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Journal of Ecology and The Natural Environment

July 2019
ISSN 2006-9847
DOI: 10.5897/JENE
www.academicjournals.org

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DOI: 10.5897/JENE2019.0756
Article Number: FD7228A61405
ISSN 2006-9847

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Journal of Ecology and The Natural Environment

Full Length Research Paper

Ecological factors favouring mosquito breeding in Ifedore local government area of Ondo State, Nigeria

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Received 3 March, 2019; Accepted 17 May, 2019

The physico-chemical and biological characteristics affecting the breeding ecology of mosquitoes in Ifedore local government area of Ondo State, Nigeria was investigated. Mosquito larvae were collected from 33 breeding sites using standard plastic dippers, transported to the laboratory and reared to adulthood. Physico-chemical characteristics, distance of each breeding site to the nearest residence and other biotic and abiotic features were determined per site. 2051 imagoes were morphologically identified including *Anopheles gambiae* s.l. (n=348), *Aedes* spp. (n=394), *Culex* spp. (n=1270), *Mansonia* spp. (n=7), *Toxorhynchite* spp. (n=20) and *Coquillettidia* spp. (n=12). Distance of breeding sites to the nearest residence ranged from 0.5 to 300 m. Temperature in all breeding sites ranged from 20.80 to 32.60°C; dissolved oxygen, 2.70 to 7.80 mg/L; total dissolved solids, 043 to 1933 ppm and pH was between 5.30-8.50. Temperature and dissolved oxygen had significant effect on all the species' larvae, as higher values increased their presence. Each of the other physico-chemical parameters had effects on some of the mosquito species. Adequate knowledge of the physico-chemical and biological factors may help in modifying the breeding environments to curb their proliferation. Similarly, the attention of the government to provide basic amenities that would reduce the temporary breeding sites suffices.

Key words: Breeding, ecological factors, Ifedore local government area, mosquitoes, Ondo State, Nigeria.

INTRODUCTION

Various species of mosquitoes are found all over Nigeria and are not restricted by change in topography across the country (Awolola et al., 2002). Many species act as vectors of diseases such as malaria, yellow fever, West Nile virus, dengue fever, filariasis, and other arboviruses (Gatesnote, 2015). 3,500 species of mosquitoes grouped into 41 genera have been identified and many are vectors of diseases (CDC, 2015). Good understanding of the breeding ecology of these organisms including, the types and preferences for larval habitats as well as, the physical, biological and chemical characteristics of the habitats are required to make vector control measures successful (Olayemi et al., 2010). Of note is that convenient breeding sites for certain mosquito species may be inconvenient for other species (Adebote et al., 2008). All types of lentic aquatic habitats can be used for breeding and mosquito larvae have been found to thrive in aquatic bodies such as fresh or salt

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water marshes, swamps, plantations, grassy ditches, streams, lakes and rivers and small, temporary rain pools. Some breed in habitats with vegetation cover while some breed in open, sunlit pools. Kitching (2001) reported that some species breed in tree holes or the leaf axils of some plants. Various studies of larval habitats of mosquito fauna in Nigeria found that abandoned vehicle tyres, used and abandoned containers, stagnant pools, unused septic tanks etc. contained high number of these nuisance organisms that act as vectors of debilitating diseases (Adeleke at al., 2008, 2013; Afolabi et al., 2013; Idowu et al., 2014). According to Okorie (1978) and Mutero et al. (2004), mosquitoes show preference to water with suitable pH, optimum temperature, dissolved oxygen, concentration of ammonia and nitrate. These physico-chemical parameters have been found to affect larval development and survival in breeding water. A study done in northern Nigeria indicated that physico-chemical characteristics such as habitat type, floating debris and emergent plants were key factors determining the presence of *Anopheles* larvae in the habitats (Oguoma and Ikpeze, 2008). The oviposition preferences of gravid females and the ability of immature stages of mosquito to survive both biotic and abiotic environmental conditions of a given aquatic habitat determine the abundance and distribution of mosquito larvae (Okogun et al., 2014). The latter will dictate endemicity of, or predisposition to, infectious agents in any locale. In Ifedore local government area of Ondo state, the ecology of breeding sites of mosquitoes was investigated to identify larva preferences of different mosquitoes across the study area.

MATERIALS AND METHODS

Ondo State is situated in the south western part of Nigeria with geographical coordinates of 5° 45 ˈ N, 4° 20ˈ E and 7° 52ˈ N, 6° 05ˈ E (Wikipedia, 2014). The state lies in the tropical rainforest biome with lush vegetation that spawns almost all year round, indicative of good breeding environment for all sorts of fauna and flora. Aside the state capital, Akure, and a few other towns where dwellers are largely civil servants, a good number of inhabitants engage in one form of agricultural activity or the other. Ifedore local government area (5° 21ˈ N, 5° 04ˈ E) (Maphill, 2018) is one of the eighteen (18) local government areas in the state with eleven (11) towns including Owode-Owena, Ibuji, Igbara-Oke, Isarun, Eroo, Ilara, Ipogun, Ibule, Aaye, Ijare and Irese. They are all largely rural and agrarian communities with cocoa and kolanut being the main cash crops apart from lumbering, which also thrives in the area. Three (3) different breeding sites/habitats were selected in each of the eleven towns with the assistance of local guides, and these ranged from open water bodies, streams aid, puddles to tyre tracks, discarded containers, rock pools and footprints. The coordinates were recorded using GPS (eTrex©, Garmin International Inc., Olathe, USA). Before larval evacuation at each site, the physico-chemical parameters were determined using H19813-6 multi-meter (Hanna, USA) for pH, total dissolved solid, electrical conductivity and temperature while a portable dissolved oxygen meter (H196732, Jenway, United Kingdom) was used to measure the dissolved oxygen at each of the collection points. The fauna and flora found at each site were recorded and predators amidst them noted. Subsequently, immature stages of mosquitoes were collected using standard plastic dippers, ten dips were done per site and contents emptied into collection containers (each specific for a site) and transported to the laboratory where the larvae were reared to adulthood. The emerging adults were preserved in 1.5 ml Eppendorf tubes containing silica gel. All specimens were identified morphologically using Standard keys (Gillett, 1972; Gillies and Coetzee, 1987; WHO, 2013). Mean of physical factors and mosquito species among different breeding sites were determined using one-way analysis of variance (ANOVA), and where there were significant differences, Tukey test at $p<0.05$ was used to separate the means using SPSS 16.0 version. Correlation of physico-chemical factors with the number of larvae was done using the Pearson correlation coefficient test.

RESULTS

2051 imagoes reared from the 33 breeding sites were morphologically identified. The identified mosquitoes were *Anopheles gambiae* s.l. 348 (194 males and 154 females) (16.97%), *Aedes* spp. 394 (248 males and 146 females) (19.21%), *Culex* spp 1270 (740 males and 530 females) (61.92%), *Mansonia* spp. 7 (1 males and 6 females) (0.34%) *Toxorhynchite* spp. 20 (14 males and 6 females) (0.98%) and *Coquillettidia* spp 12 (3 males and 9 females) 0.59%. Breeding sites where these larvae were recovered include gully, tyre tracks, discarded containers, streams, open water bodies, puddles, artificial holes, discarded truck tyre, blocked drainage system, used tyres and concrete hole. The study encountered high number of mosquito larvae especially at Igbara-oke site 3 (dominated by culicines), while the lowest larvae collection was at Owena site 2, which was dominated by *Anopheles* species as described in Table 1. The males were more than the females except for the *Coquillettidia* spp and *Mansonia* spp. and various predators were recorded in the sites including, tadpoles, damsel flies, dragon flies and anurans. The recorded flora was majorly grasses and a few trees like Pride of Barbados, bamboo and orange trees. The distance of the breeding sites to the nearest residence ranged from 0.5 to 300 m. The larvae density ranged from 0.01 to 0.10 and there were significant differences in the larvae density at Isarun and Irese breeding sites. The temperature in all breeding sites ranged from 20.80 to 32.60°C as shown in Table 2, dissolved oxygen ranged from 2.70 to 7.80 mg/L across investigated sites. Total dissolved solid ranged between 043 and 1933 ppm and pH range was between 5.30 and 8.50.

DISCUSSION

Most of the mosquito breeding sites were exposed to direct sunlight and turbid. According to Minakawa et al. (1999), gravid females use open and turbid habitats for oviposition because such sites are warm and reduce larva and pupal development time. Majority of the sites encountered were temporary breeding sites and

Table 1. Physical characteristics of sampled habitats.

Town	Site No. (Coordinate)	Habitat type	Nearness to residential building (m)	Mean nearness to residential building (m)	Mean larvae density	Colour and appearance	Fauna and flora found around breeding site
Owode Owena	1 (7.40413101 and 5.0158392)	Gully	5	17.17±14.48[a]	0.03±0.16[ab]	Turbid	Tadpoles, lizards, midges, dragon flies,damsel flies and grasses.
	2 (7.40413101 and 5.015839)	Tyre track	46			Turbid	Elephant grass, grasses.
	3 (7.04043403 and 5.0075186)	Discarded containers	0.5			Greenish	Green algae.
Ibuji	1 (7.4463251 and 5.0626339)	Stream	10	9.33±1.76[a]	0.04±0.01[ab]	Greenish	Damsel flies, dragon flies, tadpoles, midges, lizards and water spiders. Grasses and green algae.
	2 (7.4268265 and 5.0590556)	Open water bodies	6			Turbid	Damsel flies, dragon flies, tadpoles and anurans, midges, water spiders and fishes. Green algae, bromeliad plants, trees and grasses.
	3 (7.4455370 and 5.0637899)	Stream	12			Turbid	Dragon flies, damsel flies, grasses, bamboo trees.
Igbara-Oke	1 (7.4348889 and 5.0610074)	Puddle	4.6	5.87±3.24[a]	0.04±0.01[ab]	Greenish	Dragon flies, tadpoles, lizards with grasses.
	2 (7.4029373 and 5.0571038)	Tyre track	1			Greenish	Tadpoles, dragon flies and damsel flies and green algae.
	3 (7.3603494 and 5.1023863	Puddle	12			Turbid	Tadpoles, dragon flies, green algae.
Isarun	1 (7.4025111 and 5.0597061)	Marsh	1	13.00±6.03[a]	0.01±.000[a]	Greenish	Tadpoles, anurans, lizards, midges, water spiders, damsel flies dragon flies, grasses and pride of barbados trees.
	2 (7.3966387 and 5.0638127)	Artificial holes	18			Turbid	Damsel flies, dragon flies. brown algae, bamboo trees, grasses and stubborn grasses.
	3 (7.3976025 and 5.0650115)	Stream	20			Clear	Lizards, midges, water spiders, damsel flies, dragon flies, pride of barbados and bamboo trees.
Ero	1 (7.3991562 and 5.0639352)	Tyre track	300	160.00±83.87[b]	0.02±0.01[ab]	Turbid	Midges.
	2 (7.381727 and 5.0867100)	Discarded containers	170			Clear	Grasses.
	3 (7.38643 and 5.095697)	Puddle	10			Turbid	Dragon flies.
Ilara	1 (7.3568315 and 5.1046776)	Discarded truck tyre	12	5.33±3.33[a]	0.07±0.02[ab]	Greenish	Dragon flies, pride of barbados trees.
	2 (7.344503 and 5.1052663)	Open water body	2			Greenish	Green algae, green grasses, bromeliad plants. Water spiders, midges, damsel flies and dragon flies.
	3 (7.346225 and 5.1091159)	Blocked drainage system	2			Greenish	Damsel flies, dragon flies, tadpoles and adult anurans, midges, lizards and water spiders.

Table 1. Contd.

Ipogun	1 (7.2888774 and 5.1460546)	Blocked drainage system	5	13.67±6.33^{a}	0.03±0.02^{ab}	Clear	Dragon flies.
	2 (7.3023612 and 5.0833001)	Discarded container	26			Greenish	Midges and dragon flies. Green algae.
	3 (7.315477 and 5.078567)	Used tyres	10			Greenish	Green algae.
Ibule	1 (7.3095428 and 5.1321278)	Puddle	5	3.50±0.76^{a}	0.09±0.03^{ab}	Turbid	Green algae, full of anuran's eggs.
	2 (7.3139539 and 5.1244894)	Discarded container	2.5			Clear	Trees.
	3 (7.3240689 and 5.1171348)	Discarded container	3			Clear	Midges.
Aaye	1 (7.3118911 and 5.2024889)	Tyre track	5	2.52±1.32^{a}	0.05±0.01^{ab}	Turbid	Tadpoles and dragon flies. Trees and grasses.
	2 (07.3203745 and 5.1582515)	Concrete hole	2.05			greenish	Dragon flies, tadpoles and adult anurans, midges, lizards and water spiders. Green algae.
	3 (7.3129921 and 5.21030121)	Discarded container	0.5			Clear	Tadpoles.
Ijare	1 (7.360816 and 5.1641861)	Artificial pool	60	5.33±17.37^{a}	0.05±0.03^{ab}	Greenish	Algae and dragon flies.
	2 (7.3636545 and 5.1665048)	Discarded tyres	6			Greenish	Green algae, mallophaga and midges.
	3 (7.3622923 and 5.1614825)	Open water body	10			Greenish	Midges and damsel flies. Grasses.
Irese	1 (7.3118911 and 5.2024889)	Discarded tyre	1	6.33±10.14^{a}	0.10±0.01^{b}	Greenish	Dragon flies larvae and green.
	2 (7.308335 and 5.1975811)	Discarded tyre	13			Clear	Midges, damsel flies and dragon flies. Orange tree.
	3 (7.3066596 and 5.2374935)	Tyres	5			Greenish	Dragon flies.

Mean followed by the same letter along the column are not significantly different (p>0.05) using Tukey test.

supported mosquito larvae breeding, only 10 of the 33 sites were permanent/semi-permanent water bodies as illustrated in Table 1, and were populated with different kinds of predators. Similar reports are found in other works (Vince et al., 1976; Coen et al., 1981; Stav et al., 1999; Dida et al., 2015). A good number of the tyre tracks were made by lumber trucks driven through farms and forest and had become more or less permanent breeding sites for mosquitoes. Physical description of each of the sites showed that larvae were found in shallow and muddy habitats. The various predators recorded in Table 1 feed on mosquito larvae. Grasses were present in some of the sampled sites, these plants facilitated breeding by slowing down water current, blocking water flow and providing shade and points for laying eggs(Asaeda et al., 2005). The observed larvae density ranged from 0.01 to 0.10, the larvae were equally distributed across breeding sites in 9 of the 11 towns, with significant differences observed only at the sites in Isarun and Irese. The observed distance between the breeding sites and residential abodes ranged between 0.5 to 300 m, a distance that can easily be covered by the vectors, and can allow effective transmission of mosquito borne diseases in the local government area.

Temperature, total dissolved solids, electrical conductivity and dissolved oxygen were found to be the main variables influencing the abundance and distribution of mosquito larva and predators in the habitats investigated. These abiotic factors could inhibit adult mosquitoes' oviposition (Minakawa et al., 1999, 2012).

The temperature in all breeding sites ranged from 20.80 and 32.60°C, mosquito larvae were seen in breeding sites with temperature as low 20.8°C at Igbara-Oke, although relatively higher than the value observed by Kleinschmidt (2001). Temperature had significant effect on all the mosquito species larvae as higher temperature values increases the presence of these species. Mean temperature from all the sites showed that sites at Owode-Owena, Ero, Ilara and Ipogun were

Table 2. Physico-chemical parameters of larvae collected per site.

Town/village	Site number	Total dissolved solid (ppm)	Dissolved oxygen (mg/L)	pH	Temperature (°C)	Electrical conductivity (mS/cm)	Dominant species
	1	543	6.70	5.70	31.12	0.65	*Anopheles* species
OwodeOwena	2	510	5.90	8.50	31.80	0.48	*Culex* species
	3	540	6.50	5.30	32.30	0.51	*Culex* species
	1	1691	2.70	6.40	23.20	2.26	*Culex* species
Ibuji	2	1147	4.50	7.20	22.60	1.50	*Culex* species
	3	578	7.20	6.50	23.50	0.80	*Culex* species
	1	375	5.90	8.00	25.80	0.50	*Culex* species
Igbara-Oke	2	543	6.10	7.10	29.30	0.73	*Culex* species
	3	620	5.30	7.40	20.80	0.87	*Culex* species
	1	778	5.60	6.20	24.70	1.07	*Anopheles* species
Isarun	2	505	7.00	6.60	21.20	0.77	*Aedes* species
	3	1029	6.10	6.70	28.90	1.47	*Culex* species
	1	1099	4.60	6.40	28.90	1.51	*Aedes* species
Ero	2	615	5.10	6.60	29.30	1.01	*Culex* species
	3	1085	3.20	6.30	31.20	4.30	*Culex* species
	1	513	6.00	7.20	32.20	0.71	*Culex* species
Ilara	2	352	3.00	6.50	31.20	0.49	*Culex* species
	3	781	4.00	7.30	31.80	1.09	*Culex* species
	1	257	7.80	6.30	31.70	0.36	*Culex* species
Ipogun	2	400	5.30	7.10	32.60	0.55	*Culex* species
	3	1423	4.50	6.50	29.90	1.14	*Culex* species
	1	520	6.10	7.20	29.90	0.71	*Culex* species
Ibule	2	1933	4.99	6.90	29.30	2.59	*Culex* species
	3	1868	7.11	7.30	29.00	2.49	*Aedes* species
	1	277	5.60	6.50	29.20	0.38	*Anopheles* species
Aaye	2	488	5.10	6.50	27.40	0.49	*Anopheles* species
	3	131	5.30	6.70	28.20	0.17	*Culex* species
	1	043	7.40	6.90	27.80	0.05	*Culex* species
Ijare	2	261	6.00	6.40	28.80	0.37	*Culex* species
	3	256	6.30	6.70	29.40	0.63	*Culex* species
	1	074	6.40	6.20	25.50	0.09	*Culex* species
Irese	2	126	5.69	6.70	25.60	0.17	*Culex* species
	3	262	6.15	6.30	26.00	0.36	*Culex* species

significantly different from other sites as presented in Table 2. The temperatures of breeding sites at Ibuji were significantly different from other sites at Aaye, Igbara-Oke, Isarun, and Irese. Culicines seemed to adapt to a wide range of temperature as they dominated most of the habitats revealing that temperature is a key factor in the distribution of mosquitoes as also reported (Piyaratne et al., 2005; Henri et al., 2010; Abdel-Hamid et al., 2011).

The range of pH was between 5.30-8.50, pH similar with the observations of Afolabi et al. (2013). pH had a significant effect on the breeding of *A. gambiae* s.l, *Culex* sp, *Toxorhynchites* sp and *Coquillettidia* sp larvae, these species tend to be acidophilic in nature, as higher pH values reduced their presence. pH had no significant effect on the other species, mean pH from all the sampled sites showed no significant difference across settlements. Electrical conductivity (EC) affected the presence of *A. gambiae* s.l., *Toxorhynchites* sp, *Mansonia* sp larvae and *Coquillettidia* sp larvae in the various sites as higher values of EC reduced their presence, but did not seem to affect *Aedes*, and *Culex* species. Mean of electrical conductivity from all the settlements showed that sites at Irese were significantly different from other sites. The range of total dissolved solid (TDS) was between 043 and 1933 ppm as shown in Table 2. TDS had a significant effect on the breeding of *A. gambiae* s.l., *Culex* sp *Mansonia* sp and *Coquillettidia* sp larvae as higher TDS values reduced the presence of these species, but had no effect on the other species. Sites at Ibuji, Aaye, Ijare and Irese had significantly different TDS values from other sites. Tyres had the highest TDS as also reported by Obi et al. (2016). The range of the dissolved oxygen was 2.70-7.80 mg/L, the dissolved oxygen was highest in small water bodies in comparison to larger water bodies due to low usage of free oxygen in the small water bodies. Dissolved oxygen had significant effect on all the mosquito species larvae as higher dissolved oxygen values increased the presence of these species, as also reported by Surendran and Ramasamy (2005), Muturi et al. (2008), Oyewole et al. (2009) and Dejenie et al. (2011). Mean of dissolved oxygen from all the sites showed no significant difference across sites. Culex spp occurred in habitats with wide range of dissolved oxygen levels; Opoku et al. (2007) gave a similar report.

Temperature, total dissolved solids, electrical conductivity and dissolved oxygen were identified to play significant roles in the survival and breeding of these vectors in Ifedore local government area of Ondo state. *Culex* species, arising from its dominance in most of the sites are better breeders being able to tolerate a wide range of physico-chemical variations; though not vectors of malaria, they are incriminated in the transmission of debilitating agents particularly the filariasis parasites. This also predisposes the local government area to *Culex*-vectored pathogens.

Anopheles larvae were dominant in four of the breeding sites, and against previous reports (CDC, 2015), they were not found in clear water but turbid environments. Despite the small number of breeding sites for these malaria vectors, malaria is endemic in the study area which may be indicative of a small number with high vectoral capacity or in-house residual breeding where most transmission takes place. Most malaria vectors in the tropics are anthropophilic and endophilic.

Adequate understanding of these breeding sites is needed to control mosquito particularly in deploying environmental modification of breeding sites. The latter will be advisable over deployment of chemicals into such sites that may also serve other functions to non-target organisms. In conclusion, all the three tiers of government in the country should endeavour to provide adequate social amenities like pipe borne water, proper drainages and good roads so as to prevent the creation of temporary mosquito breeding sites, which were more in number in the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors acknowledge with thanks the assistance of Messrs Sunday Ogunleye and Timilehin Oluwateru during sampling. Gratitude also goes to Dr. Dapo Adeogun and the Mosquito Sentinel Site of University of Ibadan for morphological identification.

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Vol. 11(6), pp. 75-83, July 2019
DOI: 10.5897/JENE2019.0765
Article Number: BCB01DE61425
ISSN 2006-9847

http://www.academicjournals.org/JENE

Journal of Ecology and The Natural Environment

Review

Is the expansion of *Eucalyptus* tree a curse or an opportunity? Implications from a dispute on the tree's ecological and economic impact in Ethiopia: A review

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Received 1 May, 2019; Accepted 5 July, 2019

This review was made to bring forth the contradicting outlooks from different research findings, challenges on the Eucalyptus species and show the opportunities we have with the tree. Due to the impact of Eucalyptus tree species on ecological health and agricultural productivity, ecologists, policy makers and politicians have had a negative view on this tree species. Hence, attempts are made to remove the tree from the agricultural landscape in some part of Ethiopia. In contrast, the farmers of Ethiopia prefer the fast growing, economically attractive, and the quality wood yields of Eucalyptus tree species. So we need to look for other dimension to coincide the existing contradictions. Eradication of the tree cannot be solution without replacing with suitable tree species for maintaining biodiversity and ecological balance. The tree can continue to supply fuel wood and construction material and thereby retard the rate of deforestation and loss of biodiversity resources of the remnant forests of the country. Collaborative work is crucial to gear efforts towards the establishment of a proper management system for the cultivation of Eucalyptus tree. Appropriate management practices such as species selection, planting site selection, correct site-species matching and efficient utilization can maximize the opportunity obtained from the tree. It is also very important to look for alternative trees species to replace Eucalyptus trees, and further studies are required to test the level of Eucalyptus species impact on specific ecosystem. Also, polices need to achieve a reasonable trade-off between the socio-economic value and agro-ecological conservation.

Key words: Agro biodiversity, biodiversity, ecology, eucalyptus, forest.

INTRODUCTION

Eucalyptus species are the most widely introduced long and ever green exotic trees from Myrtaceae family (Rassaeifar et al., 2013). Eucalyptus was introduced to Ethiopia as modern tree plantation from Australia in 1895 during the time of Emperor Menelik II to alleviate shortage of firewood and construction wood in the capital,

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Addis Ababa (Amare, 2010; Yitebitu, 2010). Today, Eucalyptus is the characteristic feature of the rural landscape and it is very important in smallholder livelihood in most parts of Ethiopia. It covers higher share of fuel wood and construction materials supply compared to other forest resources in Ethiopia (Mekonnen et al., 2007).

Currently, more than 100 species of *Eucalyptus* are grown in Africa, and about 55 of them are cultivated in Ethiopia (Friis, 1995). Ethiopia holds the largest Eucalyptus plantation in East Africa and it produces the most important commercial species: *Eucalyptus globulus* locally known as *Nech-Baharzaf* and *Eucalyptus camaldulensis* locally known as *Key-Baharzaf*. However, *Eucalyptus grandis, Eucalyptus saligna, Eucalyptus veminalis, Eucalyptus citiodora,* and *Eucalyptus bicostata* are also wide spread popular species in the country (FAO, 2009).

The problems of *Eucalyptus* tree planation cited are mostly related to its effects on the environment. In FAO (1988) and Anonymous (1992), the adverse effects of Eucalyptus tree species on the soil are related to the leaf litter on soil humus, and failure to control or sometimes to aggravate soil erosion. In addition, it is mentioned that the tree inhibits the growth of other vegetation under their canopy and refrains food supplies or adequate habitat for wildlife (Cordero–Rivera et al., 2017).

However, the success of this species in Ethiopia landscapes is not without limitations. The increasing interest of smallholder farmers to cultivate *Eucalyptus* species in a monoculture stand complicates systematic *Eucalyptus* management to minimize environmental impact and insure sustainable land use system (FAO, 2009). This conflicting interest between short term benefit from *Eucalyptus* plantation by farmers and long term benefits from conserving biodiversity and the environment needs wise decision. Therefore, this review was made to synthesize literatures on the impact of *Eucalyptus* tree plantation on the ecosystem and the environment, and on the high interest of farmers towards this tree species. Then, this review forwards ways of reconciling the existing views, recommends the opportunities we have of *Eucalyptus* species and raises research gaps.

Rationale of the review

This review is framed to have in-depth look on existing literatures and personal observations regarding the controversial responses of people towards the impact of *Eucalyptus* tree species on socioeconomic, biodiversity and sustainable food production system. Major emphasis is given to portray the need of balanced judgment towards the *Eucalyptus* tree species. Besides, the future site specific research gaps were indicated to fill the technical and attitudinal gaps. The review is based on information published in journal articles since 1993, M.Sc. thesis and PhD dissertation papers, proceedings, recent reports from libraries and other relevant information including personal observations.

EXPANSION OF *EUCALYPTUS* PLANTATIONS IN ETHIOPIA

In Ethiopia due to the population pressure and unwise resource utilization, forest lands and marginal lands are converted to cultivation and fast growing trees plantation like *Eucalyptus* species. For this reason, the replacement of well-adapted, nutrient additive indigenous trees by *Eucalyptus* tree plantations is becoming a common practice (Jouquet et al., 2007). This is on the other hand reasoned out that the expansion of fast growing native and exotic tree species plantation is with the intention of delivering the current market demand of quality timber and other wood products in Ethiopia (Laclau, 2003; Lemma, 2006). The natural forests in Munesa Shashemane, Ethiopia was converted into agricultural land for crop cultivation, and later on the same land was converted to *E. saligna* and *Cupresus lusitanica* tree plantations when the land productivity got low (Lemenih et al., 2004). Apart from this, there are several examples in southern part of Ethiopia where *Eucalyptus* has expanded at the expense of natural forests, agro-biodiversity in the cultivated lands, and grazing lands (personal observation). The land use land cover classification with the use of landsat4 TM image has shown that exotic tree plantation mainly *Eucalyptus* has spatially increased with time next to cultivated land use while the forest, shrub lands, wetlands, and grass land cover was shrinking from 1984 up to 2010 in Wallecha Watershed, Southern Ethiopia (Babiso et al., 2016).

Eucalyptus is one of the most important planted tree species in Ethiopia, covering about 506,000 ha (FAO, 2009). Out of 133,041 ha of community tree plantations in Ethiopia between 1978 and 1989, *Eucalyptus* species comprise 58% (Yitebitu et al., 2010). Nearly all of the reports on *Eucalyptus* tree species indicate that the rate of expansion of *Eucalyptus* is accelerated by a quality and amount of goods it provides per a given land use time, and economic importance of this species compared to other tree species (FAO, 2011).

The farmers noticed the negative influence of *Eucalyptus* on neighboring food crops from the low performance for crops which might be due to the competition of soil moisture and nutrients, and shade effect of the tree in Amhara region, Ethiopia (Alebachew et al., 2015). Despite farmers recognition of adverse effects of *Eucalyptus* tree on the ecosystem; the *Eucalyptus* plantations are expanding at the expense of biodiversity of the forest and the agricultural lands from time to time in Ethiopia. This is mainly influenced by the economic benefits, ease of cultivation and high productivity of the tree (Mekonnen et al., 2007; FAO, 2009; Bekele, 2015). The expansion of *Eucalyptus* tree species can also be attributed to the rapidly changing global market for products from the tree and the interest of wide-scale planting for the production of biofuels (Richardson and Rejmanek, 2011).

THE IMPACT OF *EUCALYPTUS* TREE SPECIES

Water resources

Farmers in the Ethiopian highlands perceive that *Eucalyptus* plantation have affected the flow rate and even dried up springs when planted around them. *Eucalyptus* tree species lowers the ground water table as a result of a high rate of evapotranspiration it has; and aggravates desertification (FAO, 2009). *E. grandis* takes up, almost twice as much water as *Pinus patula* does during the first decade after planting (Dye and Bosch, 2000). The rate of water uptake by the *Eucalyptus* plantation is expected to be high at the young age due to its fast growth habit. At the peak of the dry season, *Eucalyptus* transpires 4-5 times more than *Podocarpus* and *Cupressus* trees of similar size (Fetene and Beck, 2004). *Eucalyptus* has three times fine root biomass in the surface soil compared to mixed plantations; which indicates that planting herbaceous crops in association and adjacent to *Eucalyptus* may lead to water competition stress on crops (Gindaba, 2003). In heavily waterlogged areas and flood plains, *Eucalyptus* trees have commonly been planted to drain water, which could otherwise harbor mosquitoes (FAO, 2009).

Allison and Hughes (1983) have found a change in the ground water recharge after the clearing of *Eucalyptus* tree in semi-arid region of Southern Australia. In their study, the recharge rate beneath native *Eucalyptus* species was <0.1 mm/year, but the recharge increased to 5 and 30 mm/yr following the clearing of the *Eucalyptus* species. There is evidence that *Eucalyptus* trees competes for water with agricultural crops lowering agricultural output as far as 10 m away from where trees are planted (Jagger and Pender, 2000). This may indicate that *Eucalyptus* trees if planted in drought prone regions can cause depletion of soil water and water sources. This impact is often manifested in terms of its canopy interception, runoff regulation, water uptake, and soil moisture depletion (FAO, 2009). This hydroulogic behavior of *Eucalyptus* is the same for Ethiopia. Although the impacts of *Eucalyptus* such as depletion of water table and the effect on hydrological cycle remain uncertain, they are still the agenda of arguments.

Nutrient resources

Eucalyptus trees have been shown to deplete soil nutrients when it was integrated in agroforestry system (Jagger and Pender, 2000), and this characteristics is believed to aggravate the stress of competition when the trees are planted adjacent to agricultural crops. Chanie (2009) found out that there was a 10 fold difference in biomass of maize between the 1 and 20 m distance from *Eucalyptus* tree bole. The nearer the crops to the *Eucalyptus* canopy were, the lower were the crop yield and biomass production, and the impact of *Eucalyptus* was higher as compared with *Croton macrostachyus* trees in the farmlands (Chanie, 2009). Another similar study by Alebachew et al. (2015) showed that with distance from the tree stand (2 to 20 m), plant height of maize, biomass, and plant count were increased as compared to the control in Amhara region, Ethiopia. This may indicate the influence of the tree on the yield and yield components of maize which could be associated with soil nutrient depletion close to the unmanaged *Eucalyptus* trees plantations.

Jagger and Pender (2000) questioned the potential of *Eucalyptus* trees to increase soil organic matter stocks and found the potential to recycle soil nutrients is very weak. In the experiment made to compare the soil organic matter (SOM) under the tree canopy, the trees have not changed the soil organic matter compared with outside the canopy soil (Chanie, 2009). Considering long term land use effects in Munesa Shashamane, Ethiopia, *E. saligna* was indicated to be less preferable plantation species for soil fertility restoration as compared with *Cupresus lusitanica* tree species (Bajigo, 2017). Moreover, due to the fast growth and short rotation time, there is high chance of mining the soil nutrient by *Eucalyptus* tree plantation stand. In contrast to other commonly used afforestation and agroforestry species such as *Leucaena spp.* and *Acacia spp.*, *Eucalyptus* species do not fix nitrogen and less likely restore the land with essential elements sustainably (Jagger and Pender, 2000). The yield of wood product is higher from *Eucalyptus and* therefore expected to have taken more nutrient too (Bajigo, 2017). Various soil physical quality indicators and some soil chemical properties, mainly organic carbon, and total N, P and K decreased as a result of reforestation with *Eucalyptus tereticornis* plantations and further decreased with increasing age of the plantations in the central Himalay (FAO, 2011). Despite of the aforementioned negative connotations with Eucalyptus plantations, however forest management such as litter management and frequency of harvesting can affect the SOM. Afforestation with *E. grandis* for 20 years returned the total SOC to nearly the native forest level after consecutive 35 years of pasture and 20 years of agriculture (Lemma et al., 2006).

Allelopathic effect on other species

Despite the benefits the *Eucalyptus* trees provide, some adverse reactions against planting of this tree is taking place; however, based on different aspects of technical, ecological and socio-economic arguments, the reactions on planting *Eucalyptus* spp vary (Teketay, 2000a). One of the ecological arguments is that eucalypts has allelopathic effect on other species close to or under the *Eucalyptus* and therefore threaten biodiversity and habitat quality (El-Darier, 2002; Watson, 2004). In the highlands of Ethiopia, farmers relate hampering effect of *Eucalyptus* trees on the growth of other understory or adjacent intercropped crops to competition for water and nutrient rather than allelopathic effects (FAO, 2009). *Eucalyptus* species allelo chemicals have caused understory suppression especially in drier climates (May and Ash, 1990). However, the crop yield reduction is the major influence that *Eucalyptus* has when crops are present under or adjacent to it. The leaf litter of *Eucalyptus camaldulensis* has shown inhibitory effect on nodulation of test plants in laboratory experiment although the trend of effect was increasing with the increase of leaf litter (Ahmed et al., 2008). It has been hypothesized that long term exposure to allelopathic chemicals may result in a bare soil and thereby to a risk of soil erosion, which may have implications for sustainable land use over time (Jagger and Pender, 2000).

Fikreyesus (2011) showed in a laboratory studies that *Eucalyptus camandulensis* has allelopathic potential from its inhibitory effect on agricultural crops in the absence of fungi and bacteria. In both laboratory and greenhouse experiment, the effect of essential oil extracted from the leaves of *Eucalyptus globulus* against two weeds indicated a decrease in the germination percent and other growth parameters (Rassaeifar et al., 2013). This may depict that *Eucalyptus* essential oils could possess inhibitory potential against crops. The study to understand the allelopathic effect of the leaf extracts of *Eucalyptus globulus* on eggplant showed the reduction of eggplant growth parameters such as root and shoot lengths, and fresh and dry weights with increasing concentration of the leaf extract (Dejam et al., 2014). The mechanisms of inhibition of crop growth were not clearly known; hence, different field and laboratory experiments may strengthen the justification that *Eucalyptus* trees have inhibitory chemicals that can affect the other plants in its vicinity. However, the techniques employed in many studies do not mimic the natural ecological processes, and there is still a need to further experiment to partition and understand the level of allopathic effects of different *Eucalyptus* spp.

Agro biodiversity and human nutrition security

There is a global growing consensus that business as usual approach is not working for sustainable nutrient dense food production system. Rather, a paradigm shift, conserving the natural form and quality of land scape is critical (GPAFSN, 2016; IPES, 2016). As stated in the International Panel of Experts on Sustainable Food Systems (IPES) 2016 report, a fundamentally different model of agriculture based on diversifying farms and farming landscapes is required for sustainable food system to satisfy the ever blooming food demand in terms of quantity, and nutritional value. The 2030 Agenda and its Sustainable Development Goals provides a framework that includes nutrition goals in farming systems; increasing yields without increasing the levels of inorganic and synthetic chemicals in the system; shaping landscapes and improving environmental integrity (Bioversity International, 2017). In this case it gives emphasis to agro-biodiversity that also includes agroforestry (Lundgren and Raintree, 1982). Beyond ecological services, agro biodiversity insures more sustainable and productive land scape and sustainable food production system (FAO, 2017).

Maintaining the landscape for agro-biodiversity is far better contributing to sustainable food system than converting it to monoculture tree plantation such as *Eucalyptus* tree species. Beyond its antagonistic characteristics to other plants monoculture plantations of *Eucalyptus* species simplifies the ecosystem ecologically and economically that meaningfully affects its ecosystem function. For instance, fast growing *Eucalyptus* tree plantations affected hydric resources which in turn lead to diminish macro-invertebrate richness and diversity (Cordero–Rivera, 2017). This kind of practices posing environmental impact and compromises the food production system through threatening the agro-biodiversity. In Wolaita, southern Ethiopia, *Eucalyptus* trees are planted as boundary demarcations, home gardens, woodlots and as roadside plants (Alemu, 2016) in the expense of loss of agro-biodiversity. The current land use changes favors the expansion of *Eucalyptus* tree woodlot while exacerbating agricultural biodiversity loss (Bajigo and Tadesse, 2015).

There are ample research evidences to show the negative impact of *Eucalyptus* tree species plantation on the biodiversity of the plantation site, and affects the nutrition security by discriminating a diversified food production (Scott, 2005; Jaleta et al., 2016; Cordero–Rivera, 2017). It is very aggressive characteristics to make *Eucalyptus* not compatible to the diversified stands, mainly the agroforestry systems. On the comparison made, the average undergrowth density of the *Eucalyptus* trees was lower than that of under coffee garden shade in agricultural land set up depicting that *Eucalyptus* with high fine root density competes more for nutrient than understory herbaceous crops (Chanie, 2009). Despite the *Eucalyptus* trees competition and allelopathic effects on the biological diversity in agroecosystem, land conversion to *Eucalyptus* tree plantation is aggravated due to high economic value (Gebrehiwot, 2013). *Eucalyptus* has expanded at the rate of about 18.82% at the expense of grassland and bush land, and its expansion was mainly due to the socio-economic benefits it provides to the community; as it was one of the few cash earning means in Ethiopia (Jaleta et al., 2016). Hence, farmers in Ethiopia convert the land uses from ecologically and economically diversified agrobiodiversity into monocultural *Eucalyptus* plantation stands, which in turn affects the nutrition security of the community/ecoregion.

SOCIO-ECONOMIC VALUE OF *EUCALYPTUS* PLANTATION

Land use change is a product of socio-economic and environmental factors. Land use change is influenced to a great extent by the performance, priorities and livelihood strategies of the local people, but also influenced by policies and regulations, institutional and cultural factors too (Maitima et al., 2004). Economic returns from crops like khat (*Catha edulis*) and *Eucalyptus* are taken as a main factor for the land use change from diversified and ecologically complex system to mono-cropping system in the Southern Ethiopia (Gebrehiwot, 2013); hence, *Eucalyptus* tree plantation expanded on homegarden agroforestry land use and the trend has been steadily increasing due to household financial income attraction from the tree crop. Consequently, the diversified food production, which is expected from homegarden agroforestry, and associated livestock products were declining (Gebrehiwot, 2013).

In the study undertaken in central Ethiopia, the result show that the majority of farmers, urban dwellers, and experts of the district agricultural office; about half of government extension agents; and some researchers preferred planting *Eucalyptus* tree species on agricultural landscape (Mekonnen et al., 2007). This finding also indicated major factors for the preference of planting *Eucalyptus* were the increasing demand for wood products in the market; ease of cultivation, wider adaptability and high rate of biomass production of the tree; and the decline in land productivity for agricultural uses. Chanie (2009) has shown that *Eucalyptus* tree planting is the most dominant tree plantation practice in the Koga Watershed in north western Ethiopia for fuel wood production, income generation and construction material demand that may not be adequately supplied with indigenous species. In south central Ethiopia, all of the construction, 20% of the charcoal, 93% of other wood products come from the *Eucalyptus* (FAO, 2011). In Lake Tana plain, *Eucalyptus* tree planting was intended for fuel wood (100%), income generation (96%) and construction (84%) despite the tree was not preferred for environmental conservation (Chanie et al., 2013).

It has been found out that the income generated from *Eucalyptus* is by far higher than the income generated from cereal crops, although the largest proportion of land was allocated for agricultural activities (Bekele, 2015; Jaleta et al., 2016). The study in central highlands has shown that *Eucalyptus* contributed about half of household income when compared with cereal crops (Kebebew and Ayele, 2010). Several studies in Ethiopia (Senbeta and Teketay, 2001; Lemenih and Teketay, 2004; Bekele, 2015) reported a positive economic role of *Eucalyptus* tree. *Eucalyptus* tree has determined the rural households' income generation practices even under moisture stressed seasons and maintained the food security status of the households through the tree products sale (Alemu, 2016). *Eucalyptus* is the tree of choice for wood production and economic benefit by farmers in Ethiopia regardless of the claims that indicate the tree is harmful to the environment and biodiversity (Chanie et al., 2013).

ECOLOGICAL ROLES OF *EUCALYPTUS* TREE PLANTATION

The 2% actual deforestation rate in Ethiopia was reported by WBISPP (2005); however, the tree is over utilized for various kinds of wood and non-wood based forest products; fuel wood consumption is significantly high in Ethiopia. The national energy balance is dominated by fuel wood, which is accounting for over 90% of the primary total energy supply (Yitebitu et al., 2010). While the main source of fuel wood is natural forest, the eucalyptus plantation shares the burden and lets the natural forest protected of deforestation Table 1.

However, *Eucalyptus* plantation has positive contribution in light of meeting the increasing demand of fuel-wood and construction materials. Since *Eucalyptus* tree species are fast growing and providing quality wood in small woodlots for the population that meets their demand, the tree species reduce the destruction and degradation of indigenous species of natural forests. The tree therefore indirectly serves to protect the biodiversity away from the planted site by preventing the destruction of natural forests (Kenya Forest Service, 2009). In line with this, several studies have confirmed that the introduction of *Eucalyptus* species to Ethiopia was a great success in perpetuating the indigenous species, which implies that this tree is playing a positive ecological role (Senbeta and Teketay, 2001; Lemenih and Teketay, 2004; Bekele, 2015).

One of the criticisms associated with *Eucalyptus* elsewhere is that it prohibits the establishment of understory plant species due to the fact that the tree is usually taller than other plants of equal age, so that shade over the understory species. Besides, the annual crops grown close to *Eucalyptus* plantation yield less than those grown far from the edge (Chanie, 2009). This may show the lack of sound management besides the effect of the tree species (Teketay, 2000b). Despite of these facts, *Eucalyptus* tree species expansion by itself is

Table 1. Status of fuel wood demand in Ethiopia.

Source	Annual wood supply	Annual consumption	Deficit or surplus
World Bank (1984)	8.1 MT (13.5 million m^3)	20.34 MT (33.9 million m^3)	Consumption is 2.5 annual yield
ENEC/CESEN (1986)	63 MT	24 MT (40 million m^3)	Positive balance
EFAP (1994)	8.6 MT (14.4 million m^3)	35 MT (58.4 million m^3)	Consumption 4 times higher
UNDP/World (1996)	n.a.	31.5 MT (52. million m^3)	Deficit indicated
WBISPP (2005)	50.1 MT (84.9 million m^3)	53.6 MT (89.4 million m^3)	Deficit of 3.5 MT
EFAP (1994) projection for 2020	-	-	Deficit 87-121 million m^3

Source: Yitebitu et al. (2010).

not hazardous to the ecosystem when a proper management and species selection is in place. Rather, if possible to overcome the limiting factors with *Eucalyptus* species, it can improve the efficiency of the land performance (Aramde and Hailu, 2013). As intercropping of rice and beans with *Eucalyptus camaldulensis*, and *Eucalyptus urophylla*) show good yield in Brazil (Ceccon, 2005; Ceccon, 2007), *Eucalyptus* based agroforestry system in the waterlogged highlands of Ethiopia has shown a rise in the productivity without an effect on the soil nutrients (Kidanu, 2004).

Not all *Eucalyptus* tree species have a detrimental shading effect on the growth of understory plants (Yirdaw and Luukkanen, 2003); rather, some evidences show a positive relation to biodiversity. For instance, the older *Eucalyptus* tree plantations exhibited a significantly larger proportion of woody plants richness in its understory although a lower richness of herbaceous species in this age class in China (Jianping et al., 2015). In the same context, *Eucalyptus globulus* and *E. saligna* plantations established near to seed sources from nearby natural forest have fostered the regeneration of native woody species (Senbeta et al., 2002). Similar finding was reported by Telila et al. (2015) that the small *Eucalyptus* plantations have a potential to foster native woody plant diversity in central Ethiopia. Despite the reality that the herbaceous species richness is low under *Eucalyptus* tree shade, Teketay (2000a) has found greater richness of herbaceous plant species under *Eucalyptus* than adjacent natural forest. On a heavy clay soils, wheat production was not affected by *Eucalyptus* tree (Kidanu et al., 2005). Furthermore, when *Eucalyptus* tree was used as coffee shade, it was found that the coffee quality was as acceptable as that from indigenous forest coffee (Alem and Woldemariam, 2010). The implication is that *Eucalyptus* tree species selection, matching to the agro-ecology, silvicultural management, and appropriate land use planning would help to utilize the potential of *Eucalyptus* tree species in an ecologically harmonious manner.

Growing the *Eucalyptus* tree can serve as a source of shade, erosion control, windbreak and shelterbelt roles of the tree in farmlands and can moderate the climatic factors (temperature and rainfall extremes) (Alemu, 2016). The experiment of Jaleta (2017) in central highlands of Ethiopia shows that the moisture content under Eucalyptus woodlot was significantly higher than cultivated land, while there was no significant difference when compared to the grassland as indicated in Table 2. Hence, the experiment revealed that the expansion of Eucalyptus has no significant impact on surface runoff generation if it is expanded on previous grassland; rather it could significantly reduce the surface runoff generated if it is planted on previously cultivated land.

Due to its fast growth rate and high biomass accumulation, *Eucalyptus* can play very important role in carbon sequestration, and may be the most preferable plantation tree species to combat global warming (Lemma et al., 2006).

CONCLUSION

The existing knowledge and practices indicates that there are opposing views on the *Eucalyptus* tree species depending on the view point they consider. With some empirical evidences on the *Eucalyptus* tree species impact on soil quality, biodiversity, agricultural productivity, and the hydraulic system, numerous ecologists have shown a negative view on the tree. With the conviction of the evidences, policy makers and politicians have also expressed their negative attitude towards this tree species. These groups forecast the long term detrimental impact of *Eucalyptus* tree on ecosystem of the landscape which integrates the tree. Land use system must lean towards maximization of the overall land economic value in a sustainable manner. In contrast, farmers who plant *Eucalyptus* and benefit from it desire the fast growing, economically attractive, and the quality wood yielding *Eucalyptus* tree species without regarding the environment. On the other hand, the meaningful contribution of this fast growing tree in safeguarding the remnant, and newly developing natural forest is very crucial through fulfilling the wood demand of the country. Despite the existing evidences on *Eucalyptus* tree plantation's negative ecological impact, eradication of the tree cannot be solution. Rather, it is better to gear efforts towards the establishment of a proper management

Table 2. Mean of rainfall, runoff and runoff coefficient from three Land use land cover.

Land use	Daily rainfall (mm)	Daily runoff (mm)	Runoff coefficient (%)	Total runoff (mm)
Cultivated land	11.8 ± 0.53	(2.53 ± 0.08)[a]	(23.92 ± 0.33)[a]	(191.9 ± 4.2)[a]
Grassland	11.8 ± 0.53	(1.95 ± 0.07)[b]	(17.90 ± 0.25)[b]	(147.8 ± 4.5)[b]
Eucalyptus woodlot	11.8 ± 0.53	(2.03 ± 0.07)[b]	(18.92 ± 0.25)[b]	(154.0 ± 2.9)[b]
LSD (5%)	-	0.19	0.77	5.57

Source: Jaleta et al. (2017).

system for the growth and development of the *Eucalyptus* tree plantations in agricultural landscape, and large plantation stands. For instance, thinning reduced stem density by two-thirds, and substantially raised the activity and richness of bats, and bats species composition (Gonsalves et al., 2018). The *Eucalyptus* trees can continue to combat the growing deforestation rate and loss of biodiversity due to deforestation by reversing the fear of ecologists and other concerned bodies regarding ecological deterioration. Appropriate management practices such as species selection, planting site selection, and correct site-species matching efficient utilization can be sustained with little adverse impact on the ecology of agricultural landscape. Despite of this, contradictions may persist until alternative trees that replace *Eucalyptus* trees with equivalent socioeconomic value while bringing positive ecological function is found. It seems not possible to totally refuse and eradicate the tree, particularly from Ethiopia and developing countries in general, whose current dependency on *Eucalyptus* is enormous. Rather, more researches are required to test the level of *Eucalyptus* species' specific impact on ecosystem while fulfilling all the interest of the land users at all level. Therefore, wise utilization of the potential of *Eucalyptus* tree on the areas having large land size holdings with well-designed integration to other land uses can solve the current aggressive deforestation and forest degradation from the increasing wood product demand.

ACKNOWLEDGEMENT

The authors appreciate the local farmers around Wolaita zone. The farmers who have raised controversial questions on the ecological problems of *Eucalyptus* while they still prefer the tree for their livelihood by resisting government push to stop planting this tree inspired the authors to conduct this review.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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