GROWTH AND CARBON SEQUESTRATION POTENTIAL OF MORINGA (*Moringa stenopetala*) ALONG AN ALTITUDINAL GRADIENT IN SOUTHERN ETHIOPIA †

[CRECIMIENTO Y POTENCIAL DE SECUESTRO DE CARBONO DE MORINGA (*Moringa stenopetala*) A LO LARGO DE UN GRADIENTE ALTITUDINAL EN EL SUR DE ETIOPÍA]

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SUMMARY

Background. Altitude affects growth and distribution of plants and influences the impacts of other environmental factors on plant growth and development. **Objective**. The objective of this study was to investigate the effect of altitude on the growth performance and carbon sequestration potential of *Moringa stenopetala* in the Konso Zone, Southern Ethiopia. **Methodology**. The three sites that were selected for the study include Bayde (1300-1500 masl), Gamole (1501-1700 masl) and Fasha (1701-1900 masl). From each site three age classes (6-10 years, 11-15 years and 16-20 years) were selected for the study. Six farmers were selected from each location and three trees from each farmer's land under each age class were selected for measuring height and diameter. Non-destructive method was used for estimation of biomass and carbon contents of different age groups. **Results.** The results indicate that growth performance (height, diameter, volume, biomass production) and carbon sequestration of *M. stenopetala* was significantly higher ($p < .05$) at lower altitude as compared to mid and high altitude. It was concluded that *M. stenopetala* tree within 6-10 age class can sequester 10.96 kg of carbon stock by capturing 40.17 kg of carbon dioxide, while for age class of 11-15 the value of carbon storage and carbon dioxide sequestered is 27.87 kg and 102.20 kg respectively. Similarly maximum sequestration of carbon dioxide was recorded (42.31 Kg and 155.11 Kg respectively) for 16-20 age class. The annual sequestration of carbon was found maximum for class 16-20 (8.62 kg) followed by 11-15 class (7.86 kg) and lowest for 6-10 class (5.02 kg). **Implications**. The findings of present study will be helpful in knowing the effect of age and altitudinal variation on carbon sequestration potential of *M. stenopetala*. **Conclusions**. It is concluded that carbon sequestration potential of Moringa decreases with altitude and increases with stand age.
Keywords: Altitude; age classes; biomass; Moringa; tree diameter; tree height.

RESUMEN

Antecedentes. La altitud afecta el crecimiento y la distribución de las plantas e influye en diferentes factores ambientales que determinan el crecimiento y desarrollo de las plantas. **Objetivo**. El objetivo de este estudio fue investigar el efecto de la altitud sobre el crecimiento y el potencial de secuestro de carbono de *Moringa stenopetala* en la Zona Konso, Sur de Etiopía. **Metodología**. Los tres sitios que fueron seleccionados para el estudio incluyen Bayde (1300-1500 msnm), Gamole (101-1700 msnm) y Fasha (1701-1900 msnm). De cada sitio se seleccionaron tres clases de edad (6-10 años, 11-15 años y 16-20 años) para el estudio. Se seleccionaron seis agricultores de cada ubicación y se seleccionaron tres árboles de la tierra de cada agricultor en cada clase de edad para medir la altura y el diámetro. Se utilizó un método no destructivo para la estimación del contenido de biomasa y carbono de diferentes grupos de edad. **Resultados**. Los resultados indican que el crecimiento (altura, diámetro, volumen, producción de

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biomasa) y el secuestro de carbono de *M. stenopetala* fue significativamente mayor ($p < 0.05$) a menor altitud en comparación con la altitud media y alta. Se concluyó que el árbol de *M. stenopetala* dentro de la clase de edad de 6-10 puede secuestrar 10.96 kg del carbono almacenado mediante la captura de 40.17 kg de dióxido de carbono, mientras que para la clase de edad de 11-15 el valor del almacenamiento de carbono y el dióxido de carbono secuestrado es de 27.87 kg y 102.20 kg. respectivamente. De manera similar, se registró el secuestro máximo de dióxido de carbono para la clase de edad 16-20 de 42.31 kg y 155.11 kg respectivamente. Se encontró que el secuestro anual de carbono fue el máximo para la clase 16-20 (8.62 kg) seguido de la clase 11-15 (7.86 kg) y menor para la clase 6-10 (5.02 kg). **Implicaciones**. Los hallazgos del presente estudio serán útiles para conocer el efecto de la edad y la variación altitudinal sobre el potencial de secuestro de carbono de *M stenopetala*. **Conclusiones**. Se concluye que el potencial de secuestro de carbono de Moringa disminuye con la altitud y aumenta con la edad.
Palabras clave: Altitud; altura de árboles; biomasa; clases edades; diámetro de árboles; Moringa.

INTRODUCTION

There is a growing awareness all over the world about the adverse impact of greenhouse gas emission and the consequent climate change. At the dawn of third millennium, greenhouse gases are widely accepted by international scientific community as one of the potential threats to the existence of humankind coupled with extinction of other flora and fauna (Sheikh *et al*., 2014). The industrialization, urbanization and land use are responsible for increasing the concentration of CO_2 and other greenhouse gas in the atmosphere. Thus, increasing CO_2 emission is one of the major environmental concerns and it has been well addressed in 'Kyoto protocol' (Ravindranath *et al*., 1997).

The forest ecosystem serves as the one of the most important reservoirs of atmospheric carbon as it captures huge amount of CO_2 through the process of photosynthesis and thus helps in mitigating climate change and maintaining global carbon cycle (Suryawanshi *et al*., 2014). However modern human interventions had led to destruction and degradation of the vegetation. Ethiopia is also sufferer of that where 420,000 square kilometers (35% of Ethiopia's land) forest cover was there during 20th century which have declined to 16% in 1952, 3.6% by 1980, 2.6% by 1987 and an estimated 2.4 % in 1992 (Sayer *et al*., 1992). The tree cover of the Ethiopia is only 14.2 % as per the present study. About 2.76 billion tons of carbon is expected to be stored in the above ground biomass by current forest resources of Ethiopia. But if the current rate of deforestation (2%) continues, it will be released to the atmosphere in 50 years (Yitebitu *et al*., 2010). Therefore, this environmental issue needs immediate attention.

Removing atmospheric carbon (C) and storing it in the terrestrial biosphere is one of the options, which have been proposed to compensate greenhouse gas (GHG) emissions (Albrecht and Kandji, 2003). So, agroforestry based agrisilvicultural system of agriculture production is one of option which will not only reduce our dependence on forests but will also serve as potential sink of C absorption. Thus, in addition to agricultural sustainability, agroforestry for climate change can also receive wider recognition. Agroforestry is a dynamic, natural resource management practice that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits (Chauhan *et al*., 2009, 2012, 2015; Villa *et al*. 2020a). Approximately 1.2 billion people (20% of the world's population) depend to a large extent on agroforestry products and services for their survival (Loden, 2000). The introduction of native trees with high carbon storage capacity not only helps in reduction of atmospheric carbon but also help in maintaining the natural heritage of state.

When we talk about agro-forestry, our attention goes for selection of multipurpose trees which are having impact on social, economic and cultural aspects and are acceptable to the farmers or society. Moreover, farm friendly and fast growing trees are the sustainable, cheaper and efficient source of carbon sequestration and carbon stock. *Moringa stenopetala* is also one of such trees where farmers are growing it on their farm in large scale to improve their livelihood. Moringa is being used to combat malnutrition in many parts of the world by World Health Organization (WHO) and other international humanitarian relief organizations. This plant can play an important role in poverty alleviation and it offer climate smart choice of plant to be developed for the betterment of present as well as future generations (Mohammed, 2015). However, very limited studies have been conducted on *Moringa stenopetala* in the past related to evaluation of its growth and carbon sequestration potential.

Therefore, this study aimed to evaluate the effect of the altitudinal gradient on the growth and potential of carbon sequestration of *Moringa stenopetala* in Konso, Ethiopia.

MATERIALS AND METHODS

Description of the study area

This study was conducted on peasant's small scale farmland at Konso Zone, Southern Ethiopia where Bayde (32°66′N; 6°07′E; 1300-1500m above sea level), Gamole (31°54′N; $5^0$89′E; 1501-1700m above sea level) and Fasha (31°74′N; 5°85°E; 1701-1900 m above sea level) representing low, mid and high altitude. In the study area *Moringa stenopetala* is mostly grown by the farmers on their farm land as a part of agri-silvicultural agroforestry system. The area experiences mostly hot and warm temperature (NMA, 2008). Rainfall distribution follows a bimodal pattern i.e. from mid-February to end of April (main rainy season) and August to October. The area receives average total annual rainfall of 550mm, with the annual rainfall variations between 280 and 880mm (Tadesse, 2010). The soils of the study area are moderately alkaline and neutral in reaction. The contents of silt in the soils were very low as compared to clay and sand separates in the study area (Muhaba, 2018).

The farmers in the area used to cultivate number of varieties of cereals such as sorghum, maize, millet, teff, wheat and barley, pulse crops such as haricot beans, pigeon beans, lablab, peas, chickpeas and cowpeas, root crops such as cassava and cash crops such as coffee and chat (*Catha edulis*) together in the fields, and also in combination with trees and shrubs (similar to traditional agro forestry system), they also keep cattle, small ruminants, chicken and donkeys. Generally, agriculture of the Konso area is dependent on rainfall.

Sampling techniques

On the basis of altitudinal variation three different locations were selected for investigating the growth performance and carbon sequestration potential of a native Moringa plant. The low elevation was represented by location Bayde (1300-1500 m), mid location by Gamole (1501-1700 m) and high location by Fasha (1701-1900 m). In each location six volunteer farmers were considered for sharing their farmlands for the research. For data collection *M. stenopetala* was clustered into three age classes as 6-10 yrs, 11-15 yrs and 16-20 yrs, and then 3 plants per class were

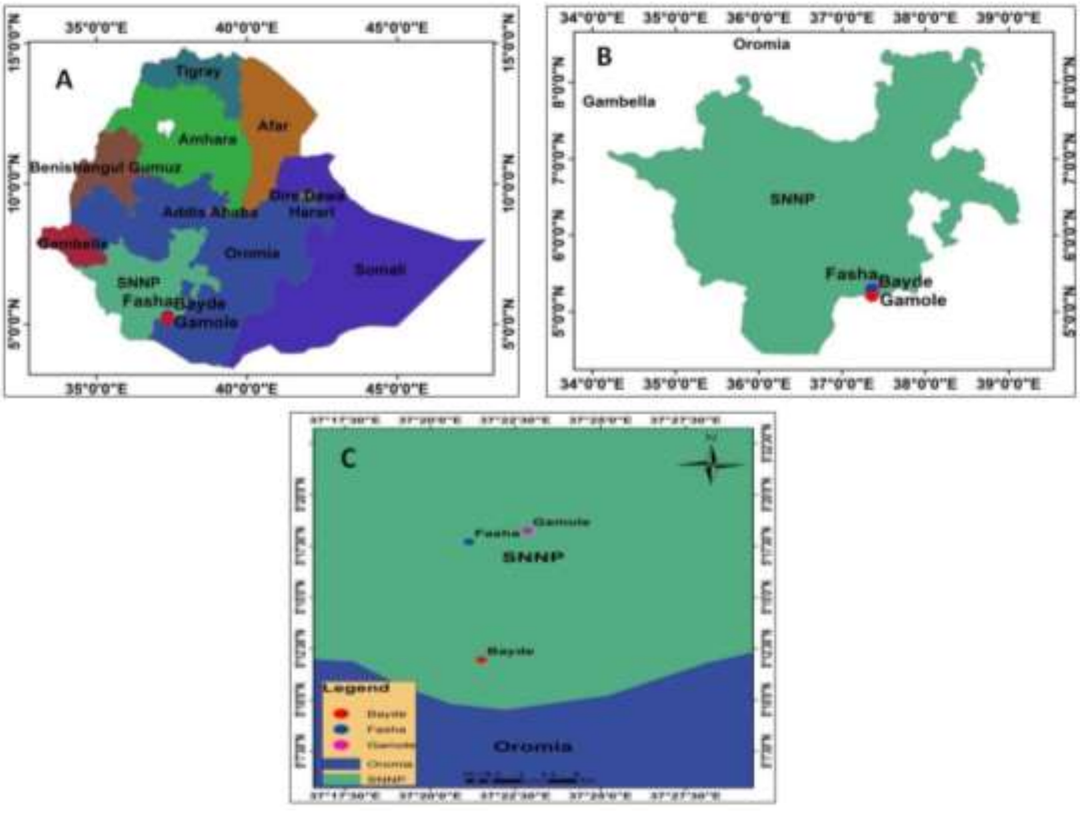

Figure 1. Location Map of the study area. A) Ethiopia; B) SNNP (Southern Nation and Nationality People Region); C) Study area.

randomly selected which having uniform age as per their opinion. These plants were measured for diameter at breast height (DBH) and height by using tree caliper and Telefix height measurer on each farmer's land and averaged into one replication. Each of these age classes were replicated six times across the altitudinal gradient per location. Thus, 6 replications/altitude/age class were recorded for both diameter and height estimation. The height and diameter data were further used to determine growth performance, expressed as biomass, and carbon sequestration potentials by age class and location.

Height and diameter (DBH)

Height (m) of the trees were taken directly by Measuring pole (Telefix height measurer) while girth was recorded at breast height (GBH) with the help of measuring tape and converted later into Diameter (D) by the following formula:

$GBH = 2\pi r$ and $2r = GBH/ \pi$ as $2r = D$ thus $D = GBH/ \pi$

On each location 6 farmers were selected (replications) for each age class. So in this way 6 trees/altitude/age classes (6x3x3=54 treatment combinations) were recorded for height and diameter estimation. The height and diameter were further used to calculate volume, Biomass and carbon contents.

Carbon contents estimation

Above-ground biomass and below-ground biomass was estimated by using non-destructive method of carbon estimation of the tree. The above-ground biomass pool was estimated by using the following parameters:

Above Ground Biomass (AGB)

AGB includes all living biomass above the soil and is calculated by multiplying wood density with volume where volume calculation was based on diameter and height (Pandya *et al*., 2013).

Volume

No equation is available for Moringa species through which its volume (V) can be calculated. So, tree volume value established by multiplying of diameter and height of tree species to factor 0.4 (Pandya et. al, 2013).

$V = 0.4 \text{ X } (D)^2 \text{ x } H$

Where $D = (GBH/\pi)$ in m; H= Height in m; GBH = girth at breast height; π = appx. 3.142
Density of *Moringa stenopetala = 0*.262 g/cm^3 (262 kg/m^3) [used from Global wood density database, Zanne *et al.,* 2009; FRL, 2016].

However, volume calculated by this formula is exclusive of leaves and fruits. Pandya *et al*. (2013) evaluated volume of 25 different tree species by using this formula

AGB = Volume (m^3) x wood density (kg/m^3)

Below Ground Biomass (BGB)

BGB includes live roots biomass, excluding fine roots with diameter <2 mm (Chavan and Rasal, 2012). However, the equation available in the literature for calculation of tree root biomass directly is relatively uncommon. BGB has been obtained by multiplying AGB with 0.20 as the root shoot ratio in case of *Moringa oleifera* (Mohammed, 2015).

BGB = 20% of AGB = AGB x 0.2

Total Biomass (TB)

It is calculated by adding above and below ground biomass (Sheikh *et al.*, 2011).

TB = AGB + BGB

Carbon Estimation

Carbon of any species is usually considered to be as 50% of its total biomass (Pearson *et al.*, 2005) i.e. Carbon Storage = Biomass x 0.5

So, by this way Carbon storage (kg)/Tree was evaluated for different age group of *Moringa* trees.

The amount of CO_2 captured

CO_2 is made up of 1 molecule of Carbon and 2 molecules of Oxygen

The atomic weight of (Carbon = 12.001115; Oxygen = 15.9994)

Thus, atomic weight of CO_2 = C+2xO=43.999915

CO_2 / C= 43.999915/12.001115=3.6663

Therefore, to determine carbon dioxide sequestered by any tree, multiply its carbon contents with 3.6663 (https://www.unm.edu/~jbrink/365/Documents/Calculating_tree_carbon.pdf).

Weight of CO_2 sequestered/year

Total carbon sequestered per tree was divided by average age of that group. The average age for these classes includes 8, 13 and 18yr for 6-10, 11-15 and 16-20 years, respectively.

Data analysis

Data were analyzed using linear mixed-effect model with random and fixed effects to test the main effects of age and altitude on above ground biomass (Villa et. al, 2020b).

$$Y_{ijk}=\mu+A_i+E_j+AE_{ij}+B_k+AB_{ik}+EB_{jK}+e_{ijkl}$$

Where:
Y_{ijkl} = observation of i^{th} plant in k^{th} replication of j^{th} elevation in i^{th} age;
A = fixed effect due to i^{th} age; E = fixed effect of j^{th} elevation; B = k^{th} Block effect.

Interaction of age, elevation and block is random. Mean were compared using Tukey's post hoc test (HSD=0.05). Different letters indicate significant differences between stand ages and altitudes.

RESULTS

Effect of altitude and age classes on growth performance and biomass production

It is clear from Table 1 that altitude affects significantly ($p<.05$) the height of the *Moringa stenopetala* (Table 4). The maximum mean height (6.92 m) was recorded for low altitude (Bayde) and minimum (6.06 m) for high altitude (Gamole) but statistically at par with mid altitude (6.34 m). On the other hand, effect of age on height was found highly significant ($p<0.05$) with maximum height (7.34 m) for 16-20 age class, followed by 6.57 m for 11-16 age class, and lowest 5.40 m for 6-10 age class. However, the interaction effect of age and altitude was found non-significant (Table 4).

The effect of both altitude and age on diameter was also found highly significant ($p<0.05$) and interaction of age and altitude was also found significant ($p<0.05$). The maximum average diameter (0.32 m) was recorded for low altitude followed by mid altitude (0.21 m) and lowest (0.17 m) for high altitude where later two were at par with each other. Similarly, maximum (0.29 m) average diameter was recorded for age class 16-20 followed by 11-15 age class (0.25 m) and lowest for 6-10 age class (0.16 m). (Table 1).

Similarly, altitude as well as age both significantly ($p<.05$) affect the volume of the *Moringa stenopetala* where maximum (0.30 m^3) volume was recorded for low altitude followed by mid altitude (0.12 m^3) and lowest (0.08 m^3) for high altitude where later two were at par with each other (Table 4). On the other hand, maximum volume was recorded for 16-20 age class (0.27 m^3) followed by 11-16 age class (0.18 m^3) ad lowest (0.07 m^3) for age class 6-10. The interaction effect of age and altitude was also found significant ($p<0.05$).

The biomass (Above, below and total) of the *Moringa stenopetala* also significantly affected by both altitude and age (Table 4) where maximun above, below and total biomass (79.87 kg, 15.97 kg and 95.84 kg, respectively)

Table 1. Effect of altitude and age on growth performance of *Moringa stenopetala*.

Altitude effect					Age effect				
Tr.	**Age classes**	**Plant height (m)**	**DBH (m)**	**Volume (m^3)**	**Tr.**	**Age classes**	**Plant height (m)**	**DBH (m)**	**Volume (m^3)**
	A_1	6.44ab	0.22bc	0.13cd		E_1	6.44ab	0.22bc	0.13cd
E_1	A_2	6.77a	0.34a	0.31b	**A_1**	E_2	4.68c	0.15d	0.04d
	A_3	7.54a	0.39a	0.47a		E_3	5.09bc	0.12d	0.03d
	Mean	**6.92 a**	**0.32a**	**0.30a**		**Mean**	**5.40c**	**0.16c**	**0.07c**
	A_1	4.68c	0.15d	0.04d		E_1	6.77a	0.34a	0.31b
E_2	A_2	6.87a	0.22bc	0.14cd	**A_2**	E_2	6.87a	0.22bc	0.14cd
	A_3	7.47a	0.25b	0.19c		E_3	6.08abc	0.18cd	0.08d
	Mean	**6.34ab**	**0.21b**	**0.12b**		**Mean**	**6.57b**	**0.25b**	**0.18b**
	A_1	5.09bc	0.12d	0.03d		E_1	7.54a	0.39a	0.47a
E_3	A_2	6.08abc	0.18cd	0.08d	**A_3**	E_2	7.47a	0.25b	0.19c
	A_3	7.00a	0.22bc	0.14cd		E_3	7.00a	0.22bc	0.14cd
	Mean	**6.06b**	**0.17b**	**0.08b**		**Mean**	**7.34a**	**0.29a**	**0.27a**

E_1 = Low altitude (1300-1500 masl); E_2 = Mid altitude (1501-1700 masl); E_3= High altitude (1701-1900 masl); A_1 = age class 6-10; A_2 = age class 11-15; A_3 = age class 16-20; Ht = Height, DBH = Diameter at breast height Tr = Treatments was found at lower altitude followed by mid altitude (32.69 kg, 6.54 kg and 39.23 kg, respectively) and lowest biomass (22.67 kg, 4.53 kg and 27.20 kg, respectively) was recorded for high altitude. Similarly, maximum above, below and total Biomass (70.51 kg, 14.10 kg and 84.61 kg) was recorded for oldest age class i.e. 16-20 followed by age class 11-15 with above, below and total biomass production of 46.46 kg, 9.29 kg and 55.75 kg, respectively (Table 2). The lowest biomass production (above, below and total) was recorded for youngest age class i.e. 6-10 with production of 18.26 kg, 3.65 kg and 21.91 kg, respectively for the same. The interaction effect of age and altitude was also found significant ($p<0.05$).

Effect of altitude and age classes on carbon sequestration potential of *Moringa stenopetala*

A significant effect of both altitude and age classes was observed on carbon stock (Total carbon, CO_2 fixed/tree and CO_2 fixed/tree/yr). It was observed that carbon sequestration potential of *Moringa stenopetala* decrease with increase in altitude and increases with increase in age (Table 3 and Fig. 2).

Maximum total carbon (47.92 kg), CO_2 fixed/tree^{-1} (175.70 kg) and CO_2 fixed tree^{-1} yr^{-1} (12.82 kg) was recorded for low altitude followed by 19.61 kg, 71.90 kg and 5.12 kg,

Table 2. Effect of altitude and age on biomass production of *Moringa stenopetala*.

Altitude effect					Age effect				
Tr.	**Age classes**	**AGB (Kg)**	**BGB (Kg)**	**TB (Kg)**	**Tr.**	**Age classes**	**AGB (Kg)**	**BGB (Kg)**	**TB (Kg)**
	A_1	35.02cd	7.00cd	42.02cd		E_1	35.01cd	7.00cd	42.01cd
E_1	A_2	81.63b	16.33b	97.96b	**A_1**	E_2	11.07d	2.21d	13.28d
	A_3	122.97a	24.59a	147.56a		E_3	8.69d	1.74d	10.43d
	Mean	**79.87a**	**15.97a**	**95.84a**		**Mean**	**18.26c**	**3.65c**	**21.91c**
	A_1	11.07d	2.21d	13.28d		E_1	81.63b	16.33b	97.96b
E_2	A_2	36.14cd	7.23cd	43.37cd	**A_2**	E_2	36.14cd	7.23cd	43.37cd
	A_3	50.84c	10.17c	61.01c		E_3	21.60d	4.32d	25.92d
	Mean	**32.69b**	**6.54b**	**39.23b**		**Mean**	**46.46b**	**9.29b**	**55.75b**
	A_1	8.69d	1.74d	10.43d		E_1	122.97a	24.59a	147.56a
E_3	A_2	21.60d	4.32d	25.92d	**A_3**	E_2	50.84c	10.17c	61.01c
	A_3	37.73cd	7.55cd	45.28cd		E_3	37.73cd	7.55cd	45.28cd
	Mean	**22.67b**	**4.53b**	**27.21b**		**Mean**	**70.51a**	**14.10a**	**84.61a**

E_1 = Low altitude (1300-1500 masl); E_2 = Mid altitude (1501-1700 masl); E_3= High altitude (1701-1900 masl); A_1 = age class 6-10; A_2 = age class 11-15; A_3 = age class 16-20; AGB = Above Ground Biomass, BGB = Below Ground Biomass, TB = Total Biomass; Tr = Treatments

Table 3. **Effect of altitude and age on carbon sequestration of *Moringa stenopetala*.**

Altitude effect					Age effect				
Tr.	**Age classes**	**TCC (Kg)**	**CO_2 fixed/tree (Kg)**	**CO_2 fixed/tree/yr**	**Tr.**	**Age classes**	**TCC (Kg)**	**CO_2 fixed/tree (Kg)**	**CO_2 fixed/tree/yr**
	A_1	21.01cd	77.03cd	9.63bc		E_1	21.01cd	77.03cd	9.63cd
E_1	A_2	48.98b	179.57b	13.81ab	**A_1**	E_2	6.64d	24.36d	3.04d
	A_3	73.78a	270.50a	15.03a		E_3	5.21d	19.11d	2.39d
	Mean	**47.92a**	**175.70a**	**12.82a**		**Mean**	**10.96c**	**40.17c**	**5.02b**
	A_1	6.64d	24.36d	3.05d		E_1	48.98b	179.57b	13.81b
E_2	A_2	21.69cd	79.51cd	6.12cd		E_2	21.69cd	79.51cd	6.12cd
	A_3	30.50c	111.84c	6.21cd	**A_2**	E_3	12.96d	47.52d	3.65d
	Mean	**19.61b**	**71.90b**	**5.12b**		**Mean**	**27.87b**	**102.20b**	**7.86a**
	A_1	5.21d	19.11d	2.39d		E_1	73.78a	270.50a	15.03a
E_3	A_2	12.96d	47.52d	3.66d	**A_3**	E_2	30.50c	111.84c	6.21c
	A_3	22.64cd	82.99cd	4.61d		E_3	22.64cd	82.99cd	4.61cd
	Mean	**13.60b**	**49.87b**	**3.55b**		**Mean**	**42.31a**	**155.11a**	**8.62a**

E_1 = Low altitude (1300-1500 masl); E_2 = Mid altitude (1501-1700 masl); E_3= High altitude (1701-1900 masl); A_1 = age class 6-10; A_2 = age class 11-15; A_3 = age class 16-20; TCC = Total carbon contents; Tr = Treatments.

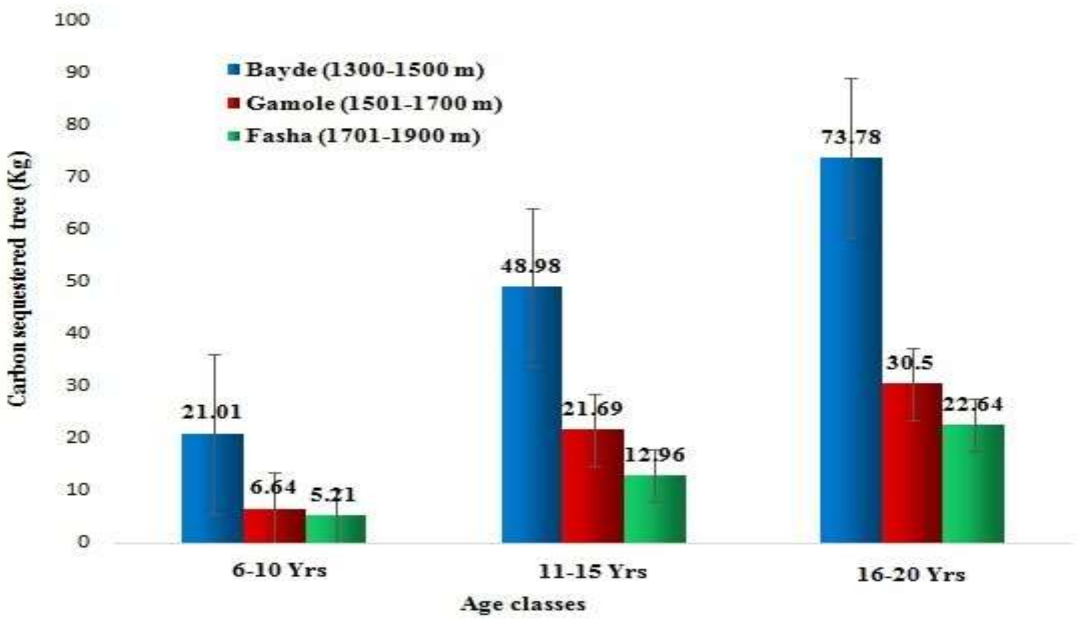

Figure 2. Carbon sequestration by different age classes along altitude.

respectively for mid altitude while lowest for high altitude i.e. 1.60 kg, 49.87 kg and 3.55 kg, respectively.

Similarly, maximum total carbon (42.31 kg), CO_2 fixed tree^{-1} yr^{-1} (155.11 kg) and CO_2 fixed tree^{-1} yr^{-1} (8.62 kg) was recorded for oldest age class (16-20) followed by middle class (11-16) i.e. 27.87 kg, 102.20 kg and 7.86 kg for total carbon, CO_2 fixed tree^{-1} and CO_2 tree^{-1} yr^{-1}, respectively, while lowest for youngest class (6-10) i.e. 10.96 kg, 40.17 kg and 5.02 kg, respectively (Table 3 & Fig 3).

The interaction effect of altitude and age for carbon fixed/tree^{-1} and CO_2 tree^{-1} was also found significant whereas a non-significant interaction between these two was observed for CO_2 fixed tree^{-1} yr^{-1} (Table 4).

DISCUSSION

Growth performance and biomass production parameters

It was observed that all the growth and biomass parameters were significantly affected by altitude and age classes. Except height, all other growth and biomass parameters like diameter, volume and biomass (above, below and total) show highly significant ($p<0.05$) variation with change in age and altitude while its effect on plant height was slightly significant ($p<0.05$). Thus, a significant but reverse increase in all growth parameters with increase in altitude but positively increase with increase in age was observed. However, the growth parameters for mid and high altitude were at par with each other (Table 2). Similar to this study Yohannes *et al.* (2015) also reported inverse relationship between altitude and biomass (above & below), deadwood carbon and total carbon density. The significant higher growth at lower elevation is due to its better adaptability to lower altitude and better photosynthetic efficiency as contributed by more exposure to light as compared to other altitude. All interactions except for height, between altitude and age was found significant ($p<.05$).

A number of researchers (Benecke and Nordmeyer, 1982; Enquist and Niklas, 2002; Richardson *et al*., 2005; Coomes, 2006; David and Robert, 2007; Takahashi, 2010) reported that growth rate decreases with an increase in altitude. However, it has been attributed to different factors by different authors. According to Wardle (1984) the reason being shortening of growing season and reduction in mean summer temperatures. Similarly, some author reported that fall in mean temperature with increase in altitude is responsible for changes in growth rate (e.g. Benecke and Nordmeyer, 1982; Richardson *et al.*, 2005). Enquist (2002) reported that because trees have an efficient transport system then whole-tree photosynthetic rate is simply related to the number of leaves on a tree. However, only the leaf number or size responsible for it is suspected as it may depend

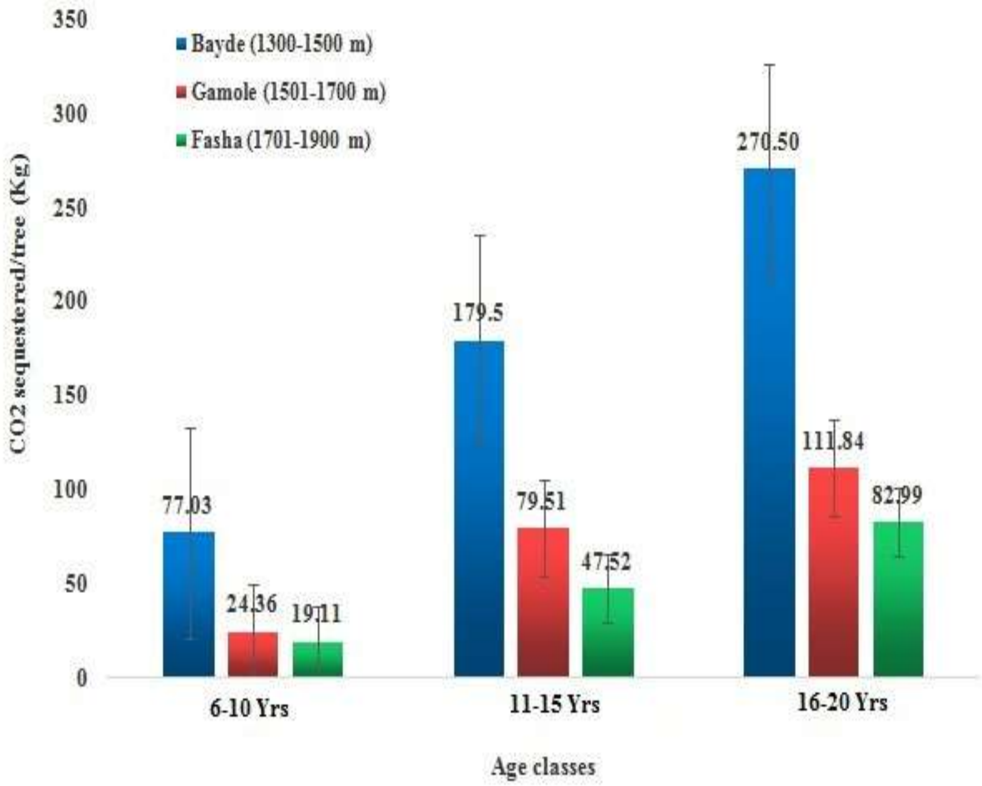

Figure 3. Carbon sequestration/tree by different age classes along altitude.

upon water, light and nutrient supply (Coomes, 2006; Richardson *et al.*, 2005). Takahashi (2010) reported intensity of light competition also declines with altitude. In similar study David and Robert (2007) reported decrease in growth rate may be due to reduced air and soil temperatures (an adiabatic effect), shorter growing seasons, increased exposure to wind, and reduced supply of nutrients and tree become stunted and have more open canopy at high altitude. The partial pressure of CO_2 in air is less at higher altitude (Shigeto *et al.*, 2010).

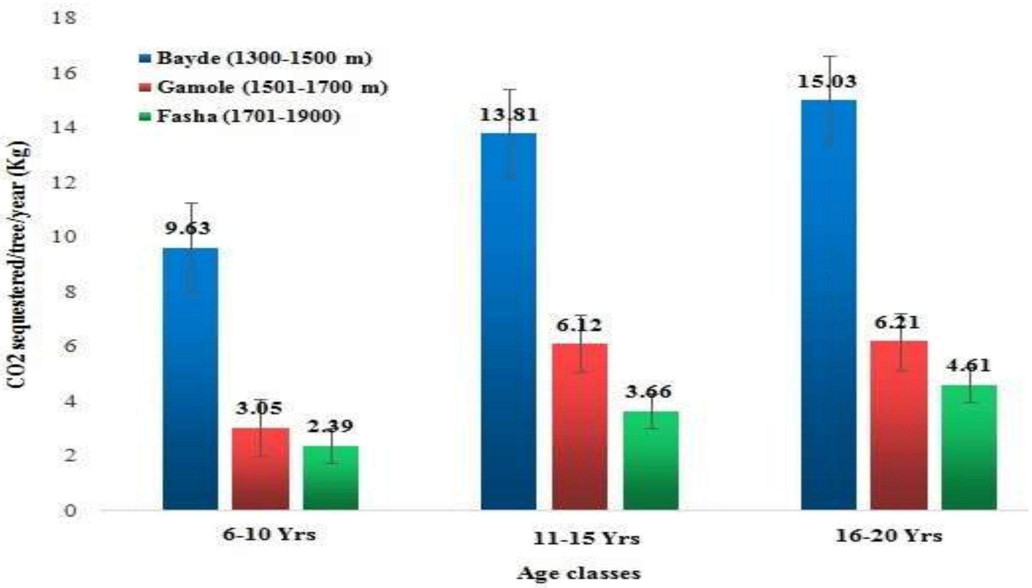

Figure 4. Carbon sequestration/tree/year by different age classes along different altitude.

Table 4. Summary of the analysis of variance for effects of treatments on growth parameters, biomass and carbon sequestration.

Parameters	p-value			F-value		
	Altitude	Age	Altitude x Age	Altitude	Age	Altitude x Age
Height	*.0426*	*<0.0001*	*0.1038*	*4.4002*	*38.833*	*2.216*
DBH	*<0.0001*	*<0.0001*	*0.0496*	*66.4200*	*103.7998*	*2.8730*
Volume	*<0.0001*	*<0.0001*	*0.0053*	*131.6784*	*60.7348*	*5.1029*
AGB	*<0.0001*	*<0.0001*	*0.0053*	*131.6784*	*60.7348*	*5.1029*
BGB	*<0.0001*	*<0.0001*	*0.0053*	*131.6784*	*60.7348*	*5.1029*
TB	*<0.0001*	*<0.0001*	*0.0053*	*131.6784*	*60.7348*	*5.1029*
TC	*<0.0001*	*<0.0001*	*0.0053*	*131.6784*	*60.7348*	*5.1029*
CO_2 fixed/tree	*<0.0001*	*<0.0001*	*0.0053*	*131.6784*	*60.7348*	*5.1029*
CO_2 fixed/tree/yr	*<0.0001*	*0.0022*	*0.6239*	*86.3289*	*11.9908*	*0.6646*

DBH = Diameter at breast height, AGB = Above Ground Biomass, BGB = Below Ground Biomass, TB = Total Biomass, TCC = Total Carbon Contents.

Carbon sequestration potential

The present study indicates decrease in carbon contents with increase in altitude as has also been reported by Yohannes (2015) that altitude has inverse relation with carbon content and carbon sequestration in a forest ecosystem. Physiological studies also confirm reduction in productivity with increase in altitude resulting from falls in both photosynthetic and respiration rates (Benecke and Nordmeyer, 1982). Under present study it is clear that at young stage (mean average age of 8yrs) *Moringa stenopetala* on an average having potential to sequestered 10.96 Kg of carbon; 40.17 Kg of CO_2 tree^{-1} and 5.02 Kg CO_2 tree^{-1} yr^{-1}. In similar study, Nawaz *et al*. (2017) reported production of 0.8 Kg Carbon, 2.95 Kg CO_2 and 1.47 CO_2 tree^{-1} yr^{-1} from 2 years old plantation of *Moringa oleifera*. With increase in age and decrease in altitude there is an increase in amount of Carbon sequestered and CO_2 fixed per year by a single tree. A *Moringa stenopetala* tree sequester 27.87 Kg of carbon; 102.20 Kg of CO_2 tree^{-1} and 7.86 Kg CO_2 tree^{-1} yr^{-1} at the mean average age of 13 years and 42.31 Kg of carbon; 155.11 Kg of CO_2 tree^{-1} and 8.62 Kg CO_2 tree^{-1} yr^{-1} for an average age of 18 years.

A tree with life span of 40 years can sequester 1000 Kg of CO_2 (annual CO_2 sequestration of 25kg) in tropical climate. However, carbon sequestrations are lower at cooler climate (The Green Earth Appeal, 1989). One more study reported that CO_2 sequestration potential of a tree depends upon growth rate, age, and species of the particular tree. Young and fast growing tree can sequester more carbon than mature tree with a slower growth rate (Kohl *et al.,* 2017). The sustainability of current economic activities is hampered by environmental impact. It is a new opportunity with small scale farmers by introducing Moringa in their land use system but necessitate strong policies, research and market development strategies in order to realize its full potential (Mohammed, 2015).

CONCLUSION

Moringa stenopetala is a multipurpose tree. The tree is not only contributing to livelihood of the farmers of the area but is also important environmental point of view. From this study it is concluded that the tree performed better at lower elevation by sequestering much higher carbon contents and it decrease with increase in elevation. A single tree of *M. stenopetala* can sequester on an average 42.31 Kg of Carbon, 155.11 Kg of CO_2 and can fix 8.62 Kg of CO_2 tree^{-1} yr^{-1} if tree is in the range of 16-20 age class. The increasing level of CO_2 in the atmosphere can pose threat to human survival which can be checked by incorporating trees like Moringa in agricultural land use system which not only ensure their economic profitability but also contribute to environmental sustainability as it sequester the atmospheric CO_2 at high rates. Thus its cultivation on farm land should be encouraged. The study will also be helpful in estimating the potential of Moringa as a carbon sequester tree in Moringa based land use system and can be useful in providing information for planners, policy makers, and farmers for effective management practices related to climate change mitigation and carbon budgeting etc.

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Conflict of interests. Author declare that there is no conflict of interests.

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Compliance with ethical standards. There is no ethical issues related to this research.

Data availability. Author is ready to share the raw data upon request subject to either meeting the conditions of the original consents and the original research study. Further, there is no ethical or legal obligations of user complies on data controllers to allow for secondary use of the data outside of the original study.

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