REVIEW PAPER

Potentials and Limitations of Plantation Crop Combination Agroforestry Practice in Southwest Ethiopia

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Abstract

Plantation crop combination agroforestry practice (PCCAP) is an agroforestry practice containing plantation crops (such as coffee, cocoa, tea, rubber, oil palm, spices, coconut, fruit crops, etc.) and/or shade trees, fuel wood/fodder trees, or shade tolerant herbaceous crops as its main components. It is a very common agroforestry practice in humid and subhumid tropical regions of the world including southwest (SW) Ethiopia. In SW Ethiopia, coffee agroforestry is a dominant and an old PCCAP, and recently, the spice, tea and rubber agroforestry practices are started. However, the agroecology of SW Ethiopia is suitable for many other types of PCCAP such as cocoa, oil palm and coconut. Moreover, practically neither scientific research nor even systematic data collection has been done on the agronomic management of this agroforestry practice, except a few in coffee-shade trees, in the region so that there is lack of information. This work, therefore, describes the different PCCAP and its agronomic potentials and limitations for the high productivity of the components and the system as whole using personal experiences, available literatures in the region and elsewhere, with aim of forwarding future research and development directions to realize the full potential of this agoforestry practice in SW Ethiopia.

***Key words*:** Plantation crops, coffee and spice agroforestry practices, suitable agroecology for plantation crops, agronomic potentials and limitations, Southwest Ethiopia

INTRODUCTION

Several definitions of the term 'agroforestry' are used in science and practice. As per Nair (1993) agroforestry is a landuse system incorporating trees with agricultural crops and/or animals, in which their ecological interactions are managed for social, economical and/or environmental products and benefits. However, Leakey (1996) defined it as "a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the landscape, diversifies and sustains production for increased social, economic and ecological benefits". There are two important terminologies of agroforestry; i.e., *agroforestry system* that denotes a specific local example of a practice, characterized by environment, plant species and their arrangement, management, and socioeconomic functioning, and *agroforestry practice* that denotes a distinctive arrangement of components in space and time (Nair 1993). The plantation crop combination agroforestry practice (PCCAP), an agroforestry practice consisting of plantation crops (such as coffee, tea, rubber, cocoa, oil palm, coconut, perennial spices, fruit crops, and the like), shade trees, fuel wood/fodder trees, or other herbaceous and/or shade tolerant agricultural crops as main components, is one of the 20 distinct agroforestry practices. It is very common in tropical humid lowlands or humid/subhumid high lands.

The arrangement of the components in PCCAP can be: (i) integrated multi-storey mixtures of plantation crops, (ii) mixtures of plantation crops in alternate or other regular arrangement, (iii) shade trees and plantation crops; shade trees scattered, and (iv) plantation crops intercropping with agricultural crops (Nair, 1993). Many authors (e.g., Somarriba and Beer, 1987; Singh, 1989; Oladokun, 1990; Nair, 1993) described several examples of this practice in different tropical countries of Africa, Asia and America; cocoa, coffee, rubber, coconut and cashew as main crops; and shade trees, timber trees, other perennial crops, and/or annual food crops as subsidiary crops, and others (Nair, 1993; Hartemink, 2005; FAO and WFP, 2006) show a contribution of some plantation crops (e.g., oil palm, rubber, coconut, cocoa, coffee, tea, cashew and black pepper) for national economy of the producing countries.

Smallholder famers in humid and subhumid areas of southwest (SW) Ethiopia also integrate plantation crops like coffee and spices with shade trees and/or with fruit and annual crops, primarily to meet their subsistence and cash income requirements. There are also some large-scale coffee, tea and rubber plantations in the region, which are very less in

integrating of different plant species. However, the potentials of the agroecology of the region for this and other types of PCCAP are not well utilized, and there are limited empirical data on descriptions and agronomic managements of the PCCAP and other agroforestry practices in the region. In order to exploit the region's potential for PCCAP and improve the system, it is pertinent to study the various components individually as well as the interactions of the components or the system as a whole. Therefore, this work describes the major PCCAPs in SW Ethiopia together with its agronomic potentials and limitations for high productivity and economic returns using own experiences, and available literatures in the region and elsewhere in the world. The main aim of the paper is to forward research and development directions to realize the full potential of PCCAP in SW Ethiopia.

Characteristics of Southwest of Ethiopia

SW Ethiopia is physically diverse with extensive plateaus at over 2,000 m amsl and plains along the Sudan border at 800 m amsl. Rainfall varies from 2,400 mm in the highlands to less than 1000 mm in the lowlands, while the vegetation grades with rainfall from tropical montane rainforest to savannah grasslands. Its minimum and maximum temperatures vary from 7.6°C to over 13.8°C and from 29.9°C to over 34.7°C, respectively. It has red clay loam soil and high natural forest cover (Wood, 1993). The region is agroecologically suitable for a wide range of crops, including plantation crops like coffee, tea, spices (e.g., cardamom, black paper, ginger, turmeric, long pepper and *Korrorima*), fruits (e.g., avocado, mango, banana, papaya, guava and pineapple), rubber, sugarcane and others like cocoa, oil palm and coconut. Consequently, land use systems in SW Ethiopia are chiefly dominated by Silvopastoral systems involving cultivation of perennial crops (chiefly coffee and *enset*) and in some instances, annual subsistence crops in the stands of these perennial crops plus livestock (chiefly cattle, sheep, horses and donkeys) grazing under them and beekeeping. *Enset* is mainly grown in the homegardens.

Coffee, spices (mainly ginger, turmeric, *korrorima,* long pepper) and fruits (mainly mango, avocado, papaya, banana, orange, pineapple) are the major marketable crop commodities (Anonymous, 2007), and coffee, honey, spices, climbers, fruits and bamboo are the major agroforestry and non timber forest products (Reenen, 2005; Chilalo and Wiersum, 2011; Damte and Koch, 2011). Among the livestock sectors, beekeeping is very important, followed by small ruminants (mainly sheep), cattle and poultry (Anonymous, 2007).

Furthermore, coffee production in this region accounts for between 40-45% of the country's total production (Wood, 1993), and all rubber and tea plantation farms in the country are found in this region. The region is also rich in a variety of wild edible and medicinal plants (Bekele, 2007; personal observation). However, except coffee, the potentials of the region for various types of plantation crops' production and PCCAP are not yet well studied and exploited.

PCCAP Common in Southwest Ethiopia

Some of the common plantation crops growing as PCCAP in SW Ethiopia include coffee, spices (cardamom, black paper, long pepper and *korrorima*), fruits (avocado, mango, banana, papaya, guava, orange and pineapple), tea, rubber, *enset* and khat (Shumeta, 2010; personal observation). Coffee and spices such as cardamom, black paper, long pepper and *korrorima* are entirely grown under the shade of different tree species (Table 1; Fig. 2), and sometimes with fruits, *enset* and khat (Table 1; Fig. 1). Tepi and Beneka Coffee State Farms also grow cardamom, black paper, long pepper and *korrorima* under the shade of rubber, oil palm and fruit (e.g., avocado) plantations, and *Grevillea robusta*. Coffee as main crop planted under sparsely grown shade tree species is also intercropped with one or two of the aforementioned spices, fruits or khat plants (Fig. 1). During its young stage, coffee is sometimes grown in association with annual crops (e.g., maize, haricot bean), root crops (taro, sweet potato and yam), spices (ginger and turmeric), pineapple, sugarcane and green manure crops (e.g., *Desmodum* and *Crotalaria*). *Grevillea robusta,* vetiver grass, banana and other fruit trees are usually observed growing around the boarder of a coffee, tea and spice plantations. Vetiver grass is also used as hedgerow to control soil erosion in sloppy areas of most plantations. In this region, PCCAP is also characterized by the integration of livestock and beekeeping (Fig. 3; personal observation).

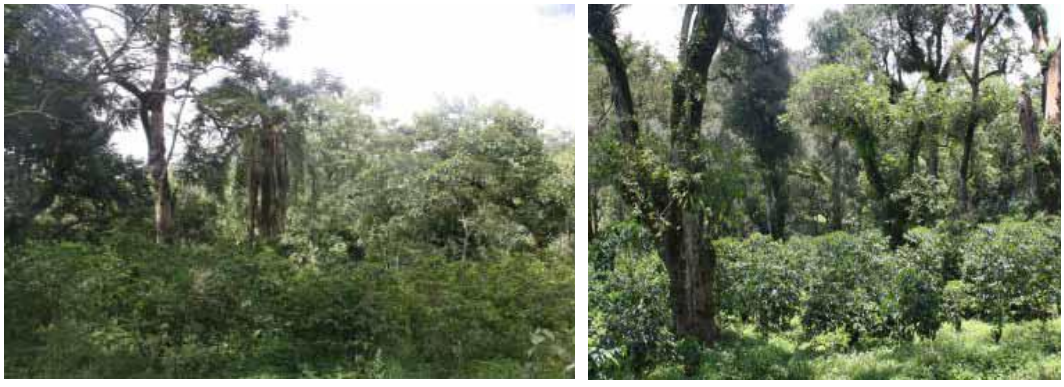
Table 1. Species of trees and fruits associated with coffee plantation in SW Ethiopia

Common shade tree species	Common name (Amharic Name)*	Trees and fruits mostly observed in homegardens	Common name (Amharic Name)*
Croton machrostachyus	(Bisana)	*Podocarpus falcatus*	Podo (Zigba)
Albizia schimperiana	Large-podded albizia (Sessa)	*Aningeria altissima*	(Keraro)
Cordia africana	(Wanza)	*Combretum molle*	Velvet-leaved Combretum(Abalo)
Albizia gummifera	Peacock flower (Sessa)	*Erythrina abyssinica*	Flame tree (Korch)
Acacia abyssinica	Umbrella thorn (Bazra girar)	*Mangifera indica*	Mango
Ficus vasta	Oat (Shola, Warka)	*Citrus sinensis*	Orange (Birtukan)
Millettia ferruginea	(Birbira)	*Schinus molle*	Pepper tree (Qundo berbere)
*Grevillea robusta***	Silky oak (Tebenja enchet)	*Ensete ventricosum*	False banana (*Enset*)
*Sesbania sesban***	River bean (Girangire)	*Catha edulis*	Khat (Chat)
Calpurnea subdecondra		*Persea Americana*	Avocado
			Banana, peach, guava, papaya, apple

*Names in the bracket are names in local language (Amharic), **Shade trees used for young coffee Sources: Bossolasco (2009); Kebebew *et al*. (2011)

Figure 1. A plantation crop combinations agroforestry practice with more than two components

A



B

C

Figure 2. Coffee and spice based agroforestry practices in SW Ethiopia: (A) Coffee-shade tree agroforestry practice in Jimma area (Limu State Farm), (B) Coffee-shade tree agroforestry practice in Jimma area (smallholder farms), (C) Spices-shade tree agroforestry practice (*Korrorima*-left and long pepper- right) in Bonga area (smallholder farms)

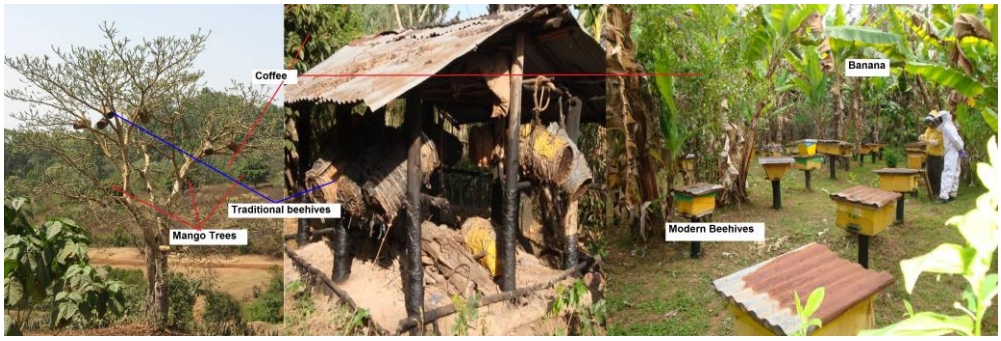


Figure 3. Beekeeping in coffee and spice based agroforestry system in SW Ethiopia

Potentials of PCCAP

The ecological potentials of SW Ethiopia for PCCAP can be speculated easily from its climatic and edaphic information given in section 2. Here, I want to show primarily the agronomic potentials of PCCAP for the high productivity of its components and economical returns of the whole system based on available information in SW Ethiopia and other regions of the world.

Under proper management, many researchers reported better productivity of the components of this agroforestry practice. This most often could be due to the positive or complementary interactions of the components, mainly related to microclimate amelioration and nutrient balance (Nair, 1993). For instance, the microclimate amelioration and nutrient addition through litter and N-fixation by shade trees enhances regular and balanced fruit bearing in coffee. Under small holder

subsistence farmer's management in SW Ethiopia, a shade level of 50-60% of the prominent trees (Table 1) improves productivity of coffee. Shade also affects both physical and sensory qualities of coffee beans. Bote and Struik (2011) reported heavier cherries with better bean quality from coffee plants grown under shade trees than those grown without shade in Jimma. Yield and quality of coffee also vary according to the species of shade trees. A recent finding in Jimma Research Centre depicted the highest and stable coffee yield performances under *Albizia schimperiana*, *Acacia abyssinica* and *Cordia Africana* trees (Kufa *et al.*, 2011), which could be due to their better contributions to enrich soil fertility and moderate light intensity through their feathery leaves than others. A study in Afromontane rainforest of SW Ethiopia also showed significant effects of shade tree species on beverage acidity, flavour, aftertaste and overall quality of coffee. Coffee samples collected under *A. abyssinica* and *C. africana* shade were more acidic, with bitter flavour and overall cup quality as compared to those collected under shade of *Albizia* species. Moreover, the proportion of marketable beans was higher under *Acacia* (92.73%) and *Cordia* (91.79%) than under *A. schimperiana* (89.48%) and *A. gummifera* (88.42%). Contrarily, the proportion of very small (nonmarketable) beans was higher under *Albizia* species than *Acacia* or *Cordia* (Yadessa *et al.*, 2008). This positive effect of shade on bean qualities may be due to the delaying and synchronizing of berry flesh ripening, and the coffee plants' protection from adverse environmental stresses such as high soil temperature and low relative humidity. Shade also triggered differences in physiological behaviour of the coffee plants, such as improved photosynthesis, and increased leaf area index and specific leaf area, resulting in better performance in the shade than possible in direct sun light (Bote and Struik, 2011). Furthermore, shade reduces infestation of coffee by some fungal diseases (e.g. coffee leaf rust) and insect pests (e.g., Antestia bug) in the lowland areas of SW Ethiopia.

Other studies conducted on coffee-shade tree agroforestry systems somewhere in the world also showed similar results (Nair, 1993). *Coffea arabica* plants grown with native trees and fruit trees in Brazil increased in growth, resulting in a reduction in the magnitude of diurnal temperature variation and maximum temperature; but with a smaller number of productive nodes and flower buds, leading to smaller berry yield than plants in monoculture system (Campanha *et al.*, 2004). It seems that shaded coffee out yields unshaded one only under adverse climatic conditions. A reduction of diurnal temperature variation, vapour pressure

deficit and Piche´ evaporation were also reported in a coffee plantation under *Inga jinicuil* shade as compared to open-grown coffee in Mexico (Nair, 1993). By evaluating the effects of *Grevillea robusta* plant densities on inter-planted coffee plants in Brazil, Baggio *et al*. (1997) found higher total economic productivity of both coffee and *Grevillea* at 34, 48, and 71 *Grevillea* trees per ha. The grevillea trees at densities of 71 and 119 trees per ha was also effective in protecting the coffee plants from the severe radiative frost. Growth performance evaluation of a timber tree (*Cordia alliodora*) growing in combination with arabica coffee, cocoa or pastures in Central America showed an increasing diameter growth rates in the order of pasture, sugarcane, coffee, and cocoa (Somarriba and Beer 1987). Though no empirical study results are available on other PCCAPs in SW Ethiopia, observations indicated that growing of such spices like cardamom, black paper, long pepper and *korrorima* under open-sun seems impossible, but not tested under frequent water supply condition. Especially cardamom and *korrorima*, which requires relatively high shade level, showed good performance under heavy shade conditions of *G. robusta,* avocado and Jackfruit at Tepi area. Black paper, a climbing spice, showed a good association with *Erythrina abyssinica*. Similarly, a research conducted in Tanzania showed better yield of cardamom when it was growing with grevillea than in natural forest. The Land Equivalent Ratio analysis showed that black pepper and cardamom intercropped with grevillea produced 3.9 and 2.3 times more than in monoculture, respectively (Reyes *et al*., 2009).

Other plantation crop combinations in different countries showed good productivity potentials of this agroforestry practice. In Sri Lanka, for example, an intercropping of one row of rubber with three rows of banana gave the greatest dry matter production of young rubber plantations (Rodrigo, 2001). Higher land expectation value for rubber-tea intercropping than rubber and tea monocultures has been reported in Hainan, China (Guo *et al*., 2006), and high yield and low costs of weeding for coconut-cocoa combination in Southeast Bahia, Brazil (Alvim and Nair, 1986). A study in Kerala, India showed nutrient absorption alteration by coconut due to the inter-planted multipurpose trees. *G. robusta* enhanced 32P uptake by coconut, while *Ailanthus triphysa* and *Vateria indica* exerted a modest depressing effect (Kumar *et al*., 1999). The former indicates complementary root-level interactions between coconut and *Grevillea*.

Osei-Bonsu *et al*. (2002) obtained significantly higher yield of cocoa growing at 2.5 m triangular spacing (1739 plants ha^{-1}) with coconut spaced at 9.8 m triangular (105 plants ha^{-1}) than other treatments in Ghana, and yield increase of coconut when it was grown with cocoa compared to sole-stand is cited in Nair (1993). In the tropical humid lowlands of Costa Rica, Kapp and Beer (1995) found the greatest productivity with an average total stem volume increment of 19 m^3 ha^{-1} $year^{-1}$ for *Cordia alliodora* associated with crops (*Zea mays, Zingiber officinale* and *Eugenia stipitata*), and greater root rot of *Acacia mangium* in pure plots compared to associated plots**.**

The agronomic potentials of PCCAP that can be exploited to improve its productivity and economical returns are generally related to:

1) wider spaces between tree crops during the early stages of growth, e.g., cocoa and oil palm combination;
2) the intercrops reduce soil erosion between widely spaced tree crops;
3) roots of some tree intercrop combinations complement each other, e.g., coconut and *G. robusta*;
4) stems of climber crops and some tree intercrop combinations complement each other, e.g., black pepper, vanilla and *E. abyssinica,* fruit trees;
5) shade tolerance of understory crops, e.g., cassava, favour cultivation of them under plantation crops;
6) complementary use of light by the component crops, e.g., coconut and cocoa intercropping;
7) some crops require shade e.g., coffee, cocoa, cardamom, k*orrorima*, etc. benefit from the shade cast by taller tree plants or intercrops, such as rubber;
8) intercropping in perennial tree crops during their early growth period is economically viable while waiting for harvest of long maturity tree crops; and
9) cropping systems consisting of perennial plant association often improve the chances for conserving soil and soil fertility.

Limitations of PCCAP

One of the limitations in PCCAP is high competition and allelopathic interactions between its components and our limited knowledge for its proper management. Because all members of a plant community in agroforestry systems utilize the same reserves of growth resources such as light, nutrients and water, competitions for these resources are likely to occur in every plant association. The major yield decreasing effects arise from the competition for light, water and nutrients, as well as from interaction via allelopathy. Microclimatic modifications that favor the development of pests and diseases can also be another limitation (Nair, 1993).

Generally, research reports on these facts of agroforestry in SW Ethiopia area are also very limited. However, the latter is observed for the coffee berry disease pathogen (*Colletotrichum kahawae*) in the highland coffee growing areas of Ethiopia including SW region. The incidence of this pathogen increases greatly when coffee is growing under shade compared to open sun, probably due to greater relative humidity, which tend to favor fungal growth. However, reduced temperature and humidity fluctuations under shade can also have suppressing effects on some other pests and diseases, for example, coffee leaf rust and antestia bug. It seems that the balance between positive and negative effects need to be assessed and appropriate management practices should be followed for each particular situations of an agroforestry system. Regarding light effect, shade tolerant/loving crops such as coffee, cocoa, vanilla and black pepper can be expected to exhibit depressed yields as intensity of shade increases unless they are subjected to nutrient or water stress (Nair, 1993). In this case, in SW Ethiopia, which has reliable rainfall and good soil fertility, growing of coffee under the dense crown of avocado and mango trees may reduce yield of coffee. Nutrient competition between components of plantation crop combinations in SW Ethiopia is also likely to occur as observed on coconut-multipurpose trees (*Ailanthus triphysa* and *Vateria indica*) inter-planting in India (Kumar *et al*., 1999). In case of water competition, though SW Ethiopia have high and relatively well-distributed rainfall, it is also likely to occur during dry period of the year between November and February. For instance, Bonsu *et al*. (2002) reported the greatest moisture stress in cocoa-*Gliricidia sepium* shade system in Ghana. The effects of water competition depend on the severity of the drought and the drought tolerance of the plants, as well as the degree of competition for other resources, especially nutrients (Nair, 1993). However, higher sensitivity to water stress during short dry seasons is usually observed for drought susceptible plantation crops such as cardamom, *korrorima* and young coffee plants when they grow without shade than with shade.

Long time lag between planting and profitable production is another disincentives of PCCAP. Famers in Jimma area have reported long time to bear fruit and failure to bear fruit at all in avocado (Garedew and Tsegaye, 2011). However, this can be somewhat compensated by intercropping with annual crops like maize, ginger, turmeric, root crops, and annual food crops. Physical damage on understory crops by broken and felled branches of shade trees and fruit trees, particularly avocado at its fruiting period, is also another problem. Moreover, diseases (e.g.,

root-rot), pests and shortage of improved varieties are constraints for avocado production in the region, e.g., in Jimma and Illubabor (Shumeta, 2010; Garedew and Tsegaye, 2011).

Summary and the Way Forward

SW Ethiopia is ecologically suitable for many plantation crops and many types of PCCAPs. The common PCCAP found in SW Ethiopia include coffee and shade trees; spices and shade trees; coffee, spices and shade trees; and coffee, shade trees, fruit trees (e.g., avocado, mango) and/or khat, *enset*, banana and spices. Of which, coffee-shade tree agroforestry practice is a dominant one. Integration of traditional beekeeping with coffee agroforestry practice is also a long tradition. Tea, rubber and oil palm are recently introduced plantation crops in the region, but they are grown in monoculture and covered a small area of land. Although the agroecology of SW Ethiopia is suitable for other plantation crops such as cocoa, coconut, plantain and the likes, and other types of PCCAP that are common in other areas of the world having similar agroecology, they are not yet studied and produced in this region.

By its nature, PCCAP has high agronomic potentials to increase the productivity of the components and economic returns of this agroforestry practice. The main ones include shade-tolerant or shade-requiring nature of some crops; wider spacing between young tree crops; root complementarities in some crops and/or trees; and complementarities between some crops and/or trees in light use and conserving soil and nutrients, nutrient cycling and amelioration of microclimates. Conversely, development of some diseases and pests due to microclimate ameliorations by the components, competition among components for resources, allelopathy, and our limited knowledge on the interactions of the components and appropriate management techniques of this practice are the major constraints that limit the realization of the full potentials of the system.

Overall, the region's potential for different PCCAPs and their potentials and limitations for high productivity, economic return and ecological services are not yet studied. Therefore, this agroforestry practice in SW Ethiopia generally needs research and development to realize its full economical and ecological potentials. Particularly, broadening of the research agenda on production and productivity of different adaptable tree crops in the region (e.g., tea, spices, rubber, oil palm, cocoa, cocoanut, etc.) as well as selection of suitable species of tree and herbaceous crops for PCCAP and appropriate

agronomic management techniques for the components and the systems in relation to the age of the over storey species, optimal population density of each component, microclimate amelioration, disease and pest control, nutrient cycling, allelopathic effects, ecosystem services, etc., have to be determined to realize the full potential of this agroforestry practice.

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