Chapter

The Role of Woody Plant Functional Traits for Sustainable Soil Management in the Agroforestry System of Ethiopia

Hana Tamrat Gebirehiwot, Alemayehu Abera Kedanu and Megersa Tafesse Adugna

Abstract

A woody plant functional trait that directly affects its fitness and environment is decisive to ensure the success of an Agroforestry practice. Hence, recognizing the woody plant functional traits is very important to boost and sustain the productivity of the system when different plants are sharing common resources, like in Agroforestry system. Therefore, the objective of this paper was to understand how woody plant functional traits contribute to sustainable soil management in Agroforestry system and to give the way forward in the case of Ethiopia. The contribution of woody plant species in improving soil fertility and controlling soil erosion is attributed by litter accumulation rate and the season, decomposability and nutrient content of the litter, root physical and chemical trait, and spread canopy structure functional trait. However, spread canopy structure functional trait is used in coffee based Agroforestry system, while with management in Parkland Agro forestry System. Woody species of Agroforestry system added a significant amount of soil TN, OC, Av.P, K, Na, Ca, and Mg nutrients to the soil. Woody plant species of Agroforestry system and their functional traits are very important to ensure sustainable soil management. Thus, further investigation of the woody plant functional traits especially the compatibility of trees with cops is needed to fully utilize the potential of woody species for sustainable soil management practice.

Keywords: woody plant, functional trait, sustainability, soil fertility, soil erosion, agroforestry system

1. Introduction

Woody plant functional trait, morphological-physiological-phenological characters that measured at an individual level and directly affects its fitness [1] and environment [2] is decisive to ensure the success of the Agroforestry practice. Agroforestry is indicated to be a prominent strategy to address land degradation, food security, and climate change challenges in Africa in general and in Ethiopia in particular too [3]. This is due to Agroforestry is a dynamic, ecologically based, natural resource management system that, through the integration of woody plants in farm- and rangeland, diversifies and sustains smallholder production for increased environmental, economic and social benefits [4].

Land degradation is a common environmental problem in Ethiopia for many years back to date due to the natural capital of the land resource is declining from time to time [5–7]. The primary reason of land degradation is land exploration for agricultural purpose to feed the ever increasing population [5, 6, 8] and predicted to be continued with the current trend [9]. As a result, soil erosion, droughts, loss of biodiversity and food insecurity are challenging the daily life of the rural population in Ethiopia [10, 11].

Therefore, integrated land use system such as Agroforestry system is very essential to combat land degradation and its consequences like soil degradation to ensure sustainable use of resources [12]. Hence, recognizing the woody plant functional traits are very important to boost and sustain the productivity of the system when different plants are sharing common resources like in Agroforestry system [13]. The canopy feature of woody plants, the height, diameter, specific root length and leaf area are among others refer to the morphological traits while the internal process and chemical composition of the woody plant denotes to physiological traits of the plant [14]. Phenology of woody plant species defines the timing of different phases of life cycle such as leaf shading and re-growing, flowering, fruiting and seed dispersal [15, 16]. Thus, these functional traits of woody plants in Agroforestry system are the core feature in supporting sustainable soil management. Wherein sustainable soil management refers to an optimum level of field soil health and productive capacity to provide ecosystem services such as provision of clean water, hydrologic and nutrient cycling, habitats for microorganisms and mesofauna, carbon sequestration, and climate regulation [17].

Hence, Agroforestry systems provide different ecosystem services. Different researchers confirmed that Agroforestry systems in Ethiopia endowed with highly diversified woody species [18–20]. The woody species diversity in Agroforestry system have indispensable role of natural forest conservation [21] as the farmers use woods from the Agroforestry system than natural forest. Moreover, the Agroforestry practices are central for keeping biodiversity and soil fertility at levels which are similar to the natural forest [22]. Research from Southern Tigray in Ethiopia indicates that Agroforestry practice has decreased soil erosion of the area [23]. However, how woody plants' functional traits support sustainable soil management has not been explored and reported in detail. Thus, in this review, how woody plants' functional traits support sustainable soil management in the Agroforestry system are discussed from soil fertility improvement and soil erosion control perspectives.

2. Woody plant functional traits and sustainable soil management

2.1 Above ground woody plant trait

Woody plants improve soil fertility and control soil erosion through their litter, canopy and root systems [24]. Ref. [25] holds a similar opinion when he states that from litter perspectives, 100% of the respondent from Jabithenan District, North-Western Ethiopia confirmed that Home garden Agroforestry system produce higher litter stock from weeds, grasses, and tree leaves than non-tree system. A similar finding by [26] reveals that in West Guji Zone, South Ethiopia, farmers noted that tree species that sheds its leave before the onset of rain and can easily decomposed are integrated in to farm land to increase the soil fertility. For example, *Faidherbia albida* and *Ziziphus mucronata* tree species are special fertilizer trees used to integrate on cropland in the parkland Agroforestry system [27]. These trees shed their leaves before the onset of rain and regrow their leaves and flower during dry season [28]. Ref. [29] state that majority of trees contribute leaf litter fall to the system in the dry season. Ref. [30] holds a similar opinion when he states that litter accumulation rate and season of the leaves fall, the decomposability of woody plant leaf are very important aspects of functional trait for improving soil fertility of the system.

Regarding to canopy, [31] state the shape of the canopy of the woody plants and the size of the leaves are very crucial in minimizing soil erosion rate. Their major findings reveal that in the case of Bonga and Yayu-Hurumu districts, Southwestern Ethiopia, 98.2% of respondents preferred woody plants with thin and small leaves in decreasing the intensity of soil erosion than broader and larger leaves as coffee shade. Additionally, spreading canopy nature of woody plants can reduce the energy of raindrops by intercepting rainfall than narrow one. Hence, protecting the soil surface against the impact of rainfall drops by intercepting runoff [32].

However, [28] states that trees such as *Cordia africana*, *Croton macrostachyus*, *Acacia etbaica*, *Ficus thoninngii*, *Sesbania sesban* and *Leucena leucocephala* has an adverse shade effect on crop production and managed through pruning to be used on agricultural land. In the parkland Agroforestry system, trees like *Cordia africana*, *Croton macrostachyus*, and *Acacia tortilis* have generally a negative effect on total aboveground biomass and grain yields of Maize in the case of Meki and Bako, Ethiopia [33]. Ref. [34] show that wheat is the most compatible crop when integrated with *Acacia albida* under shade conditions followed by maize, while teff is highly susceptible to shading effect pointing the importance of lopping to minimize shade effect. Similarly, conventional agriculture with trees highly reduces crop yield in the equatorial savannah of East Africa [35].

Concerning tree phenology of leaf fall and flowering period of woody plants, [36] indicated that farmers especially women, have limited knowledge. Their finding also reveal that farmers have better knowledge on fruiting time of edible fruit tree species because it is related to their income generation for Lemo District in SNNPR Region.

2.2 Below ground woody plant trait (root trait)

From root morphological trait perspective, uses of mixture of plant species are advised on sloppy areas for soil and water conservation practices [37]. However, research in South Ethiopia, indicates that *Salix subserrata* is promising plant species for slope stabilization because it shows better root mechanical properties and has better root cohesion [38]. Nitrogen fixing ability of woody plants is the root chemical trait that centrally considered while integrating trees and shrubs in Agroforestry system to improve the soil nutrient [30, 39, 40]. Though tree species are used to improve soil fertility and combat soil erosion, there is limited knowledge regarding the root attribute of the woody plant species in the case of Ethiopia due to limited laboratory and well skilled manpower on the area [41, 42].

However, the belowground functioning of Agroforestry systems is still lacking, because numerous and complex site-specific interactions and trade-offs are at play [43]. For example, [44] state that the existence of *F. albida* tree highly improved N and P use efficiencies, leading to pointedly higher grain yields in wheat in the case of Mojo, the Central Rift Valley of Ethiopia. In contrast to this, *Gravilia robust* (*G. robusta*) (in Bugesera, Rwanda) and *Acacia tortilis* (*A. tortilis*) (in Meki, Ethiopia) trees lowered nutrient use efficiencies in maize, leading to significantly less maize grain yields compared with open fields receiving the same fertilization [44]. The research done on the effect of *F. albida* and *A. tortilis* on yield and biomass of wheat grown under canopies of both trees in Bora district Central Rift-valley, Ethiopia by [45] pointed out significant difference in nutrient availability between under canopy and open plot leading to greater grain yield under the canopy. The effect of the *F. albida* (*Del*) and *C. macrostachyus* (*Lam*) tree species on soil fertility parameters as well as grain yield of maize was significantly higher within the canopy of the tree than outside of the canopy in the case of umbulo Wacho watershed, southern Ethiopia [42]. Furthermore, [46] reported higher grain yield of sorghum (*Sorghum bicolor*) under canopy of *Faidherbia albida Delile* and *Cordia Africana Lam* trees species as compared to the open field in East Hararghe Zone, Oromia National Regional State; Ethiopia. Since these trees have the potential to improve soil fertility and moisture under its canopy. Ref. [47] also indicate yield of sorghum is significantly higher under the *F. albida* canopy than away from in the Tahtay Maychew district, central zone of Tigray region in the Northern part of Ethiopia.

The positive impact of trees on yield may be attributed by different factors. For example, there is higher Arbuscular Mycorrhizal Fungi under and at the periphery of the *F. albida* canopy than away from it and inhibit the growth and development of striga which is an obligate root hemi-parasitic weed of maize and sorghum [47]. Ref. [48] hold the same view when they state that an agroforestry system has increased abundance of soil bacteria and fungi and soil-N-cycling genes than monoculture cropland and open grassland. Other approach to minimize the negative effect of trees on crop yield is management. For instance, repeated tillage and weed management tended to minimize the negative impact of trees on crops, underlining the importance of agronomic practices that minimize competition between trees and crops for belowground resources [33].

Regarding to water use between trees and crops, [49] show that there is higher soil infiltrability under single trees than in the open areas indicating a positive impact of trees on soil hydraulic properties influencing groundwater recharge. Further, [50, 51] indicate the occurrence of plant hydrologic niche segregation in the agroforestry system suggesting weak competition for water between the components of the system. In coffee based Agroforestry system, [52] reported the coffee water uptake is mainly sustained from shallow soil sources (< 15 cm depth), while all shade trees relied on water sources from deeper soil layers (> 15 to 120 cm depth).

Concerning to allellopathic effect, different woody plant species produce different chemicals with allelopathic contents such as benzoic, cinnamic and phenolic acids, which have the potential to inhibit neighboring plants either positively or negatively depending on their concentrations [53]. The potential allelopathic effect of different Agroforestry tree species on Ethiopian main crops was studied in different parts of the country by different authors. For instance, the study conducted by [54] on the effects of four woody species on seed germination, radicle and seedling growth of four main Ethiopian crops namely; *Cicer arietinum* (chickpea), *Zea mays* (maize), *Pisum sativum* (pea) and *Eragrostis tef* (teff) reveals that Aqueous leaf extracts of all the tree species significantly reduced seedling growth, germination rate and radicle growth of the majority of the crops. Other studies conducted in the country also illustrate the effect of different woody species on different crops. For instance, chemical extracted from *Eucalyptus grandis* and *Eucalyptus camaldulensis* reduces germination rate, collar diameter, root length, and shoot length of Haricot Bean and Maize [55]. Ref. [56] reported also chemical extract from *Prosopis juliflora* reduces radicle and plumule length, *Z. mays*, *Panicum maximum*, *Chloris gayana*, *Gossypium hirsutum*. The adverse effect of chemicals from woody plant species on yield components like; shoot length, root length and collar diameter of crops significantly reduce the yield of the crops. In reverse to these studies, study conducted by [57] shows that, chemicals extracted from *Gravellia robusta* and *Casuarina equisetifolia* have stimulatory effect on the germination and radicle growth of Wheat and Maize.

3. Role of woody plants in soil fertility enhancement

Trees have impressive potential to improve soil fertility and forbid soil erosion in land management like farmland and watershed management [58–61]. For example, benefits of farmland woody plant species in the case of Northwestern Ethiopia are tremendous and soil fertility enhancement and management role indicates 35.14% among other benefits [62].

Dispersed trees on smallholder farms enhance soil fertility. For instance, research done in Tigray region reveals that *Dalbergia melanoxylon* woody species added a significant amount of nutrients to the soil indicating a negative linear relationship between the radial distance of the woody species and soil total nitrogen (TN), organic carbon (OC) and available phosphorus (AvP) contents (see **Table 1**) [60]. Ref. [42] investigated also a negative linear relationship between the radial distance of the woody species and soil TN, OC, and AvP contents for *F. albida* and *C. macrostachyus*. Ref. [64] shows that *Sesbania sesban* tree is also significantly ($P < 0.05$) improves soil TN, OC, Av.P, potassium (K), sodium (Na), calcium (Ca), and magnesium (Mg) of degraded lands from Lemo District, Hadiya Zone, Southern Nations, Nationalities and Peoples' Regional State (SNNPR) (see **Table 1**). Ref. [63] share a similar opinion when they state that higher K and Mg soil nutrients are observed under *Ficus vasta* and *Albizia gummifera* trees, compared with open fields, in parkland Agroforestry in central rift valley of Ethiopia (see **Table 1**).

Likewise, [66] states *Acacia abyssinica* specie is the most common in the crop-livestock farms in Borodo Watershed, Central Ethiopia because of its capacity to improve soil fertility and provide another service as well. According to the experience of farmers from highlands of the Kembatta zone, in the SNNPR, Ethiopia, Erythrina spp. and *Vernonia amygdalina* tree species are commonly grown in the hedges to improve soil fertility [67]. According to the Farmers' experience in Adola Rede District, Guji Zone, Southern Ethiopia, *Ficus sur* and *Cordia africana* tree species are found to be the most preferred coffee shade tree species for soil fertility improvement in the first and second rank respectively. Furthermore, the soil laboratory analyzed results indicates that soil chemical properties under canopy of both *Ficus sur* and *Cordia africana* shade tree species are in line with farmers' rank of shade tree preferences based on soil fertility improvement character (see **Table 2**) [65]. This is due to higher organic matter input through litter fall, root biomass, uptake and return of nutrients from deeper soil profiles under the tree canopies [68]. Furthermore, regulating services of trees on parklands are the protection of the soil against wind and water erosion, reduction of temperature through their shade as well as supporting services through improvement of soil fertility [69].

4. Role of woody plants in soil erosion control

Regarding to soil erosion control, biological soil and water conservation measures like tree and shrub planting are used to strengthen physical structures. The strengthened physical structure enabled to stabilize soil along the physical structures and to reduce the speed of surface runoff, henceforth increasing the infiltration rate of soil [70, 71]. Tree species that commonly being planted along soil and water conservation structures such as bunds and trenches namely are *Croton machrostachyus*, *Acacia abyssinica*, *Sesbania sesban* and *Vernonia amygdalina* [70]. *Sesbania sesban* species is the farmers' most preferred woody plant for planting in soil bund in the semi-arid sites in Oromia, Ethiopia while *Leucaena leucocephala* and *Sesbania sesban* are in the sub-humid sites of the same region [72]. Additionally, *Acacia abyssinica* (37%) and *Fiaderbia albida* (30%) were the top woody species that

Species name	Sample plots	Chemical properties of soil, exchangeable base (Meq/100 g soil)							References
		Na	K	Ca	Mg	OC %	TN %	AvP (ppm)	
Ficus vasta	CN	0.55 ± 0.21^{a}	2.64 ± 1.75^{a}	7.87 ± 1.84^{a}	2.81 ± 0.76^{a}	—	—	—	[63]
	OP	0.43 ± 0.23^{a}	1.47 ± 0.221^{b}	6.21 ± 1.48^{a}	2.44 ± 0.32^{a}	—	—	—	
Albizia gumifera	CN	0.69 ± 0.11^{a}	4.42 ± 1.65^{a}	12.41 ± 3.24^{a}	3.39 ± 1.76^{a}	—	—	—	
	OP	0.60 ± 0.28^{a}	1.86 ± 0.89^{b}	12.15 ± 2.45^{a}	3.27 ± 0.92^{a}	—	—	—	
Oxytenanthera abyssinica	CN	—	—	—	—	1.73 (0.16)^{a}	0.26 (0.01)^{a}	7.21 (0.20)^{a}	[60]
	NCN	—	—	—	—	1.28 (0.09)^{b}	0.13 (0.01)^{b}	6.55 (0.19)^{a}	
	FCN	—	—	—	—	1.30 (0.11)^{b}	0.12 (0.01)^{b}	6.02 (0.21)^{b}	
Dalbergia melanoxylon	CN	—	—	—	—	1.02 (0.06)^{a}	0.13 (0.005)^{a}	6.37 (0.28)^{a}	
	NCN	—	—	—	—	0.70 (0.06)^{b}	0.09 (0.005)^{b}	5.78 (0.21)^{a,b}	
	FCN	—	—	—	—	0.65 (0.05)^{b}	0.07 (0.004)^{c}	5.32 (0.17)^{b}	
Sesbania sesban	LS	0.05 ± 0.00^{a}	1.57 ± 0.10^{a}	25.48 ± 1.33^{a}	3.39 ± 0.17^{a}	2.37 ± 0.11^{a}	0.21 ± 0.01^{a}	3.85 ± 0.31^{a}	[64]
	LEG	0.042 ± 0.00^{a}	1.41 ± 0.18^{a}	24.14 ± 4.6^{a}	3.20 ± 0.6^{a}	2.17 ± 0.03^{b}	0.185 ± 0.0^{b}	3.52 ± 0.46^{a,b}	
	DGL	0.032 ± 0.0^{b}	1.15 ± 0.18^{b}	17.58 ± 0.8^{b}	2.33 ± 0.11^{b}	1.97 ± 0.15^{c}	0.165 ± 0.0^{c}	2.86 ± 0.47^{b}	
Ficus sur	CN	—	2.27^{a} ± 0.95	—	—	6.49^{a} ± 1.31	0.67^{a} ± 0.15	7.52^{a} ± 1.87	[65]
	OP	—	0.41^{b} ± 0.32	—	—	2.54^{b} ± 0.65	0.41^{b} ± 0.12	3.81^{b} ± 0.91	
Cordia africana	CN	—	1.05^{a} ± 1.15	—	—	4.51^{a} ± 1.15	0.49^{a} ± 0.09	4.58^{a} ± 0.85	
	OP	—	0.56^{b} ± 0.24	—	—	2.31^{b} ± 0.91	0.42^{b} ± 0.07	2.50^{b} ± 0.41	

Species name	Sample plots	Chemical properties of soil, exchangeable base (Meq/100 g soil)							References
		Na	K	Ca	Mg	OC %	TN %	AvP (ppm)	
F. albida	1.5 m distance from the canopy	0.34 (0.03)[a]	1.33 (0.32)[a]	42.05 (1.83)[a]	13.22 (2.29)[a]	2.03 (0.21)[a]	0.41 (0.03)[a]	11.33 (0.6)[a]	[42]
	3.5 m distance from the canopy	0.27 (0.09)[a,b]	1.13 (0.3)[a]	39.04 (1.7)[a]	11.21 (2.1)[a]	1.49 (0.32)[b]	0.31 (0.04)[b]	10.03 (0.4)[a]	
	25 m distance from the canopy	0.24 (0.06)[b]	0.79 (0.16)[b]	29.38 (0.79)[b]	8.70 (0.66)[b]	1.38 (0.29)[b]	0.23 (0.03)[c]	8.73 (0.47)[b]	
Croton machrostachyus	1.5 m distance from the canopy	0.31 (0.04)[a]	0.90 (0.14)[a]	36.94 (8.31)[a]	10.25 (1.12)[a]	1.26 (0.25)[a]	0.14 (0.00)[a]	9.03 (1.08)[a]	
	3.5 m distance from the canopy	0.28 (0.07)[a,b]	0.84 (0.22)[a]	34.16 (8.8)[a]	10.81 (0.82)[a]	1.03 (0.16)[b]	0.13 (0.04)[b]	8.71 (0.74)[b]	
	25 m distance from the canopy	0.26 (0.04)[b]	0.49 (0.11)[b]	24.64 (3.54)	9.88 (0.45)[b]	0.76 (0.09)[b]	0.08 (0.01)[c]	8.47 (0.55)[b]	

[a,b,c]Means followed by different letters are significantly different.
CN, under woody species canopy; OP, open field; NCN, near to canopy; FCN, far from canopy; LS, lands treated with Sesbania; LEG, lands treated with elephant grass; DGL, degraded grazing land.

Table 1.
Impact of woody plant species on chemical properties of soil in the case of Ethiopia.

Species	Sample plots	Chemical properties of soil, Exchangeable base (Meq/100 g soil)							References
		Na	K	Ca	Mg	OC%	TN%	AvP (ppm)	
Ficus sur	CN	—	2.27^a ± 0.95	—	—	6.49^a ± 1.31	0.67^a ± 0.15	7.52^a ± 1.87	[65]
Cordia africana	CN	—	1.05^b ± 1.15	—	—	4.51^b ± 1.15	0.49^b ± 0.09	4.58^b ± 0.85	

^{a,b}*Means followed by different letters are significantly different.*

Table 2.
Comparison of the impact of woody plant species on chemical properties of soil in the case of Ethiopia.

practiced by farmers for soil conservation purpose in West Hararghe Zone, Oromia National Region State, Ethiopia [27].

5. Conclusions and recommendations

Woody plants of Agroforestry system improve soil fertility and forbid soil erosion from farmlands/water shade. Therefore, integration of woody plants on farming system based on the functional trait of woody plant is crucial to sustain soil management benefits of woody plants in Agroforestry systems.

Based on this review, the following are recommended to researchers to undertake study and policy makers to design agroforestry system that enable farmers to fully utilize the woody plant species potential in the Agroforestry system from functional trait point of view to achieve sustainable soil management practice in Ethiopia.

5.1 For researchers

1. Woody plant phenology such as leaf fall and re-growing and flowering seasons should be clearly investigated as per the Agro ecology because tree phenology is differing per Agro-ecology of the country. There is also lack of clear data on the phenology of major agroforestry woody plant species.

2. Woody plants' litter decomposability and their chemical compositions should be investigated further. Similarly, [73] recommend the importance of woody plants' litter decomposability and their chemical compositions analysis because litter quality is one among various factors which affects soil fertility based on its type and chemical contents.

3. The root system of woody plants used for soil and water conservation practice should be investigated.

4. The significance of the use of single species versus multiple species for soil nutrient improvement and soil erosion control should be evaluated.

5. Tree management practices of Parkland Agroforestry system to increase crop yield.

5.2 For policy makers

Woody plant functional traits should be considered when policy is designed to ensure sustainable soil management benefits of woody plants while introducing Agroforestry technologies.

Acknowledgements

We would like to express our special gratitude and thanks to Mr. Melkamu Teklu Kisi for his constructive comments and guidance during this work. Our gratitude and thanks also goes to Darko Hrvojic who invites and remind us to send our work to new book project "Biodiversity of Ecosystems" an Open Access book edited by Dr. Levente Hufnagel.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author details

Hana Tamrat Gebirehiwot*, Alemayehu Abera Kedanu and Megersa Tafesse Adugna
Department of Natural Resource Management, College of Agriculture and Natural Resource, Salale University, Fiche, Ethiopia

*Address all correspondence to: hanatamrat87@gmail.com

References

[1] Violle C., Navas M.L., Vile D., Kazakou E., Fortunel C, Hummel I., Garnier E. (2007). Let the concept of trait be functional. Oikos 116: 882-892.

[2] Poorter, L. et al. (2015) 'Effects on competition', Nature, pp. 1-15. DOI:10.1038/nature16476.

[3] Mbow, C. et al. (2014) 'Science direct agroforestry solutions to address food security and climate change challenges in Africa', Current Opinion in Environmental Sustainability, 6, pp. 61-67. DOI:10.1016/j.cosust.2013.10.014.

[4] Leakey, R. R. B. (2017) 'Definition of Agroforestry Revisited', in Multifunctional Agriculture, pp. 5-6. DOI:10.1016/b978-0-12-805356-0.00001-5.

[5] Hailemariam, S. N., Soromessa, T. and Teketay, D. (2016) 'Land use and land cover change in the bale mountain eco-region of Ethiopia during 1985 to 2015', Land, 5(4). DOI:10.3390/land5040041.

[6] Miheretu, B. A. and Yimer, A. A. (2018) 'Land use/land cover changes and their environmental implications in the Gelana sub-watershed of northern highlands of Ethiopia', Environmental Systems Research, 6(1). DOI:10.1186/s40068-017-0084-7.

[7] Hundera, H., Mpandeli, S. and Bantider, A. (2020) 'Spatiotemporal analysis of land-use and land-cover dynamics of Adama District, Ethiopia and its implication to greenhouse gas emissions', Integrated Environmental Assessment and Management, 16(1), pp. 90-102. DOI:10.1002/ieam.4188.

[8] Tokuma, U. and Debissa, L. (2020) 'Spatiotemporal Landuse Land Cover Changes in Walmara', 9(1), pp. 32-37. DOI:10.11648/j.earth.20200901.14.

[9] Gashaw, T. et al. (2017) 'Evaluation and prediction of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia', environmental Systems Research, 6(1). DOI:10.1186/s40068-017-0094-5.

[10] Deribew, K. T. and Dalacho, D. W. (2019) 'Land use and forest cover dynamics in the North-Eastern Addis Ababa, central highlands of Ethiopia', Environmental Systems Research, 8(1), pp. 1-18. DOI:10.1186/s40068-019-0137-1.

[11] Gebremedhin, Y. G. (2019) 'Soil Erosion Hazard in Errer Dembel Sub-Basin, in Shinille zone of the Ethiopia Somali regional state', international journal of environmental sciences and natural Resources, 17(1), pp. 1-9. DOI:10.19080/ijesnr.2019.17.555951.

[12] Bishaw, B. and Abdelkadir, A. (2003) 'Agroforestry and Community Forestry for Rehabilitation of Degraded Watersheds on the Ethiopian Highlands', Combating Famine in Ethiopia (October), pp. 1-22.

[13] Martin, A. R. and Isaac, M. E. (2015) 'Plant functional traits in agroecosystems: A blueprint for research', Journal of Applied Ecology, 52(6), pp. 1425-1435. DOI:10.1111/1365-2664.12526.

[14] Pérez-Harguindeguy, N. et al. (2013) 'New handbook for standardised measurement of plant functional traits worldwide', Australian Journal of Botany, 61(3), pp. 167-234. DOI:10.1071/BT12225.

[15] Haggerty, B. P. and Mazer, S. J. (2008) 'The Phenology Handbook'.

[16] Rodriguez, H. G., Maiti, R. and Sarkar, N. C. (2014) 'Phenology of Woody species : A review phenology of

Woody species: A review' (January). DOI:10.5958/0976-4038.2014.00595.8.

[17] Kassam, A. et al. (2013) 'Crops are grown', pp. 337-400.

[18] Guyassa, E. and Raj, A. J. (2013) 'Assessment of biodiversity in cropland agroforestry and its role in livelihood development in dryland areas: A case study from Tigray region, Ethiopia', Journal of Agricultural Technology, 9(4), pp. 829-844.

[19] Molla, A. and Kewessa, G. (2015) 'Woody Species Diversity in Traditional Agroforestry Practices of Dellomenna District, Southeastern Ethiopia: Implication for Maintaining Native Woody Species', International Journal of Biodiversity, 2015(iii), pp. 1-13. DOI:10.1155/2015/643031.

[20] Buchura, N. W., Debela, H. F. and Zerihun, K. (2019) 'Assessment of woody species in agroforestry systems around Jimma town, Southwestern Ethiopia', International Journal of Biodiversity and Conservation, 11(1), pp. 18-30. DOI:10.5897/ijbc2018.1207.

[21] Yasin, H., Kebebew, Z. and Hundera, K. (2018) 'Woody species diversity, regeneration and socioeconomic benefits under natural forest and adjacent coffee agroforests at belete Forest, Southwest Ethiopia', Ekologia Bratislava, 37(4), pp. 380-391. DOI:10.2478/eko-2018-0029.

[22] Kassa, H. et al. (2018) 'Agro-ecological implications of forest and agroforestry systems conversion to cereal-based farming systems in the White Nile Basin, Ethiopia', Agroecology and Sustainable Food Systems. Taylor and Francis, 42(2), pp. 149-168. DOI:10.1080/21683565.2017.1382425.

[23] Gebru, B. M. et al. (2019) 'Socio-ecological niche and factors affecting agroforestry practice adoption in different agroecologies of southern Tigray, Ethiopia', Sustainability (Switzerland), 11(13), pp. 1-19. DOI:10.3390/su11133729.

[24] Young, A. (1990) 'Maintenance of soil fertility for sustainable production of trees and crops through Agrof ores try systems sustainability and soil conservation', Japan International Research Center for Agricultural Sciences, pp. 198-206.

[25] Linger, E. (2014) 'Agro-ecosystem and socio-economic role of homegarden agroforestry in Jabithenan District, North-Western Ethiopia: Implication for climate change adaptation', SpringerPlus, 3(1), pp. 1-9. DOI:10.1186/2193-1801-3-154.

[26] Bussa, B. and Feleke, K. (2020) 'Contribution of Parkland Agroforestry Practices to the Rural Community Livelihood and Its Management in', 8(4), pp. 104-111. DOI:10.11648/j.hss.20200804.11.

[27] Yusuf, H. and Solomon, T. (2019) 'Woody Plant Inventory and Its Management Practices in Traditional Agroforestry of West Hararghe Zone, Oromia National Region State, Ethiopia', 8(5), pp. 94-103. DOI:10.11648/j.ajep.20190805.11.

[28] Ernstberger, J., 2017. Perceived Multifunctionality of Agroforestry Trees in Northern Ethiopia.

[29] Ssebulime, G. et al. (2018) 'Canopy management, leaf fall and litter quality of dominant tree species in the banana agroforestry system in Uganda', African Journal of Food, Agriculture, Nutrition and Development, 18(1), pp. 13154-13170. DOI:10.18697/ajfand.81.16700.

[30] Hundera, K. (2016) 'Shade tree selection and management practices by farmers in traditional coffee production systems in Jimma Zone, Southwest Ethiopia', Ethiopian Journal of

Education and Sciences, 11(2), pp. 91-105-105.

[31] Muleta, D. et al. (2011) 'Organic benefits of shade trees un coffee production systems in Bonga and Yayu-Hurumi districtis southwestern Ethiopia: Farmers' perception', Ethio. J. Educ. And Sc (1).

[32] Zhao, B. et al. (2019) 'Effects of Rainfall Intensity and Vegetation Cover on Erosion Characteristics of a Soil Containing Rock Fragments Slope', Advances in Civil Engineering, 2019. DOI:10.1155/2019/7043428.

[33] Sida, T. S., Baudron, F., Hadgu, K., Derero, A., and Giller, K. E. (2018). Crop vs. tree: Can agronomic management reduce trade-offs in tree-crop interactions? Agriculture, Ecosystems and Environment, 260(July 2017), 36-46.

[34] Haile, G., Lemenih, M., Itanna, F., and Agegnehu, G. (2021). Comparative study on the effects of Acacia albida on yield and yield components of different cereal crops in southern Ethiopia. Acta Agriculturae Scandinavica, Section B—Soil and Plant Science, 1-13.

[35] Ndoli, A., Baudron, F., Sida, T. S., Schut, A. G. T., van Heerwaarden, J., and Giller, K. E. (2018). Conservation agriculture with trees amplifies negative effects of reduced tillage on maize performance in East Africa. Field Crops Research, 221(March), 238-244. DOI:10.1016/j.fcr.2018.03.003

[36] Kuria, A. et al. (2013) 'Local Knowledge of Farmers on Opportunities and Constraints to Sustainable Intensification of Crop – Livestock – Trees Mixed Systems in Basona Woreda, Amhara Region, Ethiopian Highlands', p. 72.

[37] Ghestem, M. et al. (2014) 'A framework for identifying plant species to be used as "ecological engineers" for fixing soil on unstable slopes', PLoS ONE, 9(8). DOI:10.1371/journal.pone.0095876.

[38] Tsige, D., Senadheera, S. and Talema, A. (2020) 'Stability analysis of plant-root-reinforced shallow slopes along mountainous road corridors based on numerical modeling', Geosciences (Switzerland), 10(1), pp. 25-37. DOI:10.3390/geosciences10010019.

[39] Sharma, K. L. (2008) 'Effect of agroforestry systems on soil quality – Monitoring and assessment', academia. Edu, pp. 122-132.

[40] Mehari, A. (2012) 'Traditional agroforestry practices, opportunities, threats and research needs in the highlands of Oromia, Central Ethiopia', International Research Journal of Agricultural Science and Soil Science, 2(5), pp. 194-206.

[41] Reubens, B. et al. (2011) 'Tree species selection for land rehabilitation in Ethiopia: From fragmented knowledge to an integrated multi-criteria decision approach', Agroforestry Systems, 82(3), pp. 303-330. DOI:10.1007/s10457-011-9381-8.

[42] Manjur, B., Abebe, T. and Abdulkadir, A. (2014) 'Effects of scattered F. albida (Del) and C. macrostachyus (lam) tree species on key soil physicochemical properties and grain yield of maize (Zea Mays): A case study at umbulo Wacho watershed, southern Ethiopia', Wudpeckers J. Agric. Resear., 3(3), pp. 63-73.

[43] Cardinael, R., Mao, Z., Chenu, C., and Hinsinger, P. (2020). Belowground functioning of agroforestry systems: Recent advances and perspectives. Plant andSoil,453(1-2),1-13.DOI:10.1007/s11104-020-

[44] Sida, T. S., Baudron, F., Ndoli, A., Tirfessa, D., and Giller, K. E. (2020). Should fertilizer recommendations be adapted to parkland agroforestry

systems? Case studies from Ethiopia and Rwanda. Plant and Soil, 453(1), 173-188.

[45] Desta, K. N. (2018). Wheat yields under the canopies of Faidherbiaalbida (Delile) a. Chev and Acacia tortilis (Forssk.) Hayenin Park land agroforestry system in central Rift Valley, Ethiopia. Agriculture, forestry and Fisheries, 7(3), 75.

[46] Abdella, M., Nigatu, L., and Akuma, A. (2020). Impact of parkland trees (Faidherbia albida Delile and Cordia Africana lam) on selected soil properties and Sorghum yield in eastern Oromia, Ethiopia. Agriculture, Forestry and Fisheries, 9(3), 54.

[47] Birhane, E., Gebremeskel, K., Taddesse, T., Hailemariam, M., Hadgu, K. M., Norgrove, L., and Negussie, A. (2018). Integrating Faidherbia albida trees into a sorghum field reduces striga infestation and improves mycorrhiza spore density and colonization. Agroforestry Systems, 92(3), 643-653.

[48] Beule, L., Corre, M. D., Schmidt, M., Göbel, L., Veldkamp, E., and Karlovsky, P. (2019). Conversion of monoculture cropland and open grassland to agroforestry alters the abundance of soil bacteria, fungi and soil-N-cycling genes. PloS one, 14(6), e0218779.

[49] Bargués Tobella, A., Reese, H., Almaw, A., Bayala, J., Malmer, A., Laudon, H., and Ilstedt, U. (2014). The effect of trees on preferential flow and soil infiltrability in an agroforestry parkland in semiarid Burkina Faso. Water resources research, 50(4), 3342-3354.

[50] Wu, J., Liu, W., and Chen, C. (2016). Below-ground interspecific competition for water in a rubber agroforestry system may enhance water utilization in plants. Scientific reports, 6(1), 1-13.

[51] Wu, J., Zeng, H., Chen, C., Liu, W., and Jiang, X. (2019). Intercropping the sharp-leaf galangal with the rubber tree exhibits weak belowground competition. Forests, 10(10), 924.

[52] Muñoz-Villers, L. E., Geris, J., Alvarado-Barrientos, M. S., Holwerda, F., and Dawson, T. (2020). Coffee and shade trees show complementary use of soil water in a traditional agroforestry ecosystem. Hydrology and Earth System Sciences, 24(4), 1649-1668.

[53] Iqbal, J., Rauf, H. A., Shah, A. N., Shahzad, B., and Bukhari, M. A. (2017). Allelopathic effects of rose wood, guava, eucalyptus, sacred fig and jaman leaf litter on growth and yield of wheat (*Triticum aestivum* L.) in a wheat-based agroforestry system. Planta Daninha, 35.

[54] Nigatu, L., and Michelsen, A. (1992). Allelopathy in agroforestry systems: The effects of leaf extracts of Cupressus lusitanica and three Eucalyptus species. on four Ethiopian crops. Agroforestry Systems, 21, 63-74.

[55] Gurmu, W. R. (2015). Effects of aqueous Eucalyptus extracts on seed germination and seedling growth of Phaseolus vulgaris L. and Zea mays L. open access Library Journal, 2(09), 1.

[56] Asrat, G., and Seid, A. (2017). Allelopathic effect of Meskit (Prosopis juliflora (Sw.) DC) aqueous extracts on tropical crops tested under laboratory conditions. Momona Ethiopian Journal of Science, 9(1), 32-42.

[57] Ayalew, A., and Asfaw, Z. Allelophatic effects of Gravellia Robusta, Eucalyptus Camaldulensis and *Casuarina equisetifolia* on Germination and Root Length of Maize and Wheat.

[58] Mushir, A. and Kedru, S. (2012) 'Soil and water conservation management through indigenous and traditional practices in Ethiopia: A case study', Ethiopian Journal of

Environmental Studies and Management, 5(4). DOI:10.4314/ejesm.v5i4.3.

[59] Belayneh, M., Yirgu, T. and Tsegaye, D. (2019) 'Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed, upper Blue Nile Basin, Ethiopia', Ecological Processes. Ecological Processes, 8(1). DOI:10.1186/s13717-019-0188-2.

[60] Gebrewahid, Y. et al. (2019) 'Dispersed trees on smallholder farms enhance soil fertility in semi-arid Ethiopia', Ecological Processes. Ecological Processes, 8(1). DOI:10.1186/s13717-019-0190-8.

[61] Kuyah, S. et al. (2019) 'Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa. A meta-analysis', agronomy for sustainable development. Agronomy for Sustainable Development, 39(5). DOI:10.1007/s13593-019-0589-8.

[62] Giday, K. et al. (2019) 'Studies on farmland woody species diversity and their socioeconomic importance in Northwestern Ethiopia', Tropical Plant Research, 6(2), pp. 241-249. DOI:10.22271/tpr.2019.v6.i2.34.

[63] Asfaw, Z. et al. (2016) 'Development Research Woody Species Composition and Soil Properties Under Some Selected Trees in Parkland Agroforestry in Central Rift Valley of Ethiopia'.

[64] Sinore, T., Kissi, E. and Aticho, A. (2018) 'International Soil and Water Conservation Research The effects of biological soil conservation practices and community perception toward these practices in the Lemo District of Southern', International Soil and Water Conservation Research. Elsevier B.V., 6(2), pp. 123-130. DOI:10.1016/j.iswcr.2018.01.004.

[65] Emire, A. (2018) 'Status of soil properties under canopy of farmers' preferred coffee shade tree species, in Adola Rede District, Guji zone, southern Ethiopia', American Journal of Agriculture and Forestry, 6(5), p. 148. DOI:10.11648/j.ajaf.20180605.15.

[66] Sisay, M. (2013) 'Tree and shrub species integration in the crop-livestock farming system', Tree and Shrub Species Integration in the Crop-Livestock Farming System, 21(1), pp. 647-656. DOI:10.4314/acsj.v21i1.

[67] Astrid, M. (2019) Internship Thesis GEEFT 2018-2019, Hedgerows and Agroforestry Practices in the Highlands of Kembatta zone, Ethiopia

[68] Wolle, H. S., Lemma, B., and Mengistu, T. (2019). Effects of Ziziphus spina-christi (L.) on selected soil properties and sorghum yield in Habru District, north Wollo, Ethiopia. Malaysian Journal of Medical and Biological Research, 6(2), 85-92.

[69] Sanogo, K., Binam, J., Bayala, J., Villamor, G. B., Kalinganire, A., and Dodiomon, S. (2017). Farmers' perceptions of climate change impacts on ecosystem services delivery of parklands in southern Mali. Agroforestry systems, 91(2), 345-361.

[70] Kuria, A. et al. (2014) 'Local Knowledge of Farmers on Opportunities and Constraints to Sustainable Intensification of Crop-Livestock-Trees Mixed Systems in Lemo Woreda, SNNPR Region, Ethiopian Highlands'.

[71] Gemechu, T. and Hunde, K. K. (2015) 'Assessment on Farmers' Practices on Soil Erosion Control and Soil Fertility Improvement in Rift Valley Areas of East Shoa and West Arsi Zones of Oromia, Ethiopia"', EC Agriculture 2.4, 4(March), pp. 391-400.

[72] Derero, A. et al. (2020) 'Farmer-led approaches to increasing tree diversity

in fields and farmed landscapes in Ethiopia', Agroforestry Systems, 7. DOI:10.1007/s10457-020-00520-7.

[73] Mohammed, M., Beyene, A. and Reshad, M. (2018) 'Influence of Scattered Cordiaafricana and Crotonmacrostachyus Trees on Selected Soil Properties, Microclimate and Maize Yield in Eastern Oromia, Ethiopia', American Journal of Agriculture and Forestry. Vol. 6, No. 6, 2018, pp. 253-262. DOI:10.11648/j.ajaf.20180606.23, 6(6), pp. 253-262.