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The impacts of shade trees on fodder and food crops integrated with or without coffee farming system in times of climate change: brief review

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ABSTRACT

Shade trees can be planted either as wind breaks, woodlots or scattered individuals to buffer outdoor environmental conditions for crops and livestocks. The aim of this paper is to summarize the current understanding of the use of shade trees on fodder, food and coffee farms, and identify research gaps in Africa. Shade trees influence agricultural productivity by altering microclimates, mulching the soil, altering heat exchange, conserving soil and providing substrate for soil arthropods. Shade trees also improve the health and biodiversity status of agricultural landscapes. The productivity of coffee under shade trees is optimal with improved carbon dioxide assimilation and better quality of beans. However, farmers are reluctant about shade trees because of arboreal wild animals' and allelopathy. Although there is a general awareness of the negative and positive impacts of shade trees, minimal attention has been given to develop targeted strategies of planting shade trees by smallholders. Benefits of shade trees on coffee farms have been inconsistent in low input small scale farms, while limited investment is made to improve adoption and management of shade trees, which are highly needed in drylands, especially in times of climate change. Shade trees are removed where annual crops are planted. Actually, effective shading need to minimize competition and this can be achieved with deciduous trees that have thin and small leaves like *Acacia albida*. Since the majority of farmers in rural areas of Africa are poor, smallholder, and less educated, there should be extensive training on shade tree species selection and management.

Key words: annual crops, coffee, management, productivity, and shade tree

1. INTRODUCTION

Shade trees are trees that provide shade for protection from wind, sunlight and torrential rain to the soil surface, understorey vegetation of fodder, food crops and coffee plants. Shade trees are usually large with spreading canopies that are arranged as wind breaks, woodlots or scattered individual trees on farm lands, rangelands or road sides. In the natural vegetation the complex ecosystem provides shade to the other plant and animal species (Beer et al., 1998). The shade system which could also provide shelter is a functional part of the food web in an ecosystem. Shade influences productivity through protection of plants, and livestock, alteration of microclimate, and reduction of excessive heat loss, moisture loss and soil loss. Shade trees reduce excessive light, mulch the soil with their biomass (litter), create hostile conditions for pests and diseases, and harbor a variety of predatory animals (Beer et al., 1998).

In dry lands (40% of the world's terrestrial land (WRI, 2002), 81% of Eastern Africa (Jama and Zeila, 2005), and over 65% of Ethiopia (NCS, 1993) where free grazing is common, shade trees are highly important for their sustainability of ecological functions (controlling air and water erosion, providing sinks for carbon dioxide, improving the fertility of the soil, conserving biodiversity) and providing other products. Shade trees are also effective in reducing the metabolic energy used in cooling plants and animals in hot drylands (MuletaDiribaet al., 2011).Ethiopia's temperature is estimated to rise by 1.7-2.1°C by 2050, an increase that is far ahead of the IPCC prediction of global mean temperature increase of 1.4-5.8°C by the end of the 21st century. It's predicted that by 2050, this could lead to a 10-20% decrease in overall crop yield because of climate change. One way of addressing the rising temperatures in the areas in which agricultural and other human activities are practiced is introducing shade canopy, trees, blocking some of the sun's light and heat.

The use of shade trees is usually common in small scale organic coffee farming. Shade trees improve the health and biodiversity of the surrounding environment by reducing leaching of nutrients, such as nitrates and phosphates into the groundwater and provide habitats for native flora (such as local fodder species) and fauna (especially bird species) (Rice and Bedoya, 2010). The presence of shade trees increase diversity of large arboreal animals, soil animals and a wide variety of microbes including fungi, bacteria, and actinomycetes, among others. Therefore, integrating shade trees with annual crop production improves agricultural production, and reduces environmental degradation (Albertin and Nair, 2004).

Shade for dry land agriculture like coffee production is important because it reduces evaporation of moisture from the soil by reducing the temperature at the soil surface and transpiration from agricultural crops. Shade trees provide natural mulching material (Albertin and Nair, 2004). The natural mulch from shade trees decomposes and adds nutrients to the soil. Shade trees provide additional benefits such as fruit for consumption, fodder for animals, bee forage, timber, and extra firewood to farmers (Ibero, 2005); these would include income from potential carbon sequestration. Presence of shade trees benefits other crops, such as spices, cereals, and root/ tuber crops and fodder crops, which are integrated within coffee farm. They also provide cooler and more pleasant working environment for undertaking heavy work tasks in farm lands such as planting and hand weeding. Under the shaded African farming conditions, it should be expected that productivity of labor would be higher.

It is apparent that there is a dearth of information to support development of protocols for the selection and management of shade trees, to derive the most productivity and environmental benefits in coffee growing landscapes, especially in small scale landholder systems in Africa. Since the African farmers lack education, transferring the technology of shade tree selection and management is difficult. The information available is scattered and lack future directions of research. The effort towards shade trees propagation and distribution is very rare and shade trees are usually cut and removed where there is large scale annual crop (fodder and food crops) cultivation. Although trees harbor vermin's and cause competition, there is lack of targeted strategies for tree species selection and management. The objective of this review is to synthesize the major findings of the importance of shade trees at the same or different farming systems of fodder, food and coffee and to highlight research gaps for further study.

2. CHARACTERISTICS OF COMMON SHADE TREE SPECIES

Shade trees are selected on the basis of root and shoot growth, and architecture that reduce competition and have no allelopathic effect. The roots need to be deep enough to extract nutrient, instead of laterally spreading roots in order to reduce sidewise competition. The leaves need to be small and thin instead of broader and large leaves, because the former enhance transmission of solar radiation and minimize the size of rainfall/ water droplets. The leaves need also to be deciduous, shedding leaves during active growth period of the integrated food/ fodder crops. Evergreen trees are not particularly preferred because of extended periods of active competition for resources with underneath fodder or food crops (Muleta Diriba et al., 2011).

Shade trees need to provide optimal shade, and additional benefits without competition with crops for nutrients. The most preferred shade trees are nitrogen fixing**,** leguminous species which improve soil fertility (Ibero, 2005).

Good examples of nitrogen fixing shade tree species include *Leucaena*, *Sesbania, Calliandra*, *Acacia*, and *Albizia*; and timber providing species include *Grevillea* (Ibero, 2005). Commonly preferred shade trees in Africa are *Albiziagummifera*, *Acacia albida, A. abyssinica*, *Millettiaferruginea*, *Vernoneaamygdalina, Cordiaafricana, Croton macrostachyus,and*sometimes *Ekebergiacapensis (*Muleta Diribaet al., 2011) (*Figure 1).* In tropical countries, the African tulip tree, *Hopeaodorata*, some *Erythrinaspecies, Pouteriaadolfi-friederici, Diospyrosabyssinica, Oleacapensis,* and *Oleawelwitschii* are used as shade trees (Tadesse and Feyera, 2008).

Figure 1: Shade trees commonly maintained in coffee plantation.

Although many tree species are known as shade trees, less attention is given to shade tree expansion in many countries, and the characteristic effect of specific tree species on specific food or fodder crop remains with limited information. Many smallholder farmers currently incorporate shade trees in their organic farming practices, but the outcome has been inconsistent due to a lack of clear and consistent advice. The mixed opinions have dissuaded many growers from planting and keeping shade trees. There have been instances where the shade trees have been removed in the mistaken belief that the use of mechanized modern synthetic inputs (chemicals and fertilizers) are not compatible with shade trees (Mejia, 2007). The agricultural investment in Southwestern Ethiopia deforested potential shade trees in around 2007-2008 and caused conflicts (TolaGemechu, 2018). Farmers experience showed that, shade trees have the potential to improve coffee yields, more so where modern inputs are unaffordable by majority of small holder farmers(Rice and Bedoya, 2010), such as in majority of coffee producing nations in Africa, Papua New Guinea, and several southeast Asian countries.

3. MANAGEMENT OF SHADE TREE SPECIES

Selection and management (density, pruning, thinning, weeding, pollarding, harvesting, and controlling disease and pest) of shade trees for optimal productivity of food and fodder crops and coffee remains a challenge in many coffee production regions of the world. Few studies showed that timely pruning of shade trees for example in taro (*Colocasiaesculenta*) cropping improves productivity and corm quality (Rogers and Iosefa, 1980). Planting Eucalyptus as shade tree in narrow spacing, negatively affects the growth of annual crops (Tilashwork Chanie, 2009). This is especially so in Africa where input resources and farmer technical capacity are both limited due to poor access to training of applied research. Root pruning, or thinning of shade trees need to be done at the required interval in order to reduce competition in dry tropics. The effects of competition can be minimized by appropriate structure (porosity, shape, width and height of shade trees) and layout of border trees or wind breaks (orientation, and spacing of tree planting). Biophysical processes on the orchard, such as leaf litter decomposition and associated nutrient dynamics arising from the presence of especially leguminous shade trees are generally poorly understood (Grossman, 2003). Usually the mixed occurrence of different shade trees species in a farm limits the specific management of each species. Management practices required especially for pest and diseases occurrence by different shade tree species are also very few in published works, except in the case of weedy bush encroachers. Therefore, without extensive research and subsequent training, it is difficult for farmers to effectively manage shade trees and reap the benefits of such practice. Farmers in rural areas of Africa are poor, smallholder, and less educated, then there should be extensive training and site specific development research because farmers' knowledge about tree planting can be improved in line with new shade tree management techniques (Dumont et al., 2019).

4. EFFECT OF SHADE TREE SPECIES ON SOIL FERTILITY

The formation of secondary forest for shade to grow food and fodder crops increases water retention in the soil profile and improve water quality by reducing storm water runoff, sediments transport and other potential contaminants (Albertin and Nair, 2004). Studies further elaborated that shade trees increase soil organic matter and340 kg N $ha^{-1}year^{-1}$through leaf litter, pruning residues and through symbiotic relationships with N_2-fixing bacteria on the roots of legumes (Beer et al., 1998).

5. EFFECT OF SHADE TREES ON FODDER CROPS

A study conducted in Australia (Lowry et al., 1988) recorded a 250%higher yield of guinea grass *(Panicum maximum)* under the shade of *Albizialebbek* trees compared with that of the same species in the full sun outside the canopy. Providing shade from direct sunlight prolongs unirrigated pasture growth into the dry season because of the reduction in the rate of soil water loss through evapotranspiration. Shade trees increase the availability of soil nitrogen and this leads to better growth of grass under shade than in full sun when nitrogen is deficient. However, the effects of shading on the nutritive value of forage are less clear (Wilson and Wild, 1992). Fodder crops species diversity and growth habit in the understorey vary greatly depending on the type of shade tree species. For example, growth of pastures under a stand of Eucalyptus at any density was lower than under *Acacia*, *Millittia*, and *Albizia* trees species used as coffee shade (TilashworkChanie, 2009).On the other hand weedy bush encroachers like *Acacia drepanalobium*, *A,bussie*, and others affect pasture although they are weeds and not shade trees.

6. EFFECT OF SHADE TREES ON LIVESTOCK PRODUCTIVITY

Shade trees in tropical and sub-tropical climates alleviate heat stress and potentially livestock mortality. Cooler conditions also improve feed conversion efficiency in the livestock. Heat stress also reduces fertility in sheep, and the birth size and subsequent weight gains of calves (Bird et al., 1992). Energy requirement by livestock is reduced by shade trees that also provide shelter from cold winds, especially during rain and this is translated into better growth rates, livestock yields and productivity (Lee, 1985). However, the problems that are caused by weedy bush encroachers on the livestock productivity require proper management.

7. EFFECT OF SHADE TREES ON FOOD CROPS

Annual crops such as spices, cereals, root and tuber crops are planted as intercrops under the coffee and shade trees complex agroforestry system. Shading improves water-use efficiency for dryland and irrigated crops by buffering effects of hot, dry winds, reducing evaporative water losses, and then improves grain yields. The microclimate near trees is modified by shading from direct sunlight during the daytime and protection from radiation losses at night leading to lower maximum and higher minimum air temperatures (Lee, 1985). Plants under shade undertake certain morphological modifications and physiological adaptations, and their leaves are capable of absorbing more than 90% of the energy contained in the wavelengths between 400 and 700 nm and perform high photosynthetic rate within the limited solar radiation (Lee, 1985). Shade may be limiting if there is insufficient light for growth, if shading increases, the duration of frost, or if it leads to water logging. Trees can provide protection from wind damage especially for high value products such as fruits and crops (Bird et al., 1992).

Many farmers consider partial tree shade as being beneficial to improve crop establishment soon after planting, particularly during drier months (Yunusa et al., 2005). Results indicated that plant height and leaf area are higher under shade conditions compared to full sunlight. The fact that total plant biomass increases under shade indicates greater photosynthetic efficiency. Shade-grown plants produce corms with better cooking and taste quality for the market. However, partitioning of assimilates into corm is not enhanced by shade (Rogers and Iosefa, 1980). The vegetative advantages observed under shade conditions may be translated into improved corm yields if proper branch pruning is done after one or two months of growth (Kasai, 2008).

Selections of shade tolerant crops are also important in shaded agroforestry system. *Afromumumkorrorimum*, *Piper capense*, and *Zingiber officiale* spices; *Zea mays*, and *Sorghum bicolor* cereals; *Viciafaba* and *Phaseolusspp* legumes; *Musa paradisic* fruits, can be grown under shade. However, the broad leaves oftomato (*Lycopersiconesculentum*), chili pepper (*Capsicum sativum*), radishes (*Raphanussativus)*, cucumbers (*Cucumissaitvus*), cilantro (*Coriandrumsativum*), onion (*Allium cepa*), cabbage (*Brassica oleracea*), and squash (*Cucurbitaceae spp*.) requires wider space selection of shade trees (Albertin and Nair, 2004).

A study that compared taro (*Colocasiaesculenta*) cultivar production and weed growth under full sunlight and fifty percent shade found higher crop biomass and better corm production but reduced weed growth under fifty percent shade (Rogers and Iosefa, 1980). That is, crops benefit from mild conditions under shade trees and avoid adverse responses to harsh meteorological conditions, such as high solar radiation intensity. The high temperature reduces the electron transport capacity and increases the rates of CO_2 evolution from photorespiration (Farquhar and Sharkey, 1982; Kasai, 2008). In Ethiopia, some farmers commonly observed that food crops like potato (*Solanum species*) grown under the shade of *Sesbaniasesban* seedlings had tuber sizes three times the size of those grown without leguminous shade trees. However, farmers are reluctant about shade trees (TilashworkChanie, 2009) because of the arboreal wild animals that affect crops and allelopathic effect of some trees.

8. EFFECT OF SHADE TREES ON COFFEE

Cultivation of coffee involves planting of young coffee plants in the understorey of native shade tree cover (TayeKufa, and Burkhardt, 2015). Farmers in shaded coffee producing areas consider shade is a pre-requisite for coffee production (Tadesse Woldemariam and Feyera Senbeta, 2008). Shade trees assist in maintaining coffee yields in the long term by reducing periodic over-bearing and subsequent die-back of coffee branches. Shading delays the maturation of coffee berries, slower ripening process resulting in a better bean filling and larger bean size with better coffee quality (Muschler, 2001). Therefore, coffee yield is highly correlated with the branching habit of coffee shade trees (Adugna Boteand Struik, 2011).

Producing coffee by integrating with food and fodder crops under shade trees is an organic farming which is more beneficial for economic, and health purpose than conventional coffee production (production using chemical fertilizers in direct sun) (Muschler, 2001). Coffee grows best in highland tropical forests as an understory tree. Coffee can however, be grown successfully without shade trees in monocultures under intensive management systems where high amounts of agricultural inputs such as chemical fertilizers, and irrigation are used (Petit, 2007). Such intensive system reduces the genetic diversity of coffee and increases vulnerability to environmental factors (Aerts et al., 2015). Shade trees generally reduce radiation and heat load on the coffee trees and consequently reduce potential evapotranspiration. Coffee growth is affected by high light intensity, high temperature and low soil moisture (Ashenafi Nigussie *et al,* 2014). Ambient temperatures can easily exceed 25ºC during transient or prolonged drought but shade trees can lower air temperatures by as much as 5ºC during the hottest time of the day (Isa et al., 2015).

Shade grown coffee could provide lower yields than coffee in the direct sun (Adugna Boteand Struik, 2011) making the profit of organic farmers earning lower than the conventional (unshaded) coffee growers. However, the moderate yield under shade trees could be more sustainable than a onetime higher yield in the direct sun. The organic methods produce quality crop that has strong and increasing market demand already in existence. Certified organic coffee (shade grown coffee) has well established market, which will likely increase in the future (Petit, 2007). In traditional small holder farmers, timber and fruit production from shade trees used in coffee plantations can provide significant income, which may exceed that of coffee when coffee prices are low (Muschler, 2001; TolaGemechu, 2018]. Smallholder shaded coffee growers depend on diversification of crops under the shade for avoidance of heavy dependence on a single product (coffee) which suffers either from yield failure or serious price fluctuation in the international market (MuletaDiribaet al., 2011). According to Ramirez *et al*. (1992; 2001), planting a timber tree, *Cordiaalliodora,* with coffee in Ecuador at a stocking rate of 100 trees ha^{-1}in a 12-16 year rotation period resulted in a viable and less risky timber volume greater than what has been calculated for the harvest of primary forest trees alone in the region with a rotation age of more than 30 years.

The major physiological benefits that coffee plants receive from shade trees are mainly associated with reduced plant stress, stabilized local thermal balance, reduced heat flux, and improved soil structure and fertility ((Siebert, 2002; Campanha et al., 2005; Morais et al., 2006). The shade also reduces the quantity and quality of light reaching the coffee plants, which helps to avoid excessive vegetative growth. The reduction of light intensity leads to the avoidance of dieback and overbearing allowing a more consistent harvest from each individual coffee tree (Beer et al., 1998).

Dry and sunny seasons are critical times of shading coffee plants for all development and phonological stages. According to Adugna Boteand Struik (2011) coffee plants grown in the shade have higher values of leaf area index (LAI) and leaf nitrogen content so that these plants have higher potential for CO_2 assimilation and dry matter production than open grown plants (McNaughton and Jarvis, 1983). Shaded leaves are also darker in color than leaves from plants grown in open because of the larger amount of nitrogen accumulation (Titus and Pereria, 2005). Milder microclimatic conditions with shade trees produce heavier and larger coffee beans with better liquor taste than those developed on plants grown in open. Shading enhances the size of coffee beans and quality, taste of finished products in terms of biochemical composition, including the contents of caffeine, oil and chlorogenic acid (Morais et al., 2006). The temperature regulation and weed suppression advantages of shade trees generally outweigh the negative impacts of competition imparted by shade trees on coffee (Muschler, 2001).

As can be seen in Table 1, growing coffee under shade increased leaf nitrogen content. However, the relative growth, bean yield and liquor quality of shade and open grown coffee plants are not different at 5% statistical significant level, which could be because of short time observation of few farms (Adugna Boteand Struik, 2011). Other studies found that shaded coffee plants had higher specific leaf area (SLA) resulting in higher relative growth rate and higher productivity (Li et al., 2005), compared with un-shaded plants that had lower SLA (Poorter and Werf, 1998).

Table 1: Characteristics of coffee plants grown under shade or direct sun light (Modified from Muschler (2001).

Variable	Treatment		Significance (two tailed)
	Under shade trees	Exposed trees (direct sun light)	
Specific leaf area (SLA) (cm^2g-1)	116	98	0.04*
Leaf area index (LAI) (m^2 m^{-2})	3.8	2.8	0.01*
Relative Growth Rate (RGR) (cm cm^{-1} $month^{-1}$)	12.3	9.7	ns
Leaf Nitrogen content (mg g^{-1} leaf dry matter)	288	219	0.03*
Coffee weight (g 1000-1 beans-1)	148	134	ns
Liquor quality (% of maximum score)	65	50	ns
Bean yield (Mg ha^{-1})	2.13	3.1	ns

ns, not significant at 5%.

Photosynthetic rate and growth of coffee plants grown under shade is not reduced unless the level of shade exceeds 90% (Bartlett and Remphrey, 1998) and in some cases over 50% shade decreases coffee yield (Lorena Soto-Pinto et al., 2000). A study conducted at Bonga and Yayu, Ethiopia on shade trees revealed that most farmers prefer 50% light penetration for maximum coffee harvest and no farmer preferred 100% light penetration (YitebituMoges, 2009). It is generally true that over shading results in reduction of growth and yield of coffee (Chetana and Ganesh, 2012). Coffee plants in direct sunlight show a higher incidence of premature death (Steiman, 2003). Coffee without shade trees result in stunted growth, which gradually result in coffee yield reduction and quick wilting of coffee plants, bean size reduction, increase in weed problems, increase in unfavorable effect of heavy rain and hail damage that cause withering of flowers and change of coffee leaves to yellow/ red (Adugna Boteand Struik, 2011).

9. SHADE TREES AND CLIMATE CHANGE

Shade trees reduce pollution of the groundwater caused by fertilizers and pesticides, and sustain nutrient cycling. Shade trees may benefit from the increased level of CO_2 in the atmosphere because of carbon fertilization effect (CFE). The phenomenon may increase the water use efficiency and productivity of crops (Sievänen et al., 2013). The CFE can increase plants photosynthetic rate. Moreover, shade trees maintain the biodiversity of the ecosystem (Moguel and Toledo, 1999), genetic connectivity with adjacent habitats (Romero-Alvarado et al., 2002; Jha and Dick, 2008) and are resilient to environmental changes, and create ecological balance (Lorena Soto-Pinto et al., 2000). Shade grown coffee systems in Indonesia showed 58% more total carbon stock in the soil and biomass than direct sun-grown coffee (Albertin and Nair, 2004). In the presence of shade trees, fodder and food crops could adapt to the higher heat stress expected to occur in the times of climate change. Moreover, grazing and browsing animals need shade to cope with the heat during the hot periods of the year. Therefore, continuous growth of selected green plants, sustained CO_2 intake and reduced rates of evapotranspiration under shade enables climate change adaptation and mitigation, and increases resilience to climate change.

Shade trees in urban environment

Especially in times of climate change, urban trees need to be increased because urban areas have multiple artificial surfaces and high levels of fossil fuel use that exacerbate climate change impacts (Nowak, 2000). Urban shade trees benefit the society by increasing job satisfaction, faster recovery time for hospital patients, and improved child development. In hot season, shade trees ameliorate climate by transpiring water from their leaves, which has a cooling effect on the atmosphere. Well-established urban forest trees provide sustainable ecosystem services like soil and water conservation, soil development, water and air purification, mitigate storm water runoff and ameliorate contaminated soils while providing environmental amenity at the local scale, heat and sound reduction (MoE, 2010; FAO, 2016). Urban shade trees reduce air and sound pollution by trapping particulate matter in their leafy canopies and by absorbing noxious pollution into their leaves. Shade trees increase the aesthetic value of land by increasing land property values as much as 20% when compared with land without trees (Kane, and Kirwan, 2009). However, urban environments are either monoculture type or absence totally because of the less attention given to shade trees. Therefore, site specific species site matching is essential also in urban environments.

10. CONCLUSION AND RECOMMENDATIONS

Shade trees are large trees with spreading canopies and thinner leaves grown specifically for their shade and shelter. Although all trees naturally provide shade, the required level of shading and the yield and quality of agricultural crops under shade varies depending on the tree species, altitude, climate and soil conditions, as well as with the management. Shade trees improve the health and biodiversity of the whole landscape by reducing risks of wind and water erosion, nutrient leaching while providing habitats for the local flora and fauna. Shade trees diversify biota and income. Shade is an important component of coffee production system. Shading delays the maturation of coffee berries resulting in a better bean filling and larger bean size resulting in better coffee quality. Traditionally shaded coffee is cultivated by smallholder farmers under low input production systems making the shaded African coffee production naturally 'organic'. Shade trees are alternative means of income via carbon sequestration, and production of fuel wood, timber, and fruits. Shade trees are highly required to adapt and mitigate climate change by diversifying farm product, ameliorating soil, ensuring evergreen canopy cover for continuous atmospheric carbon assimilation, sustaining the growth of crops under shade and by reducing evapotranspiration. Shade trees increase fruit yields in food crops and biomass yields in pasture in dry season when compared with those in open land. However, the presence of arboreal wild animals that attack crops and tree crop competition may reduce the interest on shade trees. Shade trees are also beneficial for on-farm operations in providing cooler, more pleasant working environment than direct sun conditions, which are better suited to carrying out heavy work tasks in hot season in rural farming activity.

Since many of the African farmers are poor, smallholders, and have little or no education, it is generally difficult to transfer shade tree selection and management technology. Such farming systems, however, can derive much benefit from the presence of shade trees, especially if they are practically demonstrated in the presence of fruit bearing trees, under growing fodder or food crops. The low technology production system is especially suited for multipurpose species that provide a range of benefits. Accordingly, farmers should be trained how to integrate shade trees to the farming system and ways of deriving the most benefit from keeping shade trees on their farms at spatial and temporal scale. Information on selection of suitable shade trees, their establishment and management, including harvesting their produce should be incorporated in the usual agronomic research practice of coffee and integrated crops. In drier areas, livestock are highly susceptible to disease which could partly be because of the lack of shade trees as known in Ethiopia, Kenya, Uganda, Sudan, and Somalia. Therefore, further research on the impact of shade trees on livestocks in open grazing system of tropics is crucial. Planting few shade trees is a pre-requisite for the rehabilitation of wind prone degraded dry lands of Africa, so that such shade trees could serve as pioneer (fostering) plant species and provide shelter for the many seedlings that will be planted. That is seedlings of many species are susceptible to dry wind, and require wind erosion control measures.

In this review we would like also to emphasize the need for future research on the effect of individual and/ or aggregate shade trees species on yield and quality (nutritive value) of fodder/ pasture species, annual food crop species and coffee berries. The effect of shade tree species on soil moisture, temperature optimization, amount of radiation passing to underneath, the pruning and thinning management of shade tree branches and roots should be well investigated and demonstrated to the local farmers. In the reviewed literatures there was lack of information that depict the effect of individual shade tree species on specific fodder/ food crop, therefore further research should be done by planting specific shade trees for different fodder, food crops and coffee in drier areas.

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