7	Angle iron	50 mm x 50 mm x 3mm	No.	1

The materials used to produce the carbonized were one iron sheet (2m x 1m), two pipes (0.5 x 1m), and 100 kg gypsum.

Design and Fabrication of Biomass Briquetting Machine

The carbonized and biomass briquetting machine was designed and constructed based on the shape and size (3 cm x 3 cm x 3 cm) of the briquettes to be produced. For this purpose, a mold of the same internal dimension where the raw materials are compressed was constructed. The briquetting machine consists of 49 welded and joined together molds and each mold has a piston at the bottom and a closing metal plate at the top, both of which can withstand the high pressure applied by the jack. The opposite ends of the piston were welded on a flat metal plate placed on a 10-ton capacity hydraulic jack. During operation, the jack drives the pistons in and out of the mold to compress and release the briquettes.

A flat metal plate, 6 mm thick, was hinged to the mold box to cover the open ends of the molds during compaction; and opened during ejection of the briquettes. The vertical motion of the pistons in and out of the molds and the ejection of compressed briquettes from the molds were pressured by the hydraulic jack that is welded on the angle bars on the frame of the machine. By this arrangement, the force from the hydraulic jack is centrally applied to the metal plate bearing the pistons.

Operational techniques of the Biomass briquette Machine

The sample biomass was mixed with the binder and fed into the dies in the compaction chamber and rammed until they are full. The lid of the machine was then closed and screwed to the position. The hydraulic jack which was under the base plate was used to lift the plate assembly carrying the transmission rods, which then pushes the piston against the mixture inside the various dies of the compaction chamber. The mix is thus compacted against the lid of the machine. The mix was then left to set for about five minutes after which the lid of the machine is opened and the briquettes were then ejected.

Design and fabrication of carbonizer

The designed carbonizer or charring kiln is an open type carbonizer which is a portable cylindrical structure with an opening at the top for loading the dry biomass and sealed at the bottom. It is composed of three parts, namely the chimney, the central cylinder, and the air inlets. The wall of the drum is gypsum filled double layer. The internal wall is made up of 6mm thick metal sheet and the external wall is made of 1mm thick metal sheet. A 100 cm long chimney is attached with a metal plate which placed on the top of the central cylinder. The drum capacity is about 50 kg of biomass. The drum size is about 1 m in height and 70cm in diameter. The drum has 12 tubular hollow extensions at the side in a symmetrical arrangement in three stages for regulating the air for generating the required thermal energy for the carbonization process**.**

Operational techniques

The collected biomass was loosely loaded into the cylindrical kiln. After loading the biomass into the kiln, the top of the kiln was closed with metal plate attached to a conical chimney. Use little amount of biomass was used in the firing portion to ignite in the kiln and the doors were tightly closed to start the pyrolysis process.

At the start of carbonization process, the air was supplied via temporarily uncovered large opening from the top and opening on the kiln lateral walls. The kiln chimney also served as a removal of smoke from the kiln. Kiln temperature was controlled by regulating the air supply. The air supply was regulated by closing the air- port opening by commencing from the bottom zone to the uppermost zone of the drum step by step. When glowing of biomass was observed through ports, the first pair of ports at the bottom of kiln was sealed. This stepwise procedure was followed until all airports were sealed, at which time carbonization was generally completed (~3hrs). When a temperature was reduced to the surrounding temperature, the kiln was opened and char yields were removed. The resultant char powder was used for the preparation of briquettes.

Results

A carbonizer and biomass briquetting machine suitable for the production of biomass briquettes on a small scale with a good production capacity was developed and successfully used in the production of biomass briquette. The briquetting machine had an overall width of 50 cm, a height of 1m and a mass of 25 kg. The produced briquetting machine was portable and cost-effective, easy to fabricate and duplicate the technology, appropriate for rural communities, and suitable to the domestic stove in size, with an estimated production cost of 6,000 ETB in 2019, which is much lower than the market price for imported ones(personal communication).

Figure 94: Manually operated biomass briquette machine

Forty nine briquettes were successfully produced for one completely filled hopper. Each briquette has 3 cm dimension in length, width and height and this size of briquette is suitable for use in domestic stove. Some of the produced briquettes are shown in figure 95.

Figure 95: Produced biomass briquettes

The designed and fabricated carbonizer is portable and easily movable to sites where raw materials are located. The complete carbonization process took about 3 hours. The cost of fabrication is low (etimated cost 1,000 ETB in 2019) and it is easy to operate (Figure 96).

Figure 96: Produced carbonizer

Conclusions

The design and fabrication of carbonizer and manual operating biomass briquette machine that can produce 49 briquettes at a time using biomasswasdesigned and constructed. Moreover,the briquetting machine is technically and econimocally feasible; so it will be useful to small and medium scale briquette manufacturers.In addition to water hyacinth, rice husk, and other agricultural wastes and residues can be used to produce briquette using this machine.It has greater importance to developing countries like Ethiopia as it addresses the issues surrounding the efficient utilization of abundant quantities of agricultural wastes and residues which make a significant impact as fuel for rural communities.

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Plastic Wastes as a Raw Material in the Concrete Mix: An Alternative Approach to Manage Plastic Wastes in Developing Countries

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Abstract

The twenty-first century can be marked as a "plastic era" where different sectors are producing and consuming a huge amount of plastic. Concurrently, the plastic waste generation rate has been increasing and causing serious problems for public health and ecosystem. Hence, recycling of plastic wastes can be one alternative management option for this peculiar waste stream. This study aims to evaluate the technical feasibility of plastic wastes as a partial replacement of coarse aggregate in a concrete mix using volcanic pumice as an admixture. Concrete test specimens prepared with standard M20 mix design were measured for a compressive and split tensile strength. Plastic aggregate made from plastic bags and bottles has shown a different degree of workability to replace the concrete mix. The compressive and split tensile strength tends to decrease with increasing the ratio of plastic aggregates for both types of plastics. However, the curve based operational cut-off value shows that the plastic bag and bottle aggregates can replace coarse aggregate from 11-14% and 35-37.5% respectively. Conclusively, utilizing the plastic aggregates as a partial replacement of coarse aggregate is technically feasible. However, applying the nominal concrete standard mix proportion is seemingly inappropriate while plastic aggregates are used as an aggregate which in turn require a specific mix design. Despite the percent replacement is low, utilizing waste plastics in the concrete mix would help countries with the weak waste management system.

Keywords

Coarse replacement; Operational cut-off value; Plastic bag aggregate; Plastic bottle aggregate

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Occurrence and distribution of PCB in urban soil and management of old transformer dumpsite in Addis Ababa, Ethiopia

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Abstract

Polychlorinated Biphenyls (PCBs) are Persistent toxic substances with a high potential to accumulate in the soil as an organic pollutant and bioaccumulate in human tissues. In the current study, conducted in 2019, 45 composites (0–20 cm) soil samples were collected from 9 sampling sites that are situated in an area that is being used as a maintenance workshop and dumpsite of transformers in Addis Ababa, Ethiopia. The extraction and cleanup of samples were done using Accelerated Solvent Extraction (ASE) with Pressurized Liquid Extraction (PLE). The analysis was done using GC/MS to determine levels and distribution of PCBs, and a checklist was used to assess the existing management practice of the site. The data were analyzed by SPSS version 20 and Origin pro 9.1. The result of the 18∑PCBs concentration is 17.16 mg kg^{-1}. The range (in dry weight) of 18∑PCBs, Dioxin-Like (DL) 12∑PCBs, and Non Dioxin-Like (NDL) 6∑PCBs, is 1.027 to 4.862; 0.561 to 1.603; and 0.166 – 4.5 mg kg^{-1}, respectively. The most dominant congeners are lower chlorinated PCBs. The distribution of total PCBs concentrations was found to be different in the entire sample tested but with a similar congener's pattern. Transformers and capacitors were observed to be improperly dumped in open fields, a condition that directly exposed them to the severity of rain and sunlight. The Soil surface around the transformer area had cracks, and burnt which is an indication of the degree of pollution of the soil. There is poor management in handling of oil and equipment containing PCBs. It was observed oil was leaking from transformers and barrel, and oil tankers to the open space which may cause leachate. Projects must be initiated to remediate the soil in the area to ensure a healthy and sustainable future for all. It will be necessary to organize training programmes for workers at the sites on the safe handling and disposal of PCB related materials.

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Detection of Organochlorine Pesticide Residues in Lake Ziway and Health Risk Assessment

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Abstract

Organochlorine pesticides (OCPs) are chlorinated hydrocarbons extensively used for agriculture pest control and mosquito control from 1940s to 1960s. The use of OCPs for the agricultural purpose was banned in many countries including Ethiopia. However, studies show that small-scale farm holders in the central rift valley of Ethiopia use a cocktail of pesticides including banned OCPs. This study was intended to detect the status of (OCP) residues in Ziway Lake, Oromia region of Ethiopia. For this study three commercially important fish species, sediment, and succulent grass samples were randomly collected in replicate. The samples were extracted using USEPA (354 °C) method and the analysis was done using USEPA (8081) method. The health risk assessment was calculated based on USEPA (1996) guidelines while the data analysis was done using SAS 93.2 statistical software. The Laboratory result revealed that Dichlorodiphenyltrichloroethane (DDT) metabolites, ($_{PP'}$DDT and $_{PP'}$DDE) were detected in all three sample types. Accordingly, mean concentrations of $_{PP'}$DDT and $_{PP'}$DDE detected in the three sample types were, 52.08 and 4.67 ng/g in succulent grass, 46.84 and 0.93 ng/g in sediment and 19.83 and 11.17 ng/g in fish samples. Among the three fish species tested, the maximum DDT metabolite residue detected was in Ciprinu scarpio fish spices (35.65 ng/g) while the minimum was in Carassius carassius fish spices (27.05 ng/g). People who regularly consume fish from the lake above estimated mean Ethiopian daily consumption (0.027 kg day^{-1}), level are exposed to DDT while that those consume all species of fish from Lake below the estimated mean, does not expose to a health problem. However, the low $_{PP'}$DDE /$_{PP'}$DDT ratio in sediment and succulent grass sample indicates that there is recent pollution of the lake by DDT. Thus, Eco-system clearance from obsolete pesticides and control of illegal band organochlorine pesticide movement has to be given due attention.

Keywords: Organochlorine pesticide, Fish, Bio-accumulation, Health risk

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Section 5: Ecosystem Managemet Research

Wetlands ecosystem service in terms of economic values: A case of Lake Hawassa, southern Ethiopia.

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Abstract

Wetlands are one of the most productive ecosystems that play a significant role in providing multiple ecosystem services. However, this resource has received less attention in national and regional planning. Hence, the objective of this study was to figure out the socioeconomic contribution of Lake Hawassa for the local and national economy and to call for the concerned body to take appropriate measures to rescue the lake from further degradation. A total of 164 households were selected randomly from each kebele for a questionnaire survey. .Then, the data were analyzed using descriptive statistics, ANOVA, and linear regressions model. The result showed that the livelihood income strategies of the majority of the households were from irrigation (54.8%), rain-fed (33.8%), livestock (6.5%), fishing (3.5%), off-farm seasonal work (1.2%) & others (0.2%). The average annual total household income was 53,716.39ETB and out of this, lake income constituted 59.7% of the total income. The income contribution of Lake Hawassa for local households within selected kebeles was significantly different by livestock, watering pasture for grazing animals, and water for washing body or clothing. Other parameters adid not reveal significant differences among the five kebeles for all the parameters analyzed. Overall result confirmed that the Lake contributed significantly to the household economy of the local people and hence, it is important to protect and improve the management of the lake and its wetlands for livelihood enhancement, while also securing their long-term ecological functions.

Keywords: degradation; driving factor; ecosystem service; household income; livelihood strategies; restoration; wetland

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Succession of Woody Plants with the Recession of a Saline Alkaline Lake Abijata in Central Rift Valley of Ethiopia

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Abstract

The present study aimed at assessing the different woody plant species that are succeeding in a recessed saline-alkaline lake area. To achieve the objectives, a total of 45 sample plots that had an area of 20 m * 20 m were laid out in three different directions of the Abijata Lake, and vegetation and soil (EC and pH) data were collected. One-way ANOVA, multiple regressions, and Pearson's correlation were used to analyze the data, and means were separated at 0.05 level of significance. The results indicated that five species were recorded in the previously lake area, and the dominant species that grow in the recessed part of the Lake was *Vachellia tortilis* (also known as *Acacia tortilis*). ANOVA indicated significant differences on the number of woody stems per plot in the different recessed part of the Lake whereas there was no significant difference in diversity (H') with an aspect of the Lake (There was no significant relationship between soil EC and the number of species recorded in each plot, the number of tree stems/ plot and also the diversity of species/plot while there was a significant relationship between soil pH and the number of species recorded in each plot, the number of tree stems/ plot and also the diversity of species/plot. Because *V. tortilis* exhibited tolerance to the high alkaline conditions, it can be used for landscape restoration purposes in such areas.

Key Words: Saline Alkaline; Abijata Lake; Woody Plants; Succession

Introduction

Land use land cover (LULC) changes are major environmental challenges in many parts of the world which are adversely affecting ecosystem services (Elias, 2018). Like in many other countries of the world, in Ethiopia, there has been a considerable LULCchange in different parts of the country, which is driven by environmental and social factors (Abera, 2016; Girmay*et al*., 2010; Gong *et al*., 2015). The Ethiopian Central Rift Valley is characterized by a chain of lakes and wetlands with unique hydrological and ecological characteristics. Increasing population pressure and economic developments put an increasing claim on the precious freshwater resources. Population pressure during the last three decades has resulted in the conversion of natural vegetation, overgrazing of natural grasslands, removal of natural shrub for firewood and clearing of forests for construction material (Abera, 2016). Until recently, water from the lakes mainly supported agriculture and commercial fishery, domestic use, industrial soda extraction and recreation, while the lakes and surrounding wetlands supported a wide variety of endemic birds and wild animals (Abera, 2016). The fastly growing water use and land degradation resulted in noticeable negative environmental changes for the last three decades (Tessema, 1998; Ayenew, 2004; Legesse*et al*., 2004; Legesse and Ayenew, 2006). Human population growth and resultant agricultural expansion, connected to poverty, government instability, and lack of coordinated planning across governmental sectors are the major drivers of LULC change in the Central Rift Valley and Abijata Lake (Flower, 2011).

The pumping of water from Lake Abijata for soda extraction since 1985 and the utilization of Bulbula and Katar, which are the main feeder rivers of Lake Abijata, for irrigation since the 1970s have resulted in rapid shrinkage of the Lake (Flower, 2011;   Legesse, 2004; Legesse and Ayenew, 2006; Kumsa and Bekele, 2014; Vilalta, 2010). Because of such factors, the surface area of Lake Abijatahas droppeddown from 19,850 ha in the year 1973 to 13,010 ha in the year 2005exhibitinga 46% shrinkage (Tadesse, 2016). Another study also reported that the Lake lost 46 % of its area between 2000 and 2006 (Temesgen, 2013). Elias et al. (2018) in their study showed that the water amount of Lake Abijata reduced by about 26% from its1985's size in the year 2005. Some models indicated that the lake could be reduced to a mere one-meter depth by 2018 from its original depth of 7- 14 meter (Flower, 2011). Overall, the Lake has undergone dramatic environmental change as a result of human-induced factors (Senbeta and Tefera, 2002; Wako, 2009). Some of the observed changes to the lake system include a drop in water level and a reduction in the fish populations in Lake Abijata, and the migrationof formerly resident pelicans from the lakes (Ayenew, 2004).

Generally, the lake is shrinking (so far greater than about 100 km ^{2}) and facing imminent threat and it is seriously impacting the ecosystem and the plants around the lakes (Bewketu, 2010; Seyoum*et al*., 2015; Dadi, 2016; Fetahi, 2016). Because of such shrinkage of the Lake,Temesgen*et al*. (2013) indicated that ecological succession took place between 1973 and 1986 on emerged lands in a horizontal dimension from old to recent image: the succession was observed along the environmental gradient of the retreating lake: emerged bare land, grassland, land with few scattered *Acacia* shrubs and open woodlands. However, the study doesn't show in detail what species are growing and succeeding in the recessed part of the Lake, which is important to understand the ecological dynamics in a semi-arid saline-alkaline Lake area and also for landscape restoration purposes. Recent advances in our understanding of ecological succession are particularly relevant in the current era of rapid global change. For example, land-use change and habitat fragmentation directly affect dispersal, species pool sizes, and priority effects (De Meester *et al*., 2016; Fukami, 2015). Therefore, the objectives of this study were 1) to assess the different woody plant species that are succeeding in a retreated saline-alkaline lake area 2) to identify species that can grow in a saline-alkaline soil which can be used for landscape restoration purposes in similar agroecology.

Materials and Methods

Description of the study area

The Abijata Lake is located in the Abijata Shalla Lakes National Park, 200 km south east of the capital Addis Abeba, in the Oromiya National Regional State. It is geographically located at 7° 33' N – 9°30´. The Lake is a relatively shallow, small, alkaline, and closed (Ayenew, 2002). The study area is characterized by a semi-arid climate with mean annual precipitation of 600 - 620 mm and an annual temperature of 25°C close to the lakes (Legesse *et al*., 2002; Debushe and Itana, 2010). The depth of the Lake ranges from 7.6 to 14.2 (Legesse *et al*., 2002). The area of the Lake was 166 - 180 km^2 while the volume of the lake wasapproximately 750 million m^3 (Hillman, 1993). Lake Abijata is fed by the Horakelo and Bulbula rivers originating from the nearby Lakes Langano and Ziway. The altitude of the

Lake ranges from 1580 m a.s.l. Lake Abijata is a saline, soda-type lake and the water has a pH of around 10 (Gilbert, 2002). The salinity of the Lake water is 16.2 gram/litter (Wood and Telling, 1988; Ayenew, 1998). Between 1926 and 1991, the salinity and alkalinity of the lake increased by a factor of 2.6 and 4, respectively, (Kebede *et al*., 1994). The area of the Lake that was recessed in different years' time is shown in figure 97 (Flower 2011).

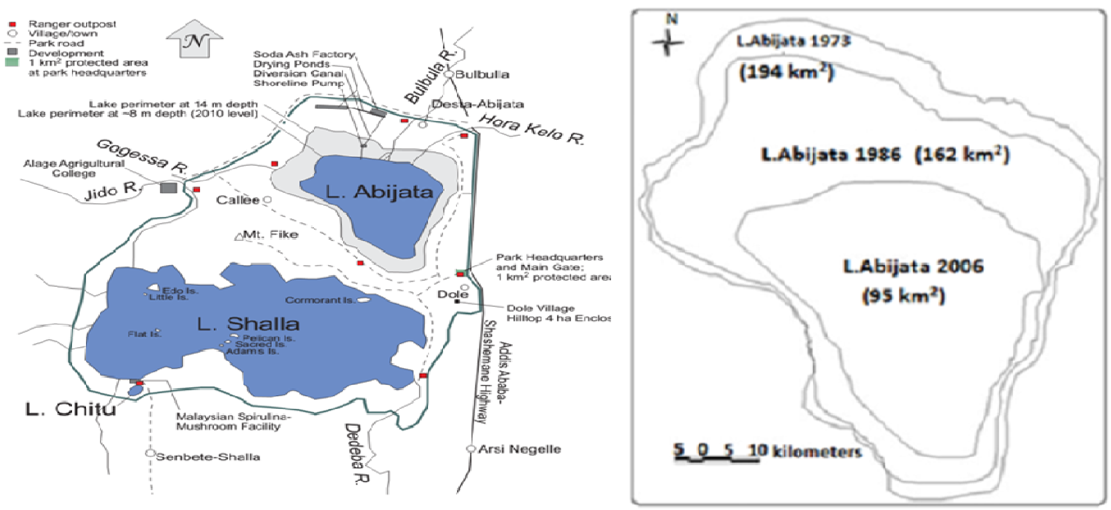

Figure 97: The map of study area

The soil of the Lake is interbedded with pumice and classified as Andosols. They are coarse-textured (loamy sand to fine sand), highly alkaline (pH of 7.6-8.2). It has a low bulk density and hence weaker structure makesitvulnerable to wind and water erosion. Abijata Lake is a highly productive alkaline lake whose muddy shore supports a wealth of birdlife that has a very great biological importance (Legesse and Ayenew, 2006; Ayenew, 2004). The dominant vegetation surrounding the lake is open *Acacia* woodland, which is extensively overgrazed and deforested because of encroachment. The pumping of water from the lake for soda extraction and the utilization of water from feeder rivers and lake Ziway for irrigation has resulted in a rapid reduction in size and level (Legesse and Ayenew, 2006; Ayenew, 2004). Ayenew (2004) reported that the level of the lake has decreased after 1985wherewater abstractions and land-use changes increased dramatically. Since the 1970's, the lake level has dropped about 5m (Alemayehu *et al.*, 2006).

Data collection

The vegetation data were collected in the different directions or aspects of the Lake; that is on the east, south and northern part of the recessed Abijata Lake. For the woody plants data collection (trees and seedlings), a total of 45 sample plots (15 in each direction)withan area of 20 m * 20 m were laid out from the periphery of the Lake towards the centre of the Lake following a transect line. The distance between the two adjacent transects were 200 m and the distance between consecutive plots along a transect line was 200 m.. In each quadrat, all the woody plant species including seedlings and saplings were measured and recorded.. Woody species were identifiedand their diameter at breast height (DBH) was measured using a calliper.. The height of the trees was measured using hypsometer. Seedlings (height < 1 m) data of woody species were collected in the major plot. Species identification in the field (90%) has been based on expert knowledge.

Soil samples were collected at a depth of 0-20 cm at the four corners and the centre of the plot, in each quadratplot independently. The collected samples in each plot (in the four corners and the centre of the plot) were mixed up to make composite samples and kept independently. The soil samples were analysed in the soil Laboratory independently, and pH and EC were measured with pH and EC metres, respectively.

Method of data analysis

The Shannon-Wiener Diversity Index (H′) was used to determine the diversity of species in the recessed part of the Lake .

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

where S is the number of species, pi, the proportion of the individual species to the total, ni / N

The equitability (evenness) of species in was calculated using H′/H′max, where H′max is ln (natural logarithm) of S (number of species).

One- way ANOVA was used to compare the species diversity (H′), the number of species per plot and the number of woody stems perplot in the different aspects of the recessed part of the Lake. The normality distribution of the data was evaluated before analysis, and for those variables that have significant differences, their mean separation was performed using Fisher’s least significant difference (LSD) test at a significance level of p=0.05. Multiple regression analysis was used to assess the effect of soil EC, and soil pH on the distribution of the woody plants. For the ANOVA analysis, for the correlation and regression analysis, the Sigma Plot 13 (Systat Software, Inc., San Jose, CA, USA) program was used.

Results

Diversity and density of tree species

The total diversity of tree species in the recession part of the Lake was H'= 0.42, while the species evenness was 0.26. A total of five tree species that belong to the Fabaceae family were recorded in the study area. The identified species that are succeeding the former lake area were *Senegalis enegal*,*Vachellia seyal*, *Vachellia tortilis*, *Pterolobium stellatum*, and *Vachellia etbaica.* The number of tree species recorded in different aspects, where the lake was recessed is presented in figure 98 and the result indicated the number of species in the eastern aspect of the lake was greater than the number of species in the north and south aspect of the lake. However, the ANOVA test result revealed no significant differences in the number of species recorded in the different aspects of recessed lake (p=0.82). Similarly, the diversity of species (H') recorded in different aspects of the lake is presented in figure 98, and the result indicated that the diversity of tree species (*H'*) in the Eastern aspect of the lake is greater than the diversity of species recorded in the southern aspect and also the northern aspect of the recessed part of the lake (Figure 98). Despite this, the ANOVA test result indicated no significant differences in the diversity (H') of species recorded in each plot in the different aspects of the lake (p= 0.25).

The number of trees/ha in the recessed part of the lake in the Eastern aspect of the lake was greater than that of the number of trees/ha in the south and northern aspect of the lake (Figure 98). The ANOVA test result showed significant differences on the density of species recorded per plot in the different aspects of the lake (p= 0.039), and the significant differences were on the number of woody stems recorded between the Eastern and northern aspect of the lake while there were no significant differences on the number of tree stems/plot between the eastern and southern aspect and southern and northern aspect of the lake.

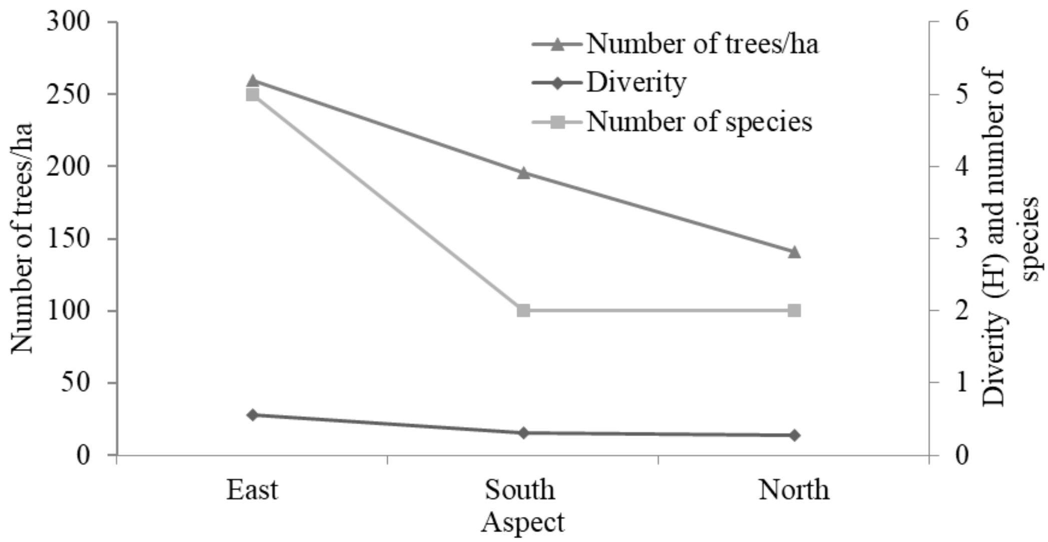

Figure 98: Mean number of trees/ha, number of species/ha, diversity in different aspects of Lake Abijata

The mean number of trees/ha of *Senegali senegal, V. seyal, V. tortilis, V. etbaica* and *P. stellatum* were 1, 44, 350, 1 and 2, respectively (Figure 98). The results on the density of different tree species from the control point (where there was no lake) towards the recessed lake is presented in Figure 98. The results indicated that at the periphery (starting point) of the lake, *S. sengal*, *V. sayal, V. tortilis, Pterolobium stellatum* and *V. etbaica* had an average tree density of 3 stems/ha, 67 stems/ha, 272 stems/ha and 6 stems/ha, respectively. *V.*seyal and *V. toritils* and *V.*etbaica were recorded at 200 meters away from the periphery of the lake, and their density were 44 stems/ha, 311 stems/ha, and 3 stems/ha, respectively. At 400 meter, 600 meters and 800 meters away from the periphery of the lake (control point) towards the centre of the lake, only the species of *V. toritils* was recorded and its density was 264 stems/ha, 25 stems/ha, and 3 stems/ha, respectively. The density of trees/ha in different directions of the lake was 260 stems/ha, 196 stems/ha and 141 stems/ha in the east, south and north direction of the lake, respectively. The result also indicated that the EC of the soil and alkalinity of the soil increases as we go from the periphery of the lake towards the centre of the lake (Figure 99).

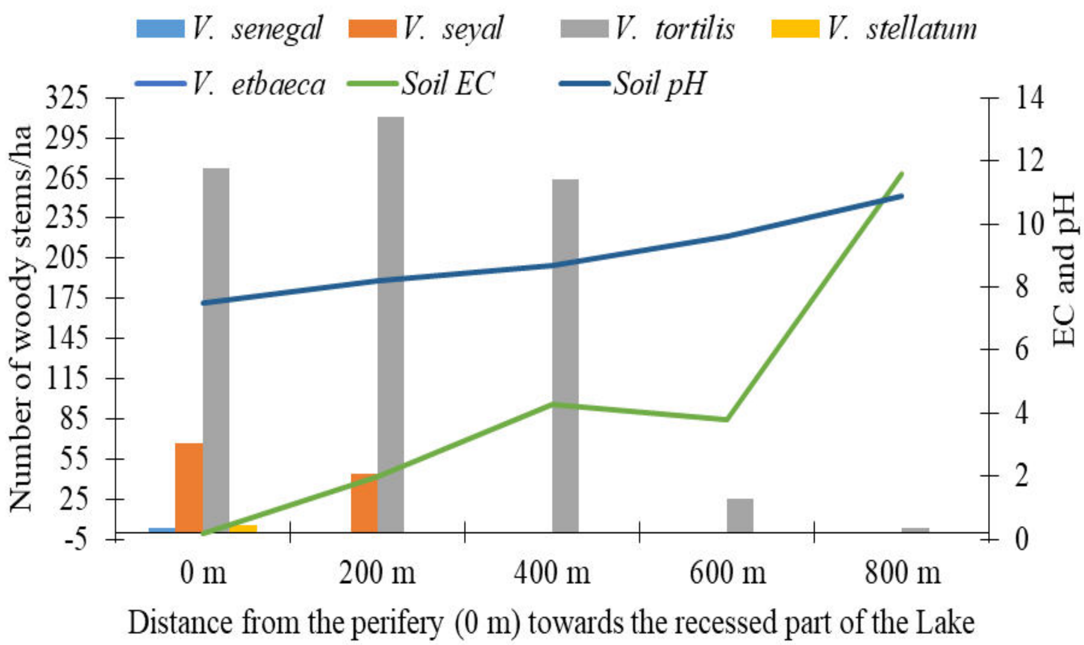

Figure 99: Mean number of individual species woody stems/ha recorded in different distances of the recessed part of the lake, from the periphery towards the lake and soil EC and soil pH at different distances of the lake

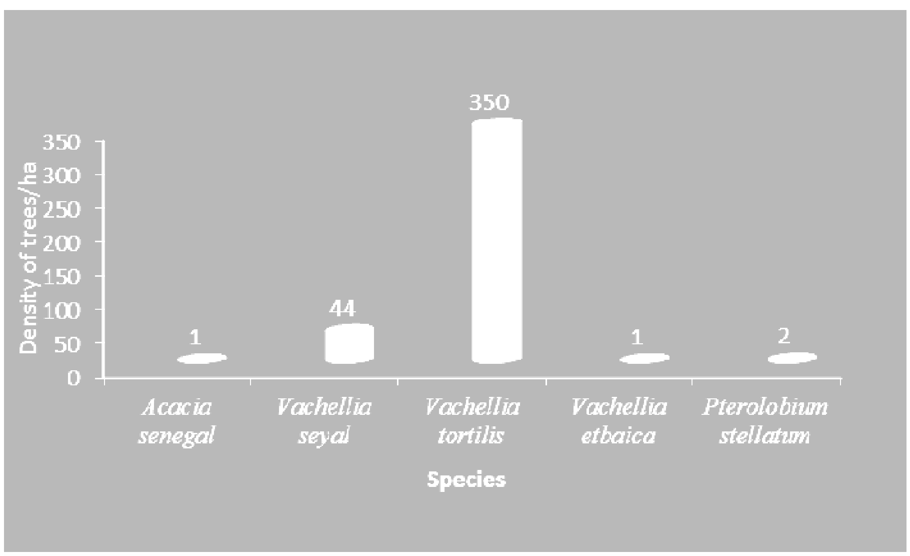

Figure 100: Number of recorded trees/ha for the different species

Vegetation structure

The vegetation structure of the woody plants that are succeeding in the saline-alkaline lake is presented in figure 101. The diameter class and height classdistribution result indicates that as the diameter and height classes increases, the relative density of woody plants decreased. The relative density of trees in the diameter classes of 0-4 cm was 58% while in the diameter classes of > 20 cm was 5.6% (Figure 101) The diameter class and the height class distribution of *V. tortilis* and *V. seyal* is presented in figure 101. The results indicated that as the diameter and height classes increases the relative density of trees of *V. tortilis* and *V. seyal* decreases. The relative density of *V. tortilis*and *V. seyal* in the diameter classes of 0-4 cm was 58% and 58%, respectively. While, the relative density of *V. tortilis* and *V. seyal* in the height classes of 0.5-1.5 meter was 37.5% and 23.1%, respectively.

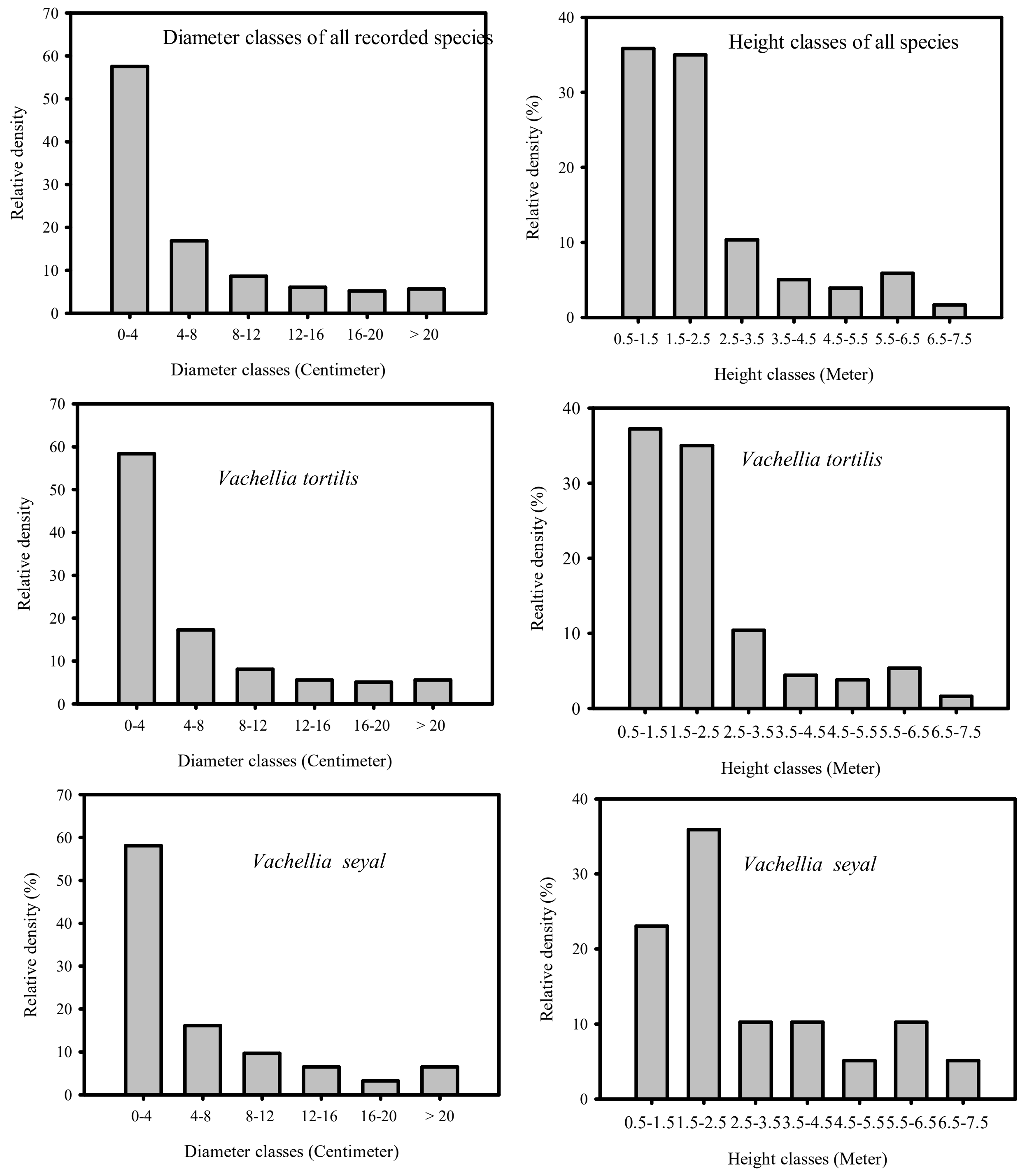

Figure 101: Vegetation structure of the different woody plants recorded in the study area

Effect of Soil EC and Soil PH on the Succession of Woody Plants

The multiple regression analysis results on soil pH with that of the mean number of trees/plot, the mean number of species/plot and mean diameter at stump height (DSH) (30 cm above the ground) / plot is presented in figure 102. The results indicated that the soil pH and the mean number of trees/plot, the mean number of species/plot and mean diameter DSH/plot hadnegativesignificantassociations with the pH of the soil ($p<0.05$). As indicated in figure 103, the soil EC and mean the number of trees/plot, the mean number of species/plot and mean diameter DSH/plotdid not have significant associations with the EC of the soil ($p > 0.05$).

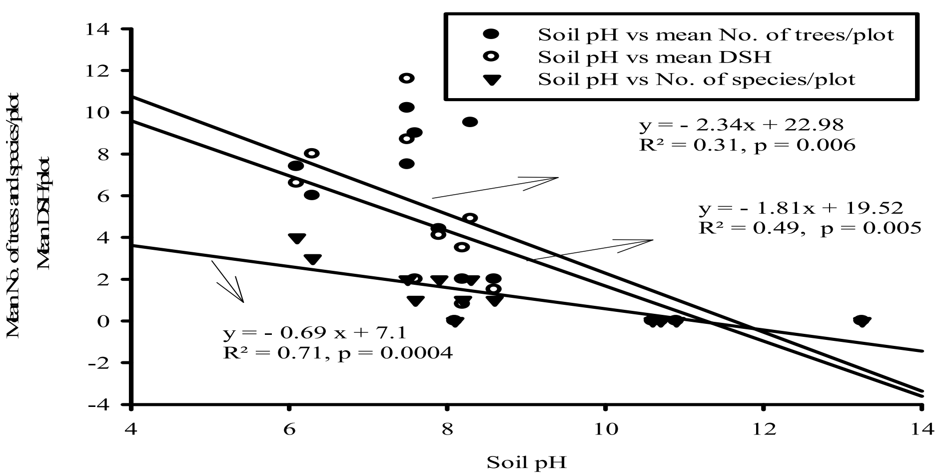

Figure 102: Multiple regression analysis results on the correlation between soil pH, with that of the mean number of woody stems /plot, mean number of species/plot and mean diameter at stump height (DSH) / plot ($p=0.05$)

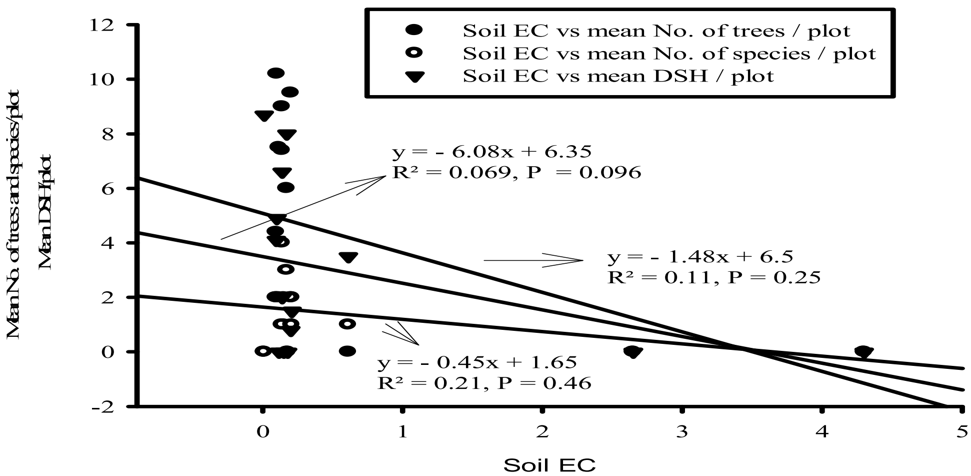

Figure 103: Multiple regression analysis results on the correlation between soil EC, with that of the mean number of trees/plot, the mean number of species/plot and mean diameter at stump height (DSH) / plot (p=0.05)

Discussion

The present study finding indicated that in the Lakes retreated area, ecological succession is taking place. The study indicated that the major tree/shrub species grown in the lakes retreated area were *S. senegal*, *V.seyal*, *V. tortilis*, *P. stellatum*, and *V. etbaica*. This result could show that only very few woody plants are succeeding in the retreated lake area. The differences observed on the density of woody plants/ha as we go from the periphery towards the retreated lake area could be associated with the salinity and pH nature of the soil. The pH of Lake Abijata is 10.1 categorized as an alkaline lake and the salinity of the lake water is 16.2 gram/litter (Gebremeskel, 2016; Kebede and Hillman, 1988). The higher density of trees/ha of *V. toritils* in the retreated area of the saline-alkaline lake could be associated with the salt tolerance nature of the species as compared with other species. Orwa *et al*. (2009) indicated that *V. tortilis* is drought resistant, can tolerate strong salinity and seasonal waterlogging. This result could also show that *V. toritilis* can grow in saline-alkaline soils and the species could be used for restorationof such area. The distribution of other identified woody species is limited and it could also be associated with dispersal limitation (Makoto and Wilson, 2016), species pool effects (Li *et al*., 2016) andpriority effects (Fukami, 2015).

The present finding also indicated that as we go from the periphery of the Lake towards the centre of the Lake, the EC and pH of the soil wasincreasing while the diversity and density of trees were decreasing. This result could indicate that in Abjiata Lake area, succession of woody plants might be influenced by the salinity and alkalinity of the soil and also the different factors that affect seed dispersal, seed germination and survival in the harsh environment. Xi *et al*. (2016) in their study found that salinity was the main driving forcethat controlled the distributions of plantfor ecosystem succession. Prach*et al*. (2007) in their study showed that pH and climate were the environmental variables significantly affecting the vegetation patterns in the course of succession. Understanding vegetation colonization patterns and soil properties can inform evaluations of environmental quality and should be considered when making management decisions about recently disturbed areas (Engel *et al*., 2014). Generally, the results indicated that dueto the retreat of the Lake, *V. tortilis* is becoming the dominant species growing in the alkaline saline soil. This could show that if projects intended to restore the watershed of the Lake Abijata, *V. toritilis*can be considered as one of the species to be planted. As a conclusion, the present study result indicated that while the Lake is retreated, woody plants are following it and unless some management are undertaken to restore the ecosystem,Lake Abijata will be changed into an Acacia dominated woodland, and the Lake could become a history.

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Section 6: Socio-economics, Policy, Extension and Gender Research

Comparing Income Contribution of Avocado and African Custard-apple Based Agroforestry for Smallholder Farmers in Jimma Zone, Ethiopia

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Abstract

In the Southwest parts of Ethiopia, it is common to see farmers planting different varieties of tropical fruit, abundantly Avocado and African custard apple in their homestead farmland. The objectives of this study were to assess the income contributions of two dominant fruit trees based Agroforestry and the major determinate factors to manage the system. Two *Woredas*, namely *Mana* and *Seka Chekorsa* were purposively identified and representative three *kebeles* were selected based on potential Avocado and African custard apple fruit production. Using non-proportional sampling a total of 276 (138: African custard apple and 138: Avocado practitioners) sample household heads were randomly selected. A multinomial logistic regression model was employed to analyze the determinants for selected system management and an independent t-test was used to evaluate the income contribution of vegetables + fruits. To gather the necessary information both primary and secondary data's were collected. The result showed that the mean total gross annual income of African custard apple and Avocado based agroforestry practitioners from vegetable production was 7,372 ETB ha^{-1} yr^{-1} and 5,859 ETB ha^{-1} yr^{-1}, respectively. The income obtained from Avocado and African custard apple contributes 20 and 6 per cent, respectively, to the income of agri-horticultural system. Access to extension service and total livestock holdings were positive and significant independent variables influencing each practitioner to obtain the highest gross annual income. In order to maximize the benefits from the system, introduction and dissemination of the new varieties of Avocado and African custard apple with the continuous extension service is paramount. Besides, land users are advised to follow integration of fruit trees in their food production activities incorporating their own farm resources to minimize input costs.

***Keyword**: Agri-horticulture system; Avocado and African custard-apple fruit, income contribution*

Introduction

Fruit-tree-based agroforestry involves intentional, simultaneous association of annual or perennial crops with perennial fruit-producing trees on the same farm unit (Bellow *et al*, 2008). Trees grown on farms for their non-timber forest products such as fruits, nuts, and spices are the basis for many vibrant and sustainable farming systems. Farmers have preferred fruit-producing species than other trees for on-farm planting (Franzel *et al.,* 1996) and have appreciated the dual contributions of food for consumption (Salam *et al*., 2000) and the potential for income generation (Ayuk *et al*., 1999). Fruit trees are considered advantageous because of the relatively high returns to labor resulting from low labor inputs (compared with annual crops). Moreover, fruit tree-based systems also offer a more uniform distribution of income throughout the year than annual crop systems.

Nevertheless, the system performance also follows some general characteristics such as their potential benefits and limitations that are applicable to wider regions (Bellow *et al*., 2008). Successful establishment of fruit-based agroforestry system can increase farm household income, enrich their diets with essential minerals, vitamins and increase varieties of fruits available in the local markets. Promotions of on-farm tree/shrub plantings could also greatly relieve the pressure on the remnant natural forest by providing the variety of forest products (Negussie, 2004). However, the relatively "free" availability of forest-based timber and fuel wood products in some areas are seen as disincentives for growing tree species for those purposes (Hellin *et al*., 1999).

In the south west part of the country, it is common to see farmers planting varieties of tropical fruit, abundantly Avocado and African custard apple. They integrate fruit trees with vegetables, *Khat* and Coffee plantations in the homestead farmland. Despite the integration of common and favorable fruit trees in the area, yet knowledge on the income contributions and the various determinant factors in the management of fruits was not well identified. Thus, the objective of this study was to assess and compare the income obtained from Avocado and African custard apple based agroforestry system for smallholder farmers in Jimma Zone of Ethiopia.

Materials and Methods

Description of the study area

Seka Chekorsa is one of the Woredas in Jimma Zone, Oromia Region, Ethiopia. It is bordered on the south by the Gojeb River, which separates it from the Southern Nations, Nationalities and Peoples Region, on the west by Gera, on the northwest by Gomma, on the north by Mana, on the north east by Kersa, and on the east by Dedo. The altitude of this Woreda ranges from 1,580 to 2,560 meters above sea level (Figure 104); perennial rivers include the Abono, Anja, Gulufa and Meti. Coffee, khat, peppers, fruits and teff are important cash crops in the Woreda. For example, in this Woreda over 50 square kilometers are planted with coffee crop. According to the 2007 national census report, a total population for this Woreda was about 208,096 of whom 104,758 were men and 103,338 were women. From the total population, 3.38% of the population was urban dwellers (CSA, 2007).

Part of the Jimma Zone, Mana is bordered on the south by Seka Chekorsa, on the west by Gomma, on the north by Limmu Kosa, and on the east by Kersa. The administrative center of this Woreda is Yebu. The landscape of Mana includes mountains, high forests and plain divided by valleys. A survey of the land in this Woreda shows that 89.1% of the land is arable or cultivable (86.1% was under annual crops), 2.7% pasture, 2.8% forest, and the remaining 5.4% is considered swampy, degraded or otherwise unusable. Khat is an important cash crop in this Woreda. Coffee is another important cash crop for this Woreda and over 5,000 hectares are planted with this crop. The 2007 national census reported a total population for this Woreda of 146,675, of whom 74,698 were men and 71,977 were women; about 3% of its population were urban dwellers (CSA, 2007).

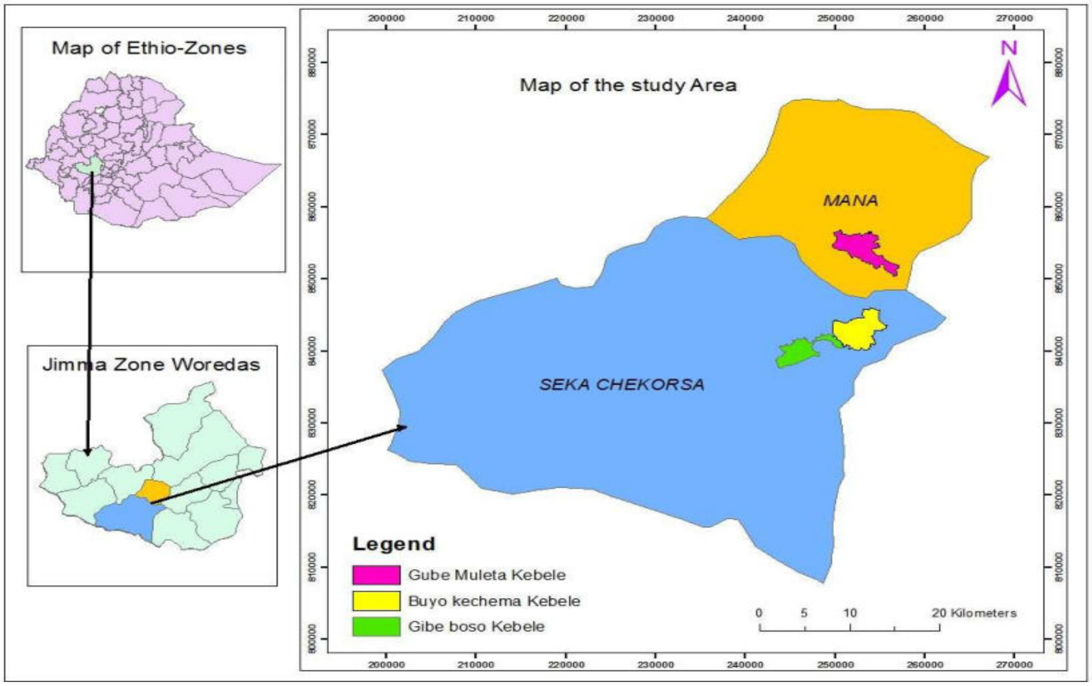


Figure 104: Map of the study areas

Sampling methods, techniques and size

To obtain information on the potential fruit producing areas of the Zone consultation with the Zone, Woreda and Kebele, office of Agriculture and Natural Resources, based on their administrative hierarchy was made. Two Woredas, Mana and Seka Chekorsa were identified and three representative kebeles namely Gube Muleta (from Mana Woreda), Buyo Kechema and Gibe Boso *(*From Seka Chekorsa Woreda*)* has been selected based on the potential of Avocado and African custard apple fruit production.

In Jimma Zone, it is considered as a culture to plant fruit trees in the farmland; this makes uneasy to find the exact household head number of Avocado and African custard apple practitioners separately. As it was observed during a transect walk almost all farmers planted trees in their farmland. Thus, a total of 276 (138: African custard apple and 138: Avocado practitioners) sample household heads were purposefully selected.

In consultation with the study areas elder people, household heads (HHHs) were divided into three income categories. Household heads with total annual income from 0-9,999 categorized as small income, 10,000-19,999, medium income, and above 20,000 as high income HHH.

Using the three categories as dependent variables with the seven explanatory variables, the various determinant factors that affect the annual income of practitioners, were analysed using the multinomial logistic regression model. This attempts to model the relationship between two or more explanatory variables and a response variable. To meet the objectives of the study, both descriptive and econometric analysis was employed. Every value of the independent variable "X" was associated with a value of the dependent variable "Y". The population regression line for p explanatory variables $x_1, x_2, ..., x_p$ was defined to be:

$Y=\beta_0 + \beta_1 x1 + \beta_2 x2 + ... + \beta_p xp$. This line describes how the mean μ_y response changes with the explanatory variables. The observed values for "y" varied about their means "μ_y" and were assumed to have the same standard deviation. The fitted values $b_0, b_1, \ldots, b_p$ estimated the parameters $\beta_0, \beta_1, \beta_p$ of the population regression line (Gujarati, 2004).

Variables used in the empirical model and hypothesized effects

Dependent variables: In this study, the income from Avocado and African custard apple fruit-based agroforestry (AF) system was used as a dependent variable.

Independent variables: It was hypothesized that farmers' annual income from African custard apple and Avocado based agriculture has been influenced by the combination of various factors. All the independent variables assumed to be influenced by the dependent variables are given below in table 65.

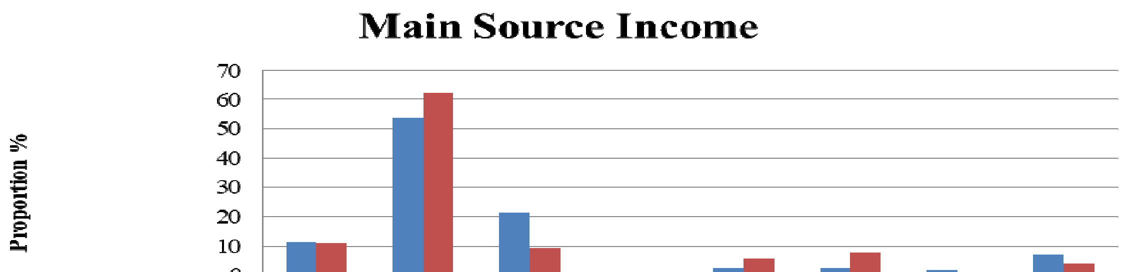
Table 65: Independent variables and expected signs

Variable code	Description	Unit of measurements	Expected sign
Income	Annual income fromAvocado and African custard apple fruits	Amount of Income (ETB)	Dependent variable
TLAHOLD	Total Land Holding	Size of Land	+
EXTEN	Access to Extension	1=Yes, 0=No	+
EDUCATION	Formal Education level of HHH	Years of formal Education	+
MARKETDIS	Market Distance	Distance in km	-
AGE	Age of household head	Measured in years	-
TLU	Total Number of Livestock	Livestock in TLU	+
DISEPES	Disease and pest	1=Yes, 0=No	-

The data obtained from all respondents were considered in the multinomial analysis. The above explanatory variables (X_i) were included in the model as TLAHOLD, EXTEN, EDU, MARKETDIS, AGE, TLU and DISEPES.

Results and Discussion

In the study area, agricultural activities are the most important source of income. Thus, among the total sampled households, 53.8 per cent of Avocado and 62.2 per cent African custard apple practitioners rely on coffee production. 21.2 per cent of Avocado and 9.4 per cent of African custard apple practitioners rely on crop production (Figure 105).



	Khat production	Coffee production	Crop production	Livestock production	Vegetable + fruit trees	Off-farm income	Remittance	Khat + coffee production
Avocado	11.4	53.8	21.2	0.8	2.3	2.3	1.5	6.8
African custard apple	11	62.2	9.4		5.5	7.9		3.9

Figure 105: Various income sources of sampled households

Households' financial return from homestead farmland

Smallholder farmers in the study area plant various vegetables in integration with Avocado or African custard apple tree and use the product for household consumption and/or as an income source. The mean annual production (in quintal) and income from vegetables and the fruits (in ETB) are summarized in Table 66 and 67.

Table 66: Households total income (ETB) per annum per hectare from the homestead farmland in Jimma Zone

	Avocado		African custard apple		
Vegetables	Mean per annum income	n	Mean per annum income	n	t-value
Onion	66	2	360	8	-1.807*
Tomato	1115	19	935	18	0.422
Cabbage	83	2	89	3	-0.064
Garlic	243	9	240	9	0.024
Chili	1953	35	1622	26	0.519
Potato	420	8	2241	15	-1.872*
Kale	1978	33	1884	30	0.179
Khat	12023	69	17379	77	-1.329
Coffee	27691	87	37850	105	-1.275
Enset	3672	31	6241	38	-1.645
Avocado and African custard apple fruit	12284		4017		
Total	61528		72858		5.11***

Source: Own survey; 2018

As shown in table 67, both African custard apple and avocado fruit based agroforestry practitioners obtained higher income from Coffee, *Khat* and *Enset*. The gross per annual income from Avocado and African custard apple fruit was 12,284 and 4017 ETB ha^{-1} $year^{-1}$, respectively. There was a positive and significant gross annual income difference at 1% level of significance with t value of (t = 5.11). Besides, Avocado and African custard apple fruit contributed around 20 and 6% of the total household heads (HHH) income, respectively.

Table 67: Avocado and African Custard apple based agroforestry Practitioners mean total gross annual income from all vegetables in Jimma Zone

Fruit type	Mean	SE	t-value
Avocado	5,859	1,155	-0.78*
African custard-apple	7,372	1,530	
Total	13,231		

Source: Own survey; 2018

As shown in table 67, the mean total gross annual income from African custard apple based agroforestry practitioners from the whole produced vegetables was 7,372 ETB ha^{-1} yr^{-1} and Avocado based agroforestry practitioners 5,859 ETB ha^{-1} yr^{-1}. An independent sample t-test was carried out to compare the mean gross annual income difference, There was negatively significant gross annual income difference between the two practitioners, p = 0.1.

Income determinants of African custard apple and Avocado based agroforestry system

Based on the gross income obtained from the African custard apple and Avocado based agroforestry system, the independent variables were identified to explain factors influencing practitioners to obtain the highest gross annual income.

Table 68: Determinants factors for the management of the two land uses based on the income group in Jimma zone

Income type	Independent variables	B	S.E.	Wald	Df	Sig.	Exp(B)
Medium	Intercept	-32.527	1.208	724	1	0.000	
	Education	-0.031	0.049	0.396	1	0.529	0.97
	Age	-0.015	0.013	1.385	1	0.239	0.985
	Land holding	-0.023	0.054	0.185	1	0.667	0.977
	TLU	**.146***	**0.076**	**3.697**	**1**	**0.055**	**1.157**
	Access to extension	**1.245*****	**0.474**	**6.9**	**1**	**0.009**	**3.474**
	Disease and Pest	0.149	0.479	0.096	1	0.756	1.16
	Market Distance	0.003	0.014	0.05	1	0.826	1.003
High	Intercept	-43.962	1581	0.001	1	0.978	
	Education	0.052	0.067	0.603	1	0.438	1.054
	Age	0.012	0.017	0.532	1	0.466	1.012
	Land holding	-0.015	0.032	0.223	1	0.637	0.985
	TLU	**0.421*****	**0.092**	**21.03**	**1**	**0.000**	**1.523**
	Access to extension	13.779	226.9	0.004	1	0.952	9.635
	Disease and Pest	-12.704	324.7	0.002	1	0.969	0.033
	Market Distance	-0.009	0.028	0.101	1	0.750	0.991

Out of the seven explanatory variables included in the model, two of them were found to be significant. Access to extension service and total livestock holdings were significant independent variables. Making the low income category as a reference, keeping other factors constant as access to extension increased, the income obtained from the homestead AF increased by a factor of 1.25 for the medium income categories. A wide range research was conducted to assess the impact of extension on households' welfare in Ethiopia which showed that extension program had a large positive impact on household welfare increasing income with about 10 percent and on investment but have not impacted on income diversification (Kidanemariam, 2014). In agreement with this finding, the present study revealed that, keeping other factors constant, as TLU increased by one unit, the income obtained from homestead AF were increased by a factor of 0.146 and 0.421 for the medium and high income categories.

Conclusion and Recommendation

From the result discussed above, it can be inferred that practitioners of African custard apple based Agroforestry obtained the higher gross annual income from the overall system than Avocado based Agroforestry practitioners. Both practitioners obtained the highest income from coffee, Khat and Enset. The mean gross income of African custard apple practitioners from vegetables + fruits was slightly higher Avocado based agroforestry practitioners. Avocado and African custard apple fruit contributed around 20 and 6% of the total household heads (HHH) income, respectively. African custard apple and Avocado based Agroforestry had both nutritious supplement and monetary value. However, the intensification of the system was influenced by access to extension and total livestock holding. Sustainable development through AF can be achieved through a concerted effort to actively and continuously encourage farmers' involvement in AF activities. Recognizing and tackling main factors that determine the participation of farmers in AF practices can improve local involvement in fruit tree-based AF.

Acknowledgements

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Socio-economic Impacts of Community-based Rehabilitated Degraded lands in Tigray, Ethiopia

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Abstract

Land degradation in the northern highlands of Ethiopia has a long history, which dates back to 5,000 years ago and caused the occurrence of economic losses and environmental hazards. To solve this problem, there have been rehabilitation efforts. This study aimed at assessing the socio-economic impact of community-based rehabilitated degraded lands. The study was conducted in *Kola Tembien* and *Kilte Awulaelo* woredas of Tigray region, Ethiopia. Data were collected from 233 beneficiary households selected through multistage sampling. Descriptive statistics, narrative and inferential statistics were used to explain the socio-economic impacts. The results indicated that the rehabilitation intervention has had a positive impact on the livelihoods of the community providing income from fattening, honey production, and sales of grass, thatches, and wild fruit, access to medicinal plants and grass, increase crop production as well as irrigation potentials. It has also contributed to strengthened social network and creation of job opportunities. Awareness about natural resource management and trust among the communities has also been built. Moreover, it increased the discharging potential of springs and wells, decreased soil erosion and flooding, and thus enhanced the restoration of the vegetation cover. However, there are considerable inhabitants who were unhappy about the rehabilitation sites due to the shortage of grazing land, unemployment, poor participation in decision-making, unfair benefit sharing, and lack of good governance. Maximization and continuity of the incentives is recommended and all potential users should be involved and empowered equally and willingly in all the steps down to project operations as well as local by-laws should also be revised.

Keywords: community participation, impact, land degradation, rehabilitation

Introduction

Land degradation is defined as long-term loss of ecosystem function and productivity caused by disturbances from which land cannot recover unaided (Bai *et al*., 2008). Land degradation is a serious problem for our planet (Mekonen and Tesfahunegn, 2011). Though, the world is getting seriously challenged by issues of sustainable use of natural resources from early twenty century (Abuto, 2009), the history of land degradation is as long as human civilization (Meseret, 2016). The range of degradation is estimated at 12 million hectare each year which is unbridled and a serious problem affecting the livelihood of 1.5 billion people globally (Yirdaw *et al*., 2017). Comparatively, Sub-saharan Africa including Ethiopia has been severely challenged by land degradation in the world (Meseret, 2016). Land degradation in the highlands of Ethiopia has a long history particularly in the northern highlands for millennia (Yami *et al*., 2018), which were likely 5000 years ago (El-Swaify, 1997). In Ethiopia, due to soil erosion, about 12 tons (ha/year) of soils are lost and this loss is estimated at about $139 million which is 3-4% of the country's GDP (Demelash and Stahr, 2010) cited in (Yami *et al*., 2018).

Several studies e.g. Bishaw, 2001; Feoli *et al*., 2002; Babulo *et al*., 2010 and Chiemela *et al*., 2018) reported that over-exploitation of resources and inappropriate land uses specifically over-grazing, deforestation, expansion of cultivation and grazing into marginal lands as well as backward agricultural practices are considered the major causes of land degradation. Moreover, exploitation of existing forest for fuelwood, fodder and construction materials are also considered causes of land degradation in the country. Land degradation particularly soil erosion, nutrient depletion as well as soil moisture stress are severe problems in Tigray region. To solve this problem, the government of Ethiopia has taken different measures and there have been rehabilitation efforts taking place in the areas where land degradation is a severe problem (Nyssen, 1998; Critical *et al*., 2010; Meseret, 2016 and Kerse, 2017).

As reported by Belay *et al*. (2004), rehabilitation is seen as the most worthwhile way of mitigating the effects of land degradation. In addition to the degraded lands with some remnants of forest species and state forest lands that have been enclosed by the government, a total of 262,000 hectares have been enclosed in Tigray (Nedessa *et al*., 2005). Mainly in the highlands, due to the remarkable improvement of productivity and reduction in soil erosion in the areas enclosed, the establishment of area enclosures has been an important strategy for the rehabilitation of degraded hillsides (Nedessa *et al*., 2005). However, local communities have uncertainty and are not convinced about the advocated benefits of rehabilitated lands. For example, as Denboba (2005) stated, since rehabilitated areas varied in ecological conditions, socio-economic, political, historical contexts, causes of degradation and ways of management, generalization is both difficult and probably not so useful unless diverse and representative studies are taken.

Birhane *et al*. (2006) reported that even though exclosures have proved instrumental in the rehabilitation of degraded lands, knowledge on vegetation status and socioeconomic contribution to local people is lacking. In line with this, despite the impressive results of the ecological rehabilitation and improvements of productivity, many communities have had a bad experience with area exclosure. This is because of lack of consistent rules and regulations, uncertainty, lack of clarity of land tenure and public land use policy. In addition, lack of real ground community decision making in the management and resource utilization and lack of knowledge about the actual amount of benefits that can be derived from exclosures and not convinced about the advocated benefits (Nedessa *et al*., 2005).

Generally, despite the emerging, promising socio-economic intervention and ecological importance of exclosures practices in Ethiopia, very little or virtually no systematic and scientific studies have been made about exclosures (Mengistu *et al*., 2005). In addition, little is known about the socioeconomic impacts of rehabilitated degraded lands in the study area. Therefore, this study, in general anticipated to evaluate community-based rehabilitated degraded lands and its socio-economic contributions to the surrounding communities in the two purposively selected rehabilitated sites. The two selected sites were *Miska* and *Abraha-We Atsebeha* in *Kola-Tembien*woreda and *Kilite-Awlaelo*woreda, respectively in Tigray, Ethiopia.

Materials and Methods

Description of the study sites

The study was conducted in *Kola*-Tembien and Kilte Awulaelo woredas, Tigray region of Ethiopia in 2017/18 and the description of the study areas is shown in table 69. Kola-Tembien woreda is found in the Central zone which is located at 109.4 km from Mekelle, on the way to Adwa. Whereas, Kilte Awulaelo woreda is located in the eastern zone which islocated at 50 km from Mekelle, on the way to Adigrat.

Table 69: Demographic and biophysical characteristics of the study sites

Indicators	*Miska*	*Abraha WeAtsbeha*
Total population	680	2024
Men	331	1002
Women	349	1022
Total household head	379	364
Men	298	243
Women	81	221
Total users	205	2024
Men	95	1002
Women	110	1022
Elevation(m)	1726-2016	1600-2100
Annual rain fall(mm)	500-800	350-600
Annul temperature(°C)	25-30	17-21
Year established (E.C)	2002	1996
Total rehabilitated area (ha.)	305	2200
Cultivated land (ha.)	431	236
Average land size per HH (ha.)	0.75	0.8
Year of benefits gainingstarted (E.C)	2004	2001
Distance from woreda to study sites(Km)	about 36	20

Source: *Merere* and *Abraha We Atsbeha* Agriculture and Rural Development Office (2017)

Sampling techniques

A multistage sampling procedure was employed to select households. At the first stage, out of 36 woredas of Tigray region, Kola Tembien and KilteAwulaeloWoredas were selected purposively based on their better experience in the rehabilitation of degraded lands. In the second stage, two Tabias namely, Merere and Abraha We Atsbeha were selected purposively from Kola Tembien and Kilte Awulaelo woredas, respectively based on theirbetter experience and performance of rehabilitated degraded lands. Then, *Miska* and Abraha We Atsbeha sites were selected from Merere and Abraha We AtsbehaTabias, respectively.

Finally, sample households were selected from the total user households using simple random sampling technique.The sample size was drawnby using proportion to population size.The target population of the study was user households from the selected community based rehabilitated degraded land sites. The total sample households were 233from two selected sites.

Data sources and collection methods

Qualitative and quantitative data were collected from primary and secondary data sources. Primary data were collected through a face to face interview by using a semi-structured questionnaire. In addition to household survey,key informantsinterview and focus group discussions were conductedwith different social groupsin order to gatherqualitative data.Secondary data werecollectedfrom different published and unpublished sources such as journals, books and reports.

Data Analysis

Descriptive statistics were used to analyze socio-economic, institutional and other characteristics of the sample households. Qualitative data were analyzed using narration. In addition, inferential statistics such as chi-square and t-test were used. For statistical analysis, SPSSsoftware was employed.

Results and Discussions

Demographic Characteristics of the Households

Gender, Marital status and Age: The majorities (87%) of the respondents in this study were male-headed households and the remaining 13% were female-headed. The marital status distribution of the respondents showed that about 86.7% were reported to be married and an insignificant proportion of the respondents fall in divorced, single, and widowed with 5.58%, 3.43% and 4.29%, respectively. The distribution of respondents by age group revealed that 25.5% of them were above 44 years old. The remaining majority of the respondents were in 18 - 43 age groups and constituting about 74.5%, this age group was considered to be more productive.

Family Size and Educational background: Results of the study revealed that 58%, 13.42%, and 28.58% of households had between 5-8, 9-11, and 1-4 family members, respectively with a mean of 5.8 and standard deviation of 2.8. The educational level of individuals within a particular community is a representation of the level of the community's human capital. The results showed that 47.21% of the household head have attained grade 1-8 (primary school) and 11.16% of household head attained grade 9-12 (secondary school). From the sample households only 2.58% of household head attained college and above and 39% of respondents are do not attend formal education. The result showed a significant variation of respondents' educational background between the two study sites ($\chi^2 = 8.9692$, $p < 0.05$, Cramér's V = 0.1962*),* at 5% level of significance*.* Itimpliesthat respondents from Miska have better education level than Abraha WeAtsbeha*.*

Approach used to establish the rehabilitated degraded lands

Of the total respondents, about 51% of the respondents replied that the approach used to establish rehabilitation of degraded lands was people-centered followed by a top-down approach (26%). Others (23%) respondents explained that the bottom-up approach was used to establish the rehabilitated sites (Figure 106).

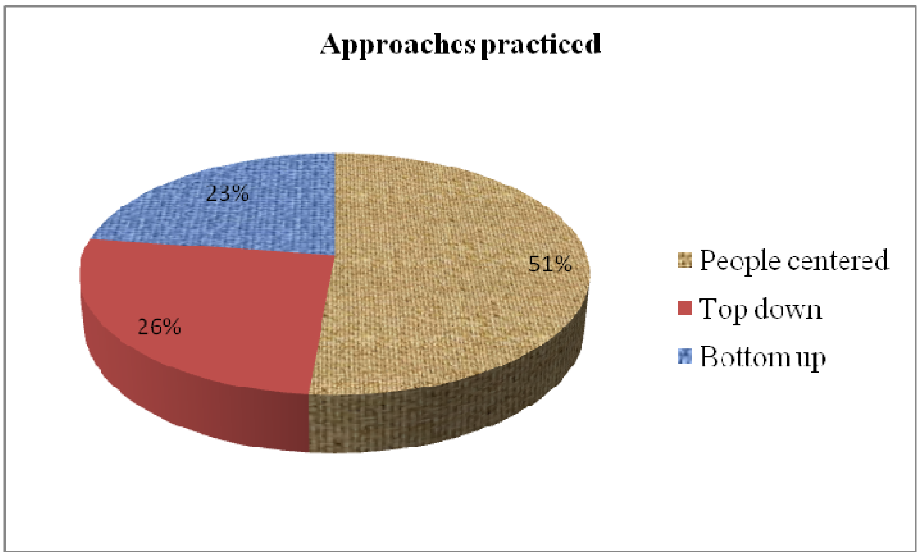

Figure 106: Approaches used to establish rehabilitated degraded lands

The finding indicated that the rehabilitation of degraded lands was a common agenda for the government and farmers at some time. But farmers enlightened, bottom-up and people-centered approach comparatively played an important role in realizing and sustainability of the rehabilitation process as it was developed a considerable sense of ownership in the community, enabled them to have a common goal and relatively common understanding. The differences in the respondents' awareness about the approaches used to establish the rehabilitated degraded lands across the two sites were not significant.

Community participation in the rehabilitation of degraded lands

The communities were participated in different activities and programs in rehabilitation of degraded lands, but the degree of participation differs among diverse groups.The rehabilitation activities include plantation, soil and water conservation, guarding, and monitoring and evaluation activities such as participation in committee, coordination, in the design of the program, in decision making and use and control of resources. The finding correspondingly indicated men participants were more active especially in guarding (65%), awareness creation (41%), decision making (60%), and coordination (51%). The level of community participation in the establishment and management of area exclosures varied from place to place and limited the decision-making process in all of the areas. Cultural and religious grounds has constrained more women's participation in decision-making forums, especially in public meetings (Nedessa *et al*., 2005).

The key informants and focus group discussantspointed out, communities were influenced by the local bylaws and threats of punishment that may follow in case of their absence from free labor demanding community mobilization work as well asextension officers explained that the trend in degraded land management practices among the community members has been increasing over time. In addition, involving in physical activity provided them legal user right and power in local decision-making concerning benefit-sharing derived from the rehabilitated lands. A community's sense of ownership may increase as it gains right over direct use, when the community participates in decision making, and establishes its own by-laws (Mengistu *et al.,* 2005)

The survey result indicated that about 32% and 28% of respondents revealed that community participation in the rehabilitation of degraded lands was very good in both at Abraha We Atsbeha and Miska sites, respectively (Table 70). While, about 18% and 9% ofrespondents reported a good community participationin Miska and Abraha We Atsbeha sites, respectively. The mean differences in community participation between the respondents in the two sites were significant (χ^2 *(3) = 11.3776,* $p < 0.05$). The*Cramér's V = 0.2215*) implies that farmers in Miska were willingly more active in participation than farmers in Abraha We Atsbeha in the rehabilitation measures (Table 70).

Table 70: Community participation in the rehabilitation of degraded lands

Study sites	VerygoodFreq.(%)	Good Freq.(%)	AverageFreq.(%)	poor Freq. (%)
Miska	67(27.88)	42(18.10)	19(8.19)	0(0)
Abraha We Atsbeha	75(32.33)	20(8.62)	8(3.45)	1(0.43)
Total	142(61.21)	62(27.72)	27(11.64)	1(0.43)
Pearson χ^2 (3)	11.3776, p = 0.010			
Cramér's V	0.2215			

Impacts of rehabilitated degraded lands

Economic impact

Livestock production: About 94% and 88% of sample households engaged inlivestock production in Abraha We Atsbeha and Miska, respectively. The average size of livestock (TLU) was 7.16 ± 5.91 and 5.41± 3.48 in Abraha We Atsbeha while 9.65 ± 6.53 and 6.15± 2.39 Miska sites before and after intervention, respectively (Table 71). The key informants and focus group participants also pointed out that livestock holding have been decreased in the study areas after intervention due to prohibition of free grazing and only allowed stall feeding and fattening through cut and carry system.

Table 71: Households' assets in the study areas

Assets	*Miska* site					*Abraha We Atsbeha* Site				
	Before intervention		After intervention		t-value	Before intervention		After intervention		t-value
	Mean	SD.	Mean	SD.		Mean	SD.	Mean	SD.	
TLU	9.65	6.53	6.15	2.39	-6.65**	7.16	5.91	5.41	3.48	3.13***
Crop	151.8	119.9	340.7	266.3	-0.25***	124.7	105.3	279.4	229.2	-3.24***

Note: ** and *** represents 5% and 1% level of significance, respectively

This result was supported by Birhane *et al*. (2017), Mekuria *et al*. (2011), Area (2016) and Demissie *et al*. (2019) that 34%, 58%, 45% and 36% of respondents, respectively experienced shortage of grazing land in their areas leading to a reduced number of livestock holding by the local communities. The t-test result showed that there was a mean differencebefore and after intervention at 1% and 5% level of significance in terms of livestock holding (t=-3.13 and t= -6.65) in the two sites respectively.

Crop production: Although the farming system is predominantly mixed farming, consisting of both crop production and livestock rearing, the crop husbandry was overriding. The major crops grown by sample households were wheat, maize, sorghum, and teff. In the study area, even if rain-fed agriculture is the major production system, key informants explained after intervention vegetables, spices, and fruits become grown through different irrigation system in the dry season. Of the sample households' 89.36% from Abraha We Atsbeha and 88.38% from Miska have crop farms. The survey results showed that most of the sample households (93.27%) from Abraha we Atsbeha and 89.26% from Miska reported that nowadays the practices of exclosures have enabled them to control soil erosion and have resulted in enhanced land value and productivity. In the study area, households produce major crops commonly one time per year. But, some households(12.4% from *Miska* and 8.65% from Abraha we Atsbeha have produced vegetables and fruits up to two and three times per year after intervention.

The result also revealed that crop production in Miska was about 6.07±4.79 and 13.63±10.65 quintal per hectare whereas 4.99± 4.21 and 11.18± 9.17 quintal per hectare in Abraha we Atsbeha before and after intervention, respectively. The t-test result revealed that there was a mean difference of crop yield before and after intervention at 1% level of significance in both rehabilitated sites.Participants of focus group discussion and key informants including extension officers pointed out that crop production have increased after intervention.

The findings were in line with Nedessa *et al.* (2005) who found that rehabilitated lands play a significant role in increasing crop production by reducing the frequency of crop failures.The increasing crop diversity and yields were some of the results of soil and water conservation measures (Mekonen and Tesfahunegn, 2011). Agricultural lands below area closures become more productive than lands below grazing (Mengistu *et al*., 2005). Similarly, rehabilitated land improved soil moisture and groundwater recharge, reduced soil erosion, runoff, sedimentation of waterways, and incentivized cropland intensification as well as restoration of upland catchment areas (Alemayehu *et al*., 2009).

Annual household income from different products of rehabilitated lands: The survey result revealed that rehabilitation has further a positive impact on the livelihoods of the local communities. The local communities obtained different forest related products from rehabilitated lands such as thatches, medicinal plants, honey production,fodder, farm tools and house construction materials.They gained annual mean income of 841.25, 935.00, 460.00, 1090.00, 1100.00, 82.50, 315.00, 735.00 and 12,500.00Ethiopian Birr (ETB) from dry wood, fodder, wild fruit, thatches, honey, farm tools, wood for fencing, wood for house construction and cattle fattening in *Miska* site before intervention, respectively.On the other hand, they obtained about 2255.00,3175.00, 1650.00, 2490.00, 1933.33, 350.00, 7160.00, 2050.00 and 16,500.00ETB, respectivelyafter intervention. Similarly, households gained about 3238.24, 1981.82, 100.25, 1179.21, 635.93, 295.45, 466.67 ETBbefore intervention while about 3866.83, 6318.18, 300.25, 3787.14, 6111.29,1257.27, 2236.67 and 6166.67 ETB after intervention fromdry wood, fodder, wild fruit, honey, farm tools, wood for fencing, wood for house construction and cattle fattening, respectively in *Miska* site. Key informants and focus group discussion participants also explained that the local community generated high income from forest related products and other alternative income sources after rehabilitation compared with before intervention.The t-test result also showed that there was statistically mean difference of annual income before and after intervention at different significance level.

The finding was supported by Yirdaw *et al*. (2014), who found that farmers were able to generate considerable income from selling of grass and fattened cattle and deposit savings from rehabilitated degraded dry land ecosystems.Other scholars also stated that,in a harsh environment, the households that have access to reclaimed land have improved their livelihoods as a result of income-generating activities such as cut grass for thatch, fodder, grass seed, renting dry season grazing and honey production (Critical *et al*., 2010).

Table 72: Average annual household income (ETB) from rehabilitated lands

	*Miska*rehabilitated site					*Abraha We Asbeha*rehabilitated site				
	Before intervention		After intervention		t-value	Before intervention		After intervention		t-value
Income types	Mean	SD	Mean	SD.		Mean	SD	Mean	SD.	
Dry Wood	841.25	1605.96	2255.00	2144.67	-2.122*	3238.24	5564.50	3866.83	4307.85	-0.460
Fodder	935.00	1152.58	3175.00	3995.15	-1.114	1981.82	5323.87	6318.18	7291.34	-2.229**
Wild fruit	460.00	622.25	1650.00	1060.66	-3.839	100.25	141.07	300.25	423.91	-1.000
Thatches	1090.00	1286.93	2490.00	551.54	-2.692	5.50	6.36	5.00	7.07	1.000
Honey	1100.00	458.26	1933.33	416.33	-3.054*	1179.21	1832.06	3787.14	5412.53	-1.837
Farm tools	82.50	53.77	350.00	129.10	-3.511**	635.93	989.01	6111.29	5884.29	-3.345***
wood for fencing	315.00	403.05	7160.00	9673.22	-1.044	295.45	268.12	1257.27	1155.50	-2.876**
wood for house construction	735.00	1177.38	2050.00	2002.50	-2.954*	466.67	461.88	2236.67	1533.96	-2.852
Cattle fattening	12500.00	10606.60	16500.00	19091.88	0.667	646.67	422.69	6166.67	7047.74	-1.999
Total	2006.53	1929.64	4173.70	4340.56		949.97	1667.73	3338.81	3673.80	

Note: *, ** and *** represents 10%, 5% and 1% significance level

Socioeconomic incentives: The finding of this study revealed that various socio-economic incentives were available in the rehabilitated sites. According to the key informants and focus group discussants, credit for environmentally friendly activities like beekeeping,supply of market-oriented fruit tree seedlings,incentives through soil and water conservation, financial and material resources for preparing their own tree nurseries in order to improve both environmental conservation and livelihoods in the study area. Credit facilities for off-farm activity, especially for the landless and unemployed youths were available for livelihood opportunity such as engaged in petty trade activity. In addition, supply of improved cook stoves were another incentives in the study areas.

However, the survey result specified the level of socio-economic incentives provided between the two rehabilitated areas was slightly different. About 34.45%, 24.34%, 15.13%, 10.92%, and 8.4% of respondents in *Miska* perceived supply of market-oriented fruit tree seedlings, credit for environmentally friendly activities, training, credit facilities for off-farm activity, and improved cook stoves wereincentivized,while in Abraha we Atsbeha about 50%,20.19%,15.38%, 9.6% and 1.92% of respondents mentioned that credit for environmentally friendly activities, for off-farm activity, supply of market-oriented fruit tree seedlings,training and improved cook stoves wereprovided to the local communities.This finding was supported by Yirdaw *et al*.(2014) who investigated that ecological, social and economic benefits obtained from rehabilitated lands are incentives that enable them to have a better commitment for the continuity and sustainability of the rehabilitated areas.

Social impact

Social network: The other issue assessed in the rehabilitated areas was the respondents' opinion about the social impact of community-based rehabilitated degraded lands. Accordingly, 92% and 95% of local communities reported the increasing of the degree of awareness about natural resource management and about 84.2% and 84% of respondents agreed that trust between actors have been built in Miska and Abraha we Atsbeha, respectively (Figure 107). Similarly, Nyssen (1998) reported, soil and water conservation practice in Tigray has contributed essential socio-economic changes as the rehabilitated area is giving social benefits to the inhabitants directly and indirectly.

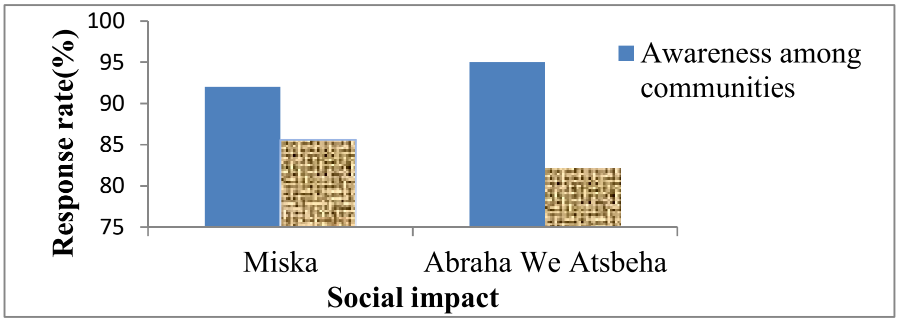

Figure 107: Social impact of rehabilitated degraded lands

Employment creation: The survey result revealed that34.56% and 17.05% of respondents from Miska and 23.04%and 8.29% of respondents from Abraha we Atsbeha were agree and highly agree on the increment of employment opportunity, respectively (Figure 108). In similar manners, key informants agreed that, the community have accessed different types of job opportunities suchas guarding, sand production, fattening, bee production, and small-scale irrigation especially for youths.On the other hand, about 1.84% and 6.0% of respondents were disagreed onthe creation of employment prospects is not improved. This was supported by key informants that the potential of the rehabilitated site is still under-utilized especially in Abraha We Atsbeha due to poor administration.This result is in linewith Getseselassie (2012) who found that exclosures have a management problem. The chi-square test was conducted to investigate the relationship between the rehabilitated lands and employment creation. The chi-squarevalue (χ^2= 14.1379, P< 0.05), which indicated that there was a significant relationship between employment creation and the rehabilitated lands. Cramer's (V= 0.2552) was also used to indicate the strength of association between the rehabilitated sites and job opportunities, which indicated that the relationship between the two variables was almost weak.

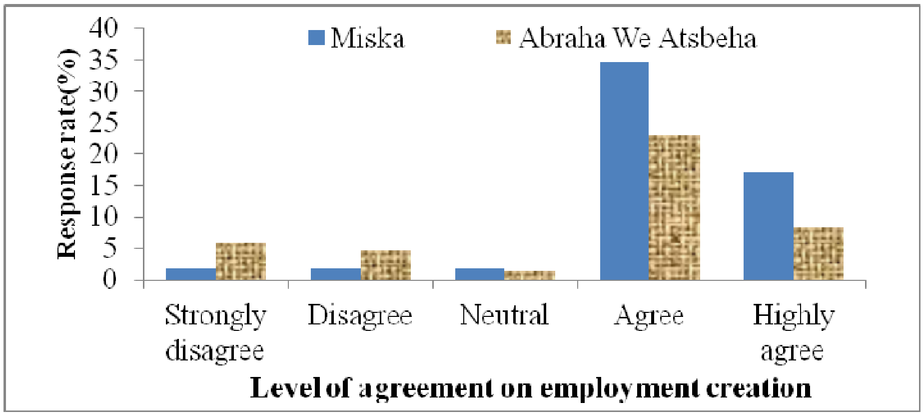

Figure 108: Farmer's perception on employment creation from rehabilitated lands

Biophysical Impacts

Communities realized that rehabilitation interventions have convinced in improvement of biophysical environment. The finding indicated that about 96%,96.5%, 81% and 80.7% of respondents from Miska and 99.3%, 89%, 85.3% and 89.3% of respondents from Abraha weAtsbeha responded that vegetation coverage, fodder supply, reduction of soil erosion and flood, and increment of water supply were improved in rehabilitatedsites afterintervention compared to pre-rehabilitation.The Key informants and focus group discussants also reported that different wild fauna and flora such as fox, monkey, ape, warthog, rabbit, hyena, and different kinds of birds, have been observed after rehabilitation of degraded lands. In addition, key informants and focus group discussants mentioned that the small irrigation developed around the rehabilitated sites was the impact of the biophysical activities in the rehabilitated lands. Different scholars also reported that diversity of vegetation and wildlife has increased obviously as compared to pre-rehabilitation intervention conditions (Getseselassie, 2012, Meaza *et al*., 2016, Mekonen and Tesfahunegn, 2011 and Birhane *et al*., 2017). Similarly, this finding was in line with Yirdaw *et al*. (2014); Getseselassie (2012); Area (2016); Kerse (2017) and Birhane *et al*. (2017)) who found that local people expressed that rehabilitated lands such as exclosures had increased grass cover, decreased soil erosion, and increased rainfall frequency following the regeneration of vegetation on the rehabilitated lands.

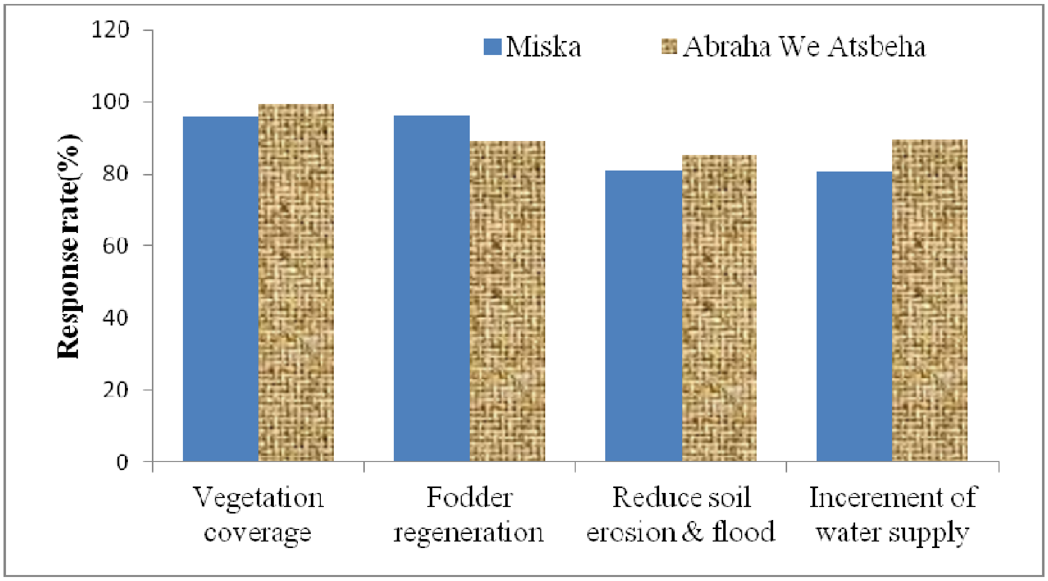

Figure 109: Biophysical impact of rehabilitated degraded lands

Conclusion and Recommendation

Community based degraded land rehabilitation is one of the mechanismsto improve the environment and livelihood of the communities in and surrounding degraded lands. Based on this, the Ethiopian government rehabilitated different degraded land through community participation. Miska and Abraha weAtsbeha sites are better rehabilitations sites that generatesocio-economic and ecological benefits among the rehabilitated landsin Tigray region.The finding of the study showed that participation of local community was improved in coordination, awareness creation, and decision-making has sense of ownership. However, the local by-lawmainly focused on punishment rather than optimizing management.

Results of the study clearly stated that degraded land rehabilitation can contribute to rehabilitation of biophysical environment and livelihoods of the local communities regarding to social, economic and environmental benefits. The findingfurther indicated that majority of local communities' livestock holding and crop production was changed after rehabilitation. This showed that the livestock holding of the community was reduced after intervention compared to pre-intervention due to change of free grazing to stall feeding and fattening through cut and carry system. While crop production was showed a significant improvement after intervention due to recovery of soil fertility and reduction of soil erosion and flood. Moreover, majority of respondents had a positive attitude towards the rehabilitated degraded lands in the study areas except some complaints associated to crop and domestic animal damage.The rehabilitated lands also provide various products to local communities such as dry wood, construction material, animal fodder, honey production, farm tools, wild edible fruits, fencing material, cattle fattening and thatches.

The provision of credit for environmentally friendly activities such as beekeeping inputs, market-oriented tree seedlings, credit facilities for off-farm activities, alternative source of energy (Improved cook stoves), and training program incentives were also available to the local communities which enable them sustaining their livelihoods and the environment. In addition to incentives, local communities obtained different social benefits such as information sharing among them, awareness increment and trust of each other due to group mobilization in benefit sharing and conservation activities in rehabilitated lands.As a result, the local communities have positive attitude to interventionof degraded land rehabilitation from socio-economic and ecological perspectives.

Even if, the rehabilitated lands contributed to different social, economic and ecological benefits,it has limitationregarding benefit sharing mechanisms such as households who have not ox do not have right for fodder access. Therefore, efforts should be made by different concerned bodies such as local community, government, and other stockholders to address complain by the surrounding community. Users should be clearly defined; revised, update, and improvelocal by-laws based on the needs of local communities in order to sustain the environment and livelihoods. Appropriatebenefit sharing mechanism should also be designed which free from discrimination. Integrated research and development interventions have to be carried out for better management of rehabilitatedsites.

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Implications of Forest Policy and Strategies in the Development of Large-scale Tree Plantations with Particular Emphasis to Ethiopia

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Abstract

Various policy initiatives were taken by the government of Ethiopia to develop forest resources and reduce forest resources degradation. However, presence of weak institutions and institutional support, failure to establish secure land tenure system, pervasiveness of poorly trained, understaffed and underfunded extension services, and existence of poor linkage between sector institution have compromised forest development in Ethiopia. This study attempted to review policy and strategy documents at global and national levels with respect to promotion of large-scale plantation development, identify the existing gaps and propose improvement options in Ethiopia. Globally, approaches advocating establishment of strong forestry institutions and creating a secure land tenure system as well as frameworks entailing direct government involvement in large-scale plantation development have proven to be the most successful policies and strategies. Additionally, direct and indirect incentive and disincentive policy approaches have shown success in various countries. Policy directions towards direct government role in large-scale afforestation, reforestation and restoration are not explicitly chaptered in the forest policy document of Ethiopia. Forest strategies and action plans are not designed in a mandatory and obligatory manner. Regional, sectorial and institutional responsibilities, coordination and linkage were not well articulated. Generally, the forest policy follows a highly decentralized approach. Therefore, government level paradigm shift in the forest sector is highly essential. Reforms in the forest policy, strategy, and institutional sectors can progress the large-scale plantation development. Additionally, active engagement and direct investment of the government in forest plantations, advocacy, resource mobilization, extension and financing can boost the forest development. Establishing strong, centralized, authoritative and self-sustaining forest institutions is vital.

Key words: Policy, Strategy, Large-scale Plantation

Introduction

Policy is defined as the guiding principles and articulation of courses of actions to execute strategies, programs and plans of a particular sector in a country (FAO, 2000). Globally, countries follow structural or pervasive approach, revolutionary of direct government investment, direct incentive or disincentive, indirect incentive or disincentive policy approaches when engaging in extensive schemes such as large-scale tree plantations (Ruitenbeak and Cartier, 1998).

The pervasive policy approach emphasizes launching strong institutions (eg. forest sector institutions) and secured land tenure system if a country peruses to engage in large-scale plantation development) (Ruitenbeak and Cartier, 1998). Advocates of this policy approach believes, sectors function well if the country establishes a strong forest institution and clearly articulate as well as secure the existing land tenure systems.

Sourhgate (2009) emphasizes building trust should be a prerequisite preceding large-scale tuned investment policing. Putnam (1993) argues policy approach that emphasizes economic efficiency over social equity likely fails. Additionally, Erskine (1991) emphasizes large-scale investment policy approach likely fails when there are weak institutions and institutional support, rural development policies are poorly articulated, governments fail to clearly identify and create secure land use system and there are weak, poorly trained, understaffed and underfunded extension services. He also added, poor linkage between sector institutions and when there are no thematic specific researches, large scale development policy approaches may not succeed.

Direct government investment policy approach is the most successful and with long historical reputation policy design in large-scale schemes such as national level extensive tree plantation development (Clapp, 1995). Provisions of direct or indirect incentive or disincentive policy approaches have also proved successful in large-scale tree plantation development strategies.For instance, the following incentive strategies were used to encourage investments in large-scale plantation developments in some countries:

- Laying marginal tax (Perley, 1992) in Ireland,
- Compensatory tax system and tax deductibility (Morell, 1997) in Costa Rica,
- Nil interest rate funding (potter and Lee, 1998) and direct government funding (potter and Lee, 1998) in Indonesia,

- Provision of subsidization of forestry products and services (Gladwell, 2000) in India

The Ethiopian Forest Policy, Conservation Strategy of Ethiopia, the Ethiopian Forestry Action Plan, the National Action Plan and the CRGE strategy are the most relevant policy initiatives taken by the government to develop forest resources and reduce forest resources degradation. However, presence of weak institutions and institutional support, poorly articulated rural development policies, failure to clearly identify secure land use system and when there are weak, poorly trained, understaffed and underfunded extension services, and existence of poor linkage between sector institution the development of the forest sector is highly compromised (Bekele, 2001; Alemayehu et al., 2013). Therefore, this study attempted to identify the pros and cons of the Ethiopian forest policy, strategies, programs and plans in the mirror of globally accepted and successful forest policies and strategies as well as countries experience to suggest strategic options with respect to the development of large-scale tree plantation development in Ethiopia.

Materials and Methods

For the purpose of this study systematic desk review, interview and discussion were used as a research designs. On the other hand,qualitative content analysis method was used to narrate and analyze gathered data.

Desk Review

Policy and strategy documents of the country that are related to forest and environment as well as industrial issues were reviewed. Policy and strategy documents of other countries that have showed a good progress on large-scale timber and pulpwood plantations were also reviewed. In the process, policy and strategic gaps were identified and policy and strategic options were also produced that could show future policy and strategic directions to policy and decision makers. Over forty documents were reviewed for this particular study.

Key informants interview

In depth interviews were carried out with selected key informants. A separate checklist was prepared to guide the interviews from different stakeholders. Perception of key actors on policy, institutional and structural impeding/promoting factors for large-scale plantation,were investigated using both open and close ended questionnaires.A total of sixty-nine key informants were interviewed in the four target regions of Ethiopia.

Focus group discussions

Focus group discussions (FGD) were held at all level with relevant groups. The FGD contained 8-12 individuals comprised of pertinent authorities, professionals, age and sex groups, cultural and religious sects, local and international NGOs, CBOs, wood industries, and so on depending on the context that called for FGD. Totally, eight focus group discussions were held.

Results and Discussions

Policy Perspectives

Objective of forest policy could be biodiversity conservation, wood production or watershed protection. Forest policy also has process, meaning policy formulation, implementation and review. The process is circular in that the review of the impact and effectiveness of a policy would lead either to a new policy or adjustments, or confirm the previous policy. Policies that can affect plantation development activities in most countries' political, social and economic settings can take one or more perspectives (FAO, 2000):direct planting by the government;direct incentive or disincentive; and indirect incentive or disincentive.

The choice of agentssuch as companies, communities or individuals is by itself a policy. The neo-liberal theories do not accept government's direct involvement in large-scale investment spending such us large-scale plantation development emphasizing economic efficiency in a particular country (Christopher, 2001). On the other hand, the neo-liberalists encourage governments to engage in strategies supporting corporate investment in large-scale commercial plantation developments (FAO, 2000).

Structural Policies and Plantation Development

The structural policy deals with assessing the forest sectors institutional capacities and the level of security of countries' land tenure system with respect to forest development (Ruitenbeak and Cartier, 1998). According to Khan (1998) secured land tenure system is a key factor for development of plantation forestry at individual, corporate and community level. Klooster (1999) suggested that jointly held legal control over forest resources by community with corporate institutions based on clearly prescribed benefit mechanisms is by far better than non-benefiting ownership right.

Accordingly, their study has found that insecurity of land tenure leads to extraction damage of logs, wastage in harvesting, suboptimal silvicultural practices and under development of non-timber forest plantation products. The distortions in once established forest policy reduce significantly if countries are able to erect strong forestry institutions (Ruitenbeak and Cartier, 1998). According to Whiltshire (2000) this is possible mainly because corporate interests function at balanced level for all involved stakeholders. Whiltshire (2000) additionally points out that utilization of potential rights and benefits is stronger in this situation over control of land than the merely exercised legal ownership rights. The forestry sector functions well in a country where clearly articulated and secure land tenure system as well as a functioning strong forestry institution exist (Ruitenbeak and Cartier, 1998).

This case has been witnessed to function in Mexico during the 1980's. Prior to 1980 the Mexico government was not able to benefit from the forestry sector and grow the country's forest cover because the forestry management system remained outside of community control. Forest land concessions were also bound under short-term agreement for forest plantation developers. This insecure land tenure system created problems like cut and run logging, corrupt local leaders, and violence between community members and corporate forest plantation developers were aggravated. Further the state Monospony starts to prevail in such kind of land tenure strategies. Forest owners become compelled to sale only for concessionaires controlled by the government at low price at their request. However, policy improvement injected in by the Mexico government after 1980 was able to increase community benefit by 600% (Klooster, 1998). During the early 1990's a significant portion (40%) of timber supply starts to come from community established plantation forests. The areas of policy improvement were:

- Increased access over control of benefits coming from forest plantation
- Skill improvement of communities on forest management and silviculture
- Improvement on access to market and market linkage

The Forest land tenure policy case of Solomon Island was also studied by Frazer (1992) and Bermett (1995). Forest resource owners in Solomon Island use to have little protection from the government legal enforcement institutions. Communities' resistance was very high on large-scale forest resource owners. Considering this problem the government tried to liaison between the community and forestry investors. However, the adjustment in policy couldn't bring any change due to the government's lack to address the wider social and environmental issues. Southgate (2009) advocates 'building trust among communities and various stakeholders in large-scale investments such as forest plantation are keys for policy and legislation implementation and control'. Putnam (1993) argues that a policy approach that emphasizes economic efficiency over social equity likely fails. Erskine (1991) has identified the causes for policy failures. According to him policy likely fails when:

- There are weak institutions and institutional support
- Rural development policies are poorly articulated
- Government's fail to clearly identify their land use system
- There are weak, poorly trained, understaffed and underfunded extension services
- There exists poor linkage between sector institutions
- There are no thematic specific researches

Direct government involvement through Institution

Direct governmental involvement in establishing large-scale plantation has a long and successful history including:

- Industrialization and import Substitution
- Regional development and employment creation
- Water and soil conservation and rehabilitation
- Biodiversity conservation and ecosystem services

New Zealand is an example in this success story. State plantations begin in the 1920's after a new forest policy was developed by the government. The policy was designed to inject improvement in areas like:

- Expertise in plantation forestry
- Infrastructural support (eg. Nurseries)
- Education and research focused in forestry
- Creating strong forestry institution that in turn analyze and assist implementation of forest policy
- Encouraging private investment in forestry by facilitating the use of government build infrastructures and expertise support

Other successful plantations were observed in Australia and South Africa (Clapp, 1995). According to the same author natural advantage should sometimes be sufficient to create state involved plantation forestry development (China, Myanmar, Korea etc.).

Direct Government Forest Plantation Development Policies

Encouraging Investors in Forest Development

Taxation varies between countries. Even with in a country one-tax legislation could be difficult. Perley (1992) suggest that changes in marginal tax rates may work to encourage and attract investors in forest plantation sector. Additionally, he advocates tax deductibility may be more effective for this purpose. Morell (1997) on the other hand argues tax exemption is the most common and more effective method to attract forest investors. Costa Rica was able to establish 50,000 hectare of plantation forests using tax deductibility method (Morell, 1997).

The other financing mechanism advocated by Potter and Lee (1998) was granting low or nil interest rates or direct government funding. For instance the Indonesia government gave zero interest rate loans to forest investors to encourage short rotation period pulpwood plantation. This act of the government gave rise to the pulpwood plantation to take one-third the cost of plantation forests established in the country with three years repayment period. Ireland was able to exponentially increase its forest plantation cover by designing a 'compensatory allowance' financing mechanism to forest plantation developers (Investors) to tackle the problem of long payback period (Gairdner, 1993). This approach was criticized by Klooster (1999) for two reasons: 1) some of the plantations were established on wetlands due to competition for land eventually disrupting the wetland ecology, and 2) It creates conflict among sector offices that has stakes to use large-scale lands (eg. the Agriculture sector). Forestry encouragement grant (1970 and 1984) was also applied in Ireland. Lands that should be included in the plantation scheme were preconditioned to be marginal. Farmers will benefit from this encouragement plan if only they were able to identify marginal lands for the plantation purpose. In South Africa plantation were encouraged to be established on abandoned agricultural lands (Keipi, 1997).

Extension, motivation and information

Motivations are not always in accord with economic rationality (Howard and Valerio, 1996). Individuals don't base decisions on economic grounds only. One of the reasons for the lack land owners' initiatives to develop plantation forests on their land is the long gestation period. Howard and Valerio (1996) argue that lack of information and expertise are the major reasons for the lack of this initiative. Comparing and contrasting individuals' preferences, perception and attitude O'leary et al. (2000) who studied the Ireland case suggests that country's approach should not only focus on economic efficiency alone. The extension and awareness approach should sometimes be generic. Additionally, policies and approaches should contextualize in accordance with implementation regions. Klooster (1999) who studied the Mexico case on the other hand emphasizes approach that considers cultural differences. He advocates the need of models in the research arena capable of analyzing individual's choices and actions within communities and cultures.

Provision of Subsidization of forestry products and services

A number of countries, especially in relation to plantation development provide direct assistance in kind to individuals or communities. Commonly, as in India and some African countries (Gladwell, 2000), this is by providing seedlings and capacity building trainings in silviculture. Extension services that provide knowledge on planting and tending are very common in both developed and developing countries often through state agencies.

The effectiveness of providing information and changing attitudes is difficult to gauge. Attitudinal change may take a generation or conversely can be caused by some unexplained trigger (Gladwell 2000). However, the constraints of information are an obvious impediment to achievement of effective forest plantation development, management and a market for information cannot exist where the participants do not know what it is they do not have.

Ethiopia Forest Policy and Strategy

The Ethiopian forest policy (2007) is composed of six major sections. These are development and protections of private forest for fuel wood, construction, industry and environment; policy and strategies for forest development technologies; policies and strategic approaches towards forest products market development and expansion;;administrative and management plan policy options for government owned forest lands for production, biodiversity conservation or land protection; and modernization of forest development, protection, utilization and erection of high tech forest related information systems.

Ethiopian Forest Policy with respect to large-scale tree plantation development

The Ethiopian forest policy (2007) doesn't provide distinct sub-sections or strategic options for large-scale plantation development either by institutionalized or governmental bodies. However, it rather provides an indirect policy provision for large-scale plantations development in the country. The policy grants the responsibility of plantation development to individuals, cooperatives (groups) and organization. The policy grants the following strategic advantages to individuals, cooperatives (groups), or organizations that wish to engage in forest/plantation development:

- Give delineated lands for plantation free of lease
- Create suitable condition to exempt particularly individual's plantation developers from tax till their first production period
- Give professional and technical support to individuals, groups or organization that wish to engage in forest/plantation development
- Give land through concession to individuals, groups or organization wishing to develop forest plantation in government owned forest priority areas (FPAs)
- Provide seedlings at subsidized price to individuals, groups or organization that showed desire to engage in environmental protection and rehabilitation plantation schemes.
- Give credit to individuals wishing to engage in plantation and wood industry development
- Delineate and propose lands for investors that wish to engage in wood industry investment and
- Provide tax subsidy for farmers engaged in agro-forestry practices

Reviewing the Ethiopian forest policy and strategies parallel to the need for large-scale plantation development, the following weak points were summarized:

- The lack of direct government role in large-scale forest development and the mere focus on individuals, cooperative (groups) and organization to develop forests

- may eventually produce fragmented plantation forests; make organized forest plantation administration and management difficult for mass production of forest and forest products;
- No article bestowing jurisdictional responsibilities to institution and its structural and capacity development have been provided in the policy and strategy document
- Regional, sector and Institutional coordination and linkage is not well articulated
- Authority of the forest sector is not well defined

Policies and Strategies of the Republic of South Korean Forest Sector

Pre-World-War II and war with Japan 60% (6.8 million hectare) landscape of Republic of Korea was covered by forest (Bae et al., 2012). Post war Korea was devastated by the consequence of extreme deforestation and forest degradation by its colonizers. Acute wood shortage (biomass energy poverty), land degradation, soil erosion, landslides, flooding, and food shortage were some of the manifestation of impacts of deforestation and forest degradation (Bae et al., 2012). The severe impacts of deforestation and forest degradations drew the attentions Korea's policy makers and the country established an independent forest sector that directly reports to the Korean president (Choi et al, 2002). The forest sector immediately launched a 5 years large-scale tree plantation and restoration policy in 1967 which was highly interlinked with the countries 5 years economic development plans. Extensive advocacy and extension works were carried out with a motto entitled 'let us first plant trees in the hearts of the people' also known as Sae-Ma-U movement (Republic of Korean Reports, 2010 and Lee, 2013). With the aim of covering 150,000 hectares of land with trees each year, government sponsored tree nurseries were established in every Korean villages with a capacity to raise 1.4 billion tree seedlings per year. Village cooperatives were established that provided compulsory labor, planting and post planting management. The government sponsors village cooperative members with food and cash payment based on their performances. Coordinated dedications from all sectors of the Korean economic development institutions had resulted covering 780,000 ha of land within the five years plantation and restoration plan acquiring 55% of the surviving seedlings (Lee, 2013).

The second 10 years (1973 – 1982) plantation and forest rehabilitation plan was launched after some institutional reforms of the Korean forest sector in 1970. During this second round plantation and rehabilitation plan budget allocation to each village was based on performance. Underperformance was accounted with serious punishment measures from the government law enforcement wing closely working with the forest sector. The pre, during and post management tasks were scaled-up from village cooperatives to local government office experts. A one month annual tree planting program was erected during the second round plan. Success was declared three years ahead of closing year of the second plantation and rehabilitation plan in 1979 (Bae, 2012). In aggregate a total of 2.8 billion seedlings were planted on 1.8 million hectare enrichment planting space in a period of six years. The third round plan was focused on commercial large-scale plantation and defined the country's land use planning. During the third action plan period a total of 1 million hectare of land was covered by commercial plantation forests. Korean government has spent a lump sum of 592 Korean Won across the three large-scale tree plantation, restoration, rehabilitation and commercial plantation schemes. This money would account to three billion USD in 2016 year equivalent (Lee, 2013).

Lessons from South Korea

Successful policy and strategic approaches that can be drawn as lessons that should be implemented in the Ethiopian large-scale plantation development endeavors.

- The presence of high level leadership in the institutional reform, development of large-scale tree plantation action plans, legislative and executive orders, and political commitments.
- Strong institutional frameworkand strong inter-ministerial coordination.
- Strong and continuous advocacy and extension work.
- Community participation.
- There was constant monitoring and punishment of forested, rehabilitated and restored areas.
- Strong tie between the forest and law enforcement sector.
- Strong linkage between the economic and forest development sector.
- The government's political commitmentand willingness to finance the forest sector.
- Strong commitment of the people to the forest development

Conclusions and Recommendations

Presence of forest policy, CRGE Strategy,development of the National Forest Sector Development Program, ratification of related conventions, declaration of forest proclamations have been found as promoting factors for the forest sector development in Ethiopia. However, Policy directions towards direct government role in large-scale forestation, reforestation and restoration are not explicitly chaptered in the Ethiopian Forest Policy document. Responsibilities and emphasis in forest plantation development is given to individuals, cooperative, groups and organizationin the 2007 forest policy document. This policy approach may only give rise to the development fragmented plantation forests. The approach may also highly compromise quantified and qualified mass production of forest and forest products in the country. Forest strategies and action plans are not designed in a mandatory and obligatory comportment between the federal and regional implementing sectors and institutions. Regional, sector and Institutional responsibilities, coordination and linkage were not well articulated in the policy documents. Currently only regional forest enterprises in Amhara and Oromia are actively engaged in large-scale plantation development in the country. Generally, the policy follows a highly decentralized and grass-root level individuals, groups or organization approach towards forest plantation development.

Therefore, government level paradigm shift in the forest sector is highly essential. Reforms in the forest policy, strategy, and institutional sectors in connection with establishing mandated forest action plans can progress the large-scale plantation development sector of the country. Additionally, active engagement and direct investment of the government in forest plantations, advocacy, resource mobilization, extension and financing can boost the forest sector. Establishing strong, centralized, authoritative and self-sustaining forest institutions is vital for sustainability of large-scale plantations serving commercial, restoration, and rehabilitation as well as eco-system services.

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Capital, labor, and gender: the consequences of large-scale land transactions on household labor allocation

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Abstract

Contemporary large-scale land transactions (LSLTs), also called land grabs, are historically unprecedented in their scale and pace. They have provoked robust scholarly debates, yet studies of their gender-differentiated impacts remain rarer, particularly when it comes to how changes in control over land and resources affect women's labor, and thereby their livelihoods and well-being. Our comparative study of four LSLTs in western Ethiopia finds that the transactions led to substantial land-use change, including relocation and decrease in size of smallholder parcels, loss of communally-held grazing lands, and loss of forests. These changes had far-reaching impacts on household labor allocation, the gendered division of labor, and household wellbeing. But their effects on women are both more adverse and more severe, expressed in terms of increased wage labor to make up for lost land and livestock, more time spent gathering firewood and water from increasingly distant locations, and increased intensity of household responsibilities where male members underwent wage labor migration. These burdens led to negative psychological, corporal, and material effects on women living in and near transacted areas compared to their situation before transactions. This article both responds to the deficit in studies on the impacts of LSLTs on gendered livelihoods, labor relations, and wellbeing outcomes and lays the groundwork for future research.

Keywords: Tenure changes; gendered impacts; agricultural investments; Ethiopia

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