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Influence of Park Land Agroforestry Trees on Soil Properties, Crop Yield and Microclimate Parameters: A Review Paper

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Abstract

Parkland agroforestry practice is part of agroforestry system where scattered multipurpose trees characterized by the range of woody or often indigenous species occur on farmlands as a results of farmer selection and protection. This practice comprises largest part of agricultural landscapes within the semi-arid and sub-humid zones of Ethiopia. Millettia ferruginea, Cordia africana, Ficus vasta, Ficus sur, Croton macrostachyus and Faidherbia albida are dominant multipurpose tree species scattered on farmland in association with crops and grazing lands in Ethiopia. The foremost objective of this paper is to review and summarized the existing studies regarding to the influence of parkland agroforestry practice on soil properties, crop production and microclimate amelioration of the area. Those multipurpose scattered trees has a potential to generate products from the ecosystem like food, manure, timber, shelter, fodder, fuel-wood required to satisfy the essential needs of the society. In addition, trees of park land agroforestry practice which gives more emphasis to sustainability of the systems through ecosystem services like; climate amelioration, reduction of loss of soil moisture, organic process and soil fertility improvement, reducing wind and wearing away, provision of shelter and shade, soil stabilization and conservation, biodiversity improvement, increment of aesthetic value, pest control etc. Therefore, this review tries to address the existing information and document it to give an emphasis on using parkland agroforestry system as a land use system for the sake of production enhancement and improvement of other ecosystem services.

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Keywords

Parkland, soil fertility, microclimate, crop yield, under canopy, open field.

Introduction

Agroforestry is recognized as one of a conspicuous land use option in which trees provide wider range of products and services from a given piece of land to alleviate the critical problem of the rural poor people income through integration of economical useful tree species (Mohammed *et al.*, 2018, Haile *et al.*, 2000). Agroforestry provides assets and income from carbon, wood energy, improved soil fertility and enhanced local climate conditions; it provides ecosystem services and reduces human impacts on natural forests (Haile *et al.*, 2000). Agroforestry trees could bring a changes in soil, microclimatic, crop yield and other components of the system through recycling of mineral elements, environmental changes and composition (Manjur *et al.*, 2014). Scattered trees on farm characterize a large part of the Ethiopian agricultural landscapes today to solve problems like deforestation, unsustainable cropping practices, loss of biodiversity, increased risk of climate change, rising hunger, poverty and malnutrition. Soil fertility has declined from time to time due to high rates of soil erosion, removal of crop residues for fuel and animal feed, rapid population growth, deforestation, inappropriate land use systems and continuous cultivation of the land without sufficient management (Lal, 2001).

A scattered tree on crop land has a positive influence on maintaining soil fertility via addition of nutrient to soil through biological nitrogen fixation and efficient nutrient cycling (Jonsson, 1995; Nair, 1993).

Trees can improve the nutrient balance of soil by reducing unproductive nutrient losses from erosion and leaching and by increasing nutrient inputs through nitrogen fixation and increased biological activities by providing biomass and suitable microclimate (Nair, 1993). Scattered trees on farmland plays a significant role in soil fertility maintenances mainly through nitrogen fixation, litter fall, root activities, nutrient cycling, and numerous additional external factors such as Cow dung, bird and wildlife droppings, reducing nutrient losses from erosion and leaching (Rhoades, 1997).

The effect of parkland agroforestry trees on associated crop productivity is based on cumulative effect from both above and below ground component interaction especially in simultaneous type of agroforestry system (Mohammed *et al.,* 2018). The influence of trees on crop yield depends on management variables, canopy and root architecture, spatial and temporal arrangement, age and size of the tree and ecological type (Nair, 1993).

Agroforestry trees have also a potential to modify the microclimate of an area due to their influence on environmental variables like temperature, prevailing wind condition and the radiation of the area. Agroforestry trees increase the soil moisture content and decreased the amount of air and soil temperature via shading (kessler, 1992; Belsky *et al.,* 1993). As compared to treeless area, the microclimatic variables such as air temperature, soil temperature and soil moisture beneath tree canopy could also be modified due to the influence of trees on radiation flux, air temperature and wind speed (Mohammed *et al.*, 2018).

Influence of parkland agroforestry trees on soil properties, crop yield and microclimate parameters of the agricultural landscape has been reported by different scholars in different time throughout the word to promote agroforestry trees on farmland, their compatibility with different field crops on specific site conditions need to be investigated. The major aim of this review is to gather and document empirical evidences on effects of parkland agroforestry trees on soil physicochemical properties, yield of crops and microclimate to convince land users and policy makers to promote the integration of trees in farming systems and designing sustainable land use that could enhance productivity of crops while maintaining and improving the resource base.

Effect of AF tress on soil physical properties

Soil texture is the measure of the relative percentage of particles such as sand, silt and clay in the soil. Soil texture influence the water holding capacity, aeration, infiltration and porosity of a given soil (Brady & Weil, 2002). Trees on farmland can improve soil temperature, water-holding capacity, aggregation of particles, permeability through root effect and organic matter addition to the soil (Rhoades, 1997; Shibu *et al.,* 2008). Soil texture is less affected by management practice and influence of trees, but sand fraction was decreased under crown than open field (Yadessa *et al.,* 2009). Several studies reported that the effect of trees on soil texture is not significant.

But, lower sand fraction was reported under the canopy of tree than open field and higher clay proportion was reported under the canopy of trees than open field. According to Mohammed *et al.,* (2018), the mean values of sand fraction was slightly higher (25.78% and 26.62%) at open field in subsurface than other radial distances and slightly lowest (21.87% and 21.87%) at radial distance of 0.5m in surface soil depth. The same author reported that, mean values of clay fraction was slightly higher at radial distance of 0.5m from tree trunk in surface and slightly lower at open field in subsurface soil depth for *Cordia africana* and *Croton macrostachyus* tree species.

Other scholars also reported that the mean amount of sand increased along tree radius (33.33% at 1.5m; 35.33% at 3.5m and 42.17% at 25m) distance from tree trunk and higher proportion of clay was also reported under tree canopies of *Faidherbia albida* than in open field (Manjur *et al.*, 2014).

Higher clay fraction under canopy (38.37%) than outside canopy (34.11%) was reported by Kassa *et al.*, (2010) in Humera district for *Balanites aegyptiaca*. A non-significant effect of tree on soil texture was also reported for *Millettia ferruginea* (Hailu *et al.*, 2000) and for *Ziziphus spina-christi* (Shiferaw *et al.*, 2017).
The soil bulk density under tree crown might decline due to litter addition which results organic matter accumulation than at open cultivated land (Kewessa *et al.*, 2015). The higher tree root concentration near the base of the trees may have also an effect on loosening the soil, thereby reducing soil bulk density. This is reported by many scholars for different species e.g. for *Acacia decurrrens* (Molla & Linger, 2017), for *Faidherbia albida* and *Croton macrostachyus* (Manjur *et al.*, 2014) and for *Millettia ferruginea* (Hailu *et al.*, 2000). For instance, results of Molla & Linger (2017) revealed that the soil bulk density increased from 0.19 to 0.26 as we move from under the crown of tree to open crown. Hailu *et al.*, (2000) reported on bulk density under and outside *Millettia ferruginea* trees revealed that both the bulk density of the surface soils (0.61 g/ cm^3) and the subsurface soils (0.76 g/cm^3) under the trees were lower than the bulk density of the surface soils (0.69 g/cm^3) and the subsurface soils (0.80 g/cm^3) in the open areas.

Effect of AF tress on soil chemical properties

Soil pH is the measure of the activity or concentration of hydrogen ions in the soil solution. It ranges with the scale 0-14, and describes the degree of acidity or alkalinity of a soil. It influences plant growth through its effect on nutrient solubility and availability (Brady & Weil, 2002). According to FAO (2008), soils having pH value in the range 6.5 to 7.5 are considered as normal, which do not require treatment, and are optimum for most crops. In most cases, the soil pH value under crown is grater as compared to open areas.

According to Young (1998), higher decomposition of litter deposition from the trees release cations to the soil system through mineralization. Many studies support this phenomenon; the soil pH under the crown of *Ficus vasta* was significantly higher than soils from open field (Asfaw, 2016). Molla & Linger (2017) reported soil pH values ranging 5.5 under the tree and 4.62 open cultivated lands. However, there is also a condition in which the soil pH under the tree crown and open field becomes similar. Hailu *et al.*, (2000) revealed that, the soil pH under the crown of *Millettia ferruginea* is similar with outside of the crown. Similarly, the surface, subsurface and overall mean values of soil pH at all radial distances from both *Cordia africana* and *Croton macrostachyus* tree trunks were not significantly influenced (Mohammed *et al.*, 2018).

Cation exchange capacity is the measure of soil capacity to retain and release elements like K^+, Ca^{2+}, Mg^{2+} and Na^+. Soils with high clay content or organic matter tend to have high cation exchange capacity, whereas sandy soils have lower cation exchange capacity (Marx *et al.*, 1999). Cation exchange capacity is affected by the nature and amount of mineral and organic colloids present in the soil (Brady & Weil, 2002).

Trees contribute organic matter through accumulation of litter and root exudates which in turn influence the cation exchange capacity of the soil. Many studies revealed that cation exchange capacity under the crown of trees is greater than open field. The values of cation exchange capacity in soil from under *Ficus vasta* canopies were significantly higher than values of soil at open from fields (Asfaw, 2016). According to Manjur *et al.*, (2014), the values of cation exchange capacity for surface soils were 51.91 and 46.79 (Meq/100 g soil) under the canopy of *Faidherbia albida* and *Croton macrostachyus* and these values were observed to decrease to 37.72 and 33.39 (Meq/100 g soil) at the distance of 25m (open field) away from the tree trunk of *Faidherbia albida* and *Croton macrostachyus* respectively. Similarly, significant higher cation exchange capacity values was reported under *Cordia africana* crown than the open field by (Yadessa *et al.,* 2001).

Trees could enhance the status of soil organic carbon and total nitrogen through litter fall and subsequent decomposition which improve soil fertility (Wang *et al.,* 2010). Leaf, fine roots, and twigs are the major source of organic matter for soil under the crown of trees. Additionally, the roots of trees absorb nitrate from the inner soil horizon and subsequently recycle to the top soil (Young, 1998). Scattered trees increase or maintain organic carbon status in the soil under their trunk crown zone can be through leave and root decomposition, reduced leaching, and nutrient recycling to the soil surface (Young, 1998).

A significant increase in concentrations of soil organic carbon and total nitrogen under both *Ficus vasta* and *Albizia gummifera* canopies as compared to open fields outside the influence of trees (Asfaw, 2016). According to Hagos *et al.,* (2013), the surface soil organic carbon of canopy zone was 1.54 times higher than subsurface soil outside the canopy zone while the soil organic carbon of subsurface soil were 1.35 times higher than the subsurface soil of outside canopy zone. Similarly, soil organic carbon of the surface soil under canopy was 25% higher than the immediate subsurface soil.

Besides, soil organic carbon of the subsurface soil under canopy was 9.14% more than the immediate subsurface soil. Soil organic carbon of surface and subsurface soils under canopy zone higher by 46.69 and 23.01%, respectively as compared to the surface and subsurface soil beyond the canopy of *Ficus thonningii* (Diress, 2008). In line with this report, tree species of *Millettia ferruginea* (Hailu *et al.,* 2000) showed significantly higher soil organic carbon under crown zone than outside crown zone.

According to Diress (2008), there is an increase of in average total nitrogen under *Ficus thonningii* crown by 85% in the surface soil and 63% in the subsurface soil depths as compared to soils in the open pasture. According to Manjur *et al.,* (2014), the total nitrogen concentration under the tree canopy at 1.5 m to the 25 m radius from the trunk decreased from 0.40 to 0.12 and 0.23 to 0.08 under *Faidherbia albida* and *Croton macrostachyus* respectively.

Gindaba *et al.,* (2005) also reported that, the total soil nitrogen of surface and subsurface soils higher under tree canopies by 22 to 26% for *Cordia africana* and 12 to 17% *Croton macrostachyus* than the corresponding soils away from the tree canopies. According to Hagos *et al.,* (2013), the surface soil under canopy was 36.91% more in soil nitrogen concentration than the respective soil outside tree canopy. Likewise, the subsurface soil nitrogen concentration under tree canopy was 32% higher than the soil outside canopy zone. Moreover, the surface soil under canopy was 16.16% higher than the immediate subsurface soil under canopy while the surface soil outside canopy zone was 12% higher than its immediate subsurface soil.

Trees significantly influence the availability of soil phosphorus and exchangeable potassium. Higher concentration of available phosphorus and exchangeable potassium in the crown zone as compared to open field may also be due to relatively higher litter input to the surface soil than organic matter removals from the surface soil layer by different forms. Higher phosphorus concentration under the crown of trees might be related to the excreta of livestock resting under their shade during the dry season (Rao *et al.,* 1998). Beyond litter effect, the higher exchangeable potassium value under tree crown might be also due to the efficient capturing of nutrients by tree roots below the root zone of crops. For instance, available phosphorus and potassium decreased with increasing distances from tree trunks of *Cordia africana* and *Croton macrostachyus* (Mohammed *et al.,* 2018). With regard to soil depth, significantly higher soil available phosphorus and potassium were recorded in the surface soil than subsurface soil (Mohammed *et al.,* 2018). The highest values of exchangeable potassium for the surface soil, 1.11, and 0.81 (Meq/100g soil) were reported at the distance of 1.5 m, and the values were found to decrease to 0.69 and 0.45 (Meq/100g soil) at the distance of 25 m away from the crown of *Faidherbia albida* and *Croton macrostachyus* trees, respectively (Manjur *et al.,* 2014). In agreement to this report, higher soil available phosphorus and exchangeable potassium under crown zone than outside crown and in surface soil than subsurface soil were reported for *Ficus vasta* and *Albizia gummifera* (Asfaw, 2016), *Millettia ferruginea* (Hailu *et al.*, 2000), *Ficus thonningii (*Diress, 2008), *Croton macrostachyus* (Mamo & Asfaw, 2017) and *Ziziphus spina-christi* (Shiferaw *et al.*, 2017).

Effect of AF tress on Crop Yield and Biomass production

Trees in agroforestry systems could enhance or reduce annual crop growth and yield by altering the microclimate and existence of sever competition for water, nutrients, and light (Tsonkova *et al.*, 2012). They have both positive and negative effect on biomass and crop productivity (Nair, 1984; Young, 1998). According to Mohammed *et al.*, (2018), the mean values of maize yield at crown zone were lowered by 8.53% and 7.75% than mean value at open field for *Cordia africana* and *Croton macrostachyus* tree, respectively. This may be attributed to the shading effect by trees on the crops; reduced growth due to intercepted solar radiation. In line with this report, a decreased in wheat yield under *Eucalyptus globules* were recorded by Kidanu *et al.*, (1993). This could be the existence of sever competition for light, water, and nutrient, and allelopathic effect of tree on crop. Kessler (1992) also reported that sorghum yield under *Parkia bioglobosa* and *Vitellaria paradoxa* trees was lower compared to the open area at Burkina Faso. This could be due to reduced light intensity under tree which might favorable for development of fungal disease which results in yield reduction (Kater *et al.*, 1992).

On the other contrary, trees could boost grain yield and biomass production of crops through improving soil fertility (Buresh & Tian, 1998). According to Jiru (1999), the grain yield of maize was increased by 15% under the crown of the tree than at 15 m away from the tree crown. In another study, Nigusie (2006) reported increased grain yield of sorghum and haricot bean under the crown of *Faidherbia albida*, *Cordia africana* and *Croton macrostachyus* trees as compared to the open cultivated land in Harergie high-lands.

Trees form an interaction with crops, and influence understory crop biomass production (Boffa, 1999). This could be the influence of light incidence under tree crown than open field substantially influence the primary production of biomass. According to Negeyo (2018), a decreasing pattern of mean biomass was reported as distance from tree trunk increases for both *Faidherbia albida* and *Acacia tortilis*. In another study, cereal crop biomass is higher under crown of *Faidherbia albida* as compared to outside the crown (Boffa, 1999). In addition, in *Faidherbia albida* alley cropping, the maize plant biomass production increases by 94.7% as compared to maize plant biomass produced without *Faidherbia albida* alley cropping farms (Chamshama *et al.*, 1998).

Effect of AF tress on Microclimate Variables

Tree influence the microclimate environment under the crown via shading effect and reduction of evapo-transpiration. Soil moisture content, soil temperature, air temperature, and relative illumination become changed as we go from under the crown of tree to open field (Mohammed *et al.*, 2018).

Variety of studies also reported that air temperature and soil temperature under trunk radius is significantly different from the open field due to cooling effect of trees. The maximum air temperature (29°C) was observed for both species at 15m far from their trunks, and minimum mean values (22 and 23°C) were observed at 2.5m from trunk of *Cordia africana* and *Croton macrostachyus* trees, respectively (Mohammed *et al.*, 2018).

Similar to air temperature, soil temperature was maximum (28°C) at 15m far from their trunks, and minimum mean values (21 and of 23°C) at 2.5m from trunk of *Cordia africana* and *Croton macrostachyus* trees respectively (Mohammed *et al.*, 2018). According to Anjulo *et al.*, (2014), mean air temperature change over open control was reported as 6.3, 6.7 and 7.3°C at 2/3 trunk radius of *Acacia tortilis*, 1/3 trunk radius of *Balanites aegyptiaca* and 1/3 trunk radius of *Acacia tortilis* respectively. Other scholar was reported reduced soil temperature by 6°C for under *Acacia tortilis* tree (Belsky *et al.,* 1993) and by 5°C to 10 °C for under *Faidherbia Albida* tree as compared to open field (Vandenbeldt & Williams, 1992). The tree crown reduces the transmission of sunshine radiation to the surface a part. According to Anjulo *et al.,* (2014), percent relative illumination received at 1/3 trunk radius under *Balanites aegyptiaca* was reduced by 86% in May, 87.9% in June and 91.44% in July over the open area. However, much higher intensity of relative illumination was received at the center and much distances of the trees species. Trees and shrubs may reduce radiation under canopies by 45 to 60% within the Sahelian zone and 85 to 95% within the Sudan savannah (Akpo *et al.,* 2005).

According to Mohammed *et al.,* (2018), relative illumination showed significant difference with maximum (100%) and minimum (40 and 44%) mean values at 15m and 2.5m from trunk of *Cordia africana* and *Croton macrostachyus* trees, respectively. Similarly, 45 to 65% reduced in incoming radiation was reported for *Acacia tortilis* and *Adansonia digitata* and 20% reduced for under *Parkia biglobosa* trees were also reported (kessler, 1992; Belsky *et al.,* 1993).

The soil moisture content is usually higher under the crown of tree because of the effect of shading which ends up during a reduction of soil water loss by evaporation, and enhancing of soil water holding capacity via organic matter enhancement. Many studies on soil moisture content showed a decreasing trend with increasing radial distances and soil depth. Kessler (1992) reported that improved availability of water under tree canopies was due to decrease in actual evapo-transpiration moreover as better water infiltration. Higher soil moisture was reported under the crown of trees than open field for *Cordia africana* and *Croton macrostachyus* (Mohammed *et al.,* 2018), and for *Millettia ferruginea* (Hailu *et al.,* 2000).

According to Mohammed *et al.,* (2018), the very best mean values of soil moisture content (17% and 16%) were reported at 0.5m crown radius of soil layer and lowest mean values (9% and 9%) were reported at 15m radial distance of subsurface soil layer for *Cordia africana* and *Croton macrostachyus,* respectively. The other finding revealed higher soil moisture content in surface 19.6% and subsurface soil 10% under crown zone than surface soils 15.9% and subsurface soils 8.9% at outside crown of *Millettia ferruginea* tree (Hailu *et al.,* 2000).

On the opposite, Akpo *et al.,* (2005) observed that soil moisture under shade was not significantly different under *Acacia tortilis* and *Balanites aegyptiaca*, suggesting that there was no species effect on soil moisture content. Tree influence the microclimate environment under the crown via shading effect and reduction of evapo-transpiration. Soil moisture content, soil temperature, air temperature, and relative illumination become changed as we go from under the crown of tree to open field (Mohammed *et al.,* 2018). Variety of studies also reported that air temperature and soil temperature under trunk radius is significantly different from the open field due to cooling effect of trees.

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Investigation of species-specific interaction with soil fertility, crop yield and microclimate has a paramount implication for better agricultural intensification in agroforestry system. Agroforestry tree improves status of soil chemical and physical properties under the crown via addition of organic matter through litter decomposition and root turnover. Many studies reported that, except soil texture both bulk density, soil organic carbon, total nitrogen, cation exchange capacity, available phosphorus and exchangeable potassium values were significantly influenced by agroforestry trees as compared to open fields. This is due to the available of inputs in the form of leaf, fine roots, and twigs decomposition. In case of crop yield and biomass production, trees in the agroforestry system influence as crown and foliage parts of a tree intercept active sunlight radiation which is important for photosynthesis, and has subsequent influence on grain and biomass production.

Regarding to microclimate parameters, agroforestry trees has a potential to change the microclimate parameters of the system due to the cooling effect of the above ground tree biomass on the understory environment of an area.

The tree crown reduces the transmission of light radiation to the surface area which results lowering under crown air temperature and surface soil temperature as well as evapo-transpiration. Finally, the authors would like to suggest on the following points;

A further study should be done on fine root distribution and biomass production of Croton macrostachyus tree as fine root affect soil fertility and yield of crops. As Croton macrostachyus tree phenology (foliage growth and trunk cove) is different in different season, thus its effect on microclimate might be different at different season.

So, further study should be done to know the effect of this tree on microclimatic parameters under their canopies in different seasons. Additional research should be done on appropriate crown management practices like pollarding, branch pruning and crown opening at the right time to enhance crop production.

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Conflict of interest

The authors declares that we have no financial or nonfinancial competing interests.

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