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Full Length Research Paper

Vegetable soybean, edamame: Research, production, utilization and analysis of its adoption in Sub-Saharan Africa

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Food and nutritional insecurity constitute a main challenge in most Sub-Sahara African countries. Efforts to provide diets with sufficient nutrients such as proteins, carbohydrates, vitamins and essential minerals should include the introduction of new vegetable and legume crops. Vegetable soybean "edamame", is a nutritious vegetable legume well known and consumed in Asia and America, but underutilized in Africa. This review paper aims at documenting the existing information on edamame and analyzing the potentials for its use in Sub-Saharan Africa. The analysis of the existing literature revealed that vegetable soybean provides great advantages in term of production because of the fresh pods having a good market value and high demand on both local and international markets. Then, the consumption of edamame can also really contribute to reducing nutritional deficiencies in children and even adults, through its great nutritional content and good health benefits. Therefore, edamame is a good crop to promote in Africa. The promotion of edamame requires many research activities starting from evaluation of agronomical adaptation, determination of consumers' preferences and genetic improvement based on farmers, processors and consumers' needs, in order to sustain a seed system for the crop.

Key words: Food security, genetic improvement, seed system, sub-Saharan Africa, vegetable soybean.

INTRODUCTION

Food insecurity is a worldwide problem and the number of undernourished people in the world rose up from 783.7 million to 820.8 million between 2014 and 2017 (FAO et al., 2018). Africa has the world's highest percentage of undernourishment (Fry, 2018) with the case of Sub-Saharan Africa (SSA) appearing to be at critical level (FAO and ECA, 2018). It carries 92.20% of Africa's undernourished people. In Benin, 71% of population is affected by undernourishment (Fry, 2018), with 51.3% of pre-school children suffering from iron, zinc and vitamin A deficiencies (Muthayya et al., 2013).

Although there are endeavors to fight-off malnutrition, more efforts are needed in most SSA countries (Saltzman et al., 2017). Actions should be more focused

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on providing sufficient nutrients, such as essential proteins, carbohydrates, vitamins and minerals (Keatinge et al., 2011). Promotion of underutilized vegetables and legume crops and introduction of new vegetable crops with high bioavailability of essential nutrients and vitamins should therefore be envisaged (Dinssa et al., 2016).

It is the trend in SSA to consume fresh legume grain and pods. This is the case with fresh common beans (*Phaseolus vulgaris*) and fresh peas (*Pisum sativum*), widely consumed in East Africa, as well as groundnut (*Arachis hypogaea*) and pigeon peas (*Cajanus Cajan*) which can also be eaten fresh. Leguminous vegetable are nutritious, as they contain up to 90% of water, 50 - 80% of carbohydrates, 15 - 30% of protein, low total lipid and low fat (Vicente, 2009). Fresh green legumes are also good sources of vitamins, minerals, fibers and antioxidants. Nutrients and medicines together are termed as nutraceuticals (Bhattacharya and Malleshi, 2012). Vegetables are rich in nutraceuticals and vegetable soybean is one of the top nutraceutical rich vegetables.

Vegetable soybean refers to soybean varieties having pods and seeds that can be harvested and consumed when they are still fresh and premature. The crop is well known and widely used in Asia and America, but less known in Africa (Chadha and Oluoch, 2004). Edamame can be eaten in salads, put in stews or mixed with rice (Mohamed and Rangappa, 1992). Beyond its nutritional traits, edamame could have medicinal attributes. It is used to purportedly reduce body pains, cure stomach heat, clean bad blood and reduce effects of poisonous drugs (Shurtleff and Aoyagi, 2009).

As a cash crop, and owing to its short cycle, vegetable soybean can be cultivated four to six times in a year, under irrigated cropping system. Edamame can yield up to 10 t/ha of marketable fresh pods. Besides, the leaves are nutritious feed and together with stems provide about 120 kg of nitrogen (N), 18 kg of phosphorus (P_2O_5) and 120 kg of potassium (K_2O) to the soil after decomposition (Shanlnugasundaram et al., 1992). Beyond its richness in micronutrients and vitamins, edamame provides as much macronutrients as grain soybean. For instance, on dry weight basis, 100 g of edamame provides 477 kilocalories, 41.3 g of proteins, 31 g of carbohydrates and 21.9 g of lipids, while 100 g of matured soybean provides 475.4 kilocalories, 40.2 g of proteins, 32.1 g of carbohydrates and 21.6 g of lipids (Takahashi and Ohyama, 2011). According to these authors, edamame contains more vitamins A, C, K and B than grain soybean. Iron, zinc, magnesium, phosphorus, calcium, potassium, sodium, cupper and manganese concentrations of edamame are higher than those of snap peas and green peas (Takahashi and Ohyama, 2011). The nutritional content of edamame makes it a potential provider of many health benefits. For instance, isoflavones or phytoestrogens are soybean polyphenols involved in the regulation of cholesterol, decreasing the risk of cancer, hypertension, osteoporosis and heart diseases (Magee et al., 2012).

There is high research interest for edamame in Asia and America. Research conducted on edamame include agronomic evaluation for yield, yield components and quality traits to check for adaptation (Basavaraja et al., 2005; Duppong and Hatterman-Valenti, 2005; Zhang and Kyei-Boahen, 2007; Zhang et al., 2010; Kumar et al., 2011). Preference analysis, nutritional and anti-nutritional evaluation of edamame varieties were also reported by various authors (Wszelaki et al., 2005; Bhattacharya and Malleshi, 2012; Carson et al., 2011; Carson et al., 2012; Castoldi et al., 2011; Jadhav et al., 2018; Mohamed and Rangappa, 1992; Takahashi and Ohyama, 2011). Furthermore, storage of edamame was also investigated (Saldivar et al., 2010; Xu et al., 2012; Lara et al., 2019). Genetic diversity was assessed with nutritional, morphological and molecular markers (Mimura et al., 2007; Dong et al., 2014; Ramya and Mummigatti, 2015; Williams, 2015; Pooprompan et al., 2006; Jadhav et al., 2018). Moreover, breeding research was done on edamame (Sarutayophat, 2012; Li et al., 2013; Mebrahtu and Devine, 2008; Jiang et al., 2018, 2018a).

In Africa, research on edamame is very scarce. The few reported are from Chadha and Oluoch (2004), who prior to introduction and distribution of edamame accessions in 26 sub-Saharan African countries, conducted evaluation trials on performance to identify suitable lines. Then, Arathoon (2015) evaluated germination rate, influence of seedling rate, effect of dryland conditions and effects of fertilizers on productivity of edamame. Besides, the adaptation and stability of vegetable soybean genotypes has been recently reported in Uganda (Tsindi et al., 2019). Research works pertaining to the nutritional content of edamame grown under tropical conditions have not yet been reported. Optimized storage techniques that suit tropical environments of SSA countries need to be investigated. In addition, consumers' preferences have to be assessed in order to develop suitable edamame varieties for SSA countries.

This paper summarizes the existing information on edamame covering history of edamame, the requirements for its production, seed systems and prospects for its introduction and adoption in Africa.

METHODOLOGY

This review used keywords such as "origin and history of edamame", "vegetable soybean production", "conservation and consumption history of edamame", "Vegetable soybean: characterization and evaluation", "genetic diversity of vegetable soybean", "physical, chemical and nutritional characteristics of vegetable soybean",…, to search for literature in popular web search engines such as Google Scholar, Research Gate, PubMed Central, Science Direct, AGORA and HINARI to get papers related to the topic. Additional literature was obtained from the websites of some International Organizations like World Health Organization

(WHO), Food and Agriculture Organization (FAO), Asian Vegetable Research and Development Center (AVRDC) and United States Department of Agriculture (USDA). Online resources were downloaded, organized into categories and summarized to draft the paper.

DESCRIPTION AND HISTORY OF VEGETABLE SOYBEAN "EDAMAME"

Vegetable soybean [*Glycine max* (L.) Merr.] is native to China and domesticated from wild annual *Glycine soja*, similar to commodity soybean (Singh, 2017). It represents a group of large seeded soybean cultivars harvested when the green seeds fill the fresh pods (R6 stage), for use as vegetable (Esler, 2011). Known under various local names, vegetable soybean is called "mao dou'' in China and ''poot kong'' in Korea (Saldivar et al., 2011). Although the local names vary among Asian countries, the Japanese name "edamame" prevails and is used worldwide. It is pronounced "ay-dah-MAH-may" which can be translated to mean "bean on branch" in Japanese.

Edamame was first reported in 1275, when the Japanese Buddhist Saint Nichiren Shonin wrote a thanking note to a parishioner, as appreciation for his vegetable soybean gift (Shurtleff and Aoyagi, 2009). It was first introduced in America by Charles C. Georgeson and William J. Morse during the world wars when searching for inexpensive source of protein (Shurtleff and Aoyagi, 2009). Though edamame improvement started in 1950 in Taiwan, vegetable soybean became more popular across the world with the creation of AVRDC-World Vegetable Center in 1971. The AVRDC published their first findings titled "immature green soybeans" and started research on mechanical harvesting of edamame in 1985 (Shanlnugasundaram et al., 1992; Sharma and Kshattry, 2013). Besides, this center became a leader on vegetable soybean research and helped to increase its production in Taiwan for exportation mostly to Japan and United States of America (Shurtleff and Aoyagi, 2009).

Assessing its phylogenetic relationship with other tropical legumes, edamame is closely related to many tropical legumes consumed fresh in SSA countries (Figure 1). These legumes are peanut (*A. hypogaea*), cowpea (*Vigna unguiculata,* (L.) Walp) and common bean (*Ph. vuligaris* L.), indicating the potential for adoption of edamame in SSA countries (Dhaliwal, 2017).

MAJOR RESEARCH ON EDAMAME

Many research works have been carried out on edamame across the world, with a very limited range in Sub-Saharan Africa. These works tackled various aspects including evaluation for adaptation and diversity studies, consumers' preferences and sensorial qualities assessment, nutritional profiling, testing for yield and yield components, breeding and evaluation of production, harvest and post-harvest constraints.

Adaptation and diversity

Diversity study and evaluation for adaptation are the first step to introduction of new crop in an area and for cultivar development. Research on adaptation of vegetable soybean has been extensively done across the world. Adaptation trials conducted in Australia showed low adaptation due to low water availability, as exotic lines require more water compared to local cultivars of commodity soybean (James, 2007). In North Centre of United States, field evaluation of 136 edamame accessions revealed only 12 promising cultivars for commercial production, and most lines exhibited poor seedling establishment (Williams, 2015). In Uganda, twenty one (21) genotypes evaluated in six (06) locations during 2 seasons, revealed that genotype "G10427" is the most adaptable to agro-ecological areas of Uganda (Tsindi et al., 2019). This shows that edamame has a generally poor adaptation in areas where new varieties are being introduced. Hence, it is necessary to conduct evaluation trials to identify adapted varieties prior to search for traits requiring improvement.

Both morphological and molecular tools have been used to assess diversity among edamame cultivars. Agro-morphological characterization of 150 soybean lines, including 136 vegetable soybean accessions was conducted for 3 years in the North-Center USA (Williams, 2015). It was reported that seedling growth, development and green harvest time of vegetable soybean varieties were faster than those of grain soybean lines. Besides, days to R6 ranged from 77 to 93 days after sowing (DAS) in vegetable soybean lines and from 87 to 112 DAS in grain-type varieties. Variations were also observed between 100-seeds weight of vegetable soybeans (23 g – 25 g) which were greater than commodity soybeans (14 g – 15 g). In India, similar research conducted with 12 soybean varieties including 10 edamame genotypes, showed variations for pod filling period, 62 to 72 days in vegetable soybean versus 70 to 73 days in grain soybean (Ramya and Mummigatti, 2015). The authors also found green seed weight of vegetable soybean lines (44.2 g) greater than those of grain soybean accessions (19.2 g). While agro-morphological assessments of edamame varieties have proven useful in understanding the existing germplasm of edamame, molecular analysis of the varieties is important to confirm variation and help depict the underlying genetic factors of those observed variations. Such a study was carried out in China using microsatellites (SSR) markers on 130 soybean accessions obtained from Japan, China and USA. Lower diversity was observed among the 107 Japanese cultivars compared to the 10 cultivars from China

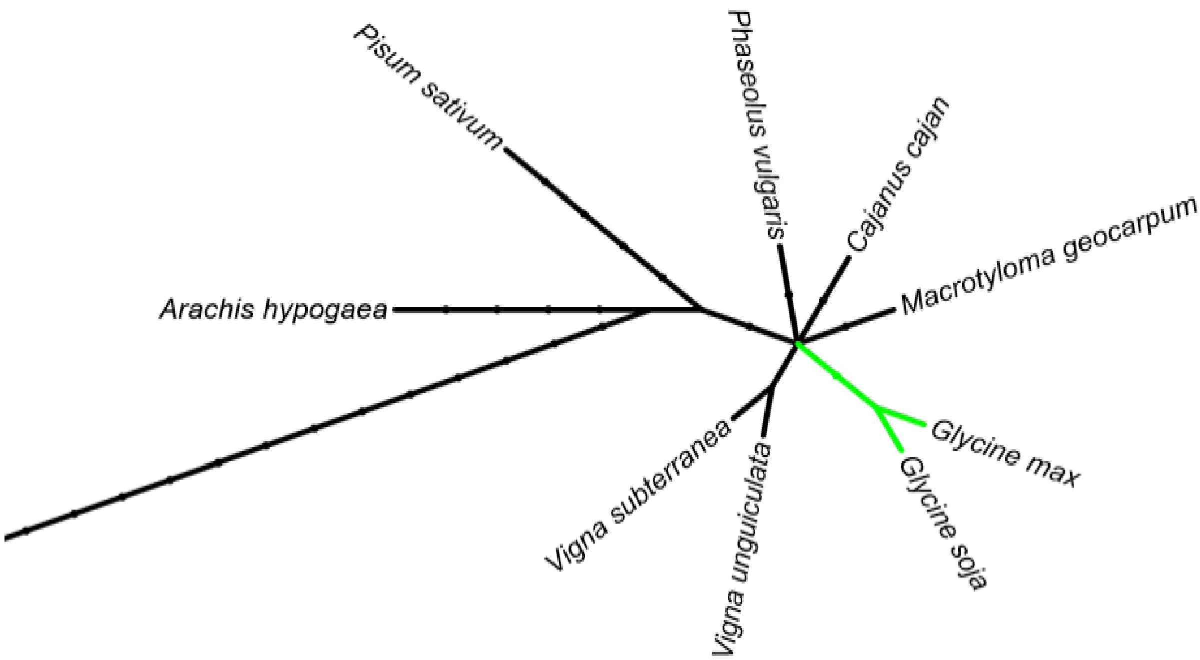

Figure 1. Phylogenetic relationship between soybeans and other tropical legumes (https://itol.embl.de/tree/2131659112773131548664928).

(Mimura et al., 2007). Similar work conducted with 53 SSR markers on hundred edamame accessions, including 77 from breeding companies of China, 13 from AVRDC, 8 from Japan and 2 from Thailand, indicated 11 subgroups based on simple agglomerative hierarchical clustering (UPGMA) method and revealed also that the Chinese cultivars were more diverse than those from the other countries (Dong et al., 2014). So, these cultivars got a broader genetic base and could be useful in breeding programs. Diversity among edamame cultivars also hints a variation in nutritional contents. This was shown at Virginia in the United States, where genetic analysis of nutritional contents performed with 86 edamame genotypes showed significant genotypic differences for protein, starch, oil, dietary fiber, stachyose, sucrose and total sugar content among cultivars (Jiang et al., 2018). These authors' findings are indication that, there is potential to select edamame for nutritional traits having great insights to consumers' preferences.

Consumers' preference and sensorial quality

Quality traits and consumers' preference based on sensory attributes have been reported in the major countries where edamame is produced. Authors have identified the most important quality traits for consumers in Australia as large seed size, high sugar content and bright green color (Nguyen, 1998; James, 2005). Researchers at Ohio State University in USA have highlighted a gender dimension in differential consumers' preference. It was pointed out that preference for the taste of bean vary between women and men (Wszelaki et al., 2005). It was also shown that chewiness and sweetness are discriminating quality traits for edamame varieties. Consumers in Quebec (Canada) reported the sweetest taste for "Beer Friend" and "Early Hakucho" varieties (Leblanc et al., 2014). At Ohio State (USA), the variety "Sayamusume" was preferred for its taste and texture while "Kenko" had the most preferred pod appearance and sweetness (Wszelaki et al., 2005). Variety "Sayamusume" was also appreciated for its large seeds at North Dakota (Duppong and Hatterman-Valenti, 2005). Other preferred quality attributes include green bright color of pods and the large seeds with high sugar content in Australia (James, 2007). In India, variety "AGS 406" was preferred because of its good pod appearance and the highest score for pod texture (lack of pubescence), pod color, seed color and seed appearance (Esler, 2011). The brightness of green pods, the sweet and savory taste and the nutritional contents of seeds are other major quality traits (Zeipiņa et al., 2017). Consumers generally dislike the "beany" taste of edamame. As solution to that, researchers at World Vegetable Center suggested the development of varieties with the aroma of fragrant rice expressed by the variety "dadachamame" (Shanmugasundaram and Yan, 2004). Some traits like astringency, bitterness and off-flavors caused by saponins and isoflavins, are found unacceptable by some target consumers in Africa and south Asia (Esler, 2011). However, the application of fertilizers such as N-P-K in 30-80-38 kg/ha formulation together with 10 t/ha chicken manure has been reported to improve the flavor, sweetness and seeds size of edamame (Zeipiņa et al., 2017). Moreover, it was demonstrated that high concentrations of compounds such as glutamic acid, sucrose and alanine enhance flavor in boiled edamame as well as its nutritional contents (Mausda, 1991).

These preferences associated with the qualities may be appreciated differently by various consumers, thereby showing the importance of taking account not only of organoleptic traits, but also nutritive components, during the introduction of a new food crop.

Nutritional content and health benefits

Many authors have assessed nutritional quality of edamame. They mainly focused on macronutrients, micronutrients, antioxidants and isoflavones, with some emphasis on anti-nutrients. For instance, Carson et al. (2011) analyzed five edamame cultivars for protein and lipid contents in Virginia State and reported that the cultivars “Midori Giant”, “BeSweet 292” and “BeSweet2001” had high protein contents (36-38%) and low fat contents (13-15%). In India, Jadhav et al. (2018) evaluated 30 soybean genotypes (12 edamame types, 4 mutants and 14 grain soybean cultivars) for nutritional contents. The authors observed ranges of 33.01 to 42.13% for protein, 17.07 to 20.87% for oil and 19.19 to 38.52% for sugar content. These authors ranked the tested cultivars and found “Karune” vegetable type from Bangalore, the mutant “AMS 353” and “Swarna” vegetable type from AVRDC having the highest contents of protein, oil and sugar, in that order. Therefore, these varieties could be useful to feed children in developing world lacking protein in their diets. Additionally, Takahashi and Ohyama (2011) presented in Japan a detailed nutritional content of edamame in comparison with grain soybean, snap peas and green peas. It appears that edamame contains more protein (41.3%) than soybean (35.3%). The same trend was observed in vitamins content, especially for vitamin A between edamame (77.1 µg/100 g) and soybean (1.14 µg/100 g). As for micronutrients, raw edamame has higher iron content (2.7 mg/100 g) than green peas (0.6 - 1.7 mg/100 g), as well as other minerals like zinc, potassium, calcium, magnesium, phosphorus, copper and manganese (Table 1). Therefore, edamame types are more nutritious than grain soybeans and both peas.

Cooking mode of edamame seems to influence bioavailability of micronutrients. Mentreddy et al. (2002) reported that fast cooking ability could reduce flatulence in human and enable doubling bioavailability of iron in edamame. Increase of iron bioavailability after cooking was observed for twenty vegetables including vegetable soybean for which, this content raised from 4 to 9% (Chadha and Oluoch, 2004). Besides, the highest iron (15.72 mg/100 g) was reported at R6 stage for genotype “TAMS-38” and the highest zinc content (5 mg/100) was also found at R6 stage in variety “AMS-73” (Jadhav et al., 2018). Therefore, frequent consumption of fresh edamame can reduce health problems, especially stunting caused by iron and zinc deficiency in diets of SSA children and women of reproductive age (Luo and Xie, 2012), because they have been reported as the most deficient nutrients in diets of SSA countries (Fry, 2018). It would therefore be important to improve iron and zinc contents and their bioavailability in vegetable soybean (Anoma et al., 2014; Akande et al., 2018).

Regarding health benefits of edamame, high isoflavones content and high antioxidant capacity have been reported for some varieties. Isoflavones are phytoestrogens known to prevent prostate, cancer, menauposal symptoms and to raise up good cholesterol rate for the prevention of cardio-vascular diseases (Magee et al., 2012; Carson et al., 2012). Castoldi et al. (2011) reported high isoflavones content (92.62 mg/100 g) in cultivar “JLM024” and low content (22.67 mg/100 g) in cultivar “JLM004” evaluated in Brazil. A high content of isoflavones detected in “Midori Giant” and high antioxidant capacity reported in both cultivars “BeSweet2001” and “BeSweet2015” are indications that vegetable soybean has potential to solve health issues due to food deficiency (Carson et al., 2012). In contrast, some anti-nutrients like phytates, saponins, trypsin inhibitor and lipoxygenase can be found in vegetable soybean. Their high contents in edamame are indicated to be responsible for sour or bitter flavor, decreasing edamame quality (Mentreddy et al., 2002). In a study conducted in Brazil, genotype “JLM030” exhibited low trypsin inhibitor content (13.9 mg/100 g) (Castoldi et al., 2011). Therefore, this variety could be chosen as parent for the development of progenies with lower trypsin inhibitor useful for increasing the bioavailability of micronutrients in vegetable soybean. Cultivars “PI 203399” and “Sooty” screened in Virginia State, exhibited low lipoxygenase activity (Mohamed and Rangappa, 1992). Hence, these varieties would have a better flavor compared to other high yielding varieties.

Yield and yield components

Yield and yield components have also been tackled by research in edamame. In general, the reported yields of edamame ranged from 2 to 5 tons per hectare for fresh seeds and 7 to 12 tons per ha for fresh pods with about 72% of water content (Takahashi and Ohyama, 2011). Between 1997 and 2003, researchers at AVRDC evaluated some lines in Africa and showed that varieties “AGS 292”, “AGS 339”, “AGS 329” and “AGS 338”

Table 1. Nutrients content of edamame as compared to other legumes vegetable and grain soybeans per 100 g.

Nutrients \ Products	Edamame (Raw)	Snap peas (Raw pod)	Green peas	Soybean (matured)	Edamame (Dry)***	Soybean (Dry)***
Energy (kcal)	**135**	**43**	**93**	**417**	**477**	**475.38**
Water (g)	71.7	86.6	76.5	12.5	0	0
Protein (g)	11.7	2.9	6.9	35.3	41.3	40.242
Lipid (g)	6.2	0.1	0.4	19	21.9	21.66
Carbohydrate (g)	8.8	9.9	15.3	28.2	31	32.148
Ash (g)	1.6	0.5	0.9	5	5.65	5.7
Minerals						
Na (mg)	1	1	1	1	3.53	1.14
K (mg)	590	160	340	1900	2083	2166
Ca (mg)	58	32	23	240	205	273.6
Mg (mg)	62	21	37	220	219	250.8
P (mg)	170	62	120	580	600	661.2
Fe (mg)	2.7	0.6	1.7	9.4	9.53	10.716
Zn (mg)	1.4	0.4	1.2	3.2	4.94	3.648
Cu (mg)	0.41	0.08	0.19	0.98	1.45	1.1172
Mn (mg)	0.71	0.22	0.48	1.9	2.51	2.166
Vitamins						
A (µg)*	22	34	35	1	77.7	1.14
E (mg)	0.8	0.4	0.1	1.8	2.82	2.052
K (µg)	30	33	27	18	106	20.52
B1 (mg)	0.31	0.13	0.39	0.83	1.09	0.9462
B2 (mg)	0.15	0.09	0.16	0.3	0.53	0.342
Niacin (mg)	1.6	0.7	2.7	2.2	5.65	2.508
B6 (mg)	0.15	0.09	0.15	0.53	0.53	0.6042
B12 (µg)	0	0	0	0	0	0
Folic acid, B9 (µg)	320	53	76	230	1130	262.2
Pantotenic acid (mg)	0.53	0.22	0.63	1.52	1.87	1.7328
C (mg)	27	43	19	Tr.**	95.3	0

*Retinol equivalent; Tr** Trace amount; *** Dry weight base.
Source: Takahashi and Ohyama (2011).

outperformed all others and produced more than 7 tons/ha for fresh pods and 3 to 4 tons per hectare for fresh seeds (Chadha and Oluoch, 2004). Similarly in India, Basavaraja et al. (2005) who evaluated ten edamame cultivars, found the fresh seed yield ranging from 2 to 4.9 t/ha. In addition, similar yield range was observed for fresh seed (4.281 tons/hectare) in Uganda for the most adapted vegetable soybean genotype “G10427” (Tsindi et al., 2019). On the contrary, much higher seed yields of 11.12 tons/ha was recorded in Brazil for the cultivar “JLM010” (Castoldi et al., 2011). Carrying out evaluation trials with five edamame varieties in North Dakota (USA), Duppong and Hatterman-Valenti (2005) reported 7 to 11.3 tons of total marketable pod yield, with “Sayamusume”, a famous variety of the Territorial Seeds Company (USA), exhibiting the highest value. In Quebec, eleven edamame varieties were evaluated, giving pod yields as high as 12 tons/ha for varieties “Miodori Giant” and “Envy” (Leblanc et al., 2014). In Virginia State, Carson et al. (2011) reported cultivar “BS2001” yielding 9.108 t/ha of fresh pods. Much higher yield was reported at Stoneville and Mississippi where fresh pods yields ranging between 20.32 and 29.75 t/ha were recorded for cultivars “GardenSoy 01”, “MidoriGiant”, “Garden Soy 21”, “Moon Cake”, and variety “Mojo Green” (Zhang and Kyei-Boahen, 2007).

Factors that influence yields have also been investigated. Plant height, plant population, number of branches/plant, and number of pods/plant, percentage of marketable pods, shelling percentage and fresh biomass have been reported as components of yield for edamame. Arathoon (2015) observed that agronomic traits such as plant height, plant population, number of branches/plant, and number of pods/plant, percentage of marketable pods and shelling percentage, influence positively beans’ yield in edamame production. More recently in the Virginia, an evaluation of 86 soybean breeding lines for yield and agronomic traits revealed significant differences among accessions for plant height, fresh biomass, pods and seeds traits (Jiang et al., 2018). They also found a positive correlation between fresh biomass and seed yield. These traits could be used to breed high yielding genotypes of vegetable soybean.

Breeding research

Breeding activities performed on edamame ranged from inheritance studies through cultivar selection and marker-assisted breeding. For instance, the analysis of combining abilities of ten edamame genotypes of edamame at Virginia State University, using full-diallel mating scheme, showed that both general and specific combining abilities as well as reciprocal variance were significant for plant height, 100-pod weight, pod width, pod length and pod thickness (Mebrahtu and Devine, 2008). These authors found a high association of green-pod yield components of parents and their general combining ability effects. Yield and nutritional traits have high heritability in edamame. In Virginia, Jiang et al. (2018a) evaluated 86 soybean breeding lines for yield and agronomic traits and found high broad sense heritability for fresh 100-seed weight (87.96%) and plant height (79.22%). Similarly, high to medium and stable heritability values were observed for protein (79.39%), oil (74.62%), stachyose (68.73%) and fiber (56.95%) contents in edamame varieties (Jiang et al., 2018). These authors found also a broad sense heritability of sugar content negatively correlated with oil and protein contents in edamame cultivars. In India, plant height, number of marketable pods per plant and green pods weight were indicated as good traits to consider for yield improvement (Sarutayophat, 2012). Li et al. (2013) and Ramya and Mummigatti (2015) reported respectively in China and India that plant height, number of branches, leaf area, photosynthetic activity, chlorophyll content, dry matter accumulation and seed characteristics, are some valuable traits to use for selecting high yielding edamame cultivars. Although few in number, marker-assisted breeding has also been implemented in edamame improvement. In 2006, SSR markers Satt132 and Satt431 were found polymorphic to reveal differences among flowering dates in inbred lines. This enabled speed selection of early flowering cultivars in Thailand (Pooprompan et al., 2006). These results showed that the traits related to the growth, yield and nutritional contents of edamame can be improved by using both conventional and molecular breeding tools for increased production.

PRODUCTION REQUIREMENTS AND GROWING SYSTEMS

The share of vegetable soybeans in world soybean production is very low and represents only 2% of total soybean production (Esler, 2011). The crop grows well in tropical warm climates with temperature ranges of 20 - 30ºC daytime and 10 - 15ºC at night (Cheng, 1991). The crop requires short daytime, sandy loam soil or irrigated loam soil having both a neutral pH (Miles and Sonde, 2002). It has short growth cycle, as it is harvested at R6 stage. Although, night temperatures match more temperate climate than tropical warm climate, edamame can be produced in Sub-Saharan Africa including Benin. In countries where bradyrhizobia *(Bradyrhizobium japonicum*) is not native, the application of 10 g of inoculant per kg of seeds enables boosting nitrogen fixation (Agoyi et al., 2017; Zhang et al., 2017), and thus circumventing nodulation failure. Another way to overcome nodulation failure would be the identification of promiscuous vegetable soybean cultivars, as this would enable achieving high yield without requiring the application of inoculant on seeds prior to sowing (Agoyi et al., 2016, 2017, 2018). Plant density plays a key role in productivity of edamame. Konovsky et al. (1994) reported that high planting density especially a short distance between rows decreases the yield and lead to dark pods. A hand planting of 75 cm between rows for a seeding rate of 200,000 seeds per hectare were identified as suitable to get beans yield ranging from 3.62 to 6.66 tons/ha (Arathoon, 2015). In general, about 40 tons/ha of biomass for 10 to 12 tons of fresh pods are produced 65-75 days after sowing (Shanmugasundaram and Yan, 2004). It has been also reported that edamame can be successfully intercropped with maize and okra (Chadha and Oluoch, 2004), with rice, peanut, tobacco and melon (Tsay et al., 1991) and with pigeonpea, cotton, sorghum, sugarcane and peanut (Esler, 2011). The crop is also used as green manure for mulching more successfully than cowpea and for growing leafy vegetables with fewer constraints of leafy vegetables (Chadha and Oluoch, 2004). Edamame' researchers reported seedling rates and fertilizer rates as ways to influence fresh pods/seeds yields. Assessing the effect of seeding rates on yield of fresh edamame in South Africa, Arathoon (2015) demonstrated that seeding rate of around 200,000 seeds per hectare could be adopted to achieve bean yield of 3.62 tons to 6.66 tons/ha. As for fertilizer rates, Potassium (K) and phosphorus (P) are macro elements that cause significant yield increase in edamame. An incorporation of 30 kg/ha of phosphorus and 80 kg/ha of potassium into the soil before planting were recommended to achieve bean dry matter yield of 2 tons per hectare for the cultivar "Lightning"(Arathoon, 2015). Besides, AVRDC suggested an application of 20-30 kg/ha of Nitrogen (N) and 60 kg/ha of P_2O_5 and 80 kg/ha of K_2O as basal dose to incorporate into the soil (Lal et al., 2001). At flowering stage, 20 kg of N + 25 kg of K_2O per hectare are required during the first side dressing and an additional application of 20 kg of N at the beginning of the stage of pods filling is important for seed size improvement. AVRDC also recommended irrigation at 10-

15 days intervals until the development of pods and especially at flowering and pod filling stages (Lal et al., 2001).

PRODUCTION CONSTRAINTS

Commercialization of edamame requires keeping high quality attributes. Pests and diseases are known to cause significant quality loss. Hence, pests and diseases management are key elements to consider for pods and beans appearance. Some pests have been reported to affect quality of vegetable soybean without reducing significantly the yield, but affect the marketability of pods. The most commonly pests reported in the USA are soybean aphids (Rutledge, 2004), stinkbugs (Hamilton, 2007), leaf hoppers (Williams et al., 2011; Tiroesele et al., 2012), bean leaf beetles (Delate et al., 2003) and defoliating caterpillars (Thrash, 2014). The population of aphids and leafhoppers on the behavior of edamame varieties was separately evaluated in field and laboratory at Minnesota University using 14 edamame varieties, three varieties of aphid susceptible soybean-grain and one variety of aphid resistant soybean-grain (Menger et al., 2018). The trials revealed a higher aphid density on vegetable soybean variety "Hokkaido Black" than on "Agate", "Kuroshinju" and "Chiba green" varieties. Therefore, the latter varieties could be directly used to decrease aphid damages on edamame. or choosen as parents to breed aphid tolerant varieties of vegetable soybean Leafhoppers damages were also reported. Edamame genotypes were more susceptible to potato leafhoppers than grain-type soybean lines, with "Kuroshinju" and "Midori Giant" being the most sensitive among the tested edamame cultivars (Menger et al., 2018). Grain soybean genotypes showed resistant genes useful for vegetable soybean improvement against potato leafhoppers.

There are also field diseases that constrain vegetable soybean production. The main field diseases are root rot and stem canker. A high susceptibility for *Phytophtora* spp*.* causing root rot disease was found in cultivars "C784" and "Bunya" in Australia (James, 2007). Resistant varieties to stem canker have been identified among edamame cultivars. Various resistance traits against *meridionalis* and *caulivora* pathovars *of Diaporthe (Phomopsis) phaseolorum* were found and reported in variety "Kitanosuzu" among thirty vegetable soybean genotypes evaluated in the humid plain of Argentina (Benavidez et al., 2010). Therefore, "Kitanosuzu" variety can serve as parental line to develop stem canker resistant edamame varieties.

In addition to pests and diseases, weeds were also reported as a major constraint in edamame production (Sharma and Kshattry, 2013). Hand weeding and pre-emergence herbicide application are mainly used for weeds control, but hand weeding depends on the availability of casual labor (Esler, 2011) which might lead to higher cost. Zhang et al. (2017) highlighted the need for more research to address this constraint by developing weed tolerant edamame varieties. Besides, labor shortage during harvesting can lead to significant yield loss during edamame production, as non-timely harvesting causes hardening of pods and seeds, leading to the crop failure. This could be solved by using harvesting equipment recommended for big edamame farms (Cheng, 1991).

Interestingly, some of the constraints pointed out above are minor in Sub Saharan Africa. For instance, the need for labor to manage weeds and harvest fresh pods can easily be met with the jobless young people living in urban and peri-urban areas growing vegetables. This is an advantage for edamame production if introduced and adopted in SSA countries.

HARVEST AND POST-HARVEST HANDLING

In edamame production, harvesting occurs around 35-39 days after flowering. During this stage, the green bright and pubescent pod shows light brown or gray hilum and contains 1 to 3 fresh seeds (Zeipiņa et al., 2017). Harvesting is done at night or daytime but keeping the pods with branch at shade, for long freshness and to maintain the sucrose level in pods (Lal et al., 2001). Pods are then removed from branches and stored in polyethylene bags, precooled and preserved at 0ºC to avoid the loss of vitamin C, freshness, hardening and discoloration (Kaiser and Ernst, 2016). Long term storage consists in maintaining pods or beans in frozen form after blanching. The cold storage of fresh beans and pods proved successful in many countries including Australia (James, 2007), United States (Wszelaki et al., 2005; Pao et al., 2008; Carson et al., 2011; Jiang et al., 2018), Taiwan (Shanlnugasundaram et al., 1992), India (Kumar et al., 2011), Thailand (Sarutayophat, 2012), China (Li et al., 2013; Zhang et al., 2017), Argentina (Benavidez et al., 2010) and Latvian (Zeipiņa et al., 2017). Most authors reported on blanching as pre-treatment before cold storage, with various target advantages. Pao et al. (2008) investigated the effect of frozen edamame on its microbiological quality and indicated that blanching treatment at 98°C for about 60 s eliminates yeasts, molds, coliforms as well as infectious species *Escherichia coli* and *Listeria* spp. Moreover, Xu et al. (2012) demonstrated that blanching for 2.5 min or more at 100°C increases the green color intensity of edamame beans, reduces the activities of yeasts, molds, total bacteria and 98% of peroxidase activities, thus alleviating the toxic effect of peroxide accumulation. Steam blanching of fresh pods has also been reported to retain more soluble sugars in edamame than the storage of edamame pods in open air at 25°C for 8 to 12 days found to be responsible for quick decrease in sucrose content

Table 2. Distribution of AVRDC' edamame varieties in Africa.

Countries	Number of lines distributed
Mauritania	30
Tanzania	71
South Africa	42
Zambia	15
Ghana	15
Zimbabwe	20
Ethiopia	17
Uganda	28
Swaziland	15
Congo	15
Lesotho	2
Kenya	4
Mozambique	4
Senegal	10
Botswana	15
Liberia	10
Chad	15
Togo	10
R.D Congo	4
SaoTome'e Principe	8
Mali	6
Angola	6
Somalia	2
Sudan	4
Malawi	4
Namibia	4

Source: Chadha and Oluoch (2004).

causing the loss of sweet taste (Saldivar et al., 2010; Mozzoni et al., 2009). The use of infrared rays heating is another advanced storage technology for dehydrating and blanching of edamame at 11.06 kW/m^2 for hundred seconds or 2 min, indicating not only to reduce pods hardness and weight (9.5%), but also to improve green color and texture of pods (Lara et al., 2019), for a more profitable market. About post-harvest handling in SSA, as edamame production will begin around urban areas, the pods will be directly sold to consumers in gardens or via vegetables resellers who are used to conserve fresh garden crops like common bean and cabbages in open air. In case of commercial production, the cold storage must also be envisaged for edamame transportation to distant areas where it is not produced yet.

SEED MARKETS, INTRODUCTION AND DISTRIBUTION

Seed markets for edamame are well developed in countries where edamame is adopted and well consumed. Many private and public organizations put interest in the crop and seeds of superior varieties are nicely packed and marketed. In Netherlands, "DutchSoy" representing "Europe Soya" organization is producing and promoting organic edamame with many soybean varieties. In addition to selling planting seeds, the company provides farmers with technical assistance. The firm conducts field trials and research to develop technologies, to supply quality seeds to producers and to provide them with advice on various aspects of non- Genetically Modified edamame production. It also assists them with market strategies and distributes rhizobia to them (Strijk, 2019). In the United Kingdom, commercial production for local market takes place and this has significantly reduced the import needs from Thailand and Taiwan (Shanmugasundaram, 2004). The production of commercial quantities of edamame has been reported in Argentina, Mongolia, New Zealand, and Italia. Other countries like France, Germany, Chile and Britain grow vegetable soybean in home gardens (Konovsky et al., 1994). Vegetable soybean has recently been introduced at Latvia (Zeipiņa et al., 2017). Part of the edamame consumed in Japan and United States is imported from China, Taiwan and Thailand (Keatinge et al., 2011). In Africa, AVRDC has distributed edamame cultivars to about ten thousand smallholder farmers in 26 African countries for trials, utilization and varietal development (Table 2). In Zambia, nutrition kits composed of edamame seeds were distributed to farmers and the initiative was successful as most beneficiary farmers adopted edamame as new crop (Chadha and Oluoch, 2004). In Sudan, about 2,000 households received and grew edamame seeds which were shared with other fellow farmers. Similar case was observed by these authors in Tanzania, where edamame seeds have been distributed to over 2,500 farmers for testing and its utilization was liked. Vegetable soybean has contributed to income generation for farmers in Mauritania. The crop is widely grown and fresh pods are sold at about 2 USD/kg (Chadha and Oluoch, 2004). Some of the 22 others African countries involved in the programme, include Ghana, Senegal, Mali and Togo in West Africa (Table 2). Some African countries like South Africa have adopted vegetable soybean production and agronomic studies of edamame have been reported recently in Kwazulu-Natal (Arathoon, 2015). Seed Company Ltd, an African seed company released one edamame variety in Zimbabwe and is being marketed although the uptake is low. Therefore, more awareness on beneficial effects of edamame production and utilization need to be initiated, especially in countries where no action has been undertaken to introduce and promote edamame.

PERSPECTIVES OF VEGETABLE SOYBEAN ADOPTION IN SUB-SAHARAN AFRICA

Edamame production and utilization show many advantages and have potential to make significant

Table 3. SWOT matrix associated with vegetable soybean potentials in sub-Saharan Africa.

Strength	Weakness
- Favorable growing areas in SSA countries. - Short life cycle and nitrogen fixation. - Few damages of pests and diseases on vegetable soybean seeds yield. - Consumption: Less cooking time, used in various diets (snacks, salads, soups, stews mixed with cereals…). - Nutritious diets for SSA people: Good levels of proteins, carbohydrates; contains few fats and provides ash, fiber, micronutrients and vitamins. - Introduction in Africa: Distribution of lines to 26 sub-Saharan Africa. - Possibility for easy access to germplasm for research with AVRDC, NARO and private Companies (Seeds-Savers-Exchange).	- Little research on the crop in Africa. - Lack of adapted varieties and local seed system for edamame. - Presence of oligosaccharides causing flatulence in human. - Cost of irrigation system for smallholder gardeners. - Imported seeds cost to guarantee a good germplasm each growing season. - Needs of post-harvest logistics.
Opportunity	**Threat**
- High yield potential - Improvement of soil fertility. - Good for intercropping and rotation. - Markets access: local sales in gardens and markets like other vegetables. - Job opportunity for young. - Possibility of exportation. -Improvement of African farmers' income.	- Land pressure especially in suburban areas. - Flooding or drought risks in lowlands. - Development of new pests associated to climate change effects. - High labor cost for production in urban and peri-urban areas.

contribution to food security in Sub-Saharan Africa. The crop is easy to grow and Africa's agro-ecological conditions are favorable for its production. Besides, edamame is suitable for intercropping and rotation systems. Due to its short cycle, edamame can be grown at least 4 times a year if water is available and well managed. This would make it a cash crop with quick return for households. Moreover, biomass debris can provide organic matter which increase natural nitrogen for the improvement of soil fertility. The possibility of obtaining germplasm from International Institutes may act as a motivation for edamame production and trigger research on interesting traits and development of seed systems for farmers in Sub-Saharan Africa (Table 3). As solution to fewer interests in production and consumption of edamame in sub-Saharan Africa, participative research work must be implemented, starting from evaluation for yield adaptation and stability, consumers' preferences and sensorial qualities to nutritional contents improvement. Initiatives to promote the crop in SSA countries may also include farmer's field schools that will involve all stakeholders to demonstrate and increase awareness for an effective and efficient use of the technology.

CONCLUSION

This review showed that edamame is well known in many countries across the world, however, the crop has not been thoroughly researched everywhere. East Asia and North America are the top regions where research on edamame has advanced the most. In Sub-Saharan Africa, edamame is still not well known and underutilized, despite the great potential of the crop. This potential illustrated in the SWOT matrix shows the strengths for its production, the opportunity to promote edamame in Africa and the job opportunity this will provide, contributing to reduced youth unemployment. Research gaps observed in Sub-Sahara Africa, especially research needs on adapted varieties and lack of facilities that would help avoid relying on rain-fed edamame production could hinder its introduction in some areas. Interestingly, other constraints that limit edamame production elsewhere in the world are minor in Africa. For instance, urban and peri-urban areas hold enough and cheap labor to effectively handle hand weeding and timely harvesting of edamame.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests

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Full Length Research Paper

Management and the influence of socioeconomic factors on tree species diversity in traditional agroforestry practices in Demba Goffa District, South Ethiopia

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The study was designed to provide a baseline data on status of woody species diversity, local knowledge in use and the influence of socioeconomic factors. Interview and discussion with key informants and formal survey with structured questionnaires were employed to collect primary data. The assessment of tree species richness was done by inventorying trees at the sampled plots of the different agroforestry practices within three social classes. Secondary data were collected from various sources. Data were analyzed by using SPSS 13.0 computer program. The result indicated that most farmers preferred planting trees around homesteads, woodlots and boundaries. The type of trees planted were those meant for fuel wood, construction and improvement of soil. Wealthy farmers maintained more number of trees than medium. The highest proportion of tree stems/ha was found in boundary plantation followed by woodlots. *Terminalia brownii*, *Moringa stenopetala*, *Eucalyptus* species and *Cordia africana* were widely maintained. Tree species richness was significantly correlated to farm size. Smaller farm size and limitation of knowledge were the major constraints to manage tree species. It can be concluded that local knowledge in use, wealth status, experiences, resources and needs of farmers were must to be considered to promote agroforestry technologies.

Key words: Constraint, management practices, socioeconomic factors, tree species, wealth status.

INTRODUCTION

As world population increases, the need for more productive and sustainable use of the land becomes more urgent. World's concern is to find alternative agricultural systems that are ecologically sustainable, economically feasible and culturally acceptable to local communities. Agroforestry is a land use systems which deals with the integration of trees on farms and in the agricultural landscape that diversifies and sustains production for increased social, economic and environmental benefits of all land users at all levels (Abiot and Gonfa, 2015; FAO, 2015, 2017; Steven, 2019).

The multiplicity of agroforestry products and services which necessitated different management strategies by various social classes in part of traditional land use systems have the role in sustaining crop production, biophysical environment, livelihood and the household

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economy (FAO, 2015; Nair, 2014). In all these land use systems, trees have the dominant role to play a sustainable agriculture and environmental protections (Melese and Abay, 2017).

To gain these roles, land users have been practicing homegardens, woodlots, boundary plantations, coffee shade trees and parkland trees in their agricultural lands (FAO, 2015; Nair, 2014). However, inappropriate land use practices, farm size, commercialization, poor market access, wealth status, access to natural resources, management skills, gender differences and extent of reliance on off-farm income brought a rapid decline in tree cover and loss of biological diversity (FAO, 2015, 2017; Jacobson and Shiba, 2014).

Though the contribution of traditional agroforestry practices is high in the study area, farmers are lacking information on tree/shrub species diversity management and major socioeconomic factors that influence their management under various social and economic settings. Therefore, this study was designed to provide a baseline data that enhance land users knowledge on traditional management and tree diversity changes in traditional agroforestry practices with a particular emphasis on status of woody species diversity and their uses, local knowledge in use and the influence of socioeconomic factors on tree diversity management.

MATERIALS AND METHODS

Description of the study area

The study was conducted in Demba Goffa District, Gamo Gofa Zone of South Ethiopia. Geographically, it is located between 8° 11' 21" to 8° 71' 84" N latitude and 42° 19' 35" to 43° 89' 86" E longitude with altitudinal range of 1350 to 2600 m. a. s. l. Demba Gofa is located at a distance of 258 km from Arba Minch, 284 km from Hawassa and 516 km from Addis Ababa (Figure 1). The district has 102,807 ha of land area coverage with 38 Peasant Associations. Total populations is 103,837 (F = 52,270) with total household of 23,149 and person/house hold ratio is 4.5. The district includes highland (7.8%), midland (15.8%) and lowland (76.4%) agroecological Zones. The daily mean minimum and maximum temperature is 17.4 and 28.4°C while the mean annual temperature is 23°C and rainfall is 1300 mm. The rainfall is dispersed throughout the year into two rainy seasons called *belg (*March-May) and *meher (*July-November) with small showers in February. The maximum rainfall is in April and October. Mixed crop-livestock production system is the major economic activity in which teff, maize and sweet potato are the main crops grown as well as oxen, cows, donkeys and shoat are the major animals reared.

Research methods

The sampling procedures include two data collection components: household survey and tree assessment at three Peasant Associations (which is the lowest administrative unit).

Peasant association and household selections methods

The purposive sampling procedures were used to select the Peasant Associations (PAs). The sampling procedures focused on the existence of similar traditional agroforestry practices. Accordingly, *Lote, Gaila, Chalbie, Borda* and *Uba Pizigo* PAs were selected. Within each PA, two villages with the similar agroforestry features were also identified.

To categorize the selected households into wealth classes, six key informants (ordinary farmers who are knowledgeable and experienced about the area) were selected by using snowball method (Nirmalya et al., 2017). Wealth ranking were used to characterize the households at each village in to poor, medium and rich. The criteria used to classify farmers to wealth classes were farm size, number of oxen, cows, shoats and the other income sources. The names of each household (HH) heads in the village were written down on a card and key informants grouped them in to three wealth classes. From each social category, 10% of HHs were selected randomly and totaled as poor (43), medium (30), and rich (17).

Tree species sampling

On selected farms, inventory was restricted to trees/shrubs species in homegardens, woodlots, parklands and farm boundaries. Counting and assessing the distributions of trees/shrub species on sampled plots of those agroforestry practices were used to estimate species richness. At farm level, the total areas of different agroforestry practices were estimated. For each practice, different species of trees/shrubs were counted and recorded. The proportion of trees/shrubs species were estimated by making sample counts on systematically selected quadrats or rows and extrapolated to the area it covered. The sample size of home gardens 10 m × 10 m (100 m^2), woodlots 10 m × 10 m (10% of the total area), parklands complete count made on 40 m × 30 m and farm boundary (10% of the total length).

Data collection methods

Household questionnaires at household level and tree species assessment at farm level were used to collect data. The botanical names of the trees/shrubs were identified by researcher himself, using tree identification manual and agroforestry data base. Secondary data was obtained from the recent reports, documented and other on line sources.

Data analysis

Quantitative data was analyzed by using Statistical Package for Social Sciences. The influence of socioeconomic factors on richness of tree species was compared by using Pearson's correlation coefficient. Variation in composition of the tree species was calculated by using Sorenson's Similarity index (Abiot and Gonfa, 2015).

RESULTS AND DISCUSSION

Traditional agroforestry practices and woody species richness

Tree species richness

The highest tree species richness was maintained at homegardens and boundary plantations followed by woodlots and parkland. The mean tree stems per

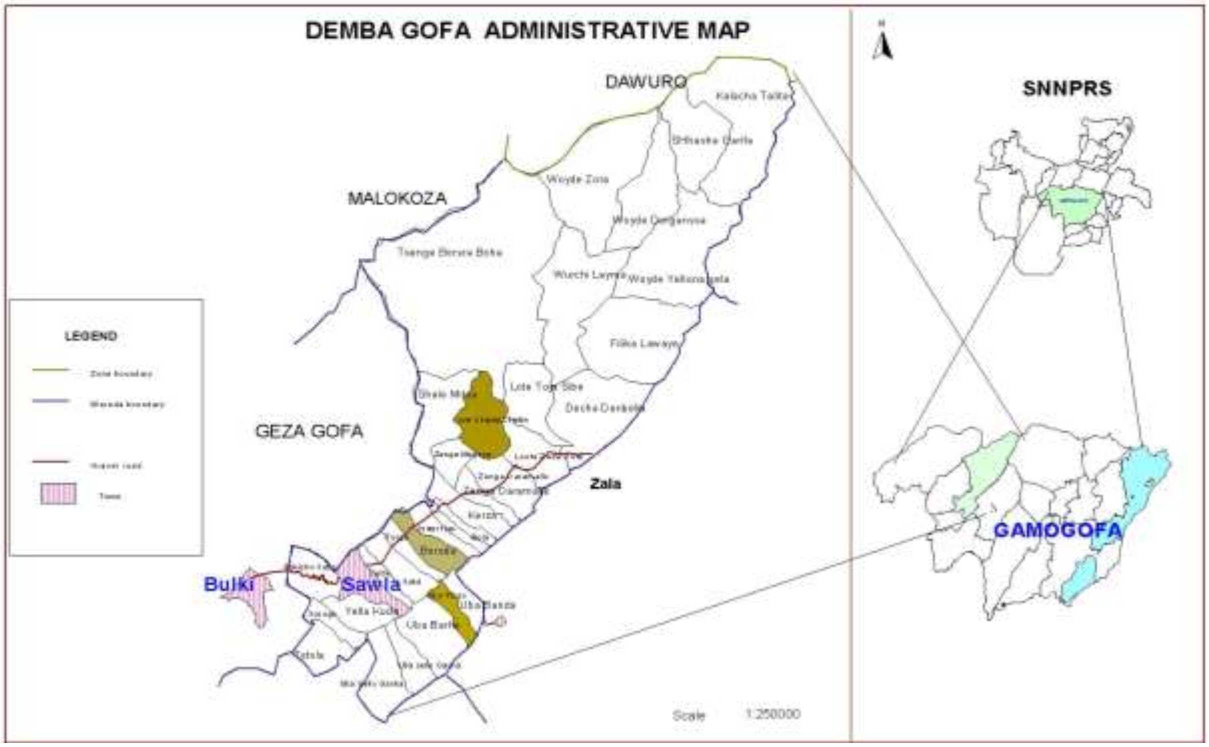

Figure 1. Map showing the location of Demba Goffa District and the research sites.
Source: BoFED (2012).

Table 1. Mean number of tree species recorded on major fields of sampled plots of different agroforestry practices and wealth categories in all villages.

Study village	Major Agroforestry practices, wealth category and tree species richness											
	Home gardens			Woodlots			Boundary planting			Parkland		
	P	M	R	P	M	R	P	M	R	P	M	R
Gaila	4.6	4.2	4.5	3.7	2.3	3.0	3.8	4.1	4.8	2.0	1.3	2.0
Chalbie	3.0	4.6	5.1	3.0	3.3	3.0	4.6	4.0	4.5	1.7	2.0	1.3
M/Gojjo	3.4	3.8	3.8	2.1	2.7	2.7	2.4	3.1	3.0	1.3	1.7	1.3
Anno	3.3	4.1	4.6	2.8	2.3	3.0	1.9	3.0	4.4	1.3	1.7	1.7
S/Tsala	3.5	4.4	4.8	2.7	3.3	3.0	2.1	3.6	3.9	1.1	2.0	2.0
Damara	3.1	4.3	4.6	2.4	2.7	2.7	3.6	3.9	4.2	1.1	2.3	1.7
Grand mean	3.8	4.2	4.6	2.8	2.7	2.9	3.1	3.6	4.1	1.4	1.8	1.7

P = poor, M = medium, R = rich.

sampled plots of the all wealth categories are compared; values were 2.8, 3.1 and 3.3 for poor, medium and rich, respectively (Table 1). The number of tree stems per farm increase with size of the farm land. As well, access to the labor and management also increases the richness of the trees species. Farm size, labor access, knowledge of tree management and preference of farmers are key factors which maintain high tree species diversity. There are other studies supporting similar trend, for example, Abiot and Gonfa (2015) in Dellomenna District of Southeastern Ethiopia, reported that well organized irrigation activities, planting pattern, site characteristics, management strategy, socioeconomic factors and farmers' preferences for the tree use increase the tree species diversity.

Stem numbers

The highest mean number of the tree stems per ha was

Table 2. Mean n^{o} of stems/ha on sampled farms at all villages and Agroforestry practices.

Village	Homegardens	Woodlots	Boundary plantations	Parkland	Over all mean
Gaila	660±105	5541±845	19400±1249	20.6±9.3	6405±552
Chalbie	720±324	5139±593	19400±2600	23.5±6.2	6320±881
M/Gojjo	607±266	5319±850	18133±2928	20.2±6.3	6019±1012
Anno	620±215	5708±220	21133±4759	26.9±9.7	6871±1301
S/Tsala	493±175	5222±937	17200±2497	24.7±10.1	5735±905
Damara	480±213	4722±924	15667±2914	28.2±12.2	5224±1015
Mean	579±216	5275±728	18488±2825	24.0±9.0	-

Table 3. The values of Sorenson's Similarity Index for all pair of locations.

Village	Gaila	Chalbie	M/Gojjo	Anno	S/Tsala	Damara
Gaila		0.76	0.81	0.92	0.79	0.82
Chalbie			0.89	0.86	0.81	0.88
M/Gojjo				0.82	0.70	0.79
Anno					0.75	0.88
S/Tsala						0.77
Damara						

The value of the Sorenson's similarity index ranges from 0-1. A value of 0 means the two villages are not similar in composition of species and 1 means species is shared among the villages.

recorded in order of Anno > Gaila > Chalbie villages while the highest number of stems per ha were found in the farms of rich and followed by medium and poor (Table 2). Similarity, the values of number of stems recorded at agroforestry practices was in the order of boundary > woodlot > homegardens > parkland. This might be due to the farmers' preference and land allocation for those practices within different social classes. Farmers with large farm size can plant/maintain more trees/shrubs than those with less farm size.

Sorensen's similarity index

The similarity of tree/shrub species maintained was summarized by Sorenson's Similarity Index (Table 3). Based on the presence or absence of tree species in the sampled plots, the highest similarity in tree species composition was maintained between Gaila and Anno villages while the lowest species similarity was recorded between M/Gojo and S/Tsala villages. The result indicated that the majority of tree species are common to all sites but differences exist in the distribution of less common species.

Use diversity of trees

The tree/shrub species identified in all villages are used for a wide range of purposes. Among the many uses, seven major uses of the trees/shrubs in all villages have been identified (Table 4). The major uses of trees/shrubs are fuel wood, construction materials, fodder values, timber, and food and soil fertility improvement. Similarly, respondents agreed that trees are also used for shade, fodder, medicine, windbreak, fences and recreations. Five exotic fruit tree species and 15 timber tree species were identified to be used for income generation. To supplement the basic roles of trees, farmers retained a few species of native trees, which they considered most important, fast growing, requires low input are left in the farm. This is in line with the report of FAO (2015, 2017) and Nair (2014).

The effect of socioeconomic factors on tee species richness

Woody species richness is positively and significantly ($p<0.01$) correlated with farm size but negatively and significantly ($P<0.01$) correlated with number of livestock and engagement in off-farm activities ($P<0.05$) of the household heads (Table 5). Tree species richness was affected by mainly farm size. Farmers with larger land holding maintained or planted more tree species on their farms. Similarly, the result of Jacobson and Shiba, (2014) indicated the larger farms have more tree species richness. The negative correlation of off-farm activities and woody species richness is supported by the results of Melese and Abay (2017).

Table 4. The use diversity of inventoried trees and shrub species at study villages (n=26).

No	Use types	Village and tree species used in (%)						
		Gaila (n=19)	Chalbie (n=23)	M/Gojjo (n=18)	Anno (n=21)	S/Tsala (n=19)	Damara (n=20)	Mean (n=26)
1	Fuel wood	78.9	78.3	77.8	76.2	84.2	70.0	77.6
2	Constructions	73.7	65.2	66.7	71.4	73.7	60.0	68.5
3	Fodder/forage	63.2	52.2	66.7	57.1	63.2	60.0	60.4
4	Timber	57.9	60.9	55.6	57.1	57.9	60.0	58.2
5	Food/fruits	62.6	47.8	55.6	57.1	52.6	55.0	55.1
6	Maintenance of soil fertility	63.2	33.3	40.0	61.9	53.3	55.0	51.1
7	Medicinal values	50.0	46.7	40.0	47.6	33.3	40.0	42.9

n= Number of species identified in each villages.

Table 5. Pearson's correlation coefficients for the effect of selected socioeconomic factors on tree species richness.

Socioeconomic variable	Pearson's correlation
Farm size	0.993**
Family size	0.030
Educational status (>Second cycle)	0.216
Off-farm activities	-0.480*
Number of livestock owned	-0.810**

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

Table 6. Number of respondents (%) mentioning types of tree management practices employed in the study sites.

Study village	Tree management practices					Overall mean
	Pruning	Thinning	Coppicing	Pollarding	Lopping	
Gaila (n=16)	93.8	75.0	81.0	50.0	50.0	70.0
Chalbie (n=15)	73.0	66.7	73.0	66.7	60.0	67.9
M/Gojjo (n=15)	66.7	6.70	13.3	26.7	26.7	28.0
Anno (n=14)	50.0	21.4	42.9	7.10	21.4	28.6
S/Tsala (n=15)	13.3	6.70	13.3	80.0	60.0	34.7
Damara (n=15)	40.0	6.70	13.3	40.0	20.0	24.0
Mean	56.1	30.5	39.5	45.1	39.7	-

n= Number of respondents in each villages.

Indigenous knowledge for agroforestry management

Tree management practices

Different tree management practices are exercised by farmers in the study areas. Among these management practices, commonly used are pruning (56.1%), coppicing (39.3%), and pollarding (45.1%) which help farmers to attain sustainable use of trees/shrubs in any agroforestry systems (Table 6). Farmers commonly prune *Terminalia brownii* (97%)*, Cordia africana* (65.2), *Acacia polyacantha* (53%), *Ficus sycomorus (*42.3%) and *Grevellea robusta* (19.6%) to produce tree products (Table 6). This result indicated that pruning and pollarding are more proffered not only to permit a sustained yield of wood over a long period but also minimizes the competition among the components in the system. Similarly, Norainiratna et al. (2016) stated that proper pruning maintains trees' health and structure provide safe environment and enhance aesthetic values.

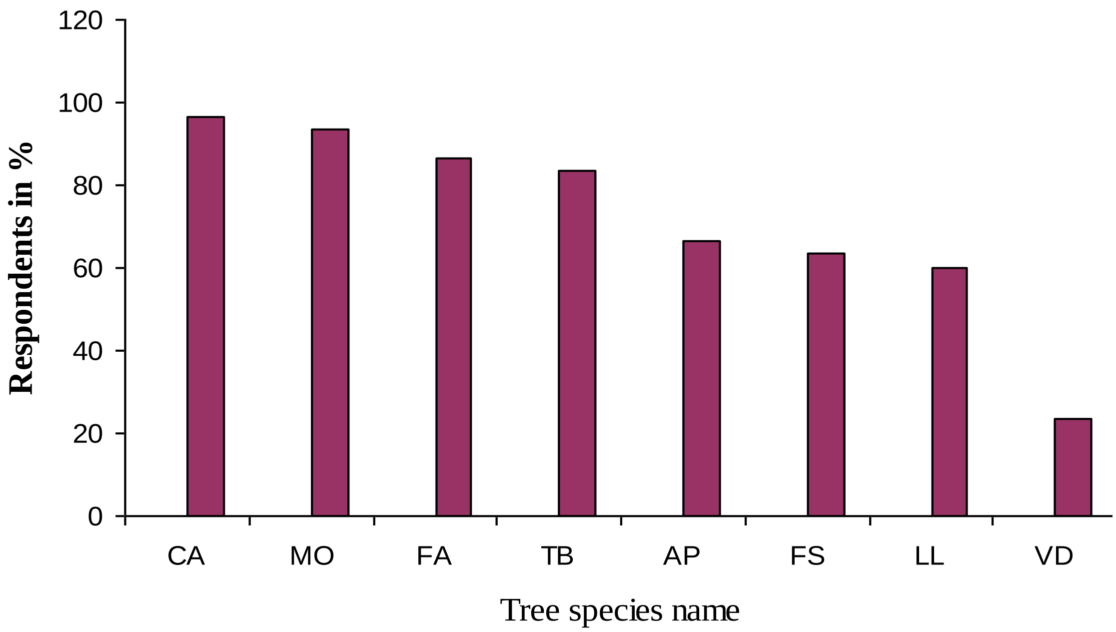

Figure 2. Number of respondents mentioning trees/shrub species preferred for improving soil fertility or agricultural crop yields (N=90). CA=*Cordia africana,* MO=*Moringa stenpetala,* FA=*Faidherbia albida,* TB=*Terminalia brownii,* AP=*Acacia polyacantha,* FS= *Ficus sycomorus,* LL=*Leuceana leucocephalla,* VD= *Vittex doniana*.
Source: Current research data.

Table 7. Number of respondents (%) who mentioned that major constraints to manage tree diversity in the study area.

Major constraint	Number of respondents (%)					
	Gaila (n=16)	**Chalbie (n=15)**	**M/Gojjo (n=15)**	**Anno (n=14)**	**S/Tsala (n=15)**	**Damara (n=15)**
Shortage of farm size	100	100	100	100	100	100
Lack of knowledge	87.5	86.6	73.3	64.3	86.6	86.6
Forest conservation ignorance	60.0	66.7	86.6	85.7	80.0	80.0
Shortage of seed sources	66.7	80.0	80.0	78.5	66.7	66.7
Shortage of labor	81.3	53.3	53.3	50.0	26.7	53.3
Lack of market access	62.5	56.3	26.7	42.9	53.3	56.3
Unsecured land use rights	31.3	26.7	46.7	21.4	46.7	46.7

Soil fertility management

According to the key informants, the soil is exhausted and does not give much production; this view was verified by all respondents. To overcome soil fertility problem, farmers have a remarkable knowledge and strategies of selecting tree species for soil fertility management. As to the key informants and respondents, trees with huge leafy biomass, easily decomposable, thorniness and fast growing are more preferred (Figure 2). Similarly, they stated that *Eucalyptus* species have both adverse and beneficial effects. Concerning the adverse effects, all respondents agreed only when planted near to the agricultural crops, on grazing and degraded lands. On the other hand, *Eucalyptus* spp. are sources for income generation and construction materials when planted on woodlots or plantations on selected farmlands. To maximize the beneficial effects and minimize the adverse effects of *Eucalyptus* spp., farmers use their own knowledge of management. The result of this study indicated that the existence of remarkable knowledge for managing and enhancing soil fertility. The present result is inconsistent with the study made by Madalcho and Tefera (2016) who reported the role of farmers' knowledge on soil fertility management in Wolayta Zone, Ethiopia.

Factors affecting tree management practices

Although farmers plant trees, maintain tree diversity and manage them for a wide range of uses, there is a trend of decrease in woody species diversity in the area. Shortage of farmland, lack of knowledge, seed sources, market access, and the ownership right of trees are the main challenges encountered in managing tree diversity (Table 7). This is in line with reports of Jacobson and Shiba, (2014), FAO (2015) and Rahman et al. (2017). They stated that market and resource access, management skills, insecured land tenure, poor extension services and extent of farmers' knowledge limits the willingness of farmers to maintain tree diversity.

Conclusions

The results of the present study confirm that traditional agroforestry practices play a major role in the conservation of tree/shrub species cover and use diversity. However, major socioeconomic factors such as farm size, practical management skill, access to resources and ignorance of conservation role brought a rapid decline in tree species cover and use.

RECOMMENDATIONS

To ensure sustainable uses of trees/shrubs species and their diversity, creating awareness at grass root level about wise utilization of tree/shrub species, practical management skills, and linking agroforestry technologies with current extension programs and indigenous knowledge in use are crucial to prevent the loss of tree/shrub species. The government, non-government and private sectors should promote tree/shrub species conservation through different agroforestry practices.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Screening of tree seedling survival rate under field condition in Tanqua Abergelle and Weri-Leke Wereda's, Tigray, Ethiopia

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Rehabilitation of degraded lands through plantations is at the frontline of natural resource management in Ethiopia. However, plantations have been faced with various challenges mainly attributed to poor survival rate of tree seedlings. Hence, this research was conducted in Tanqua 'Abergelle and Weri Leke Wereda's with the objective of screening tree seedlings for their survival rates under field conditions. Tree seedlings that were mostly produced in nurseries of the Woredas were first identified and analyzed. One watershed from Tanqua Abergelle and two watersheds from Weri Leke were selected to undertake further plantation trials. Pits were prepared one month ahead of plantation. The collected data was analyzed using simple descriptive statistics. Accordingly, almost all seedlings reduced their number at each sequence of inventory periods. The growth of *Moringa stenopetala* and *Eucalyptus camaldulensis* were better than the others in Weri-Leke. *Eucalyptus camaldulensis* recorded the highest growth performance (60.4 cm) followed by *Acacia lehay* (46.3 cm) in Weri Leke. The seedlings of *Moringa stenopetala, Leucaena leucocephala* and *Faidherbia albida* revealed relatively lower survival rates in Abergelle. However, *Ziziphus spina* Christ (L.) Desf., *Acacia tortilis* and *Parkinsonia aculeata* showed higher survival rates (>80%). *Moringa stenopetala* and *Casuarina equisitifolia* showed the lowest survival rates (<40%) in Weri-Leke. On the other hand, *A. lehay*, *Gravillea robusta* and *Eucalyptus camaldulensis* revealed better survival rates (c. 60%). Even if further research is still required, tree species that survive > 50% should be considered for plantations in the study areas, and improved post-planting attention and management.

Key words: Natural selection, rehabilitation, species, survival rate.

INTRODUCTION

Today reforestation and afforestation are not only a national issue but also an international one. This is because existing forest stock cannot satisfy the demand for the direct services made by human populations, such as fuel wood, agricultural tools, food, etc. and afford indirect advantages such as mitigating climate change and providing ecological services (Derero et al., 2011; Kissinger et al., 2012; Dent et al., 2013). In past centuries human intervention of forests were thought to be of negligible consequence. Densities of human populations were then low. As the number of people rapidly increased and changed forest into agricultural land (FAO, 2017; Cunningham and Beazley, 2018). Moreover, the flux of peoples to communal forests to collect fire wood and materials for agricultural tools created high pressure on natural stands. As the forest cover continued to decline, the processes operated with the heightening demand for animal forage and crop returns. Even the honey obtained

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today from bees is expected to be very different from what it was in past decades, in terms of its quality as well as quantity (Thomas and Bekele, 2003; Mekonen et al., 2015). This is due to the fact that there were different flowering tree species from today, a historical fact well known to even farmers. Beyond this, the dwindling of forest coverage leads to many other environmental problems such as decreasing water supplies from springs, accelerated erosion (which this leads to loss of fertile top soil), and other associated problems. Understanding this situation, the Ethiopian government has been giving due attention to replacing forest trees with new plantations. The number of seedlings being planted each year has increased in recent times (Winberg, 2010; Hughes, 2017; MEFCC, 2018). To reduce erosion effects in Ethiopia, soil and water conservation practices have been promoted at the farm level and watershed scale through mass-community mobilization programs (Bekele et al., 2018).

In Ethiopia, deforestation has been a challenging problem connected to land degradation (Teketay, 2001; Temesgen et al., 2014). To overcome the problem plantation programs were put into practice all over the country, especially in the Tigray region, in order to rehabilitate degraded areas. Even though this is happening, plantations require time because of the often poor survival rate of planted seedlings, particularly in moisture-stressed parts of the Tigray. Low survival rates of seedlings can mainly be attributable to either the inappropriate choice of tree species and/or agro-ecological unsuitability of the sites. There is also the issue of pre- and post-plantation mismanagement (Varmola, 2002; Appanah et al., 2012). In addition, the species planted two or more decades ago may not be so relevant and effective today. This is likely because, the previous environments have been altering rapidly, and at a rate the planted species could no longer resist, unless the species was able to adjust with the environment. Therefore, screening and identifying tree seedlings that can survive the existing environmental conditions, and even those more extreme that are foreseen will reduce unwanted high losses, and therefore costs, and even create an opportunity to prioritize those that are projected to survive best.

Londo and Dicke (2005) recommend landowners need to be aware of several causes of seedling mortality on implanting, such as failure to open up planting holes to sufficient depth, to avoid roots becoming bent and forced to grow too close to the soil surface. The objective of the present study was to evaluate the survival rate of seedlings of chosen tree species under field conditions.

MATERIALS

Area description

The study was undertaken in *Tanqua Abergelle* and *Weri-Leke* *woredas* (Figure 1), areas which are characterized by their high moisture-stress regime, and shallow and poorly fertile soils. *Tanqua Abergelle* is located 100 km southwest of Mekelle (13.3° N, 39° E), and lies *Weri-leke* is north of it (14°N, 39.1° E). The elevation of the study area ranges from 875 to 2948 m above sea level. The areas are covered predominantly by species of *Acacia* which are fed on by small ruminants. Sorghum, ground nut, maize, teff and wheat are the main crops grown in the area.

Rainfall and temperature

The study areas (*Tanqua Abergelle* and *Weri leke*) are characterized by a mono-modal pattern of rainfall (Figure 2). The main rainy season starts around mid-June and ends in mid-August. According to data for 1997 to 2012, (source?) the average annual rainfall of *Tanqua Abergelle Woreda* is 552 mm with 23% interannual variability. *Tanqua Abergelle* receives its highest average monthly rainfall (200 mm) in July, but for *Weri Leke* the highest monthly rainfall (300 mm) is on August. Rainfall starts earlier and ends earlier in *Tanqua Abergelle* than in *Weri Leke*. From the analysis of 7 yr of data (2006-2012), maximum and minimum temperatures of *Tanqua Abergelle* were 32.5 and 15°C respectively, with a mean annual temperature of 23.75°C. The maximum and minimum temperatures of *Weri Leke* were 31.3 and 12.8°C, with a mean annual temperature of 22°C.

METHODS

All seedlings that are being planted in the site were the target of the research, and therefore secondary data on survival rates of out planted seedlings needed to be obtained from the agricultural offices of the *Woreda's*. Seedlings at nursery site were prepared with a 3:2:1 soil mixture of local soil, forest soil and sand respectively. The soil mixture was added to a 10 cm diameter polythene tube. Accordingly, six tree species from *Tanqua Abergelle,* and five from *Weri Leke,* which were those mainly planted in these *Woreda's* were identified, and their survival rates evaluated. One watershed from *Tanqua Abergelle* and two watersheds from *Weri leke* were selected to undertake the current research. In this study six species (*Moringa stenopetala, Ziziphus spina Christ* L.) Desf.*, Faidherbia albida, Leucaena leucocephala, Acacia tortilis* and *parkinsonia acculata*) were selected, 30 seedlings per species, in *Tanqua Abergelle* (total 180), and in *Weri Leke* five species (*Moringa stenopetala, Eucalyptus camaldulensis, Acacia lehay, Gravillea robusta* and *Casuarina equisitifolia*), 100 seedlings per species in (total 500) were selected. The seedlings were produced in local nurseries, and then planted into the prepared pits (50 cm by 50 cm) of selected site. The seedlings were planted in the first week of July. The planted seedlings are indigenous except *Leucaena leucocephala, parkinsonia acculata, Eucalyptus camaldulensis, Gravillea robusta and Casuarina equisitifolia.* An inventory including measuring the height of the planted tree seedlings was done at thereafter every four months (November, March, and July) for one year. The recorded data were height and survival rate of the planted seedlings. The collected data were analyzed using simple descriptive statistics.

RESULTS AND DISCUSSION

Tree species raised in nurseries sites

In the study area various tree species had been raised in

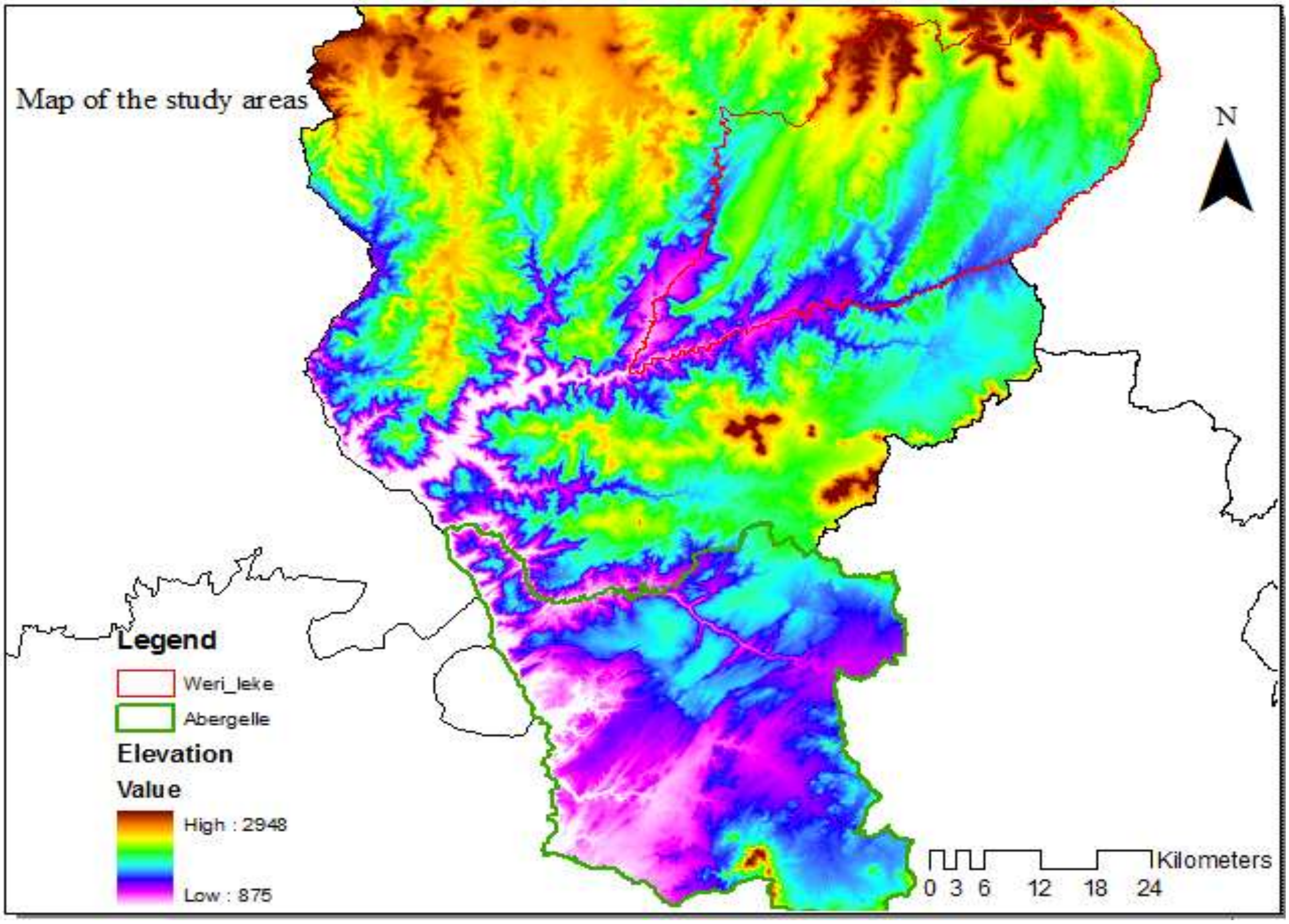

Figure 1. Elevation map of the part of the Tigray Region with the two study areas (Masked from ASTER_DEM30m spatial resolution).

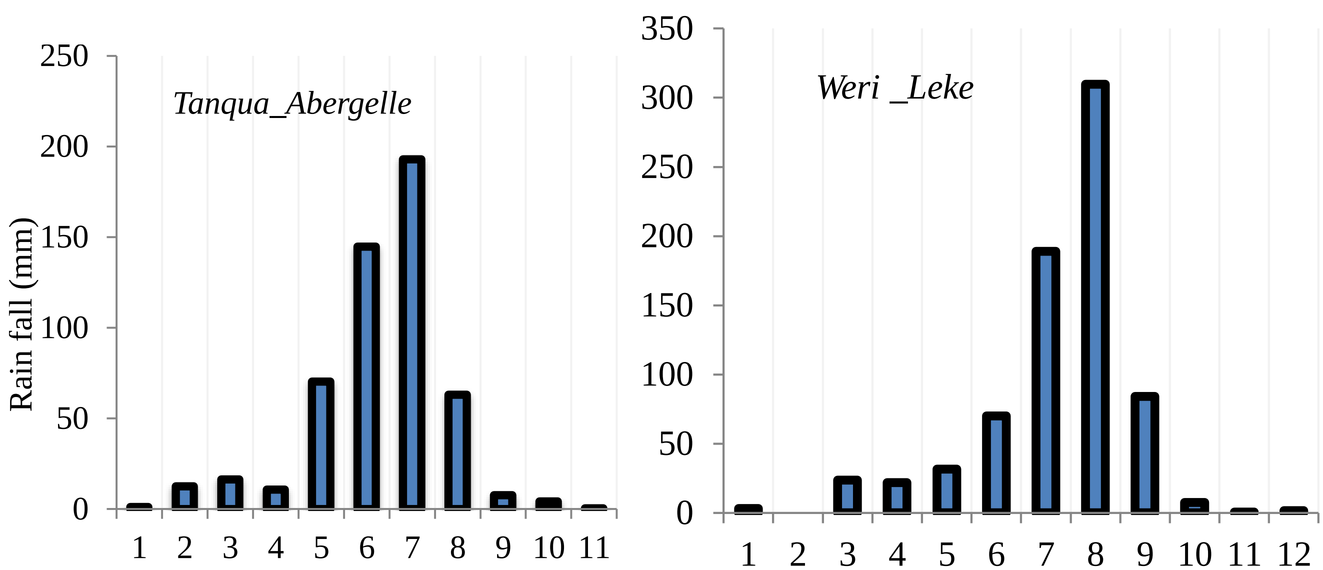

Figure 2. Monthly rainfall of *Tanqua Abergelle* and *Weri Leke* Woredas (Numbers 1 to 12 indicates the months from January to December).

Table 1. Survival rate of tree seedlings in *Tanqua Abergelle* and *Weri Leke*.

Weri Leke		Tanqua Abergelle	
Tree species	**Survival rate (%)**	**Tree species**	**Survival rate (%)**
Gravillea robusta	55.5	*Ziziphus spina-christi* (L.) Desf.	51.4
Acacia lehay	74	*Parkinsonia acculata*	50.4
Eucalyptus camaldulensis	61	*Acacia tortilis*	51.9
Moringa stenopetala	64	*Leucaena leucocephala*	48.2
Casuarina equistofilia	55.4	*Moringa stenopetala*	41.4

Source: Survival rate of secondary data for three consecutive years (2014-2016).

the nurseries for rehabilitation of degraded lands. The government initiative of closing degraded areas from human and animal entrance for rehabilitation has led to establishment of more species for plantation purposes. Seedlings raised in the nurseries of *Tanqua Abergelle* mainly consisted of *Leucaena leucocephala, Sesbania sesban, Ziziphus spina-christi* (L.) Desf.*, Acacia tortilis, Faidherbia albida, Moringa stenopetala, Parkinsonia aculeata, Jatropha curcas, Azadirachta indica, Dodonea angustifolia, Acacia etbaica, Tamarindus indica, Balanites aegyptiaca* (L.) Delile*, Acacia senegal, Acacia saligna and Schinus molle are the most importantly produced tree seedlings.* Similarly in Weri Leke, *Gravillea robusta, Eucalyptus camaldulensis, Croton macrostachyus* Hochst. ex Delile and *Casuarina equisitifolia* are grown in addition to the tree seedlings raising in Tanqua Abergelle. Three-year survival rates for the selected tree species were available from the agricultural offices of *Tanqua Abergelle* and *Weri Leke Woredas* (2014-2016). The average survival rates of the planted tree seedlings in *Tanqua Abergelle* were 50% (Table 1). However, in *Weri Leke*, except for *Grevillea robusta* and *Casuarina equisitifolia at 55.5%,* the remaining tree seedlings exhibited survival rates of > 60%.

The most preferred species in the communities in Weri-Leke were *Eucalyptus camaldulensis, Faidherbia albida* and *Gravillea robusta* trees. *Acacia species and Ziziphus spina Christ* (L.) Desf. were also preferred in *Tanqua Abergelle* since the area was moisture-stressed and the species can withstand the conditions. *Moringa stenopetala* is being promoted as a new species for on-farm planting in both areas.

Survival rate of planted seedlings

The survival rate of the different seedlings which were planted at watersheds was evaluated by conducting an inventory. For this case, an inventory was done three times per year. Almost all tree seedlings reduced their survival rate from the first to the next inventory. This reduction can be attributed to different factors such as poor management (animal trampling and browsing), moisture stress and termites (particularly for *E. camaldulensis* and *M. stenopetala*). The study of Sorecha (2017) identifies the problem of low survival rate of endemic species due to high interference by local peoples across all the watersheds. Londo and Dicke (2006) also show that in many cases, the reason for seedling mortality is mis-planting since shallowly planted seedlings have a decreased chance of survival compared with properly planted ones (Figure 3).

Eucalyptus camaldulensis had the highest recorded growth performance (60.4 cm) followed by *A. lehay* (46.3 cm) in *Weri Leke*. However, for the remaining tree species their height at the last inventory was almost same as what it was at the seedling stage before out-planting. The height of the planted seedlings during the inventory period was very low particularly at Tanqua Abergelle*.* This could have been due to lack of soil moisture, and the infertile and impermeable soil of the area. The seedlings of *M. stenopetala* and *Luecaena leucocephala* revealed relatively lower survival rates at watershed level in Tanqua Abergelle (Figure 4). The reason for this could have been due here to intervention by animals. However, *Ziziphus spina Christ, Acacia tortilis* and *parkinsonia acculata* showed higher survival rates (>80%) because these species have thorns that meant that they could not easily be attacked by the browsers. The planted tree seedlings in *Weri Leke* indicated that their survival rate was promising and hence, these trees can be planted in the area because of their importance and demand by the local people. The highest survival rate (Figure 4) was found for each species from the new field work and compared with those rates obtained bym office of agriculture, which were on average c. 50%. This seems to indicate that the reason for poor survival rate of planted seedlings in the area by the government services could mainly be attributed to poor management of seedlings after planting. Birkinshaw *et al.* (2009) showed that variation of survival rate was also related to physiology and the adaptation of each tree species.

M. stenopetala and Casuarina equistofilia has shown the lowest survival rate *(<40%)* in *Weri-Leke wereda* (Figure 5). On the other hand, *A. lehay, Gravillea robusta* and *Eucalyptus camaldulensis* revealed better survival rates (c. 60%). Except for *M. stenopetala* (35%) and

Figure 3. Photographs taken from the experimental site of Weri Leke.

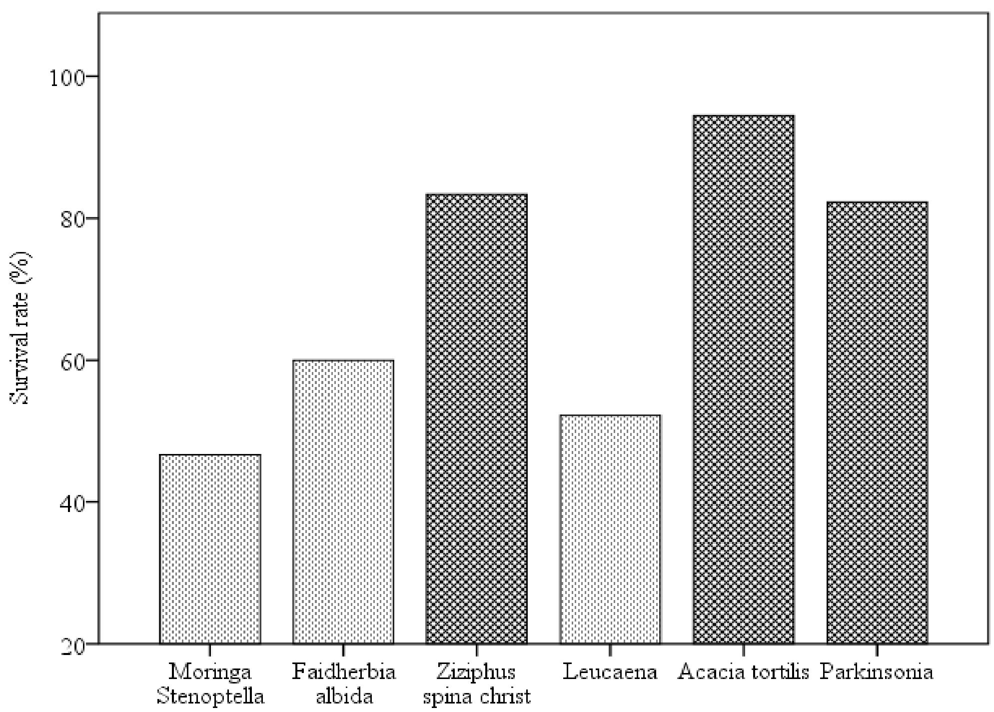

Figure 4. Survival rate of out planted tree seedlings in Tanqua Abergelle at filed condition.

Casuarina equistofilia (30%) that demonstrated lower survival rates, for the remaining tree species, *Gravillea robusta, Acacia lehay* and *E. camaldulensis,* a comparable result was observed to the results obtained

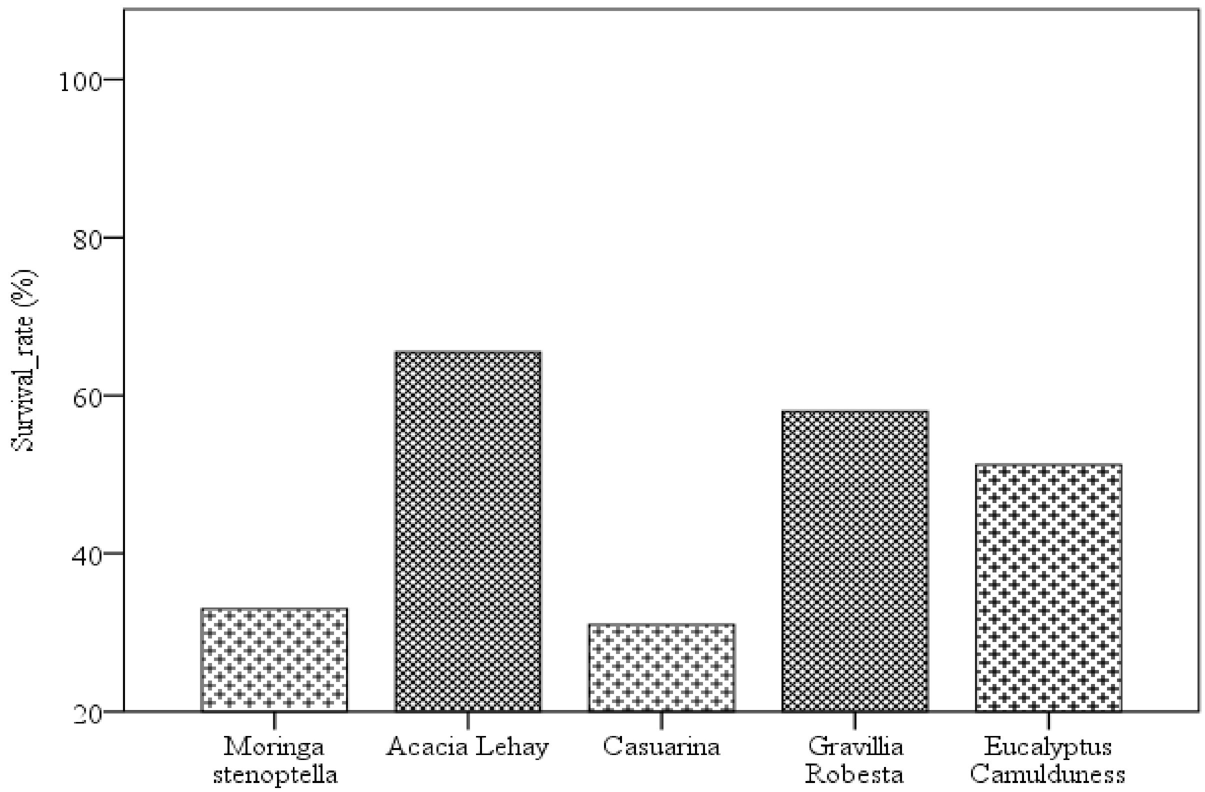

Figure 5. Survival rate of out planted tree seedlings in Weri Leke Wereda at field condition.

from *Weri Leke* office of agriculture. The poor survival rate of *M. stenopetala* and *Casuarina equistofilia* tree seedlings is mainly due to termite damage and trampling by animals. The study of Sorecha (2017), on survival rates of indigenous trees showed values of c. 38 and 56% for *O. africana* and *H. abysinicca*, respectively at three watersheds. Negash et al. (2012) and Tadesse et al. (2014) suggested that maintainance of trees may be influenced by socio-cultural factors, land use and management intensity, and awareness of the local community. Tree species grown in Weri-Leke were mostly different from that of Tanqua Abergelle. For example, *Eucalyptus camaldulensis* and *Gravillea robusta* are not commonly produced in nurseries of Tanqua Abergelle. Bishaw (2001) recommends tree planting through agroforestry and social forestry should be an integral part of rural development programs and should provide the community with food, fuelwood, income, and environmental benefits.

Conclusion

For rehabilitation of degraded lands, through either plantations or enclosures, is compulsory to have a healthy and productive ecosystem. The plantation approach has, however, been challenged because of the poor survival rates, particularly in dry-land areas. In this study the survival rate of *L. leucocephala, Z. spina-christi* (L.) Desf., *A. tortilis, F. albida, P. aculeata,* in Tanqua Abergelle, was found better. While at Were-leke *E. camaldulensis, Acacia lehay, Gravillea robusta* survived at promising performance. At both site supporting watering is required for their survival performance. Even if further research is still required, tree species that survive > 50% should be considered for in planning plantations in the study areas, or plantation strategies should be stratified (e.g. important trees that need frequent management should be planted at homesteads or at around irrigation sites). Further research should be done in the identification of challenges to obtaining higher survival rates and collecting farmer's perceptions on plantation activities, including the species that are being planted in their areas.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of multi-functional fodder tree and shrub species in mid-altitudes of South Omo Zone, Southern Ethiopia

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A study was conducted to evaluate the early growth performance and nutrient composition of some selected tree/shrub species in the fodder bank agroforestry system. *Moringa stenopetala*, *Terminalia brownii, Morus alba*, *Melia azedarach,* and *Sesbania sesban* were used for this study. Square quadrants of 16 m^2 plot sizes were established with the RCBD of three replications. Seedlings were planted with 1 m × 1 m spacing between rows and plants respectively. The growth and chemical composition of the studied tree/shrub species were evaluated with one way ANOVA. The growth parameters and nutrient composition of the studied fodder tree/shrub species are significantly (P ≤ 0.05) varied. The nutrient composition of the studied tree/shrub species ranged between percentages of 88.3 - 90.6 of Dry Matter, 5.7 - 13 of Ash, 12.45 - 22.35 of Crude Protein, 11.8 – 23.5 of Acid Detergent Fiber and 18.1 - 33.6 of Neutral Detergent Fiber. *S. sesban* and *M. stenopetala* are the consistent and superior tree/shrub species with growth performance and nutrient content parameters respectively. In addition to this, the selected fodder tree/shrub species are well adapted in the fodder bank agroforestry system and have considerable nutrient constituents. Thus the studied tree species seems to be a potential alternative for complementing the basal feed.

Key words: Fodder bank, livestock feed, South Omo, nutrient composition, agroforestry.

INTRODUCTION

Livestock is one of the major building blocks of the agriculture sector which takes part in a potential pathway out of poverty for many smallholders in Ethiopia (Lijalem et al*.,* 2015). It contributes 15 - 17% of the national GDP and more than 50% of household income (Samson and Frehiwot, 2014). South omo zone is the leading zone with livestock population (that is, cattle, goat and sheep) and apparently, the contribution is expected to be higher especially in the areas where enormous livestock population, production, and livestock-based practices are carried out (CSA, 2017). Consequently, livestock husbandry is considered primarily as the main source of income followed to crop production. Despite this the impact of feed shortage is also more pronounced in areas

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with large concentrations of livestock (Nassoro, 2014). Similarly feed shortage both in quality and quantity combined with land shortage and low productivity of local breeds are the leading constraints for livestock productivity in Southern Ethiopia (Chalchissa et al*.,* 2014; Membere, 2014). The current feed source such as natural pasture and crop residues are characterized as poor quality in terms of nutrients and minerals (Tolera et al*.,* 2012; FAO, 2018). On the other hand, fodder trees and shrubs are increasingly recognized as important components of animal feed; fodder tree leaves were found to be rich in protein, soluble carbohydrates, minerals, and vitamins, and showed great potential as alternate feed resource (Bakshi and Wadhwa, 2007; Azim et al., 2011) especially where alternative options are expensive (Hamer et al., 2007).

However, areas under fodder production are continuously reducing mainly due to the competition with cash/food crops (Cheema et al., 2011) and in turn planting of fodder trees seems difficult in uplands otherwise it is reserved for annual crops (Franzel et al*.,* 2014). According to CSA (2007) census, the total population was estimated as 212, 389 and this makes the district highly populous than the remaining districts in the zone. Despite this, the livestock feed demand is continuously increasing while accessing land for planting trees tends to be more difficult primarily due to the positive relationship between population growth and annual crop production for satisfying the increasing food demand. As it happens more lands will subject to crop production and in turn competition between trees and annual crops is expected to be more intense. Hence, the possible solution from tree planting perspective would be as Raghuvansi et al. (2007) argued that exploring alternate feed resources that do not compete with human feed is crucial. On the other hand, strengthening the existing practices as Franzel et al. (2014) noted that planting of multi-purpose fodder tree species in neglected niches such as hedges around the homestead, along field boundaries and contour lines as soil erosion barriers. This will allow another opportunity for mitigating the current livestock feed problem. With this regard fodder bank agroforestry practice has been considered as one of the substantial crop-livestock production systems that fit for both alternatives. The main objective of this system is to overcome protein deficiency of livestock and/or to supplement basal feed sources while established in areas without causing space competitions against annual crops (ESGIP, 2008).

Emmanuel and Tsado (2011) argued that of all fodder development works, legumes play a major role as they enrich the soil with nitrogen and produce highly digestible and protein-rich fodder. Moreover, the deep root of these multi-functional trees/shrubs extracts water and nutrients from deep in the soil profile enables them to maintain high protein in their parts especially during the dry season (Teferi et al., 2008; Wambugu et al*.,* 2011). The growth responses and nutrient contents of the readily available fodder tree/shrub species including the studied species in the fodder bank agroforestry system are yet unknown. Hence, this gap hinders further adoption of these tree/shrub species in the system and turn limits the potential benefits. With this context, the present study was aimed at assessing the early growth performance and nutritive values of the selected tree/shrubs in the fodder bank agroforestry system.

MATERIALS AND METHODS

Description of the study area

The present study was conducted for three years between 2016 and 2018 at Jinka Agricultural Research Centre on-station Debub Ari District, Southern Ethiopia. The station is geographically located between 05° 46' 30.4" - 05° 46' 47.8" N and 036° 33' 02.7" - 036° 33' 20.4" E with an altitude of 1383 m.a.s.l. The soil type is characterized as Cambisols with fine to very fine particles, with a pH range of 4.87 to 6.18 strongly acidic to slightly acidic (Kebede et al., 2017) which is a preferable range for majority of crop types that are potentially grown in the area. The study site has a bi-modal rainfall pattern with a shorter rainy season from March-May and the longest rainy season from August - November. The total annual rainfall is 1272.4 ± 250.7 mm. The annual mean minimum and maximum temperatures are 16.3 ± 0.9°C and 27.7 ± 1.4°C. The meteorology data was collected from Jinka station, there are some missing values for certain months and accordingly, the monthly average values for those climate elements were considered the available records only (Figure 1).

Experimental design, trial layout, and management

Moringa stenopetala (Bak.) Cuf., *Terminalia brownii* (Fres.)*, Morus alba* (L.), *Melia azedarach* (L.)*,* and *Sesbania sesban* (L.) Merr. were tested under the present study. The first two species are indigenous to southern Ethiopia and the latter three are introduced to Ethiopia during the last three decades. The multi-function, ecology, distribution and botanical characteristics of the studied tree/shrub species are described in different literatures (Stein-müller et al., 2002; Abuye et al., 2003; Jiru et al., 2006; Bekele, 2007; Chiffelle et al., 2008; Sultan et al., 2008; Orwa et al., 2009; Degefu et al. 2011; Oosting et al, 2011; Mani et al., 2011; Gomase et al., 2012; Nigussie and Alemayehu, 2013; Seifu, 2014). Square quadrants with 4 m × 4 m plot sizes were established horizontally along the strips with RCBD of three replications. Each plot was received sixteen tree/shrub individuals of the same species. Seedlings were planted during the onset of the rainy season (April, 2016) with 1 X 1 m spacing between rows and plants respectively. This spacing enables them to cut frequently and induce high herbage production (Jamala et al*.,* 2013). With the exceptions of *M. alba* cuttings for the rest of tree/shrub species seedlings were used. The following criteria are considered for choosing fodder tree/shrub species of the present study such as availability for further adoption, high survival rate, ease of propagation, and permit periodic pruning, high leaf yields and good nutritional value (Chakeredza et al., 2007). Diameter (1.3 m above ground) and height were measured by using caliper and meter tape respectively.

Sample collection and nutrient analysis

Every six months fresh leaf and tender branch/twig samples were collected from eight sample individuals (from interior two planting

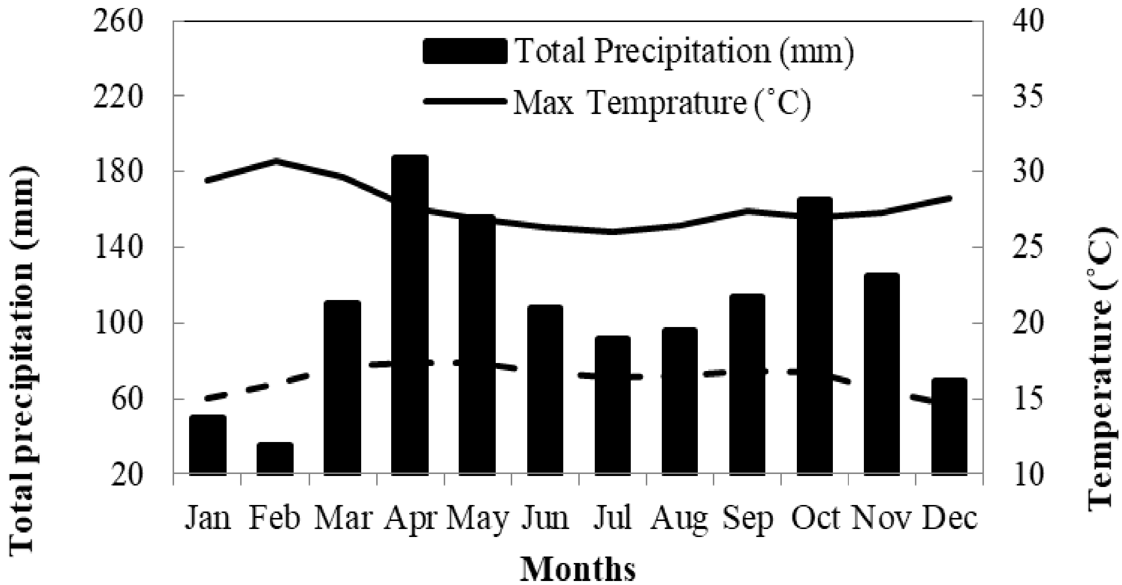

Figure 1. Climate diagram for the monthly average of the total rainfall, minimum temperature, and maximum temperature values from Jinka meteorology station of the South Omo Ethiopia. The climate data was spanned for 20 years (1996 - 2015).

rows). Composite samples were prepared for nutrient analysis from each tree/shrub species. The collected leaves were dried separately in a forced air oven at 55°C, ground to pass a 2 mm sieve, eventually labeled, stored in air-tight plastic bags and nutrient analysis was done in a laboratory at Hawassa University. Dry matter (DM) content was determined by drying the sample at 105°C in a forced-air oven untill the constant weight was obtained. Ash content was measured after igniting the sample in a muffle furnace at 550°C for 4 h. Nitrogen was determined using the micro-Kjeldahl method (AOAC, 2000). Crude protein (CP) was calculated as N X 6.25. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by methods of Van Soest et al. (1991) without the use of alpha-amylase but with the use of sodium sulfite.

Data analysis

Early establishment growth parameters such as Height, Root Collar Diameter (RCD), Diameter at Breast Height (DBH) and Branch number (BNO) were analyzed, while the nutrient composition parameters such as Ash, crude protein, Acid Detergent Fiber, and Neutral Detergent Fiber were evaluated by one-way Analysis of variance (ANOVA) among the fodder tree/shrub species. Mean separation for mean differences was computed among the mean values and Linear regression was computed both between RCD with height and Height with BNO. The data analysis was run through employing SPSS (Version 20) and for data organization Microsoft excel worksheet was used.

RESULTS AND DISCUSSION

Early performance of the selected fodder tree/shrub species

Growth performance of tree/shrub species was measured in terms of gains in Height (H), Root collar diameter (RCD), and branch number (BNO) during both year one and year two monitoring except for diameter at breast height (DBH) (considered during the second year). All the investigated growth parameters showed significant variation ($P \leq 0.05$) among the studied fodder tree/shrub species. Except height, both root collar diameter and branch number were non-significant during the first of year monitoring. *S. sesban* and *M. alba* gained significantly the highest mean height during the first and second year of monitoring and followed by *T. brownii*. Also *S. sesban* had consistent and significantly ($P<0.05$) highest mean values of RCD, DBH and BNO (Table 1).

The utilization of resources from the environment by any species is a combination of space, resource and time (Jose et al., 2004). These components influence the growth performance, root development and nutrient acquisition of individual plants in several agroforestry practices (Rao et al., 1998). According to Makumba et al. (2009), management and/or environmental and physiological factors are controlling plant growth, as a result, species response to the environment within simultaneous systems is modified by the presence of the others as well (Akinnifesi et al., 2004). Similarly, the growth difference among the studied tree/shrub species is related to the inherent physiological nature of the species in response to spacing and the resource pool. Apparently, spacing determines the intensity of inter and intraspecific competitions and fine root biomass (Singh et al., 2016) in turn influences tree growth (Hébert et al., 2016) and also determines the nutrient contents of leaves (Walker, 2007; Shinde et al., 2012). For instance, *M. alba* had higher leaf yield and growth was obtained with 1 m × 1 m and 1 m × 1.5 m spacing and this difference

Table 1. growth responses of the selected fodder tree/shrub species during two years of experimentation.

List of tree/shrub species	Year one			Year two			
	H (m)	RCD (mm)	BNO	H (m)	RCD (mm)	BNO	DBH (cm)
Morus alba L.	3.4 (±1.95)[a]	3.6 (±0.9)	10 (±1)	2.6 (±0.4)[a]	3.2 (±0.2)[b]	24 (±7)[b]	2.0 (±0.1)[ab]
Terminalia brownii Fres.	1.8 (±0.23)[ab]	4.2 (±1.9)	14 (±5)	2.2 (±0.1)[b]	3.7 (±0.4)[b]	40 (±18)[b]	1.7 (±0.5)[b]
Melia azedarach L.	0.9 (±0.05)[b]	2.2 (±0.9	7 (±2)	1.3 (±0.3)[c]	2.2 (±0.2)[c]	23 (±11)[b]	1.1 (±0.4)[c]
Moringa stenopetala (Bak.) Cuf.	0.9 (±0.4)[b]	2.5 (±2.4)	4 (±2)	0.8 (±0.02)d	3.4 (±0.02)[b]	18 (±7)[b]	-
Sesbania sesban (L.) Merr.	3.3 (±1.2)[a]	4.4 (±1.4)	26 (±25)	2.9 (±0.02)[a]	5.2 (±0.3)[a]	84 (±24)[a]	2.3 (±0.3)[a]

Mean ± Standard deviation values with different letters within the column are significantly different at ($\alpha \leq 0.05$), H= height, RCD = Root collar diameter, BNO = branch number and DBH = diameter at breast height (1.3 m from the ground), m=meter, mm= millimeter, cm= centimeter.

is more visible over time (Eltayb et al., 2013).
The root geometry and architecture of each tree/shrub species influence the intensity of competition, carbon turn over, successful growth and survival. Though for the majority of tree species, the root density varies with increasing soil depth (Mekonnen et al*.,* 1999), soil texture and organic matter contents (Savon et al*.,* 2016). Both *S. sesban* and *M.alba* establish a deeper rooting system (Mani et al., 2011; Savon et al*.,* 2016). This important rooting feature may enable these trees to explore large volumes of soil and such trees are a beneficiary in the sense of intercept leached nutrients (Akinnifes et al., 2004), and moisture capturing from the lower horizon. Due to this reason, both the tree species have revealed a considerable performance in all growth explicit parameters.

Moringa spp such as *Moringa oliefera* and *Moringa stenopetala* have a tuberous, larger taproot and wide-spreading lateral roots (Sanchez, 2006). The observed least growth performance of *M. stenopetala* may be related to the intensity within competition particularly for space and in turn nutrients and moisture competition between individual trees. Despite the species capacity to produce a large quantity of fresh biomass even with higher planting density, competition within is also caused to reduce biomass production during the second year (Sanchez et al*.,* 2006). Similarly, the average fine root biomass of *M. azedarach* is reported highest at the upper soil depth (0-15 cm) (Singh et al*.,* 2016). This implies that there is evidence of higher competition of nutrients and moisture especially during the dry season and/or when the water becomes depleted the competition becomes intense (Miller and Pallardy, 2001). When the resource competition for space and soil nutrients is becoming more intense, the growth and performance of individual trees are influenced such as height, branch number, and DBH. The same is true with the growth performance of both *M. azedarach* as well as *M. stenopetala* in the present study.

The present result revealed that there is no significant correlation between Height and branch numbers (r= 0.511: P= 0.052), while there is a significant positive relationship (r= 0.57: P= 0.026) between root collar diameter and height during the first year of establishment. This result agreed with Samuel et al. (2016)'s argument, root collar diametere is used as an indicator for taller growth especially during early establishment. With the exceptions, *T. brownii* and *M. azedarach* all the tree/shrub species showed a decreasing trend of average height values (Table 1 and Figure 2). This is due to all the tree/shrub species are subjected to frequent lopping of leaves and tender twigs during the experimentation. Bishit et al*.* (2014) reported that when the lopping intensity of *Dalbergia sissoo* increases there is decreased height and DBH. This practice may directly influence the physiological processes of plants predominantly respiration and photosynthesis rate. Hence, the rate of changes in height increment seems to decrease when the age of the studied trees/shrubs increases. Despite the height, increment in growth parameters expresses the adaptation and growth response of these tree/shrubs to the environment with fodder bank agroforestry system at least during the experimentation period.

Chemical composition of the studied tree/shrub species

The present result revealed that the nutrient contents of the fodder tree/shrub species are significantly varied ($P \leq 0.01$) consistently across all the parameters. *M. stenopetala* had the highest Ash and CP contents. *T. brownii* had the highest

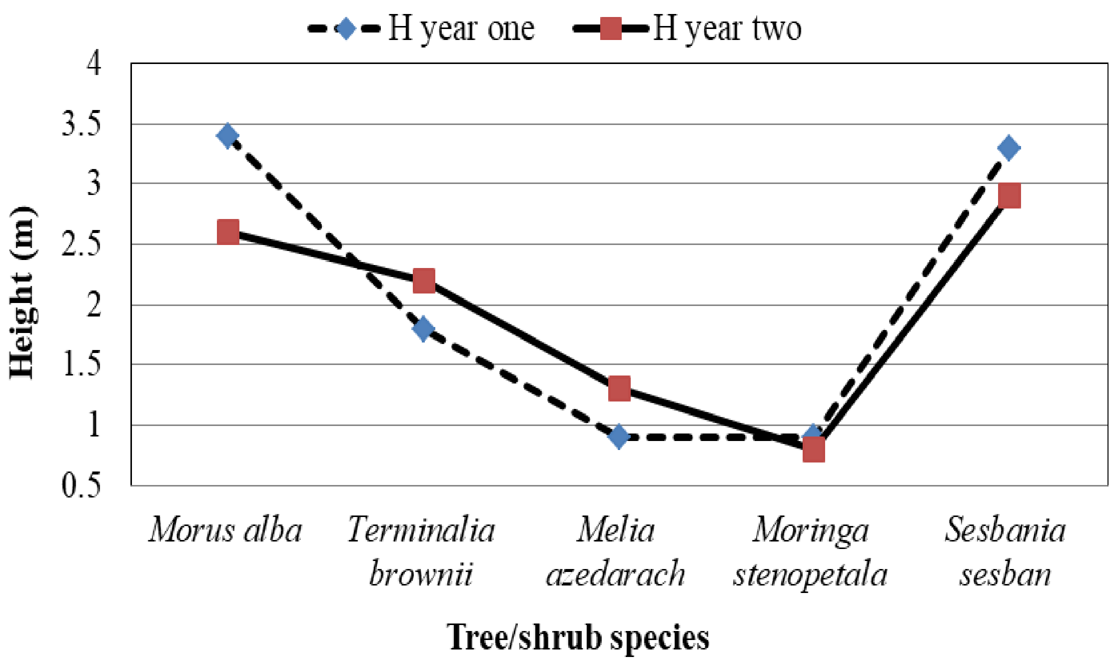

Figure 2. Trends of height measurement for the studied tree/shrub species between Year one and Year two. Height is measured in meter.

ADF, NDF and DM contents, while it had the least contents of CP and Ash. *M.alba* and *S.sesban* exhibited the least ADF and NDF values respectively, while comparable in terms of Ash and DM contents. *M.azedarach* recorded the highest DM contents (Table 2). These differences among the studied tree/shrubs may concede with different factors such as environmental factors (Jiru et al., 2006), genotypic variations and plant maturity (Aganga and Tshwenyane, 2003; Upreti and Shrestha, 2006) and differences in accumulation of protein in the leaves during growth (Cheema et al., 2011). The nutrient contents of the studied tree/shrub species were compared with study carried out by other workers in species like *M. stenopetala* (Abuye et al., 2003; Jiru et al., 2006; Melesse et al., 2009; Melesse, 2011), *S. sesban* (Tessema and Baars, 2004; Debela et al., 2011; Gomase et al., 2012), *M.alba* and *M. azedarach* (Schmidek et al., 2002; Singh and Makkar, 2002; Sultan et al., 2008; Cheema et al., 2011) and *T. brownii* (Osuga et al., 2019). The nutrient contents for the majority of roughages are less than 9% and even decline with time (Distel et al., 2005), which is inadequate to meet out required protein for microbial activities unless supplemented with protein-rich feeds (Seyoum and Zinash, 1989). Fodder trees are nutrient-rich and enable them to produce bulky biomass almost year-round makes a significant alternative for animals feed. *S. sesban* tree has a high level of foliage nitrogen and is an excellent supplement to protein-poor roughage (Manaye et al., 2009; Orwa et al., 2009; Sabra et al., 2010). There is an increasing experience of feeding *S. sesban* leaves and young twigs to supplement a basal diet for ruminants in Ethiopia (Tessema and Baars, 2004). It is easily digestible when consumed by ruminants (Gomase et al., 2012). Similarly, the nutritive value of *M.alba* is considered good, with better digestibility than that found in the leaves of many tropical pasture plants; thus it can be an alternative for totally and partially replacing concentrates (Savon et al., 2016). According to Sultan et al. (2008), the potential intake of *M. alba* is higher and in turn, it has a higher rate of preferences.

The ash contents of the studied fodder tree/shrub species are laid between the ranges of 5.7 - 13% with mean values of 9.7±2.3%. This agreed with the reports of Mandal (1997) who argued that the ash contents for most of the tree leave varied from 6 to 15%. This seemingly studied fodder tree species have considerable mineral concentrations that therefore be suggested as livestock feed supplement with low-quality roughage (Nassoro, 2014). Different factors are influencing the mineral concentration of plants such as minerals in the soil and availability to the plant, soil type, and soil pH and stage of growth (Lukhele and Van Ryssen, 2003).

Alam and Djajanigra (1994) argued that the minimum threshold for CP is 10%; if it is lower than this value it will affect rumen fermentation. The studied tree/shrub species had average CP contents between the ranges of 12.35 - 22.35%; 15.8 ±3.8%) and it is moderately higher from the threshold. All the tree/shrub species are satisfying at least 8% crude protein required for maintenance of livestock (Rubanza et al., 2003). Crude protein with this amount is adequate to support the

Table 2. Chemical composition (g/100g DM) of foliage samples from fodder tree/shrub species across the parameters (n=10).

List of tree/shrub species	ASH (%)	CP (%)	ADF (%)	NDF (%)	DM (%)
Morus alba L.	10.3^{b}	12.35^{c}	12.05^{d}	27.95^{b}	89.7^{b}
Terminalia brownii Fres.	5.85^{c}	12.45^{c}	23.35^{a}	33.55^{a}	89.7^{ab}
Melia azedarach L.	9.8^{b}	16.4^{b}	16.35^{b}	24^{c}	90.6^{a}
Moringa stenopetala (Bak.) Cuf.	12.5^{a}	22.35^{a}	13.1^{cd}	25.05^{c}	88.3^{c}
Sesbania sesban (L.) Merr.	9.75^{b}	15.4^{b}	13.35^{c}	18.9^{d}	89.8^{ab}

Means with different subscripts within the column are significantly different at ($\alpha \le 0.05$), ASH= ash content, CP= crude protein, ADF= Acid detergent fiber, NDF= neutral detergent fiber, and DM= dry matter.

requirements of cattle, sheep, and goats at low to medium production levels (Jamala et al., 2013). When the protein content decreased accompanied by increased fiber content this makes a feed low quality and relatively indigestible for livestock.

Moreover, the contents of CP also influence the digestion of structural carbohydrates by interfering with microbial growth (Orskov, 1982). A high level of CP results in increased ruminal ammonia N concentration (Hristov et al*.,* 2004). Increased ruminal ammonia N status enhances microbial activity and growth resulting in greater DM digestibility (Griswold et al., 2003). The ADF and NDF contents of the studied tree/shrub species are laid between 11.8 -23.5 (15.6 ± 4.3) and 18.1- 33.6 (25.9 ± 5.1) respectively. Lower values of ADF in these tree leaves such as *M.alba, M.stenopetala,* and *S.sesban* indicate a good potential for ruminant feed (Bakshi & Wadhwa, 2007). *T. brownii* had the highest ADF and NDF values than the rest of the studied tree/shrub species. Though, it showed a lower average value than the reports of Osuga et al. (2019) in all parameters. Moreover, the values of ADF and NDF are lower in vegetative parts of leaves than mature leaves. This indicates the vegetative leaves have a relatively smaller proportion of woody parts (Sultan et al., 2008). The concentration of NDF and ADF is negatively correlated with a relative preference of livestock and in turn palatability (Sultan et al., 2008).

Conclusion

The variation of the studied tree/shrub species in terms of growth and nutrient composition is attributed to different factors such as the inherent nature of the tree species in response to spacing and resource acquisition, genotype, the season of plant harvest and maturity. Especially the latter three are more explained with nutrient composition differences. *Sesbania sesban* and *Moringa stenopetala* are the superior fodder tree/shrub species in terms of growth performances and nutrient composition respectively. All the selected fodder tree/shrub species are well adapted in fodder bank agroforestry system and have a considerable constituent of Ash, Crude protein, Acid detergent Fiber, Neutral detergent Fiber and Dry matter for maintaining livestock production. These enable the studied tree species to be potential alternatives for complementing the basal feed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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