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RESEARCH PAPER

Farmland trees for the improvement of crop yield, soil fertilities, soil and water conservation, and carbon sequestration: A Review

Abebe Bezu Bedada[1] & Tolera Abera Goshu[2]

[1]Ethiopian Institute of Agricultural Research, Melkasa Agriculture Research Center, Adama, Ethiopia

[2]Ambo Agriculture Research Center, Ambo, Ethiopia

Corresponding Author Email: bedada.abu@gmail.com or abebe.bezu@eiar.gov.et, Tel.: +251911048796

*Corresponding Author

Abebe Bezu Bedada

Ethiopian Institute of Agricultural Research, Melkasa Agriculture Research Center, Adama, Ethiopia

*Corresponding author: bedada.abu@gmail.com or abebe.bezu@eiar.gov.et, Tel.: +251911048796

Abstract

This paper examines the role of farmland trees for the improvement of soil fertilities, enhancement of crop yield, soil and water conservation and Carbon sequestration. Natural resource degradation was one of the major problems that have been affecting social, ecological and economic situation all over the world in general and the highlands of Ethiopia in particular, where there is high population pressure, land susceptible to degradation, climate change, an exploitative farming style which further aggravated land degradation. Hence, different conservation strategies such as soil and water conservation, tree planting on degraded areas and area enclosures were launched at different times. Whereas, researchers have been recommended different ecologically sound agroforestry practices for Ethiopia especially in sloppy and areas susceptible to degradation. Some tree species were identified, and farmers conserved and maintained them on their farmlands traditionally. Hence, well-designed agroforestry practices have significantly reduced soil erosion and surface run-off due to interception of rainfall by the tree canopy, soil surface cover by litter, and formation of erosion-resistant soil structure. Studies indicated that agroforestry is efficient in insuring agricultural sustainability through enhancement of soil fertility by the addition of plant nutrients (N, P, K, Mg, Ca) because most of the agroforestry trees are leguminous that can fix nutrients that are essential for plant growth and development and helped in increasing crop yield. Besides, non-leguminous trees also add organic matter (OM) though the value varies with crop type, tree species, and agro-ecology. Therefore in introducing agroforestry practices, one has to consider crop type, tree species, and agro-ecology under which the practices will be implemented. Besides, agroforestry has the potential to sequester carbon at a higher rate than annual crops because annual crops can only accumulate through their roots and retention of crop residue, whereas the tree accumulated Carbon through roots, litter, and aboveground biomass and reduce global warming. Hence, integrating niche compatible trees into agroforestry practices has a higher potential for production and protection services mainly in sloppy areas.

Keywords: Agroforestry, climate change, natural resources, nutrients, parkland, soil, trees.

Introduction

Land degradation and recurrent drought are the major threats to rain-fed agriculture in the semiarid Ethiopian highlands (Taye et al., 2013). Climate change, soil erosion, depletion of surface, and groundwater and loss of biodiversity are among the principal problems that our planet has been confronted (Pimental, 2006). Particularly, in Ethiopian highlands, land degradation and the deterioration of natural resources have become a serious problem principally caused by the complex interactions of natural, social, and economic factors (Berhe and Kleber 2013). The high degree of dependence on natural resources, rapid population growth, lack of alternative employment opportunities for the rural population, rudimentary agricultural technology, persistent poverty, and very little or no investments in resource upgrading activities have been realized to have led the country to a severe environmental crisis (Gashaw et al., 2014). Besides, the policies that made land tenure insecure, offer little incentive to promote sustainable land-use practices and continuous cultivation with limited amendments and complete removal of OM, and widespread uses of dung and crop residues for household energy which leads to a continuous reduction in agricultural production and degradation of natural resources (Woldeamlak, 2003; Aklilu, 2006).

Globally, Agroforestry was recommended by most of the researchers for improving soil fertility, conserving soil and water, crop production enhancement, livelihood improvement, and climate change mitigation measures. This might be due to the presence of tree litters which is important in facilitating infiltration rates, preventing soil movement, and sequestering Carbon. For instance, *Faidherbia albida* is the best known for soil-improving in semi-arid tropics, including Ethiopia (Paudyal, 2003). In Ethiopia, some tree species traditionally managed in this system include *F. albida, A. tortilis, B. aegyptiaca, and A. raddiana* and they increased OM and N by 50-100% (Wolde, 2015). The integration of *C. macrostachys* into farms in West Gojam zone, *F. albida* in Bishoftu, Adama, Meki, Haramaya and Fedis, and *Acacia nilotica, E. cymosa, Cordia africana* and *C. macrostachys* in North Shoa and South Wollo area are common practices (Estifanos, 2018). Globally it was estimated that close to 50% of global agricultural land has more than 10% tree cover, nearly one-third has more than 20% tree cover and about 7% of global agricultural land has more than 50% tree cover (Zomer et al., 2014).

To address the problem of sustainable agriculture, extensive conservation schemes were launched by government and development agencies, particularly after the famines of the 1970s. Since then huge areas have been covered with different soil and water conservation (SWC) measures and millions of tree seedlings have been planted (Teramaje, 2015; Bezu and Tezera, 2019). In most of the cases, the conservation measures were physical structures, mainly stone or/and soil bands. However, in many areas, the interventions were failed primarily due to its space competition and lack of soil property improvement. Hence, biological SWC measures were given due emphasis and agroforestry and degraded land rehabilitation were widely adopted (Teramaje, 2015). In the last four decades, the government has been promoting agroforestry as an option to address poverty and food insecurity, as well as to enhance the adaptability of small-scale farmers to socio-ecological hazards. Hence, the Ethiopian government has planned to plant 100 million scattered *F. albida* trees into smallholder farms covering up to 15 million ha of land (Mekonnen et al., 2013) to make the economy green and climate-resilient, improve the food security of smallholders, adapt to and mitigate climate change (Sida et al., 2019).

In Ethiopia forestry and agroforestry based development was believed to be the core for sustainable development by considering the recurrent environmental hazards. It was initiated the national tree-planting program to improve forest coverage, mitigate climate change, improve agricultural production and maintain ecological balance by planting four billion seedlings in 2019 and two hundred million seedlings per day. Hence, the country succeeded the world record, and its name was recorded in the Guinness book of the world records by planting over three hundred fifty million seedlings in one day. For 2020 it was planned to plant five billion seedlings and twenty billion seedlings within four years even though the quality and technical feasibility were criticized by many experts. According to personal communication with MoA, most of the plantation was agroforestry and degraded land rehabilitation. Moreover, many researchers recommended agroforestry as the strategy for land rehabilitation and productivity enhancement (Estifanos, 2018).

Traditional agroforestry has been widely practiced in Ethiopia since ancient times of which home-garden agroforestry in southern Ethiopia (Gedeo). It is has been practiced on sloppy terrain where land shortage due to overpopulation are challenging for pure agricultural practices. The scattered trees of *F. albida* are also commonly practiced on the lowland plateau of croplands of the country (Mulugeta, 2014). Various studies showed that much higher crop yield, better soil and water conservation efficiency, good nutrient improvement (Sanchez and Jama, 2000) and great impact on the flux and long-term storage of Carbon (Dixon, 1995) though, some trees species compete with crops for water and nutrient and reduce yields, especially in dry climates. Hence, choosing the right tree species and managing them properly can minimize the competition (Selamyihun et al., 2004). Besides, agroforestry lowered herbicide, pesticide, and other pollutant losses by 55–100% and on average about 49% (Zhu et al., 2019). However, in Ethiopia, researches in the sector were very limited and a few existing were not well organized and documented in the way that easily accessible by development practitioners and the wider users hence, this paper aimed to exhaustively review the relevant documents from Ethiopia and international sources and make available for the users.

Agroforestry for Soil and Water Conservation

The forest cover is decreasing from time to time in many parts of the world mainly due to conversion of forest land to agriculture; thus adaptive measure needs to integrate agriculture with forestry (Dawson, 2012). Moreover, it was believed that agroforestry can improve the use of rainwater and produce more crops per drop compared to pure crop production. According to Karlsson (2018) agroforestry affects the water distribution on a farm in the landscape and on a regional scale. It can be essential to reduce surface runoff by improving infiltration and also help to increase groundwater formation, and on the continental scale, they are important for the formation of rain. Globally in most of the studies, Alley cropping is effective in conserving soil by reducing soil erosion and the erosion control effects are most pronounced in steeply sloping with intense rainstorm events (Kassa, 2016). When hedgerows are planted on contour bunds, they stabilize the bunds and significantly reduce soil erosion by the formation of terraces, especially on the lower parts of slopes (Khisa, 2001).

Soil erosion in the hilly areas was the most severe and damaging. However, it was substantially reduced when small watersheds with agriculture were replaced either by trees and grasses or with mechanical measures to reduce runoff as well as soil loss. In agroforestry systems run-off and soil loss were lower as compared with the sole crop system. Therefore, in sole maize farming runoff is 27.5 %, whereas in plots integrated *Eucalyptus* with grass treatment it reduced to 6.3 %. Concerning soil loss, in sole Maize it was about 28.27 ton ha^{-1} however in fields integrated *Eucalyptus* with grass soil loss is lowered to 3.52 ton ha^{-1} (Young, 1989). In multistory home garden agroforestry, soil erosion was varying from 0.01 to 0.14 ton ha^{-1}yr^{-1}. However, in areas where trees were completely removed, the soil loss was showed maximum result which varies between 5.92 to 104.80 ton ha^{-1}yr^{-1}. Zhu (2019), reported that on average, agroforestry systems reduced surface runoff, soil, organic carbon, and related nutrient losses by 58%, 65%, 9%, and 50%, respectively. Moreover, (Muchane et al., 2020) reviewed 17 studies conducted in humid and sub-humid tropics and found that in all studies, soil erosion rates were significantly lower under agroforestry as compared to sole cropping and they concluded that agroforestry reduced soil erosion by 50 %, infiltration rates increased by 75% and runoff lowered by 57%.

Similarly, *Leucaena leucocephala* integrated with maize on a steep slope reduced soil loss to 2 tons ha^{-1} year^{-1} as compared with a loss of 80 tons ha^{-1} year^{-1} on sole cropping (Banda et al., 1994; Sharma, 2008). In the Himalayan valley of India, run-off was reduced by 27 % and soil loss by 45 % through contour cultivation of maize on the slope of 4% (Narain et al., 1997). Contour tree rows or Leucaena hedges further reduced run-off by 40% and soil loss by 48%. Additionally, run-off and soil loss were substantially reduced when sole cropping was replaced either by silvipastoral (Sharma et al., 2017). Covering soil surface with *Senna siamea* mulch reduced soil loss to only 13 % of the standard average loss and barrier hedgerows reduces the loss to 2 % in semi-arid Kenya (Kiepe, 1996). According to Mulugeta (2014), soil loss was reduced to about 12.5 tons ha^{-1} year^{-1}, compared to fallow plots, which lost was 39 tons of soil ha^{-1} year^{-1}.

According to Labrière et al. (2015), soil losses in the humid tropics are greatest on bare land, slightly lower from agricultural land with annual crops, and very low in forested areas. Vegetation related conservation strategies such as hedgerows, mulching, and intercropping, can still decrease the erosion rate by as much as 90% compared to croplands where no conservation strategies are practiced. However, when vegetation strategies are combined with soil conservation methods such as no-till and contour planting with trees, the erosion rate can be reduced to zero. Nebiyou and Muluneh (2016), revealed that agroforestry has a significant role in erosion control through the soil cover provided by the tree canopy and litter. Paudyal (2003), elaborated that mainly leguminous trees have shown the potential of reducing soil erosion through the following principal ways: interception of rainfall impact by the tree canopy, soil surface cover by litter mulch, promotion of infiltration, and formation of erosion-resistant soil structure. Especially in sloppy areas, where cultivation on sloppy lands cannot be stopped, the inclusion of trees as SWC measures is one of the most widely convincing reasons for including trees on farmlands prone to erosion hazards (Patiram & Choudhury, 2000). Multipurpose trees planted on soil bund retards concentrated runoff, reduce soil erosion, drain excess runoff and ultimately mitigate land degradation (WRLC, 2015). Hedgerow planted trees check soil erosion through cover effect, where hedge pruning are laid along reduces runoff and soil loss and increase infiltration and ultimately lead to the development of terraces and stabilized the risers by stems and roots (Patiram & Choudhury, 2000).

Huang (2004), Yang & Zhao (2014), reported that the reduction in cumulative runoff under woodland and pastureland gradually decreased by 43% and 52% during the first and second years, respectively. Masebo (2016), also stated that the cover measures involving the use of vegetation for soil protection maintain the hydrological balance in which the surface run-off component in the hydrological cycle would be minimized. Young (1989), illustrated that maximum run-off and soil loss are from pure agriculture whereas minimum soil loss and run-off are generated from forest and agroforestry land (Table 1). Trees and shrubs in agroforestry practices have long-living nature, and it can remain throughout the year in the farmland and serve as better resources to control soil erosion and maintain moisture in-situ throughout its life

(Bekele, 1995). Dennis et al., (2013), investigated that *F. albida* canopies in the farmland increased soil water in the crop root zone and the soil water difference beneath the tree canopies rose from 4 to 53% higher than open sites.

Table 1: Runoff and soil loss under different land use

Treatment	Runoff (%)	Soil loss (t ha^{-1})
Maize alone	27.5	28.27
Maize + Leucaena	21.4	17.83
Maize + Eucalyptus	20.8	13.51
Leucaena alone	2.4	1.74
Eucalyptus alone	2.1	1.20

Source: Young (1989)

Ajayi et al. (2008), investigated that trees improved the physical properties of soils. Practically, soil aggregation is higher in agroforestry fields, which enhances infiltration and water holding capacity of soils thereby reducing water runoff and soil erosion. Kassa et al. (2010), investigated that available water capacity was 1.5 to 2 times more under a tree canopy than an open field. Hailu et al. (2000), described that the percentage of soil mc under and outside trees (*M. ferruginea*) on the surface soils (19.6 ± 0.56%) and the subsurface soils (10.0 ± 0.19%) under the trees whereas; the MC of the surface soils (15.9 ± 1.02%) and the subsurface soils (8.9 ± 0.20%) in the open areas. Similarly, Boffa (2000) revealed that soil moisture content decreased significantly with increasing distance from the tree to an open area which might be due to OM which makes the soil retain more water by increasing its surface area and improving the structure of the soil to have better porosity. Mamo & Asfaw (2017), realized that tree canopy resulted in reduced loss of soil moisture by evaporation, which contributed to higher soil moisture content under the trees. The improvement of soil structures as a result of better porosity and more OM content improved soil resistance to erosion and moisture retention.

In addition to water erosion, agroforestry systems serve as windbreaks and shelterbelts by providing solutions for the wind erosion that prominent in the arid and semi-arid regions. The protection area created by trees is on both leeward (about 15-20 time) and windward sides (about 2-5 times) of the height of a tree where the wind speed is reduced by 20 % below the incident wind speed (Atangana et al., 2014; Sharma et al., 2017). According to Teramaje (2015), agroforestry helped to reduce wind speed by up to 30 times the height of the trees on the leeward side. They also confirmed that wind speed reduction by the tree component helps crops to grow faster, protects crops from windblown soil, controls soil moisture content and protects the soil from erosion, hence, resulted in an increase in productivity. Moreover, trees are being used to stabilize dunes and protect soils from being covered by sand (Hoskins, 1990; Abdulhamid et al., 2017). In Ethiopia, where trees exists in the farmlands there is formation of mounds of soil around the trees due to the soil is accord by the root system and reduction of erosive power of rainfall due to the presence of canopy of trees. This created elevation variation with areas with no tree due to excessive soil loss at areas with not trees.

Agroforestry for Soil Fertility Enhancement

Soil fertility depletion is the fundamental cause of food insecurity and the low income of farmers in Africa. The loss of nutrients due to continuous cropping gradually reduces soil fertility, resulting in poor crop yields (Wolde, 2015). Kandji et al. (2006), reported that low soil fertility is a major problem to food production and one of the key biophysical constraints to agricultural growth. The popular benefits brought by farmland trees as an important element are the positive effect of trees on soil property improvement and consequently benefits on crop production and productivity (Pinho et al., 2012). Trees improve soil characteristics by increasing inputs such as OM, N fixation, and nutrient uptake and reducing losses such as OM and nutrients by promoting recycling and checking erosion, improving soil physical properties, including water holding capacity and having beneficial effects on soil biological processes (Paudyal, 2003). Furthermore, Sileshi et al., (2012) confirmed that N fixing trees add more than 60 kg of N ha^{-1} $year^{-1}$ and reduce the requirements of inorganic N fertilizers by 75% while achieving optimal crop yields.

According to Wolde (2015), nutrient loss from agricultural soils is huge with annual average loss of 22 kg N, 2.5 kg P, and 15 kg K for the whole of Sub-Saharan Africa. However, the incorporation of trees in the crops that have the ability of biological fixation of N is fairly common in tropical agroforestry systems even non N fixing trees can enhance soil physical, chemical and biological properties by adding a significant amount of above and below ground OM and releasing and recycling nutrients in agroforestry systems. Sharrow & Ismail (2004), also showed that most of the leguminous trees used in agroforestry improved soil characteristics that enhance soil fertility due to the addition of vegetative OM, i.e. decomposition of leafy biomass and roots. Kassa (2016), stated that integrating leguminous trees is common in agroforestry practices, which can fix atmospheric N and contributes to better soil fertility. He further explored that N fixing trees under agroforestry system increased the nutrient pool, organic biomass and activities of organisms in the soil. Paudyal (2003), indicated that farmland trees are believed to promote more efficient cycling of nutrients than pure agriculture. Muchane, et al. (2020), reported that Agroforestry practices significantly increase SOC and N storage, increased the availability of inorganic N and marginally increase the availability of inorganic P and pH in the soil.

Mugunga & Mugumo (2013), revealed that tree which fixes N cannot compete for soil N and ideally will increase the soil N capital (table 2) and the litter addition usually improves soil aggregate stability by binding soil particles together (Mugunga, and Mugumo, 2013). They also indicated that the soil outside the tree canopies dries out faster due to being exposed to direct solar radiation. This resulted in the shrinking of OM and clay colloids, thereby making the soil more compact. Soil N, SOC, and Ca^{2+} improved significantly under the canopy due to the presence of *A. sieberiana* (Table 3). Research in West Africa has shown that the presence of Acacia species increases CEC, Ca and Mg by 47%, 100% and 78% respectively, under tree crowns (Manjur et al., 2014). Wezel et al. (2000), reported that higher concentrations of C (39%), N (38%) and P (51%) were found under some tree species.

Table 2: The long-term effect of agroforestry on soil properties

Agroforestry system	Total N (%)	C/N	Exchangeable nutrients (me/100)			Avail. P (ppm)
			Ca^{2+}	Mg^{2+}	K^{+}	
Alder +crop	0.23	7.1	2.91	2.05	0.41	12.1
Albizia +crop	0.20	8.0	3.02	4.46	0.39	18.1
Sole crop	0.11	12.2	0.53	0.51	0.19	5.8

Source: Dhyani & Tripathi (1999)

Table 3: Some of the soil properties as influenced by agroforestry trees

Soil properties	Means under tree canopy	Means under open area
N (%)	0.90 ± 0.06	0.63 ± 0.05
C (%)	4.76 ± 0.31	3.63 ± 0.29
P(ppm)	45.01 ± 5.72	31.54 ± 4.14
Ca2+	9.81 ± 0.55	4.14 ± 0.56
K+	0.46 ± 0.03	0.58 ± 0.09
Mg2+	1.91 ± 0.10	1.94 ± 0.21

Source: Mugunga & Mugumo (2013)

Additionally, Sharma (2008) reported that agroforestry land-uses improved soil physicochemical properties such as, exchangeable nutrients, total nutrients, and total micronutrients as compared to pure agricultural practices. Moreover, it provided superior most in terms of maintaining higher chemical soil quality as compared to other land-use systems (Table 4). Similarly, Hailu et al. (2000), found that soil P, organic C, exchangeable base-forming cations and cation exchange capacity in the agroforestry land are much higher than in the pure agricultural lands. They also explained that nutrients declined with depth and increasing distances from the tree trunk. Poschen (1986), found that enhanced soil fertility status and improved physical conditions under *F. albida*. Likewise, Hadgu et al. (2011), found increased soil fertility for areas closer to *F. albida* than at a far distance.

Table 4: Land-use changes on soil property and nutrient status

Land use	Physicochemical properties			Exchangeable nutrients (c mol kg^{-1})				Total nutrients (mg kg^{-1})					CSQI
	EC (dS m^{-1})	OC (g kg^{-1})	CEC (cmol kg^{-1})	Ca	Mg	Na	K	N	P	K	Ca	Mg	
Agroforestry	0.11	9.6	13.7	0.92	4.71	0.18	0.23	565	787	4.6	14	5.22	0.92
Arable land	0.04	3.7	10.8	0.76	2.46	0.2	0.15	483	473	4.64	14.4	4.51	0.76

Source: Paudyal, (2003)

Parkland trees can increase the amount of available N in the topsoil in the order of 100 - 200 kg N ha^{-1} within 0.5 - 2 years (Jama et al., 2006). According to Sanchez & Jama, (2000), two-third of the N captured by the tree comes from biological N fixation and the rest from deep nitrate capture from the subsoil (Table 4). Boffa (2000), observed richer topsoil in terms of organic Carbon and K around *V. paradoxa* crowns than in the open field. Reyes et al. (2009), also observed improved soil N and OM content under *G. sepium* over the levels found in natural forests. Kassa et al. (2010), indicated that available P was significantly higher under the canopy than further away from the canopy and OM, N, P and K levels were higher under the tree canopy than outside in all directions. Research Shrubs improved soil nutrient accumulation, as evidenced by increased soil OC (39%), nitrogen (38%) and P (51%) in a semi-arid climate (Wezel et al., 2000). Augustine & Joseph (1992), generalized that soils under tree canopy have higher pH, OC, Ca, Mg, K, total exchangeable bases and cation exchange capacity (CEC) than in open grassland.

Gindaba et al. (2005), studied that under tree canopies of *C. macrostachyus* and *C. africana*; surface and subsurface soils had 22-26 and 12-17% higher N, respectively than the corresponding soils away from tree canopies. Surface soil available P under tree canopies was 34-50% higher than the corresponding soil away from canopies. Similarly, Fadl et al. (2010), found that N, P, and OC were higher under intercropping systems of groundnut, sesame and roselle with *A. Senegal* agroforestry system. Asfaw & Agren (2007), observed a significantly higher concentration of P under *M. ferrugnea* and *C. africana* than under Red gum. The concentration of available P under *C. africana* was nearly two-fold, and four and half-fold greater than under *M. ferrugnea* and Red gum, respectively whereas, the total N under Red gum was 14% and 24% lower than under *C. africana* and *M. ferrugnea*, respectively (Table 5). However, Hagos & Nigussie (2015), indicated that organic C content under Red gum was 11.6% greater than under *M. ferrugnea* and 23.8% greater than under Cordia. Topsoil under *M. ferrugnea* and *C.africana* also had significantly higher levels of exchangeable Ca and Mg than Red gum. In Zambia the N, OC and K levels were 42, 31 and 25% respectively higher under the canopies of *F. albida* than outside. Similarly, *F. albida* improved soil fertility by 95%, soil moisture retention by 90 % and rainwater infiltration by 88% (Hadgu et al., 2011; Brhan, 2016).

Table 5: Nitrogen and Phosphorus composition of litter from agroforestry practices

Species	**Nutrient composition**	
	N mgg^{-1}	**P mgg^{-1}**
Cordia Africana	19.80	0.78
Enset ventricosum	11.40	1.24
Persea Americana	8.90	0.33
Milletia ferruginea	23.80	0.59
Croton macrostachys	17.80	0.49
Ficus vasta	8.90	0.91
Coffee Arabica	10.80	0.26

Source: Asfaw, (2003)

Hailu et al. (2000), illustrated in his study that the mean total percentage N and OC in the surface soils declined with increasing distances from the tree. Available P, Ca, Mg, K, Na, total exchangeable bases, CEC) and base saturation in the surface soils were all significantly higher under the trees than in the open fields. Yeshanew et al. 1998; Abebe et al., 2001, reported that total nitrogen contents were significantly higher under the canopy of *C. macrostachyus* and *C. africana*. The total nitrogen decrease with distance from *M. ferruginea* tree and available P under the canopy was significantly higher than an open area. The available P in the soil under a tree canopy is rated low whereas in the open area rated very low. Mamo & Asfaw (2017), reported that there was a very highly significant difference between distances of under canopy to open area.

Mamo & Asfaw (2017), reported that soil bulk density under *C. macrostachyus* is by far greater for the open area than under shade. Similarly, Manjur et al. (2014) reported lower bulk densities under scattered *F. albida* and *C. macrostachyus* in the Umbulo Wacho watershed of southern Ethiopia and this decline in bulk density under tree canopy might be due to high accumulation of OM than the open area. It is well known that incorporation of OM in soil improves physical (aggregate stability, bulk density, water retention) and biological properties (nutrients availability, cation exchange capacity, reduction of toxic elements) of soils (Mamo & Asfaw, 2017). Aweto & Dikinya (2003), specified that lower bulk density and higher total porosity of soil under the tree canopies than in the open savanna using *C. apiculatum* and *P. africanum*, on the soil under their canopies in Botswana hence, Bulk density of the surface soils (0.61 ± 0.006 g cm^{-3}) was significantly lower under *M. ferruginea* trees than in the open areas (0.69 ± 0.021). Bulk Density of the subsurface soils under the tree canopies (0.76 ± 0.009) was also lower than that of the subsurface soils outside the tree canopy (0.8 ± 0.000). Nevertheless, most of the studies conducted by different scholars across the globe on the role of agroforestry didn't show a significant difference in soil pH and texture. Even though there are a few studies that have shown a significant difference, it didn't indicate consistent results. For instance, Asfaw & Agren (2007); Kassa et al., (2010); Mamo & Asfaw (2017); Abebe et al., (2001) under and outside the canopies of *C. macrostachyus, B. aegyptiaca, F. albida, M. ferrugenia and C. africana,* in Ethiopia under different agro-ecologies.

Agroforestry in improving crop production

Trees are most often integrated with agriculture for their productive, protective, socio-economic and cultural roles for individual use within the farm fields. However, these are inseparable and very much interrelated for the productivity and sustainability of the system as a whole (Estifanos, 2018). Parkland trees, contribute to livelihood strategies in different mechanisms like, production diversification which can help in offsetting crop failures and supply of forage feed for livestock (Mekonnen et al., 2013) that enables the producer to include animals in their agricultural system thus creating additional income through production diversification and food when crop harvest is low, farm tools, household implements, fuelwood, construction materials, fruit and medicine (Gizachew et al., 2015; Endale et al., 2017). Furthermore, FAO (2016) concluded that light shade farmland trees increased crop yields in the lowland tropics by about 50 to 70 % and avoid crop failure.

Integration of trees on the farmland can compensate for yield loss due to climatic variability by improving the micro-environment. Accordingly, Karlsson (2018) confirmed that planting N-fixing trees had positive effects on maize yields and that the trees stabilized yields during droughts and other extreme weather events as well as improved the water use efficiency. The concept of nutrient cycling in agroforestry is that tree roots extend into portions of the soil profile (B and C horizons) that may not be accessible to annual crop root systems and that tree crops extract nutrients from these portions of the profile. These nutrients are then trans-located to above-ground plant parts and to a much larger root mass in the surface horizons (A and B horizons). Nutrients released through the decomposition of tree litter and roots are the major perceived benefit of agroforestry systems, particularly when N-fixing trees are included in the mixture (Paudyal, 2003).

Across Africa, yields of maize, millet, groundnuts and sorghum range from 30 to 200% higher beneath *F. albida* canopies compared to surrounding areas (Kalenga et al., 1994). In West Africa, crops growing under a canopy of *F. albida* trees produce an extra 2.5 to 3 tons of stalks per hectare and two and a half times the grain yield with three times the protein content, compared to crops growing in the open plot (Gorems & Goshal, 2020). In Ethiopia Sorghum yield under *F.albida* increased is by 56% as compared to yields outside the tree canopy (Estifanos, 2018). Whereas in Burkina Faso Sorghum grain yield under *C. africana* increased by 14% in parkland trees as compared to farmlands without trees (Boffa, 2000). Dennis et al., (2013) revealed that there was a significant difference in maize yield between agroforestry and non-agroforestry farm plots in which the maize yield under agroforestry is greater by 29.9%. However, the millet, groundnut and cowpea had increased the yield by over 200%, 100% and 20%, respectively (Table 6 and 7). They further explained that the increase in crop output coupled with many other tree products from agroforestry, including the improvement made on soil fertility by trees is enough to outweigh the argument that trees take up land which might be used for crop growing. On the other hand, some of these tree products like oils, honey, nuts, tannins, gums, resins, and charcoal are the additional products of agroforestry.

Table 6: Mean crop yield from agroforestry and non-agroforestry plots

Districts	**Average yield from agroforestry & non-agroforestry plots**		Yield variation
	Agroforestry plot Yield	**Non-agroforestry plot yield**	
Guyaku	332	227	105
Garkida	338	211	128
Gaanda	163	152	11

Source: Dennis et al., (2013)

Table 7: Average crop yield of agroforestry and non-agroforestry land use

Crops	**Average yield from agroforestry & non-agroforestry plots (kgha^{-1})**		**Yield variation (kg ha^{-1})**
	Agro-forestry	**Non agro-forestry**	
Millet	1072.21	666.76	405.45
Maize	1129.31	810.00	319.31
G/corn	825.00	660.67	164.33
Rice	1005.09	850.32	154.77
Cowpea	680.33	3940.42	-3260.09

Source: Abdulhamid et al., (2017)

Catacutan et al. (2017), found that there is a higher level of productivity occurs in agroforestry systems than in monoculture owing to the complementary relationship that exists between trees and crops. Similarly, Smith, (2010) observed that crops are unable to absorb soil nutrients, water, and leached nutrients from deep underground soil horizons hence the tree component on croplands helps to capture these nutrients and water, making it available at the level of the crop's rhizosphere. Therefore, the complementarity that exists between trees and crops in an agroforestry system increase nutrient capture as well as crop yields compared to monoculture systems (Garrity et al., 2006). Jiru (1989); EARO (2000), reported that wheat and maize yields increased by over 50% when grown under *F. albida* canopy within 1.4 m radius as compared to those further away from the base of the tree at Bishoftu and Haramaya.

Reyes et al., 2009) shown that agroforestry practices with *G. robusta* found that *E. cardamomum* and pepper yield was 5.5 and 3.9 times better respectively, as compared to monoculture. Many scholars revealed that agroforestry practices produced highest crop yield, for instance, Anthofer et al., (1998) found the highest grain yield of wheat under Gliricidia tree, Reyes et al., (2009) found 76% and 36% of maize and sorghum respectively, under *F. albida*. Hadgu et al., (2011) found highest barley yield under *F. albida* and *M. ferrugunia* trees as compared to mono-cropping. Agroforestry also increased the yield of crop straws that mostly needed for livestock feed, as fuel wood and soil improvement. Hailu et al., (2000) reported that better growth responses and higher dry matter yield of maize underneath of *M. ferrugunia*. Fadl & El sheikh (2010), found highest crop yield in Sudan under *A. senegal*. Moreover, maize grown beneath agroforestry trees exhibited healthy and vigorous growth with normal green leaves and stems, while those grown on the control soils were rather stunted, with dark-green to violet leaves and stems (Hailu et al., 2000). This remarkable increase in crop production results from both increases in soil fertility and improved soil water and microclimatic conditions below the tree (Boffa, 2000).

Besides the crop yield, agroforestry increases the yield of wood and non-wood tree products. Gaafar et al., (2006) found increased gum production per unit area when sorghum was intercropped by trees in low or high density. Jama & Amare, (1991) reported that growth performance, such as height and diameter at breast height (DBH) of *F. albida* rotationally intercropped with Maize and Phaseolus aureus, found the higher mean height (140%) and DBH (24%) than tree alone. Kassa (2016), concluded that agroforestry adopters were able to produce reliable quantities of high-quality products such as fruits, vegetables, and processed honey than non-agroforestry adopters. In addition, data on global export values of agroforestry trees of 12 commodities that are grown primarily in the tropics, amounting to more than $ 66 billion in 2009. Moreover, smallholder farmers in western Kenya plant trees mainly as a living "saving account" that allows them to pay for regular expenses such as school fees and emergencies (Bishaw et al., 2013)

However all trees in the farm cannot improve soil property and crop yield; some trees even pollute the soil and resulted in yield declining (Asfaw and Agren, 2007). For instance, Selamyihun et al. (2004) found significant depression of teff and wheat yields within first 12 m from the tree line resulted in the reduction of 20 - 73% and 20 - 51% for teff and wheat respectively. Similarly, Hadgu et al. (2009) observed a decreasing trend in barley yield as distance from a *F. albida* trunk decreased. And Hagos and Nigussie (2015); Anthofer et al. (1998), reported adverse effects of *G. robusta, A. polyacantha, A. nilotica and E. abyssinica* on wheat seedlings with increased pruning loads probably due to immobilization processes or allelopathic effects. Similarly, Boffa (2000) found under tree crowns, plant height and grain yield were significantly lower, by a factor of 16% for grain yield, than elsewhere in transects using *V. paradoxa* on sorghum production in Burkina Faso. In addition, mean plant height, and mean biomass and grain production per area as well as per plant were higher at the outside edge of tree crowns than in the middle of the field. This indicated that proper tree species selection and appropriate tree-crop arrangement is required to obtain maximum yield from agroforestry practices (Mulugeta, 2014).

In contrary a study from central Ethiopia found that woodlots established outside crop fields generated the highest economic returns followed by homestead tree and shrub arrangement (Duguma, 2013; Sida et al., 2019). However, trees integrated in to maize farmland had a significant negative effect on maize yield. The mean grain yields of 1683, 1994 and 1752 kg ha^{-1} under the canopies of Cordia, Croton and Acacia, respectively. Whereas the mean grain in the open fields around those trees were 4063, 3415 and 2418 kg ha^{-1} respectively (Sida et al., 2019). Conversely, preferences for indigenous on-farm tree species are driven by context-specific values and utilization flexibilities rather than by sole financial and economic factors. Hence, farmers were maintained on-farm trees for their social and cultural values (Gustad et al., 2004; Sida et al., 2019). The field observation in central rift-valley of Ethiopia, indicated that farmers retain *Acacia albida* and similar trees which contribute significant amount of foliage that decomposes quickly and improve soil fertility and then enhance crop yield production in the area.

Agroforestry for Carbon Sequestration

The global release of SOC from agricultural activities has been estimated at 800 tera g C yr^{-1} (Wolde, 2015). The contribution of agriculture to greenhouse gas (GHG) emissions has been estimated to be as low as 20% for CO_2, 50% for CH_4 and 70% for N_2O when compared to emissions from fossil fuels. CH_4 and N_2O are emitted from livestock; CH_4 from rice cultivation; CH_4, CO, N_2O and oxides of nitrogen from burning and CH_4, CO and N_2O from agricultural soils (Manna et al., 2015). CO_2 has been singled out as a highest GHGs being emitted to atmosphere from agriculture (FAO, 2016). However, managed agroforestry practices stores more Carbon than pastures and annual crops, but less than pure forest area. The use of N-fixing trees reduces the need for inorganic fertilizers, which is a large contributor to the global emissions of N_2O (Kim et al., 2016). The agroforestry practice is estimated to have the annual C sequestration potential of 7.2 ± 2.8 t C ha^{-1}. However, home garden forms of agroforestry have shown to sequester more Carbon than any other agroforestry system (Shi et al., 2018) (table 10). When agroforestry practices implemented, the Carbon sequestration rates is high at the beginning and it decrease when the system reaches equilibrium, i.e. the trees have grown tall and high activity of microorganisms degraded and added C (Kim et al., 2016). Hence, when agricultural land is converted to agroforestry, it annually sequestered 27.2 ± 13.5 tons CO_2eq ha^{-1}, at least for the first 14 years of establishment (Manna et al., 2015).

Forests play an important role in the global C cycle because they store a large amount of C in vegetation biomass and soil. It also sinks CO_2 from the atmosphere. Especially, conversion of high biomass tropical forest to other land-uses like agriculture could lead to increased atmospheric CO_2 via biomass burning increased soil respiration and decrease in CO_2 uptake by plants (Kassa et al., 2010). The potential of agroforestry in sequestering Carbon is based on the premise that the greater effectiveness of integrated systems in resource captures and use than single species. The woody biomass of agroforestry systems could provide a source of local fuel, which would reduce pressure on forests and at the same time, provide a substitute for fossil fuel which exacerbates the emission of GHGs (Kassa et al., 2010).Integrating more trees in the agricultural landscapes has a higher potential to sequester Carbon (Meragiaw, 2017). Moreover, a review on 71 studies indicated that SOC in Agroforestry was significantly increased compared to crop monocultures. Closer examination using soil physical fractionation techniques showed that 13-29 % more soil C is stored in macro aggregates under agroforestry practices (Muchane et al., 2020). Hence, Paustian et al., (2016) stated that even small changes in SOC stock can have considerable impacts on the atmospheric CO2 concentrations and the global climate

Agroforestry plays a viable option to mitigate climate change and reduce global warming by absorbing CO_2 through the process of Carbon sequestration (Toppo & Raj, 2018). As a form of climate-smart agriculture, agroforestry is a promising adaptation option for smallholder farmers throughout the developing world (Neufeldt et al., 2013). Buchman, (2008); Jose (2009) stated that trees on croplands play a positive role in enhancing crop growth and animal welfare owing to their ability to buffer micro-climatic elements like temperature, wind speed, and water vapor present in the atmosphere. Beer et al. (1998) revealed that shade management in coffee and cacao plantations showed that shade trees buffer high and low temperature extremes by as much as 5 °C. Similarly, Mulugeta (2014) indicated that removal of shade trees increased soil surface temperature by about 4 °C and reduced relative humidity at 2 m above ground by about 12% and soil temperature under *A. tortilis* at 5-10 cm depth was found to be 6°C lower than in open areas (Belsky et al., 1993). In the Sahel, where soil temperatures often go beyond 50°C to 60°C, F. albida lowered soil temperature at 2cm depth by 5°- 10°C (Rao et al., 1989).

Agroforestry, an ecologically and environmentally sustainable land use, offers great promise towards mitigating the rising atmospheric CO_2 levels through C sequestration (Kumar and Nair, 2011). Tree crop sequestered C at a higher rate than those containing only in annual crops or grasslands (Brakas and Aune, 2011) because annual crops will only accumulate C through the roots and retention of crop residue, whereas tree crops accumulated C through, roots, litter and aboveground biomass (Nair, 2009; Jose, 2009). Kumar and Nair (2011) reported that Agroforestry has received special attention as C sequestration strategy. The post-Kyoto Protocol discussions on climate change are heavily oriented towards an agenda on mitigating the rising atmospheric CO_2 levels through C sequestration in terrestrial vegetation systems (Brhan, 2016). Hence, agroforestry such as parklands, home gardens, and woodlots stored a substantial aboveground C stock of 10.7 to 57.1 Mg C ha^{-1} with an average 19.4 Mg C ha^{-1} (Ndlovu, 2013). Moreover, Mammo et al. (2019) have shown that the average abatement rates in tone CO_2e ha^{-1} $year^{-1}$ are 7.6 for alley farming and 8.7 for improved fallow (table 8).

Table 8: The C absorption capacity of different agroforestry models

Agroforestry model	Carbon storage capacity (t C ha)
Agrisilviculture system (11 years)	26.0
Block plantation (6 years)	24.1–31.1
Populus deltoides 'G-48' + wheat	18.53
Silvopasture	31.71
Agrisilviculture	13.37
Agri-horticulture	12.28

Source: Mammo et al., (2019)

Verma et al. (2008), found that greater C content is nearer to the trees root (table 8). Vegetation controls the magnitude and composition of SOC stocks in 8 years old alley cropping systems with five different species (Table 9). The assessment conducted in different regions of the global also showed that the existence of agroforestry improved carbon storage (Shi et al., 2018) (table 11). However, the conversion of vegetation such as, subtropical evergreen forest into monoculture cropland causes to release stored Carbon into the atmosphere in the form of CO that would have a serious impact on climate change (Meragiaw, 2017).

Table 9: Carbon stock in different agroforestry practices

Agroforestry practices	AGC ha^{-1}	TBC ha^{-1}	SOC ha^{-1}	Total Carbon
Home garden home garden	6.63±2.2b	8.29±2.8b	61.57±11a	86.4±20b
Woodlot	106.47±8.5a	133.09±10.6a	48.57±0.3a	44.48±43a
Cropland	-	51.72	25.85	6754.77

Source: Bajigo et al. (2015)

Table 10: Global soil carbon (C) stocks in different agroforestry (AF) systems and climatic zones

Region	AF systems	Soil C in AF (Mg C ha-1)	Δ Soil C (Mg C ha-1)
Tropics and subtropics	Alley cropping	38.6	5.3
	Homegardens	40.8	8.7/23.4*
	Silvopasture	28.1	-1.8
	Windbreaks	30.1	6.3
Temperate	Alley cropping	17.7	2.2
	Homegardens	30.2	10
	Silvopasture	36.8	0.7
	Windbreaks	66.5	0.9

Δ Soil C represents additional C sequestered in soils under AF compared to pure cropland (or pasture).
* Δ Soil C of homegardens highly varied between tropical and subtropical climates (8.7 vs. 23.4 Mg C ha^{-1}).
Source: Shi et al., 2018

Table 11: Carbon sequestration rates in different agroforestry systems*

Location	System	Carbon sequestration (Mg ha^{-1}yr^{-1})
Chandigarh (Mittal & Singh, 1989)	Leucaena agri-silvi system	0.87
Jhansi (Rai et al., 2002)	Anogeissus agri-silvi system	1.36
Coimbatore (Viswanath et al., 2004)	Casuarina agri-silvi system	1.45
Bhadrachalam, AP (Prasad et al., 2012)	Leucaena agri-silvi system	13.7
	Eucalyptus agri-silvi system	7.5
Karnal (Kaur et al., 2002)	Prosopis silvi-pasture system	2.36
	Acacia silvi-pasture system	1.29
	Dalbergia sissoo silvi-pasture system	1.68
Himalayan foot hills (Narain et al., 1998)	Eucalyptus silvi-pasture system Leucaena silvi-pasture system	3.41 3.60
Jhansi (Rai et al., 2000)	Leucaena silvi-pasture system	1.82
	Terminalia silvi-pasture system	1.11
	Albizia procera silvi-pasture system	2.01
	Dalbergia sissoo silvi-pasture system	2.90
Hyderabad (Rao et al., 2000)	Leucaena monoculture	5.65
Tripura (Negi et al., 1990)	Gmelina monoculture	3.69
U.P. (Negi et al., 1990)	Teak monoculture	2.94
Dehradun (Dhyani et al., 1996)	Eucalyptus monoculture	5.54

* Excluding soil carbon

Recently, climate change is the most important global environmental challenge which is facing by all living organism including humans and disturb natural ecosystems, agriculture, and health. In this situation agroforestry emerges as a robust farming practice addressing the food security problem by making feeds to people, mitigate adverse effects of climate change by enhancing environmental quality, sustain economic viability and enhance the quality of life Toppo and Raj, 2018). According to Gorems and Goshal (2020), any increase in temperatures translated to reduced yield for instance, for each 1ºC increase in temperature, yields will decline by 10%. However, FAO (2016) calculated that if the area is covered by 15% shade, it would lower the temperature approximately 10ºC. Hence, agro-forestry can moderate the local climate and the additional storage of carbon (aboveground and below-ground) and contribute to national greenhouse gas targets.

Conclusion and Recommendation

Natural resource degradation, declining of agricultural production and productivity, and climate changes are the major problem of this era. Especially in developing countries like Ethiopia where the livelihood of the country is mainly depend on agriculture. Moreover, the challenges are most severe because the agricultural development interventions are usually contradicting each other. For example when agriculture is expanded it compromises the existence natural resources such as soil, water and forests. Improper cultivation and conversion of forest land to agriculture were the major problem observed in the country. However, agroforestry has solved the antagonistic effects between forestry and agriculture by combining forest, crop and/or livestock/grass in mutually benefiting each other in socially, economically and ecologically aspects. It has been commonly practiced for SWC, soil fertility enhancement, crop yield improvement and climate change mitigation measures. Therefore, the presence of scattered trees on the farmland have mostly positive effects on SWC intervention by creating resistant soil structures by adding soil nutrients through nutrient fixation, leaves soil cover and decomposition, improving infiltration and deep percolation by dissipating the erosive power of run-off and rainfall. Furthermore, agroforestry trees are important for nutrient cycling and fixation hence, farmlands with agroforestry are richer in soil nutrient contents. Therefore, the nutrient status of farmland with trees are significantly fertile than mono-cropping. Additionally, the improvement of nutrients by trees are also reduces extra chemical fertilizers requirement and this reduced the financial requirement for purchase of fertilizer. The ability of agroforestry in conserving soil and water and improvement of soil nutrients has been resulted in crop yield enhancement and diversification of production and avoid chance of failure by single crop. Besides, farmland trees improved Carbon sequestration capacity by absorbing more CO_2 which is one of the GHG that can cause climate change hence, it has been recommended and implemented by researchers and development practitioners as climate smart agricultural practices. However, all tree species are not equally friendly with all crop type in all agro-ecologies (Sida et al., 2019). Therefore a comprehensive science based review is needed to generalize agroforestry design and site adaptability for water and soil conservation, crop production and climate change mitigation (Zhu et al., 2019). Hence, the following issues should be given a serious attention.

- Before implementation of agroforestry practices there should be critical investigation on appropriate tree species and matching with crop types and agro-ecological condition.
- There should be further study on the appropriate agroforestry tree planting design and pattern under different agro-ecology.
- Integrating traditional and scientific agroforestry tree management practices and promotion for sustainable agroforestry management
- Expanding agroforestry demonstration sites, research centers and training institutions
- There should be a strong integration between agroforestry practices and soil and water conservation intervention, as agroforestry is a biological soil and water conservation

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