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BiomassWeb

Working Paper 161

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ISSN 1864-6638 Bonn, November 2017

ZEF Working Paper Series, ISSN 1864-6638
Ecology and Natural Resources Management
Center for Development Research, University of Bonn
Editors: Christian Borgemeister, Joachim von Braun, Manfred Denich, Solvay Gerke, Eva Youkhana and Till Stellmacher

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Potential of Agroforestry for Food and Nutrition Security of Small-scale Farming Households

A case study from Yayu, southwestern Ethiopia

Omarsherif Mohammed Jemal and Daniel Callo-Concha

Abstract

Food and nutrition security is a major global challenge. Enhancing the local production of food is a key alternative in impoverished agrarian countries of the south. One option is agroforestry, promoted and implemented as a land-use system capable of addressing the multifaceted problem of food and nutrition security of small-scale farming households. This paper illustrates the potential roles of local agroforestry practices to contribute to the food and nutrition security of small-scale farming households focusing on the Yayu Coffee Forest Biosphere Reserve in south-western Ethiopia as a case study. The three dominant agroforestry practices, i.e. multistorey coffee systems, homegardens, and multipurpose trees on farmland contribute substantially to the food and nutrition security of households and communities despite each having a particular purpose, species management and composition. Achievement does not depend on individual practices but on their synergistic performance. Multistorey coffee systems mainly generate cash by the sale of coffee beans, non-timber forest products and fuelwood. Crops cultivated under multipurpose trees on farmland produce the major annual food supply of the households, which is generally completed by homegardens that also generate supplementary income. Moreover, several strategies rely on the particular features of the agroforestry systems to meet specific challenges. For instance, the small-scale planting of species such as enset (*Ensete ventricosum)* to fill the food-shortage season, the cultivation of spices and ritual species to obtain supplementary income, or production of pulses and livestock to secure scarce macro- and micronutrients. Finally, the presence of a variety of edible native species detected in all agroforestry practices, but especially in multistorey coffee systems, evidences an untapped potential that is currently being investigated.

Keywords: food and nutrition security, subsistence farming, traditional agroforestry, wellbeing, Yayu Coffee Forest Biosphere Reserve

Acknowledgments

This paper is a part of an ongoing set of studies framed within the BiomassWeb project (FKZ 031A258A) funded by the German Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Economic Cooperation and Development (BMZ).

We are greatly indebted to Ato A. Hora, Ato B. Fiqadu, Ato D. Olana, Ato F. Nuri, Ato M. Bekele, T. Alebacew, Ato T. Korsa, Ato Z. Bekabil, and Ato Z. Bekele. We thank also Dr. Manfred Denich and Dr. Girma Kelboro for commenting on this work.

Contents

Acronyms

AF	Agroforestry
AFS	Agroforestry system
BOFED	Bureau of Finance, Economy and Development
CFS	Committee on World Food Security
CSA	Central Statistics Agency
FAO	Food and agriculture organization
FEWS NET	Famine Early Warning Systems Network
FNS	Food and nutrition security
HG	Homegarden
ICRAF	World Agroforestry Centre (International Council for Research in Agroforestry)
m.a.s.l.	meter above sea level
MCS	Multistorey coffee system
MTF	Multipurpose trees on farmland
UN-DESA-PD	United Nations-Department of Economic and Social Affairs-Population Division
UNESCO	United Nations Educational, Scientific and Cultural Organization

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1 Introduction

Food and nutrition security (FNS) still is a major global challenge. Despite the remarkable reduction in the proportion of undernourished people by 7.7% since the beginning of the 1990s, about 800 million people are still suffering from undernourishment (FAO et al., 2015). This is exacerbated by an annual global population growth rate of 1.2%, which is expected to grow to 2.3 billion by 2050. This will increase the global food demand by about 70% (FAO, 2009 a; UN-DESA-PD, 2015).

Nevertheless, the challenge of FNS is not evenly distributed around the world. Both population growth and prevailing undernourishment are highly localized in Asia (65.6%) and Africa (29.8%) (FAO et al., 2015). Moreover, these regions are heavily hit by other factors that trigger undernourishment, such as socio-economic problems, conflicts and natural disasters (Endalew et al., 2015). For instance, the demographic pressure in south-east Asia, conflicts in central Africa and Middle East countries, and environmental disasters in eastern Africa have contributed to the overall undernourishment of these regions (FAO et al. 2015). Moreover, the globalization of food markets has made import-dependent countries, especially in Sub-Saharan Africa, even more vulnerable to global price fluctuations and consequent food availability, as for example in 2007-2008 (Stewart et al., 2008; von Braun et al., 2008; Wiggins et al., 2010). Another challenge is the growing cultivation of energy crops and utilization of food crops as a biofuel feedstock that has created competition for land, and also adds to the instability of food markets (Afiff, 2013).

In this context, a merely small increase in global food production will not secure global food security (Pieters et al., 2013), and exploring the local production of food is suggested as an option to achieve FNS in agrarian countries of the south (CFS, 2015). However, producing food locally also has its own challenges, which are also determined by rapid population growth and food market globalization. For instance, the demand for cash to cover the production costs of commercial and/or non-food agricultural products creates competition for the basic means of production such as land, water and labour (Brüntrup and Herrmann, 2010; Kuhn and Endeshaw, 2015; Virchow et al., 2016). Furthermore, the international demand for non-food agricultural products influences the type of crops produced by small-scale farming households (Keyzer et al., 2005; Dose, 2007; Kuhn and Endeshaw, 2015; Virchow et al., 2016). This competition among crops may not only cause a decline in the amount of food but also deepen the fragmentation and marginalization of land due to over-exploitation, which would contribute to food insecurity and poverty.

Beyond the provision of sufficient food, adequate food is necessary to guarantee people’s optimal development and performance. A lack of the optimum amount of essential micronutrients in the daily food intake of individuals is another form of food insecurity, which challenges most developing countries. Often termed as ‘hidden hunger’, this may occur even during the consumption of food with sufficient calories, and may be only detectable at the clinical level (FAO et al., 2012; Biesalski, 2013). At an early age, hidden hunger leads to stunting and anaemia, irreversibly harms cognitive development, and leads to poor intellectual, physical and economic performance in adulthood (Arcand, 2001; Stein and Qaim, 2007). Currently, the combat of hidden hunger has been endorsed by national and global efforts that address the challenge of food insecurity (FAO et al., 2012; CFS, 2015).

In this complex scheme, the demand for smart farming systems that can address FNS and also satisfy other material and cash needs of the population remains an issue. An option is agroforestry, widely promoted as a land use capable of addressing the multifaceted problem of food security of small-scale farming households of impoverished agrarian countries (; Frison et al., 2011; Bishaw et al., 2013; Ickowitz et al., 2013; Jamnadass et al., 2013; Mbow et al., 2013; Dawson et al., 2014). In spite of the recognized potential of agroforestry systems to provide a variety of goods and services, the degree of its impact in enhancing household economy and food security is known to be site specific. The inherent variability among agroforestry systems requires the understanding of the circumstances where it may be implemented and the trade-offs across the achievement of its intended goals (Mbow et al., 2013).

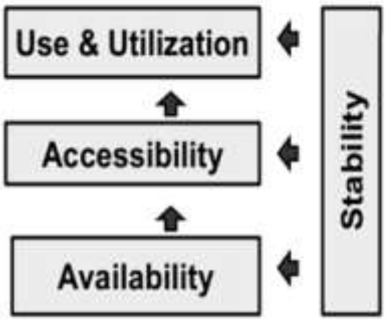
In Ethiopia, among the many farming practices traditional agroforestry systems in the southwest region are the most extended and well-performing, having been proven able to sustain the livelihoods of local populations while maintaining environmental integrity (Assefa, 2010; Senbeta et al., 2013). However, the performance of these systems with regard to the food and nutrition aspects have not yet been considered. Hence, this study investigates the potential role of local agroforestry practices as contributors to the FNS of small-scale farming households, taking the Yayu area of south-western Ethiopia as a case study. To meet this goal, the following research questions were set: What are the predominant agroforestry systems practiced? How do these contribute to fulfilling four the pillars of food and nutrition security of the small-scale farming households?

2 Background

2.1 Food and nutrition security

Since the launch of the germinal idea of food and nutrition security in 1943 (United Nations Conference on Food and Agriculture, 1943), upgrading and refinements took place as the global situation and understanding on the subject evolved (Maxwell and Smith, 1992). Nevertheless, the most common current definition dates from the 1996 World Food Summit that stated: "(…) *food security is met when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO 1996). Later, in the World Summit of Food Security in 2009, this definition was confirmed, extending its scope by adding that "*the nutritional dimension is integral to the concept*", and specified its components by detailing that the "*four pillars of food security are availability, access, utilization, and stability*". (FAO 2009 b) (Figure 1).

Figure 1. Four pillars of food security. Adapted from: Weingärtner (2004)



The first pillar of food security is food availability. It represents "*the existence and supply of sufficient amount of food ready for consumption for all individuals in the household, country and region, via production, distribution, exchange and/or aid*'' (FAO, 2006). At the household level, food availability refers to the abundance of adequate amounts of food for all household members, either through own production or by purchase. For example, in the Tigray region of Ethiopia, the average household production covers about 38% of the annual food demand (BOFED 2004), so food availability can only be met via purchasing, food aid or other.

The second pillar of food security is access. This refers to the capabilities of region, locality, households and/or individuals within those households, with respect to sufficient access to resources, and rights to acquire sufficient amounts and quality of food (Riely et al., 1999; Gross et al., 2000; Rivera and Qamar, 2003). At the household level, the access of all members of a household to a sufficient amount of food according to their physiological and psychological needs and preferences is to be guaranteed (Weingärtner, 2004; FAO, 2006). Social, economic or cultural factors such as favouritism, gender bias, and/or education influence the distribution of food among household members (Weingärtner, 2004; Pieters et al., 2013). For instance, in some parts of Ethiopia, females, mainly mothers, get relatively smaller food amounts, fewer number of meal and/or inferior quality food than male members of the same household (Mengesha and Ayele, 2015). Drivers of food access are household resources, food prices, food preferences and socio-political factors such as discrimination and gender inequality (Pieters et al., 2013).

The third pillar is utilization. It denotes the ability of an individual to use food in a way that all physiological requirements are satisfied. Besides the food quality, it involves the importance of non-food aspects, such as availability of clean water and clean cooking fuel, hygiene and sanitation. The three underpinning elements of this pillar are diets diversity, proper preparation and handling, and absorption efficiency (Weingärtner, 2004; FAO, 2008; Pieters et al., 2013; Pangaribowo et al., 2013). (i) Diet diversity. Refers to the content of an optimum amount of calories and nutrients in the food required by each member of the household. A household's staple crops may offer sufficient energy, but not contain optimum amounts of essential macro- and micronutrients, making the household members prone to malnutrition. Currently, this is the situation for more than 2 billion people around the world (FAO et al., 2012). Alternatives at household level involve economic, educational, cultural and behavioural measures to promote the inclusion of animal products, fruits and vegetables in home diets, as it has been proven that wealthier and better-educated people have more diversified diets (Hatløy et al., 2000; Ruel, 2002). (ii) Proper preparation. The presence of nutritious food does not guarantee FNS. Non-food inputs like clean water and energy are needed to appropriately prepare, consume and assimilate food. At household level, the access to sufficient clean water and energy as well as their proper usage and handling are crucial factors to guarantee a safer, more palatable and more energy-efficient consumption of food. (iii) Absorption efficiency. Also known as 'nutrient utilization', this is about an individual's physiological efficiency in absorbing the consumed food, and therefore well-correlated with the health status of the individual that, in case deficient, can impair the person ability to benefit from the food (Weingärtner, 2004). At household level, absorption efficiency depends on the economic, educational and physical characteristics of a household with respect to caring for the health of the family members.

The fourth pillar, stability, refers to the duration of the three other dimensions for long periods of time (FAO, 2009 b). Events like food price hikes, floods, droughts, pest outbreaks, etc., can cause economic or environmental shocks that may lead to an initially food-secure household becoming insecure. Stability comprises two general attributes, namely carrying capacity, referring to the tolerance level of the subject against harming events, and resilience, referring to the capability and time required to recover from those events (Pieters et al., 2013). Accumulation of assets prior to the shock occurrence such as storing food and saving cash can significantly enhance the carrying capacity and resilience of households during calamities. This implies a desirable precautionary behaviour, even more important if harming events are cyclical.

As shown above, FNS is a multifaceted and multidimensional concept, and therefore can be achieved only when all pillars are fulfilled simultaneously. This in turn requires a deeper investigation and understanding of the causes, drivers and determinants of each pillar when evaluating the potential role of a given option, as intended in the case of agroforestry as described in this paper.

2.2 Agroforestry definition and classification criteria

Agroforestry is among the ancient land-use farming practices around the world. It has been estimated to exist for more than 1300 years (Brookfield and Padoch, 1994), and its practitioners to be more than 1.2 billion worldwide (Zomer et al., 2009). Essentially, agroforestry allows farmers to produce several goods and services in the same unit of land in an integrated manner to address a broader array of demands. Since its modern scientific re-establishment in the 1970's, many definitions have been coined (King, 1978 cited in King, 1979; King, 1979; Lundgren, 1982 cited in Gold and Hanover, 1987; Young, 1983; Nair, 1985; Somarriba, 1992; Leakey, 1996, etc.) which, despite minor differences, agree on essential features characterizing an agroforestry system: (i) The presence of at least one woody perennial component and at least one annual crop or animal component; (ii) The components are deliberately managed or cultivated; (iii) The system generates more than one output; and (iv) interaction exists among components. Based on this, the World Agroforestry Centre developed a working definition of agroforestry: "(...) *an ecologically based natural resource management system that integrates trees (for fibre, food and energy) with crop and/or animal on farms with the aim of diversifying and sustaining income and production while maintaining ecosystem services*" (ICRAF, 2000).

Regardless of these common features, depending on the available resources, management purpose, and the social, economic, cultural and other attributes of an individual, family or group, agroforestry systems and practices can vary widely. For instance, homegarden, *taungya*, alley cropping, improved fallow, *kebun-talun*, coffee-shade system, shelterbelt, *dehesa*, and parklands are a few well-known traditional agroforestry systems.

To distinguish these variations, several attempts of systematic classification have been proposed (King, 1979; Grainger, 1980; Torres, 1983; Somarriba, 1992; Nair, 1993; Sinclair, 1999). For instance, Nair (1985) used structural, functional, socio-economic and ecological criteria, and Dwivedi (1992) physiognomic, historical, and floristic principles. Despite the existence of many approaches of classification, it should be clear that they ''*are by no means independent or mutually exclusive. Indeed, it is obvious that they have to be interrelated*'' (Nair, 1993).

2.3 Agroforestry for food and nutrition security of small farming households

As noted above, the attainment of the four pillars is a pre-requisite for achieving FNS, and as a variety of agroforestry systems exist, each may have a different stake in relation to each pillar. Hence, in this section the potential of agroforestry towards the improvement of each pillar is discussed in general, and some specific examples from tropical countries, mainly Ethiopia, are provided.

Agroforestry can contribute to food availability directly via the production of food from the perennial component(s), and/or through the enhancement of food production of the annual crop and/or animal/insect component(s) (Jamnadass et al., 2010; Sarvade et al., 2014). Although often disregarded, an example of the former is the Enset-coffee homegarden of the Sidama and Gedeo communities in southern Ethiopia, which include the perennial species Ensete ventricosum that serves as staple food for about 15 million people in the region (Abebe, 2013; Mellisse et al., 2017a). More frequently, and alongside the direct provision of edible products, agroforestry can enhance the yields of other food crop component(s) of the system, for instance by including nitrogen-fixing species, e.g., in Sudan the legume *Faidherbia albida* has increased the harvests of surrounding cereals and groundnut up to 200% (Fadl and El sheikh, 2010). Likewise, in Malawi, maize (*Zea mays*) cultivated in intercropping with the legume gliricidia (*Gliricidia sepium)* was reported to increase yields from 40% to more than 300% of the monocrop maize farm (Maclean et al., 1992; Rao and Mathuva, 2000; Makumba et al., 2006; Akinnifesi et al., 2006; Beedy et al., 2010). Also, agroforestry can augment the provision of feedstock for the animal component, and increase the production-derived foods, such as meat, milk, and honey. In East Africa, more than 200,000 smallholder dairy farmers use supplementary feed from fodder shrubs (Place et al., 2009). In Cagayan de Oro, Philippines, the feedstock resulting from combining fodder grasses and trees, e.g., *Gliricidia sepium,* surpasses the quality of grasses, improves the health and vigour of livestock thus preventing disease and pests risks, and spares farm labour for herding and tethering animals (Bosma et al., 2003).

Regarding the contribution of agroforestry to food access, in cash-crop dominated areas, such species tend to be the prime source of income of farmer livelihoods, which is later used to buy food from the markets. Accordingly, some agroforestry systems may focus on the production of highly valuable cash products, e.g., coffee *(Coffea arabica)* and cacao (*Theobroma cacao).* But in the majority of cases, the array of merchantable products from agroforestry is wide, i.e., fruit, stimulants, spices, wood, resins, etc., which can also generate a considerable amount of cash. For instance in Bushbuckridge, South Africa, farmers sell the fruit marula *(Sclerocarya birrea),* the main component of a valuable cream liquor, to generate cash (Shackleton, 2004). Similarly, African pear tree *(Dacryodes edulis)* and shea butter tree *(Vitellaria paradoxa)* are among the most widespread indigenous merchantable tree fruits harvested from agroforestry parkland in West Africa (Schreckenberg et al., 2006; Trade Hub and African Partners Network, 2014). In East Africa, khat *(Catha edulis)*, often associated with coffee in small farmer plots, generates regular income as it is mostly sold in local markets thus increasing farmers' economic and food acquisition capacities (Dessie, 2013; Beghin and Teshome, 2016; Gyau and Muthuri, 2016; Mellisse et al., 2017a; Mellisse et al., 2017b). Farmers in West and East Africa grow timber trees like the Tasmanian blue gum *(Eucalyptus globulus)*, flooded gum *(Eucalyptus grandis)*, teak *(Tectona grandis)*, and Mexican white cedar *(Cupressus lusitanica)* together with understorey crops to produce timber, poles, posts and other wood and fibre products (Duguma, 2010; FAO, 2011; Mathu, 2011; Luukkanen and Appiah, 2013). In Kenya, trees like neem *(Azadirachta indica)*, drumstick tree (*Moringa oleifera)* and African plum (*Prunus africana*) generate products of medicinal value used for self-treatment but also for selling (Muriuki et al., 2012). Some perennial plant components can contribute indirectly to other species production and the generation of income by supporting these physically, as in the case of trees such as silky oak (*Grevillea robusta)* and *Gliricidia sepium* that farmers in Tanzania use to support black pepper *(Piper nigrum)* (Reyes et al., 2009) or to encourage plants' physiology through shade, as in the case of coffee and cacao (Muleta et al., 2011; Asare, 2016).

The food utilization pillar relies on the quality and safety of food on the one side, and on the consumer health and physiological assimilation capacity on the other. The broad recognition of its importance has triggered different measures to alleviate problems such as increasing and diversifying the consumption of fruits, vegetables and animal products, as this is reported to be the most affordable and sustainable approach to abate micronutrient deficiency (FAO, 2010; Susila et al., 2012). Mbow et al. (2013), identified trees in agroforestry systems as good sources of food, mostly in form of fruits, nuts and leafy vegetables, which usually are rich sources of micronutrients. Using data collected from 21 African countries during the period 2003–2011, Ickowitz et al. (2013) detected a strong correlation between tree cover and dietary diversity. Abebe (2005) and Méndez et al. (2001) observed a great nutritional diversity in homegardens, mainly due to the diversity of vegetables, fruits, and spices, which are also rich in nutrients. In addition, agroforestry can also enhance the availability of animal-based protein, vitamins and minerals from meat, fish, dairy and other animal products through the production of supplementary fodder and forage. A number of reports state that the inclusion of fodder and forage from trees and shrubs into animal feed have enhanced the animal production yield of households (Dixon et al., 2010; Wambugu et al., 2011; Franzel et al., 2013; Dawson et al., 2014; Sarvade et al., 2014). In general, agroforestry potentially improves the availability of diversified foods, which in most cases compensate the nutrients lacking in starchy staple diets.

Proper cooking seems to be a vital factor in food safety and its effective utilization, as cooking helps to release the energy and nutrients contained in the food. The FAO (2008) confirmed that firewood and charcoal from trees are crucial for the survival and well-being of about two billion people. In this regard, the trees in agroforestry systems can offer locally available, affordable and renewable fuel. Thorlakson and Neufeldt (2012) observed that small-scale agroforestry plot holders in Kenya have a lesser need to purchase fuelwood and do not need to collect it from natural stands, and therefore have more time for other activities. Similarly, Kamp et al. (2016) compared the production of fuel of agroforestry and two biogas-based technologies in Ghana showing that the former was a more attractive alternative in terms of soil fertility, net soil carbon emission, labour requirement, resource use efficiency, and global renewability.

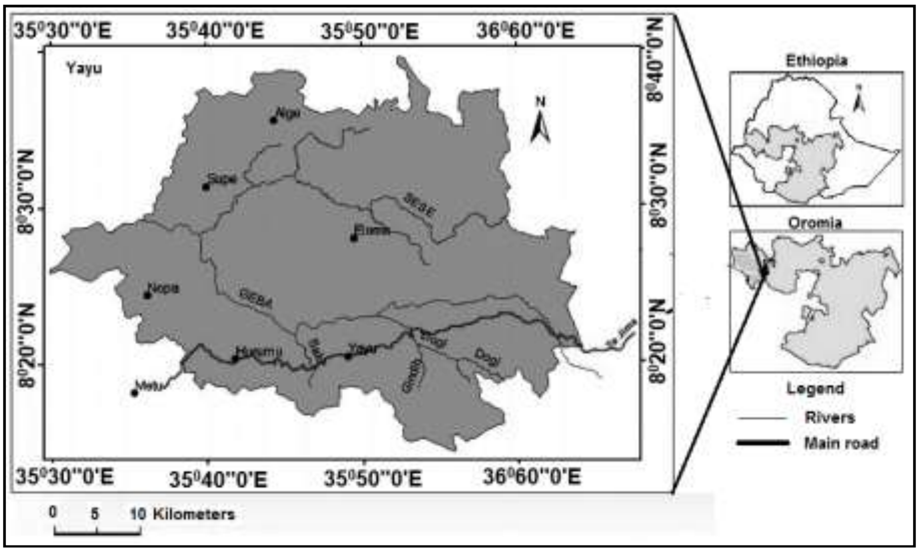
Food stability is normally reached when the other three pillars have attained relative stability. In agroforestry, the diversity of species and the presence of the perennial components underpin a system's capacity to achieve and stabilize each of the before-mentioned three pillars. In the case of food stability, the pattern remains, i.e. the presence of more than one edible species, each with different phenology and thus harvesting calendar, results in a relatively consistent availability of foods over the year. This is key for most agrarian regions of the developing world that tend to experience seasons of both food surplus and food shortage. For example, the Konso community in southern Ethiopia cultivates the cabbage tree (*Moringa stenopetala)* in diverse agroforestry arrangements, whose main function is filling a gap in the annual food supply (Förch, 2003). Similarly, the *Vitellaria paradox* and *Sclerocarya birrea*, traditional components of agroforestry parklands, are reported as potential sources of food of local communities during droughts and crop failure in several parts of Africa (Maranz et al., 2004; Mojeremane and Tshwenyane, 2004; Jamnadass et al., 2013). Furthermore, a higher diversity of cash crops means a broader harvesting calendar and availability of sellable products, a secure income for farmers and subsequent access to foods available in the local markets.

Moreover, the higher diversity of components, the complex interaction among them, and the multiple outcomes generated coupled with the physiological robustness of trees makes agroforestry systems less vulnerable and more resilient to environmental shocks than monocrop systems. According to Jamnadass et al. (2013), due to the diversity and interaction among agroforestry components, these systems react differently to natural turbulences. Hence, in Niger, farmers argue that increasing the number of tree species per purpose insures them against ‘function failure’ in their agroforest, so that even in drier years some species will provide the expected function (Faye et al., 2011). In Kenya, smallholder farmers practising agroforestry for soil conservation and fertility increase and fuelwood provision identified more coping strategies when exposed to climate-related shocks than those not practising it (Thorlakson and Neufeldt, 2012).

3 Yayu area profile and data sources

The study area Yayu is located in the Illubabor Zone of the Oromiya state, south-western Ethiopia, between 8°10'-8°39' N and 35°30'-36°4' E. The area was registered in 2011 by the UNESCO as the 'Yayu Coffee Forest Biosphere Reserve' for the in-situ conservation of wild *Coffea arabica*. It covers about 168,000 ha split into six *woreda*[1], namely Algae Sachi, Bilo-Nopa, Chora, Doreni, Hurumu, and Yayu (Gole et al., 2009). The area has a rolling topography where altitudes range from 1140 to 2562 m a.s.l., and is crossed by three major rivers, i.e., Geba, Dogi and Sese (Figure 2). The climate is hot and humid, and the mean annual temperature is around 20°C oscillating between the average extremes of 12°C and 29°C (Gole et al., 2008). The area exhibits a uni-modal rainfall pattern with mean annual precipitation of 2100 mm, with high disparity from year to year, and ranging from 1400 to 3000 mm (Gole et al., 2008). Dominant soil groups include nitosols, acrisols, vertisols, and cambisols (Tafesse, 1996).

Figure 2. Location of Yayu in Ethiopia. Adapted from: Gole et al. (2009).



In 2007, around 310,000 people lived in the six *woreda* (CSA, 2007). The Oromo ethnic group predominates and is considered indigenous. There are a significant number of Amhara, Tigreway and Kembata as they migrated from other parts of the country due to the government's forced resettlement program of 1984 (Kassa, 2004). Orthodox christian, muslim, protestant and indigenous beliefs are evenly practiced (Tulu, 2010). Currently, the population of Yayu is booming due to the high birth rate of about 3.2% per annum (Tafesse, 1996), and the intense internal migration due mainly to the thriving infrastructural development (Tadesse, 2015), such as the construction of fertilizer and coal factories, a network of roads planned to ease the trade of coffee, and the forthcoming hydroelectric dam on the Geba River (Bacha, 2014).

The main livelihood source of the Yayu households is coffee-based agriculture, which employs over 90% of the active labour of the area (Assefa, 2010). Most coffee plots are small, however it is estimated that more than 60% of the population depends on coffee production and coffee-related activities, such as collection, processing and marketing (Gole, 2003; Ilfata, 2008). Besides coffee and the other cash crop khat, smallholders produce annual crops, such as *Zea mays*, sorghum *(Sorghum bicolor)*, *teff (Eragrostis tef)*, and other cereals and pulses.

[1] A *woreda* is the second smallest political-administrative unit after Kebele. Normally, a Woreda is comprised by at least 20 Kebele.

Yayu landscape exhibits a mosaic pattern. The major land-use types are forest, agricultural land, wetland, and grazing land (Table 1). Forests cover most of the area, and consist of four major variations, namely undisturbed natural forest, semi-forest coffee systems, fully managed forest for coffee production, and old secondary forests (Gole et al., 2009).

Table 1. Land use in Yayu area (%) adapted from Assefa, (2010)

Major land-use type	Form	Percentage
Forest	Undisturbed natural forest, coffee production plots,	69%
Agricultural	Annual crops including multipurpose trees on farmland	14%
Homestead farm	Homegardens	12%
Other	Grazing land, plantation forest, wetland, settlement and waste lands	2%

Yayu forests belong to the eastern Afromontane type, identified as one of the 34 biodiversity hotspot areas in the world by Conservation International (BirdLife International, 2012). It is well conserved and particularly important as a gene pool of wild coffee (Gole et al., 2008; Senbeta et al., 2013). The Yayu Coffee Forest Biosphere Reserve comprises three concentric zones, i.e. core area, buffer and transition zones, covering about 28,000, 22,000, and 118,000 ha, respectively (Gole et al., 2009). Different land uses (Table 1) are allowed in the outer zones (transition and buffer), but in the inner (core) area, only intact forests are maintained (Gole et al., 2009).

In terms of food and nutrition security, the Yayu area is relatively food secure. No incidents of food insecurity have been reported in the last 15 years (Reliefweb. 2002; FEWS NET, 2005; FEWS NET, 2009; FEWS NET, 2013; FEWS NET, 2015; FEWS NET, 2017). Instead, it is regarded as productive and often as a destination for relocated communities from other parts of the country exposed to recurrent famine and droughts (Gizaw 2013). However, much less is known of the peoples' nutritional status, its relation to the existing livelihoods, and the potential to fulfil nutrition demands. In this study, the potential contribution of agroforestry-based coffee practices to local householders' nutritional security is assessed.

Data are from both primary and secondary sources. The primary sources include information from direct observation and personal communication with local stakeholders such as farmers, experts and officials around the study area. Published and unpublished documents were used as secondary information sources.

4 Major agroforestry practices in Yayu

Based on Jemal and Callo-Concha (in preparation a), agroforestry practices in Yayu can be clustered into three types: multistorey coffee systems, homegardens, and multipurpose trees on farmland. The former is the most common as it is practiced by 69% of households, but 81% of the households practice the three types simultaneously.

4.1 Multistorey coffee systems

Multistorey coffee systems (MCS), broadly refer to the semi-managed production of coffee under the canopy of scattered taller trees. This generally has positive side effects on the coffee stands with respect to microclimate amelioration, biodiversity, pest control, pollination, and water and soil conservation (Snoeck et al., 2000; Rice, 2010; Alemu, 2015).

In Yayu, depending on the management scale and origin of the stand, four variations of MCS exist, i.e., forest/wild coffee, semi-managed forest coffee, garden coffee and coffee plantation (Gole, 2003; Senbeta and Denich, 2006; Gole et al., 2008; Assefa, 2010). All of them involve at least two layers, i.e., coffee/shrub layer and shade tree layer and, with exception of the coffee plantation, have been practiced for at least two centuries on a small scale and are therefore regarded as 'traditional' coffee production systems (Gole et al., 2001; Gole, 2015). In contrast, the plantation coffee system is relatively new and restricted to medium and large-scale production.

In the forest/wild-coffee system, wild coffee plants grow naturally in primary or secondary forests (Gole, 2015). Farming households, depending on their proximity to the forests and their right to crop (no private land exists in Ethiopia (Crewett et al., 2008)), collect the mature coffee berries when they are ready, and barely implement any management except clearing the pathways to allow movement (Gole et al., 2001). This system is often indistinguishable from the natural forest. In Yayu, these systems have been reported to have up to four strata, and to hold 74 perennial species, including 50 trees, 10 shrubs and 14 climbers (Gole, 2003; Senbeta and Denich, 2006). As coffee grows randomly, plant densities are relatively high, ranging from 10,000 to over 30,000 per ha, however, the yields are low varying from 200 to 250 kg/ha of fresh beans (Gole, 2015) (Figure 3A).

Depending on the households' need to increase their income, farmers may opt to gradually convert forest/wild-coffee systems into semi-managed forest coffee systems by increasing the management intensity to improve productivity (Aerts et al., 2011). This starts by reducing the canopy cover and clearing the underground vegetation, continues by thinning the unproductive and diseased coffee plants to favour the vigorous ones and increase the overall yield, and finally by transplanting naturally regenerated seedlings into sparsely covered areas of the plot (Senbeta and Denich, 2006; Labouisse et al., 2008; Schmitt et al., 2009). The floristic diversity and structure of these systems differ depending on the period and intensity of the intervention, but in general, the number of perennials is lower in forest/wild-coffee systems, with 36 trees, 8 shrubs and 8 climbers. The species are selected by the farmers considering light access and improvement of soil fertility. For instance, nitrogen-fixing species dominate such as large-leaved albizia *(Albizia grandibracteata),* peacock flower *(Albizia gummifera),* flat-top acacia *(Acacia abyssinica)* and *birbira (Millettia ferruginea)* (Gole, 2003; Muleta et al., 2011; Jemal and Callo-Concha, in preparation a). These management activities can lead to a yield increase up to ca. 60% in comparison to the forest/wild coffee system (Gole, 2015) (Figure 3B).

The third production type is the garden coffee system, which takes place around farmer homesteads together with other food and non-food crops. This system overlaps with homegardens and has the lowest coffee plant density, but due to the intensive management, productivity is often higher than in other systems (Gole, 2015). Average yield oscillates from 400-500 kg/ha, but can reach up to 750 kg/ha (Teketay and Tegineh, 1991; Woldetsadik and Kebede, 2000). According to Assefa (2010), about 10,000 ha land in the Yayu area is covered by garden coffee (Figure 3C).

Figure 3. Dominant coffee production systems of Yayu. A: forest coffee system. B: semi-managed forest coffee system. C: garden coffee system.

The fourth coffee production system is plantation coffee, which is not commonly practiced by smallholder farmers but by medium- and large-scale producers (Gole, 2015). This system is either developed upon old stands of natural coffee plots or converted from other land-use types such as pastures and farmlands. Seedlings of improved coffee varieties are planted together with fast-growing shading leguminous tree species in systematic patterns. The canopy coverage and the spacing among coffee plants are lower than in forest and semi-managed coffee systems, though the yields are expected to be higher due to management intensity (Gole, 2015).

4.2 Homegardens

Homegardens (HG) refer to the cultivation of plants, husbandry of livestock and other farming activities around the farmers' homesteads to satisfy multiple needs, mainly food, and to generate extra income (Méndez et al., 2001; Watson and Eyzaguirre, 2002; Galhena et al., 2013). Homegardens of Yayu encompass a mix of useful plants including staple crops like *Ensete ventricosum* and *Zea mays*, tuber and root crops, e.g., *anchote (Coccinia abyssinica)*, taro *(Colocasia antiquorum)*, potato *(Solanum tuberosum)* and sweet potato *(Ipomoea batatas)*, leafy and other vegetables, e.g., kale *(Brassica oleracea)* and hot pepper *(Capsicum frutescens)*; exotic fruits, e.g., papaya (*Carica papaya)*, mango (*Mangifera indica)* and avocado *(Persea americana)*, and some pulse crops, e.g., haricot bean *(Phaseolus vulgaris)* and lima bean *(Phaseolus lunatus)* (Etissa et al., 2016; Jemal and Callo-Concha, in preparation a). Livestock, dairy, poultry and honey are also frequently observed, and depending on the proximity of the household to the village and markets, cash crops like khat (*Catha edulis)*, rhamnus *(Rhamnus prinoides)*, sugarcane *(Saccharum officinarum)*, and spices such as ginger *(Zingiber officinale)* may also be important (Jemal and Callo-Concha, in preparation a).

Species found in homegardens do not show a pre-determined spatial arrangement, with the exception of small plantations of *Catha edulis*. Rather, the location of individual plants and cohorts is random and conveniently determined by the farmer's needs. For instance, spices are planted closer to the homestead, or shade-loving crops under fruit trees. In addition, species density is also variable depending on the household and market demand, and generally tends to increase based on the farmers aim to introduce and test potential useful species gathered elsewhere. Vertically, multistorey systems with up to five different layers dominate, i.e., emergent (>15 m) with timber and shade trees, canopy (10 m-15 m) with exotic fruit trees, understory (5 m-10 m) with fuel and fodder trees, shrub (1 m-5 m) with food and cash crops, and herb (<1 m) with vegetables and spices. Relatively larger plots of cereals and pulses may exist depending on household needs, season, and market demand, hence even coffee plants are commonly found (Jemal and Callo-Concha, in preparation a) (Figure 4).

Figure 4. Homegarden in Yayu.

4.3 Multipurpose trees on farmlands

Multipurpose trees on farmlands (MTF) refers to the deliberate integration of woody components in annual croplands, which is the case in almost all observed farmlands in the study area In these systems, the primary purpose is the production of annual food crops for consumption and/or selling, whereas the uses of woody plant species are as non-food goods, e.g., fuel, fodder, timber, etc., and services, e.g. live fences for protection and demarcation, soil fertility enhancement, shade, etc. (Nair, 1985; Jambulingam, 1986). The most common food crops species include cereals like *Zea mays*, *Sorghum bicolor*, *Eragrostis tef*, barley *(Hordeum vulgare)*, wheat *(Triticum sativum)*, finger millet (*Eleusine coracana*), and different pulses, such as faba beans *(Vicia faba)*, field pea *(Pisum sativum)*, and chickpea *(Cicer arietinum)* (Jemal and Callo-Concha, in preparation a). The tree species, large-leaved cordia *(Cordia africana)*, flooded gum (*Euclyptus grandis)*, bitter leaf *(Vernonia amygdalina)*, water pear (*Syzygium guineense)* and jumping seed tree *(Sapium ellipticum)* are among the most common in these systems in Yayu. They are generally arranged in either a scattered or zonal fashion depending on their purpose. Occasionally, cash crops like khat and rhamnus are cultivated in subplots within the farmland. Similarly, fast-growing eucalyptus woodlots are cultivated in farming plots, especially near to bigger towns and construction spots (Personal communication, July, 2014) (Figure 5).

Figure 5. Multipurpose trees on farmland in Yayu.

5 Potential of agroforestry for food and nutrition security in Yayu

The contributions of the dominant Yayu agroforestry systems to the food and nutrition security pillars are summarized below. With respect to the first pillar, i.e. availability, it can be stated that cereal staples, the major sources of dietary energy, are mainly supplied by the system multipurpose trees on farmland. *Zea mays*, *Sorghum bicolor, Eleusine coracana* and *Eragrostis tef* are the species most commonly cultivated, as they are major ingredients of the popular food *Enjera* (Jemal and Callo-Concha, in preparation a). However, these may not cover the annual food demand of the households when farmers are confronted with the food-shortage period during the rainy season from July to September, when the previous harvest stocks are depleted and the new crops are still in the field. The situation may worsen for a number of reasons, such as low productivity, wild animal damage, lack of land, and large family size being the most prominent (Etissa et al., 2016; Personal communication, July, 2014). To fill this gap, farmers devise coping mechanisms where cultivating food in their homegardens appears key for most Yayu households (Local informants, personal communication, July, 2014). Staple species, such as *Ensete ventricosum* that is available throughout the year, and *Colocasia antiquorum,* Buri *(Dioscorea alta)* and *Solanum tuberosum*, which are harvested specifically during that gap, are the most favoured species in Yayu homegardens, complemented by leaf vegetables like Tikil gomen (*Brassica oleracea var. capitata),* Abyssinian mustard *(Brassica carinata) and* Ethiopian kale *(Brassica oleracea var. oleracea)* (Local informants, personal communication, July, 2014).

Also, species in this system may also contribute to maintaining food availability through yield enhancement and protection of plots. *Albizia grandibracteata, Albizia gummifera,* forest long-pod Albizia *(Albizia schimperiana),* lucky-bean tree *(Erythrina abyssinica),* lead tree *(Leucaena leucocephala),* Egyptian pea tree *(Sesbania sesban)* and *Acacia abyssinica* are nitrogen-fixing species, whereas *Erythrina abyssinica,* false assegai *(Maesa lanceolata),* rasberry *(Rubus apetalus), reji (Vernonia auriculifer)* and malabar nut tree *(Justicia schimperiana)* are regularly cultivated as hedgerow and live fences for protection (Jemal and Callo-Concha, in preparation a).

Staple crops, which are often used to prepare the main dish, are not served alone, but with either stew or a sauce. These are fundamental in household diets as a flavouring element, but also as a complementary provider of micronutrients. Therefore, the inputs required for preparing them are essential. The grass pea *(Lathyrus sativus)*, the most common ingredient in the popular *Shiro Wot* stew, was not observed on the farm plots in Yayu. Substitute ingredients such as *Vicia faba, Pisum sativum* and *Cicer arietinum* were rarely found in the farm plots (Jemal and Callo-Concha, in preparation a), but, together with basic ingredients such as oil, spices and salt, are purchased from the markets.

Referring to the second pillar food access, the major expenses of the households are the food-related items, together with agricultural inputs, such as seeds and fertilizers (Personal communication, July, 2014). Therefore, it is important for the farmers to generate sufficient cash to cover them. In Yayu, 90% of the population depends on coffee production for employment opportunities (Assefa, 2010), and up to 60% of their annual income (Jemal and Callo-Concha, in preparation a). Therefore, the primary contribution of the multistorey coffee system to the food security of the Yayu households is the generation of cash to enhance the food acquisition capabilities. Even households with small farming areas or even no farmland, and social groups marginal to the conventional market channels such as poor women and children, benefit through a mechanism named *kote*, which allows them to collect and trade left-over coffee from the coffee plots after the main harvest is finished (Personal communication, July, 2014).

Table 2. Contribution of the major agroforestry practices of Yayu to the four pillars of food and nutrition security

		Pillars of food and nutrition security			
Agroforestry practice	**Major component**	**Availability**	**Access**	**Utilization**	**Stability**
Homegarden	Fruits and vegetables	Provide supplementary foods	Provide cash for purchasing food.	Main sources of vitamin A and other micronutrient	Fill seasonal income shortage by providing cash Harvested during shortage periods
	Root and tuber crops	Staple foods during shortage time			Drought-tolerance species Harvested during shortage periods
	Cash crops		Provide cash for purchasing food.		Fill seasonal income shortage by providing cash
	Multipurpose trees	Provide fodder for farm animals	Provide cash from selling timber	Provide fuel for cooking Provide fodder for diary production	Improving the micro-climate during climate extremes
Multistorey coffee systems	Coffee		Provide cash for purchasing food		Fill seasonal income shortage by providing cash
	Shade trees		Provide cash from selling timber	Provide fuel for cooking Provide fodder for diary production Provide native edible fruits	Improving the micro-climate during climate extremes
	Honey bees and/or other spice crops	Provide supplementary foods	Provide cash for purchasing food		Fill seasonal income shortage by providing cash
Multipurpose trees on farmlands	Annual crops	Main sources of staple foods		Main sources of protein	
	Hedge row trees			Provide native edible fruits Provide fuel for cooking Provide fodder for diary production	Protect the main crop from wild animal damage Improving micro-climate during climate extremes
	Cash crops		Provide cash for purchasing food		Fill seasonal income shortage by providing cash
	Multipurpose trees	Enhance yield through N fixing		Provide native edible fruits Provide fuel for cooking Provide fodder for diary production	Enhancing micro-climate during climate extremes

Following the food supply gap from July to September, there is either a cash supply or an income gap from September to December, when the households have consumed their food stocks and spent their savings to purchase food on the market. Coinciding with the coffee harvest season, farmers sell their harvest in bulk generally at the lowest price of the year, as they fear a reduction in the coffee volume through storage or unexpected price fluctuations (Personal communication, July, 2014). In that setting, farmers try to increase their income through selling other merchantable agricultural products, among others from the homegarden and multipurpose trees on farmland systems (Personal communication, July, 2014). For instance, khat harvested two to three times per year ensures a continuous flow of cash. The same applies to exotic fruits, e.g., *Mangifera indica, banana (Musa paradisiaca)* and *Persea americana*; vegetables, e.g., tomato *(Solanum lycopersicum)* and onion *(Allium cepa)*, timber trees species, e.g., *Euclyptus grandis* and *E. globulus*, spices, e.g., ginger and turmeric *(Curcuma longa)*, and other cash crops, e.g., sugarcane and rhamnus, which are sold in local (less competitive) markets (Jemal and Callo-Concha, in preparation a). Likewise, most multi-storey coffee systems derive from or are related to forest stands and have a high number and diversity of species such as the spices Ethiopian cardamom *(Aframomum corrorima)* and *timiz (Piper capense)*, timber trees such as *Cordia africana*, which are all in demand at local markets (Gole et al. 2009; Jemal and Callo-Concha, in preparation a).

The third pillar, utilization, is mostly supplied by homegardens. Concerning macronutrients, despite the consumption of animal protein in Yayu being very low, milk, eggs and even meat are provided by homegardens (Jemal and Callo-concha, in preparation b). However, protein from pulses like *Lathyrus sativus, Vicia faba, Pisum sativum, Cicer arietinum, Phaseolus lunatus* and *Phaseolus vulgaris,* although they are largely accessed from the market, remain the primary sources of protein for most farming households in Yayu (Jemal and Callo-Concha, in preparation a, b).

Vitamins and minerals are provided by fruits and vegetables such as *Carica papaya,* peach (*Prunus persica),* carrot *(Daucus carota),* pumpkin *(Cucurbita pepo), Capsicum frutescens, Brassica oleracea* and *Brassica carinata,* which are frequently reported to be cultivated in Yayu homegardens (Etissa et al., 2016; Jemal and Callo-Concha, in preparation a), and to a lesser extent also species such as *Citrus spp., Mangifera indica, Musa paradisiaca, Persea americana, Solanum tuberosum, Solanum lycopersicum,* beet root *(Beta vulgaris)* and *Allium cepa* (Jemal and Callo-Concha, in preparation a). Due to the limited consumption of animal protein (heme iron), the otherwise iron-poor food in Yayu can effectively be substituted by non-heme iron in *teff*, which is commonly cultivated in the farmlands with multi-purpose trees (Baye, 2014; Jemal and Callo-concha, in preparation b). The presence of a variety of edible native species, such as *Syzygium guineense,* wild date palm *(Phoenix reclinata), Cordia africana,* red milk wood *(Mimusops kummel), Rubus apetalus,* coast gold-leaf *(Bridelia micrantha)* and Abyssinian gooseberry *(Dovyalis abyssinica)* in all agroforestry systems but especially in multistorey coffee systems reveals an untapped potential for contributing to the pillar utilization (Jemal and Callo-Concha, in preparation a).

In almost the whole of Yayu, the fuel required for cooking is obtained from agroforestry systems. In the multi-storey coffee system, fuelwood is harvested from the upper and lower storeys, i.e., *Acacia abyssinica, Maytenus arbutifolia* and *Maesa lanceolata* being the preferred species, besides the remnant dried branches from shade trees and coffee stands. Also, in homegardens and multi-purpose tree systems, broad-leaved croton *(Croton macrostachyus), castor bean (Ricinus communis), Vernonia auriculifer, Justicia schimperiana, Sapium ellipticum* and *deqo qemele* (*Ritchiea albersii)* are popular as fuelwood species (Jemal and Callo-Concha, in preparation a).

Furthermore, fodder species are key contributors to the utilization pillar, and enhance the rearing of cattle and the production of meat and dairy products. Leaves from bitter leaf*, Sapium ellipticum* and Chinese money tree *(Dracaena fragrans)* are gathered from multi-storey coffee systems as fodder (Senbeta et al., 2013; Jemal and Callo-Concha, in preparation a). *Vernonia amygdalina* and Egyptian pea tree are broadly cultivated in homegardens to supplement animal feedstock (Jemal and Callo-Concha, in preparation a). And Egyptian pea tree*,* lead tree*, Vernonia amygdalina* and bush fig (*Ficus sur)* are multi-purpose tree species purposefully maintained in MTF for procuring animal fodder.

Finally, the contribution of Yayu agroforestry to the stability pillar relates mainly to the presence of the woody components and species diversity within and between systems to prevent crop failure and minimize yield fluctuations. Homegardens were found to host about 88 species, 57% of which were perennial (Jemal and Callo-Concha, in preparation a). These create environments less susceptible to climatic extremes that protect annual food and cash crops. In the multi-storey coffee system, almost all species are perennial and are less prone to climatic fluctuations, and this also applies to shade trees (Alemu, 2015), i.e., *Albizia gummifera, Acacia abyssinica, Cordia africana, Albizia grandibracteata* and *Croton macrostachyus* the most common shade tree species (Jemal and Callo-Concha, in preparation a). The case of MTF, trees play a significant role in maintaining soil fertility and preventing soil erosion, and planted as hedges prevent damage caused by animals, wind and frost (Personal communication, July, 2014). *Eucalyptus grandis, Vernonia amygdalina, Vernonia auriculifer* and *Catha edulis* are the most frequent species in Yayu (Jemal and Callo-Concha, in preparation a). Generally, by exhibiting non-concurrent phenological stages, the tree species diversity in agroforestry offers householders a broader set of harvestable products throughout the year and thus food and eventually cash (Table 2).

6 Conclusions and recommendations

The main agroforestry practices identified in the Yayu area, despite their different purposes, management and species, contribute substantially to the four pillars of the food and nutrition security of the households and communities. In a complementary manner, these systems contribute to satisfying the various demands of the farming households. The coffee-dominated plots mainly generate cash by selling coffee beans, non-timber forest products and fuelwood. Farmlands surrounded by trees produce the major annual food supply of the households, which is completed by homegardens, which sometimes also may produce supplementary income. Therefore, a contribution to the communities' well-being can result from the benefits of each of these systems, but it would be enhanced by the synergetic performance of all three.

Focusing on the system benefits for the people's food and nutrition, the roles of the agroforestry practices differ despite some overlapping: a) the multi-purpose trees on farmland display more benefits in the availability pillar, b) the multistorey coffee system serves and shows a major potential toward the access pillar, and c) homegardens are crucial for the utilization pillar. In all three cases, the presence of woody components and species diversity strongly favour the stability pillar.

However, these broad generalizations are susceptible to the influence of multiple factors, such as a household's socio-economic situation, its location (proximity to market and forest), or the assumed production purpose, and the respective management of the system. Also, the ultimate impact of agroforestry systems on the individual food and nutrition security can only be estimated by downscaling and fine-tuning the analyses to the household and person levels. Furthermore, the contribution of species components of the system that are not obvious should be taken into account, e.g., the indigenous, native and/or underutilized species present in all agroforestry systems. This requires empirical and multidisciplinary investigations tackling the interface of socio-ecological systems with the food and nutrition security of its inhabitants at scalable measurements to improve these interface. Such studies for the Yayu case are still in progress.

Nevertheless, ongoing changes such as the thriving infrastructural development in the area may pose a risk to the stability and sustainability of the assessed systems. Therefore, subsequent studies need to add the resilience/adaptive insights as a premise.

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Published by:
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Genscherallee 3
D – 53113 Bonn
Germany

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