RESEARCH ARTICLE

TRADITIONAL COFFEE MANAGEMENT PRACTICES AND THEIR EFFECTS ON WOODY SPECIES STRUCTURE AND REGENERATION IN BALE ECO-REGION, ETHIOPIA.

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Manuscript Info	*Abstract*
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Traditional coffee management varies across location and may result in different effect on structure and regeneration of woody species. This study was aimed to investigate the effect of forest coffee management practices on structure and regeneration of woody species in Bale Eco-Region, Southeastern Ethiopia. Eighty (20 m x 20 m) quadrants and five 5m x5m subplots within each main plot were laid out along parallel transect lines across the forests for collecting data from mature, and saplings and seedlings woody species respectively. Data on traditional forest coffee management, structure and regeneration status of woody species were collected through in depth interview with fourteen key informants and field surveying respectively. All plant species found in each plot were identified, and their number, height and DBH were measured following standard procedures. The density, basal area and size of growth forms between the forests were compared using t-test at 0.05 significance level. Slashing of under growth vegetation, thinning shade trees, hoeing under forest coffee, and cutting of shrubs and saplings were the traditional coffee management practiced in the forest coffee to improve its productivity to earn more income. The density, basal area and regeneration status of woody species in forest coffee area significantly (P<0.000) differ from the natural forest. The density, DBH and Height of woody species in both forests have inverted **J** shape and were varied significantly between the forests. The natural forest has good regeneration status but the forest coffee experienced fair regeneration. However, few saplings (2.3%) and matured trees (5.7%) were recorded in coffee forest, which may lead to subsequent loss off the forest coffee if current situation will continue. Therefore, researches on development of sustainable forest coffee management methods, and enhancing technical and economic capacity of inhabitants through training and diffusion of technologies that compensate socioeconomic benefit obtained through damaging woody species are crucial to sustain the forest coffee ecosystem in Harena forest.

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Introduction:-

Tropical forest ecosystems contain diverse animal and plant species. The presence of diverse species provides resources and habitats for all species (Barbier et al., 2008). Similarly, afromontane forests comprise naturally growing coffee plants as understorey shrub or small tree in southwestern and southeastern Ethiopia. This makes Ethiopia the original habitat and center of genetic diversity of Coffee arabica (Teketay, 1999; Yadessa et al., 2008). Coffee production is associated with shade trees that contributed for the survival of most remnant forests in Ethiopia. Over 60% of remaining forests in Ethiopia are found only in the major coffee growing areas in the southwestern, southern and southeastern parts of the country, including the Haranna forest in Bale Mountain Ecoregion (BMER) (Woldemariam and Senbeta, 2008). These forest areas are called the Eastern Afromontane Biodiversity hotspot and considered as one of the 34 globally hotspot areas for biodiversity conservation (Mittermeier et al., 2005). Hence, Shade-grown coffee has been promoted as a means for preserving biodiversity in the tropics (Ambinakudige and Sathish, 2009). Moreover, indigenous communities have been utilizing wild coffee for centuries for household consumption and as a cash crop. In total, 30% of the total Ethiopian coffee production originates from forest and semi-forest coffee (Abebaw and Virchow, 2003) and contributing 41 % of the country's foreign currency income (FAO and WFP, 2006). These imply that forest coffee plays both economic and ecological roles.

Population growth and reliance on subsistence agriculture were forced rural people to encroach natural forest or protected area for the purpose of livelihood improvement. As a result, many forest ecosystems in the world have been exploited beyond their capacity to enhance and conserve native woody species diversity (Brown and Boutin, 2009; Emmanuel, 2011; Myers, 2000; Rees and Juday, 2002). Similarly, the montane rainforests of Ethiopia including the forest coffee areas are under great threat of rapid deforestation. For instance, wild coffee is growing inside the forest by removing competing undergrowth vegetation and some canopy trees at least once a year (Schmitt and Grote, 2006; Teketay, 1999) to the extent that can modify forest structure or convert them in to agricultural land, new settlements and timber extraction (Reusing, 2000). Moreover, Woldemariam et al., (2002) reported an estimated deforestation rate of 10,000 ha/year in the coffee growing areas in the southwest Ethiopia.

In forest coffee systems of BMER, farmers traditionally managed forest coffee in three different systems (forest coffee, semiforest coffee and garden coffee) to increase coffee density and optimize its productivity (Senbeta and Denich, 2006; Woldemariam and Senbeta, 2008). The conversion of a forest coffee system into a semi- forest coffee system affects the floristic composition and diversity of plant species in the forest (Senbeta, 2006; Tesfaye, 2006; Woldemariam, 2003). Studying population size structure of plant species based on the outcome of past demographic events provides valuable information as an indicator of its demographic future (regeneration/recruitment status) for devising evidence based sustainable management, use and conservation (Hundera et al., 2013; Tadesse, et al., 2014). Hence, understanding the impact of coffee management on regeneration of native woody species is crucial to sustainably mange the remnant forest coffee ecosystem. Therefore, this study was aimed to investigate effect of traditional forest coffee management practices on structure and regeneration of woody species in BMER, Southeastern Ethiopia.

Materials And Methods:-

Description of the study Area:-

This study was conducted in Bale Eco-region particularly in Dalomena and Harena Buluk districts, southeast Ethiopia. Dalomena and Harena Buluk districtss are found southeast of Addis Ababa and they have a total area of 1,339km^2 and 1934 km^2, respectively. Both districts are situated between 07˚00' - 7˚25'N Latitude and 35˚55' - 36˚37'E Longitude and within altitudinal range from 1600 to 1900 m asl. The area characterized by bimodal rainfall where the short rain season and long rain season occur form March to April, and from August to October, respectively. The Mean annual rainfall and mean annual temperature are 700 to 1200 mm and 18^{0}C respectively (Woldemariam and Senbeta, 2008). The forest in the study area including the forest coffee is called "Harena forest". The Harena forest is one of the montane forest located in southeastern Ethiopia (Senbeta and Denich, 2006; Woldemariam and Senbeta, 2008). This forest supports many over 300 vascular plant species and many endemic plant species than other rainforests (Senbeta, 2006). Forest coffee occurs in the dry lower lying areas of the forest between 1300 and 1850m asl. *Podocarpus falcatus* and *Strychnos mitis* are the dominant plant in the upper canopy and *Coffea arabica* chiefly dominates the understory (Woldemariam and Senbeta, 2008).

Sampling and data collection Techniques:-
Eight of parallel transects were laid out systematically both in forest coffee and natural forest in line with the method used by Bullock (1996) and Woldemariam (2003). Then, eighty (40 in forest coffee and 40 in adjacent natural forest 20 m x 20 m sample quadrats were laid along the line transects at 200m intervals and located at least 100 m from forest edge/road to avoid edge effect. Within the main quadrats by designating "X" design, five 5 m x 5 m (25 m^2) subquadrats were laid out. In line with Woldemariam (2003), vegetation data [species, height, diameter at breast height (DBH) and number of individual of each species] of all matured woody plants with DBH of greater than 5 cm were collected in the main quadrats. Moreover, vegetation data (number of individuals, height, collar diameter and species) of saplings (with DBH from 5 to 2.5 cm and height greater than 1 m) and seedlings (height ≤1 m and DBH less than 2.5 cm) in both forests were collected from the subquadrats following procedure of Senbeta and Teketay (2001). All woody species in the quadrats were identified by their local names ("Afan Oromo") and scientific name with the help of published volumes of Flora of Ethiopia and Eritrea (Friis, 2009), and Useful Trees and Shrubs of Ethiopia (Bekele, 2007). DBH of trees with less than 60 cm and greater than 60 cm were measured by caliper and diameter tape respectively. DBH measurement was taken independently for trees branched below 1.3m above the ground. Hypsometer and graduated stick were used for height measurements. Moreover, forest coffee management practices and their intensities were identified through field observation and interviewing key informants. In addition, seedlings and saplings of woody species were counted and recorded in the sub-quadrats.

Data Analysis:-
Structures of forest coffee and natural forest was determined based on analysis of data of the most important structural parameters such as species density, DBH, height, basal area and frequency of those species having DBH greater than 2.5 cm and height greater than 2 m. To do so individuals of the same woody species were categorized in to five arbitrary diameter and five height classes. The frequency of individuals belongs to each class was recorded to compute percentage of frequency distribution of individuals in each class which thereby constructed in to bar graphs that show population structure of the two forests. The woody species density and basal area values were computed on hectare basis for each class. Density was calculated by summing up all stems across all sample plots and

converting into hectare basis. Whereas basal area was calculated as $g = \dfrac{\pi d^2}{4}$ for each woody species with diameter

(d) ≥ 2.5cm in which **g** is basal area (m^2) and **d** is diameter at breast height or diameter at collar point (cm). Then the density and basal area of forest coffee and natural forest will be compared statistically using t-test at 0.5 significance level using SPSS version 20 to show structural difference between them. Regeneration status of the two forests was analyzed by comparing the number of saplings and seedlings with the matured trees following method used by Gebrehiwot and Hundera (2014); Dhaulkhandi et al. (2008); Shankar (2001), and Tiwari et al. (2010). The regeneration status of the forest was determined as (1) Good regeneration, if seedlings > saplings > adults; (2) Fair regeneration, if seedlings > or ≤ saplings ≤ adults; (3) Poor regeneration, if the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults); (4) not regenerating, if a species is only in an adult form, and (5) 'new', if a species has no mature, but only sapling and/or seedling stages. Qualitative data collected via in-depth interview were first organized in to theme, then transcribed and finally narrated in the eyes of the key informant and objective of the study.

Result:-
Traditional forest coffee management practices in the forest Coffee:-
Traditional forest coffee management in this study refers to all practices carried out by local people to minimize the effect of woody and herbaceous plant species on existence and productivity of coffee plants. Key informant revealed that forest coffee users carried out slashing of undergrowth (herbs, seedlings and saplings), hoeing under coffee plants, decreasing density of shade trees through thinning, planting of seedlings of improved coffee varieties, cutting of woody plants and girdling of trees (Table 1). However, clearing under growth vegetation, thinning of shade trees and cutting of woody plants were intensively and widely practiced in the forest coffee to minimize the shade and competition other plants with coffee plants.

Table 1:- Indigenous coffee management practice in the coffee forest and natural forest

Indigenous coffee management practices	Forest coffee	Adjacent Natural forest
Clearing under growth vegetation	‡‡	-
Thinning (decreasing density of shade trees)	‡‡	‡
Hoeing under forest coffee	‡	-
Planting improved coffee cultivars	‡	-
Cutting woody plants	‡‡	‡
Girdling (debarking stems) of trees	‡	-

‡‡ = very intensive; ‡ = present; - = absent

The key informant revealed that they practiced them to maximize the productivity of coffee plants to earn more income for house household expenditures and to compensate reduced productivity of agricultural crops and livestock. On contrary, it was observed that significant number of forest coffee users have practiced extensive clearance of woody and herbaceous plant species and hoeing under coffee plantation, which largely harm regeneration of plants other than coffee in the forest coffee (Figure 1). Such practices have resulted in formation of human made coffee production systems like semi-forest coffee, garden coffee and coffee plantations in the Ecoregion. Among the canopy trees, those species with big leaves and dense canopy were felled or their stems were debarked around root collar area. Moreover, planting of improved coffee cultivars were practiced in some areas in the Ecoregion.

Figure 1:- Regeneration status and human interferences in forest coffee (A) and natural forest (B) (Photo by: Lemma Tiki)

Effect of coffee management on population structure of woody species:-
Most individuals in both forest coffee and adjacent natural forest were in the 0–2.5 cm DBH class and 0-1.3m height class. The number of woody plants in the first and second diameter and height class were higher in natural forest than forest coffee. It significantly decreases with increasing both in diameter and height classes. The overall diameter and height class distributions of woody plants recorded in all quadrats of both natural forest and forest coffee exhibited inverted **J** shaped curves (Figure 2 a and b).
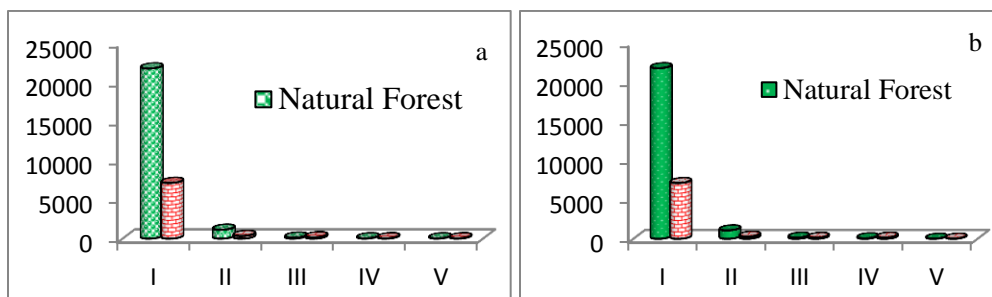
I = <2.5Cm; II = 2.5-20cm: III = 20.1 - 40cm;
IV = 40.1 – 60cm; V > 60 cm

I<1.3m; II =1.3-15m; III =15.1-29.1m;
IV =29.2-43m; V>43m

Figure *2*:- Abundance of woody species across diameter classes (a) and height classes (b) distribution of natural forest and forest coffee.

The average basal areas of woody species having diameter $\geq$ 2.5cm were 41.98 m^2/ha in the natural forest and 54.85m^2/ha in the forest coffee (Table 2). The average basal areas were not significantly differ (P $\leq$ 0.20) between the two forests though the number individuals of woody plants in the natural forest was significantly higher than coffee forest.

In aggregate, woody plants density of 23,923.8 plants ha^{-1} and 7688.8 plants ha^{-1} were found in forest coffee and natural forest respectively (Table 2). Of which about 635$\pm$58.75 and 402.5$\pm$35.75 matured plants/ha, 659$\pm$109 and 176.25$\pm$38.75 saplings/ha, and 22,630$\pm$1872 and 7,110$\pm$1009 seedlings/ha were recorded in natural forest and forest coffee respectively (Table 2). Most individuals in both forest coffee and adjacent natural forest were seedlings. The number of plants of each life form showed significance difference (P < 0.05) between forest coffee and the adjacent natural forest (Table 2). The density of woody plants of all life forms was higher in natural forest than forest coffee.

Table *2*:- Density of woody plants of different growth forms in natural forest and coffee forest in BMER

Land use	Density of woody plants/ha				Basal area (m²/ha)
	Woody plant density	**Seedlings**	**Saplings**	**Matured plants**	
Natural forest	23,923.8$\pm$74.15a	22,630$\pm$1872a	658.75$\pm$109a	635$\pm$58.75a	41.975$\pm$ 6.25a
Forest Coffee	7688.75$\pm$41.13b	7110$\pm$1009b	176.25$\pm$38.75b	402.5$\pm$35.75b	54.85$\pm$6a
P-Value	0.001**	0.000**	0.000**	0.001**	0.200

**Values with different letters in each column indicate presence of significant difference between natural forest and forest coffee.

Effect of indigenous coffee management on regeneration of woody plants:-
The results in Table 2 depicted that natural forest in BMER experienced good regeneration as the number of seedlings > sapling > matured woody plants. Of the total woody plants in the natural forest, 94.6%, 2.7 % and 2.7% were seedlings, saplings and mature trees respectively. Regeneration of woody plants in the forest coffee was fair since the number of seedlings > sapling < matured woody plants. In this study, 92.5% seedlings, 2.3% saplings and 5.2% mature trees were recorded in forest coffee. In the forest coffee, few saplings were recorded.

Discussion:-

This study revealed that local people in the study area have increased intensity of traditional forest coffee management predominantly through slashing undergrowth vegetation, hoeing, planting of improved coffee varieties, cutting of woody plants and thinning of shade trees to increase productivity of coffee plants. Similarly, Hundera et al. (2012) and Senbeta and Denich (2006) reported presence of intensive slashing of under growth, planting of coffee seedlings and frequent tree-cutting practices in forest coffee of montanae rainforests of Ethiopia. Local people only retain only large trees of species with low shade intensity and that can maintain microclimate and conserve soil moisture. However, they did not even give due attention for regeneration of the preferred tree species through retaining of their seedling and saplings. This may significantly affect conservation of genetic resources of the indigenous coffee and woody species diversity in forest coffee if it is not wisely carried out.

The overall distribution of diameter and height classes of individuals of all woody species in the study quadrants indicates a relatively high proportion of individuals fall in the lowest diameter and height classes in both forests. The distribution of woody plants among diameter and height classes experienced inverted J shape in both natural forest and forest coffee (Figure 2 a & b). Similarly, inverted J-shaped distribution of DBH and height classes in matured natural forest were reported (Alemnew et al., 2007; Girma and Mosandl, 2012; Lykke, 1998). This showed healthy population structure of woody species in both forests because of high proportion of seedlings that can grow to successive diameter/height classes if properly managed. However, the lower number of individuals in the higher diameter classes especially in forest coffee suggesting that poor recruitment of matured plants because of death of emerging seedlings and saplings in the understorey. Isango (2007) also revealed that caution should be exercised in the use of inverse J-distribution as stock control in management since the distribution assumes equal mortality rates among size classes, which regarded as biologically unrealistic like in the case of forest coffee in BMER. This study confirmed poor potential for recruitment of matured woody species has resulted in a negative impact on woody species structure in the forest coffee.

The density of woody species in natural forest (Table 2) is greater than what was reported in other Afromontane rainforests in Ermich (9,199/ha) by Zewude (2012), and Bonga (19,232/ha), Birhane-Kontir (18,981/ha) and Maji (18,183/ha) by Senbeta (2006). However, it is less than the density of Yayu forest (69, 130/ha) (Senbeta, 2006). The density of woody species in forest coffee in this study is less than all the aforementioned study results. Similarly, Lo´pez-Go´mez et al. (2008) reported that the density and basal area of trees >5 cm DBH were higher in forest than in coffee farms in Veracruz, Mexico. These clearly notice that better density of woody plants in natural forest and negative effect of coffee management on the structure (density and distribution of diameter and height class) of woody species in the forest coffee of BMER. Woldemariam (2003) confirmed structural modification of the forest coffee in Ethiopia because of coffee management practices and wood product exploitation.

Regeneration is one of the major variables that are useful to determine healthiness and sustainability of conservation of plants. Fair regeneration status in the forest coffee indicates that poor recruitment of matured trees by saplings. As clearing of under growth vegetation, seedlings of shade trees and cutting of some canopy trees are common and continuing practices in the Ecoregion, the replacement of even shade trees will be under question. Similarly, a number of studies reported the potential impact of coffee management practices on forest structure and regeneration capacity in coffee forests of in montanae rainforest of Ethiopia (Aerts et al., 2013; Hundera et al., 2013; Senbeta and Denich, 2006; Woldemariam, 2003). Moreover, El-Sheikh (2013) and Neelo et al. (2013) revealed that the ultimate loss of forest canopy through lack of regeneration was resulted in extremely negative impacts on coffee yields and loss of biodiversity. Hence, if the current traditional forest coffee management practices continue with the same trend in BMER, it is possible to forecast that most of woody species in forest coffee will be lost and the forest coffee gradually will be converted into farmland as the coffee plants gradually lose its productivity.

Conclusions And Recommendations:-
The findings of this study revealed that forest coffee management practices and exploitation of the forest products by the local communities has critically affected population structure and regeneration of woody plants of forest coffee in BMER. This is evidenced by the very low density of woody species and the dominance of individuals at lower diameter and height classes as compared to the adjacent natural forest. In general, it was noted that the forest coffee is experiencing serious human pressure mainly through indigenous coffee management for optimizing coffee productivity to compensate loss due to low agricultural crop and livestock productivity. However, the high density and regeneration of large number of seedlings of woody species in forest coffee areas can guarantee sustainability of forest coffee through recruitment if sustainable forest coffee management will be devised. This could help BMER to remain as one of forest coffee and biodiversity/indigenous woody plants conservation area in the world. Therefore, research on development of forest coffee management techniques that can maintain balance between coffee production and conservation of woody species, and enhancing capacity of inhabitants through training and technology diffusion are recommended to sustain the forest coffee.

Acknowledgments:-

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