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—Original Article—

Forest conservation from the perspective of local fuel production and its consumption in the southern part of Kilite Awlaelo district in the Eastern zone of the Tigray Region, Ethiopia

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Abstract: For the conservation of natural forest land from the viewpoint of local fuel production and its consumption in the Tigray Region of the Ethiopian Highlands, the purpose of this paper is 1) to determine the types of resources utilized as fuel and their frequencies, and the amount of fuel consumption per household, 2) to estimate the production amount of dung cake and woody plants for analyzing the balance of fuel consumption and production, and then 3) to discuss strategies to preserve forests. The local farmers used dung cake, firewood, crop residue and charcoal as fuel. The average consumption per household (all in kg DM/day/household) from June 2017 until July 2018 was 8.3 (range 0.0-20.7) of dung cake, 2.3 (0.0-8.9) of firewood, 0.1 (0.0-3.5) of crop residue and 0.2 (0.0-2.0) of charcoal. Consumption of dung cake was 3.6 times higher than of firewood. Thus, it became clear that dung cake was the main fuel, and woody plants were also an important resource. It was estimated that a household produced 10.0 kg DM/day/household of dung cake during the dry season, approximately 10 months from September to June for using the dung cake by the average of 8.3 kg DM/day/household throughout the year, with no provision for other households or any excess. Consumption of woody plants as firewood exceeded production by 2.9 times. This indicated that production and consumption of woody plants were not balanced in southern parts of Kilite Awlaelo district, and that consumption was excessive. It is extremely important to introduce solar power generation, increase the number of livestock animals (by addition of one or two adult cattle per household), change the livestock feeding management (conversion of a part of livestock keeping from grazing to barn feeding) and to popularize improved cooking stoves in order for people of the Tigray Region to reduce the pressure on use of woody plants and protect the forest environment, while using a minimum amount of firewood. The local governmental support is indispensable for these trials to reduce the consumption amount of firewood.

Keywords: fuel, firewood, dung cake, *Acasia etbaica*, forest conservation

1. Introduction

The Ethiopian highlands comprise hilly terrain with steep slopes. In these areas, soil erosion, forest decline and vegetation regression have advanced rapidly due to population increase, deforestation, expansion of cropland and increasing pressure of livestock grazing (Stahl, 1990; Thomas, 1993; Rasmussen *et al.*, 2001; Nyssen *et al.*, 2004). To handle this issue, Ethiopia began environmental conservation activities in the 1970s, as a part of a food-for-work project with financial assistance from various other countries. This project was led by the Ethiopian Government, and led to planting *Eucalyptus camaldulensis*, *Acacia senegal*, *Dodonaea* sp. and *Acacia etbaica* on land where vegetation had regressed, and installing stone arrangements such as stone bund and stone terrace to facilitate growth of planted trees and prevent soil erosion. In planted land, environmental conservation was facilitated by completely prohibiting grazing of livestock and collection of branches fallen from woody plants (Humphery, 1999). This prohibited grazing and protected forest land is called *deni meret* in the Tigray Region. In addition, an environmental conservation activity called *netsa gadeba* was promoted with free, voluntary labor of local farmers for 20 days a year in the Tigray Region following discussion among the region's farmers and advice from the municipality after the democratization in 1991. The *netsa gadeba* activity constructs the stone bund called *gadeba* in the *deni meret* of the prohibited grazing

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and protected forest land to prevent soil erosion. As to these environmental conservation efforts, the vegetation in natural grassland and forest land in the Tigray Region has gradually recovered (Haregeweyn *et al.*, 2012, 2015; Nyssen *et al.*, 2014; Tahir *et al.*, 2017). The Tigray Region was awarded the Future Policy Gold Award from the World Future Council Foundation in 2017, which led to global awareness of their environmental conservation activities in restoring and protecting forests (World Future Council Foundation, 2017).

Expansion of the prohibited grazing and protected forest land has resulted in decreases in area of natural grassland and forest where livestock can be put to graze—thus the environmental protection policies can suppress the numbers of livestock in the region, and have negative effects on livestock management (Hirata *et al.*, 2018). If the livestock numbers per household decrease, the amount of livestock feces available to farmers for fuel and fertilizer will also decrease. In addition, the areas available for farmers to gather fallen branches also decrease with expansion of the prohibited grazing and protected forest land, resulting in less firewood collected. Livestock feces and firewood are essential resources for cooking for the local people, and decreases in their amounts can be a serious matter of the living life. Thus, expansion of prohibited grazing and protected forest land is effective for environmental conservation, but can have negative effects on local people in terms of securing fuel resources.

Estimates on the current existing amount and growth of woody plants have been made in the Tigray Region, from the viewpoint of environmental conservation (Giday, 2002; Ubuy *et al.*, 2014; Abebe *et al.*, 2017; Shimelse *et al.*, 2017). Few studies have reported the consumption of firewood derived from woody plants, or on the amounts of livestock feces production and its consumption. The amount of livestock feces used for manure on cropland has increased and the amount of dung cake used as fuel has decreased (Mekkonnen and Köhlin, 2008). The decreased use of dung cake as fuel leads to concern that this may lead to increase the use of firewood and excessive felling of woody plants. Therefore, it is important for the conservation of natural forest land from the viewpoint of fuel utilization to estimate the amounts of local fuel consumption and its production in the same area, and then examine the balance of local fuel production and its consumption in the area for analyzing the strategy of sustainable fuel use.

To examine the conservation of natural forest land from the viewpoint of local fuel production and its consumption in the Tigray Region of the Ethiopian Highlands, the purpose of this paper is 1) to determine the types of resources utilized as fuel and their frequencies, and the amount of fuel consumption per household, 2) to estimate the production amount of dung cake and woody plants for analyzing the balance of fuel consumption and production, and then 3) to discuss strategies to preserve forests.

2. Location and method

2.1. Location of study area and its natural environment

The field survey was conducted in three locations, Debre Birhan community, Kihen community and Agulae town, in the Kilite Awlaelo district, Eastern zone, Tigray Region in northern Ethiopia (**Figure 1**). The monthly average air temperature of Wukro town where is located in the central-eastern part of the district is nearly constant throughout the year at around 20°C, because it is close to the equator. The diurnal temperature difference is much larger than the annual difference, with monthly maximum and minimum average temperatures of approximately 30°C and 10°C, respectively. Wukro is a semi-arid region with an average annual rainfall of 572 mm from 1992 to 2013 (National Meteorological Agency, 2014). There is a large variation in rainfall between years, with 984 mm in 2000 and drought of 305 mm in 1992. The dry season is September through June, and rainfall occurs during the rainy season of July and August, although the rainy season may linger into September. As described above, the natural environment of the location of study area in the Ethiopian highlands, which is close to the equator, has an average temperature warm throughout the year, semi-arid climate comprising rainy and dry seasons, and large variations in rainfall between years.

2.2. Survey households

The amounts of fuel consumption were measured from July 2017 to June 2018 for nine households: five in Kihen, three in Agulae and one in Debre Birhan (**Table 1**). Household 1 had a family structure of father (44 years old), mother (37) and five children aged 2-14 living together. Although Household 1 had seven children in total, family members who lived together were only counted in order to relate the number of people to the fuel consumption. They kept a total of six animals as livestock: five head of adult cattle aged 4 years or older and one calf. The family structures for Households 2 to 9 consisted of 5 to 9 members and the total numbers of livestock animals were 3 to 9 heads.

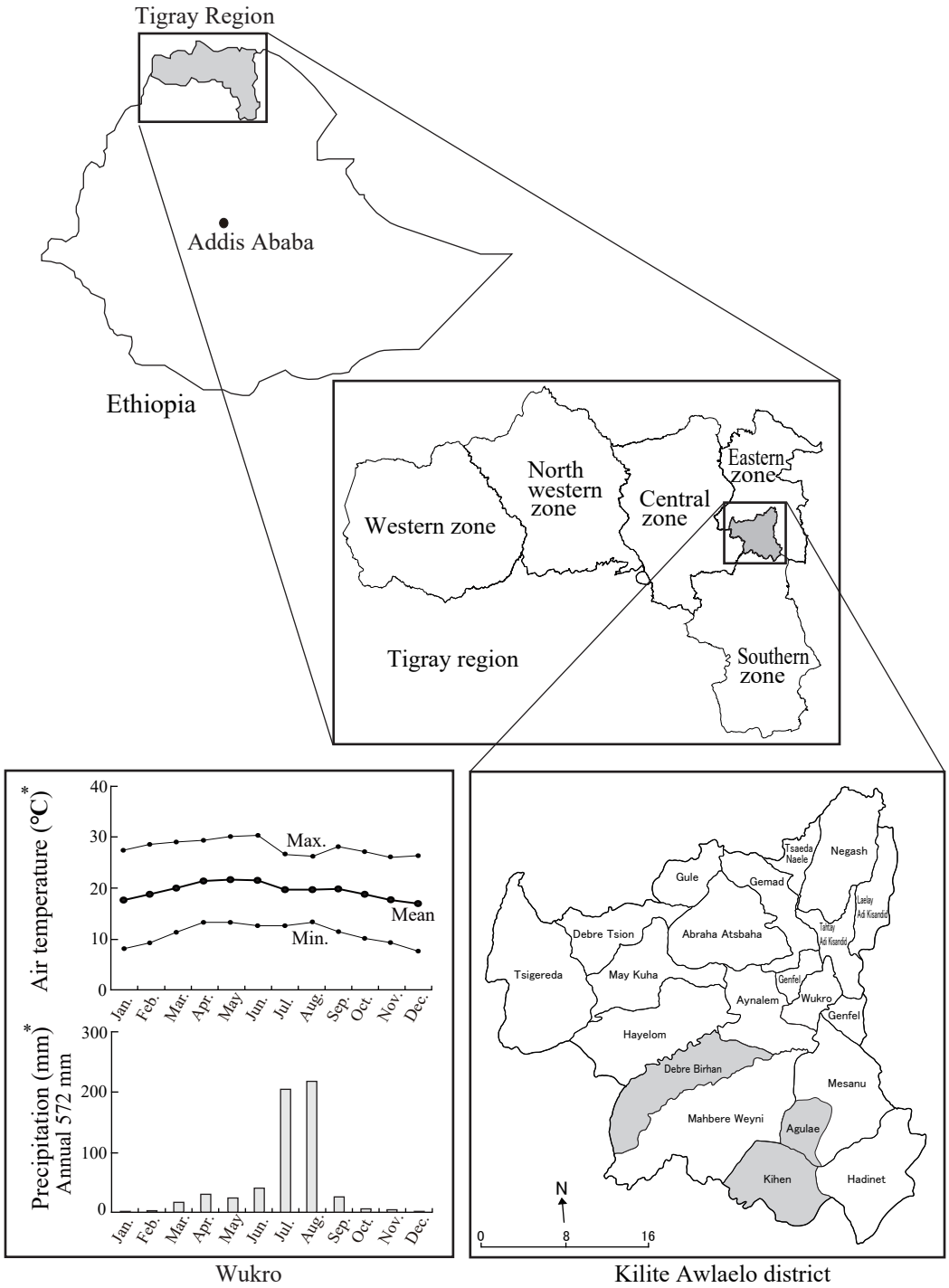

Fig. 1. Air temperature (˚C), precipitation (mm), and survey area (▭) in Kilite Awlaelo district, Eastern zone, Tigray region in northern Ethiopia.

*: Air temperature and precipitation are the 22 years' average from 1992 to 2013.

2.3. Resources consumed as fuel, frequency of use and amount of consumption

The fuel resources consumed by the nine households were counted once a month, and the frequency of those uses was calculated by fuel type. The amount of fuel consumption was calculated by measuring a certain amount of fuel the day before the survey date and measuring the remaining amount the day after the survey date using a spring balance (SHINWA 74460). When firewood was used, the species of used wood were identified visually. Baking injera called *taita* or bread called *gogo*[A)] which are staple foods for the local people, requires a large amount of fuel. We also interviewed the households about what they cooked on the day of actual measurement.

We asked the local people to dry the dung cake and firewood ready to be used as fuel, and randomly collected 11

Table 1. Family structure and feeding cattle structure of the nine survey households in June 2018.

Case study	Place	Total family members	Family structure (age)	Cattle number		
				Ox and cow	Calf	total
Household 1	Kihen community	7	Husband (44), wife (37), 5 children (2-14)	5	1	6
Household 2	Kihen community	7	Husband (37), wife (32), 5 children (2-13)	4	1	5
Household 3	Kihen community	5	Husband (42), wife (38), 3 children (3-17)	5	1	6
Household 4	Kihen community	5	Husband (53), wife (46), 3 children (6-14)	6	0	6
Household 5	Kihen community	7	Husband (57), wife (41), 5 children (7-17)	3	0	3
Household 6	Agulae town	7	Husband (58), wife (41), 6 children (11-28)	7	2	9
Household 7	Agulae town	6	Husband (59), wife (46), 4 children (15-23)	5	2	7
Household 8	Agulae town	9	Husband (49), wife (38), 7 children (8-18)	4	0	4
Household 9	Debre Birhan community	5	Husband (64), wife (49), 3 children (11-19)	3	2	5

samples of dung cake and 10 of firewood as the samples of air-dried weight. The samples were dried at 105°C for 24 hours and calculated the dry matter rate. The dry matter rate for *A. etbaica* was used as the representative rate for firewood, because the frequency of firewood use was highest for *A. etbaica*. The dry matter (DM) of the consumed fuels was calculated at each household based on the air-dried weight and the dry matter rate.

2.4. Amount of fuel production

Livestock is kept inside the house from evening until early morning. The local people stated that they only used the feces that animals excreted inside the house as dung cake. The rate of excretion while the animals were inside the house and while they were grazing on rangeland during the day was interviewed in the surveyed households to estimate the total amount of livestock feces production per day.

For the amount of production of woody plants which are the resources of firewood, the mean annual increment (MAI) per ha (1,000 kg/ha/year) for *A. etbaica* was estimated in an area called Adi Zaboy in Kihen. *A. etbaica* is a dominant species in the forest land. The aboveground biomass for five individual plants of *A. etbaica* was cut and measured in 2014 and an estimation equation for aboveground biomass was calculated as: $Y = 154.7(BA_0 \times H)^{0.9044}$, where Y is aboveground biomass (1,000 kg DM/ha), BA_0 is total cross-sectional area of the tree at the ground (cm^2) and H is tree height. BA_0 and H for the same *A. etbaica* were actually measured in 2014 and 2017, and the aboveground biomass was calculated using the estimation equation in each year. The MAI for *A. etbaica* was estimated from the change in aboveground biomass in 3 years (Takenaka, 2015).

2.5. Examination of consumption-production balance for fuels

The amounts of fuel consumption and production were estimated in X community as a case study. X community had a total of 1,402 households with residents in 2017 (Woreda Kilteawlaelo Planning and Finance Office, 2018). The annual consumption of dung cake by the entire X community was estimated by multiplying the average amount of livestock feces consumption per household by the number of households in X community. The annual amount of livestock feces production by the entire X community was estimated by multiplying feces production per household by the number of households in X community.

The annual amount of firewood consumption by the entire X community was estimated by multiplying the average amount of firewood consumption per household by the number of households in X community. Similarly, the annual amount of firewood production by the entire X community was estimated by multiplying the MAI (Mg DM/community/year) for *A. etbaica* per hectare by the total forest area in X community.

The total forest area in X community was estimated using the Landsat-8 Operational Land Imager images taken on 26 April and 17 September 2018. In the Tigray Region, 26 April 2018 was before seeding of cereal crops and 17 September 2018 was before their harvest. The normalized difference vegetation index (NDVI) value was calculated for each using Esri ArcGIS 10.5. The areas with NDVI≥0.2 in the satellite image on 17 September 2018 was considered as forest and cropland (Tilahum, 2015). The difference in NDVI values also calculated between 26 April and 17 September 2018. The cropland areas were estimated by comparing the variation values in NDVI and the field survey

data (Hentze *et al.*, 2016; Jayawardhana and Chathurange, 2016). Finally, the total forest area in X community was estimated by subtracting the area of cropland from the total area of forest and cropland.

As energy conversion for fuels, conversion values were adopted as 15.8-18.8 MJ/kg for firewood, 12.2-13.1 MJ/kg for dung cake, 15.2 MJ/kg for crop residue (maize stem) and 28.1 MJ/kg for charcoal (Misra, 1995; RWEDP in Asia, 1997; Tripathi, 1998; Torres-Rojas, 2011).

2.6. Vegetation and land management

An overview on the land management and states of vegetation condition in the study area is provided in this section, because fuel consumption is also related to the number of animals kept, density of woody plants in natural grassland and forests.

During the Imperial era which finished in 1975, the natural grasslands and forests were managed jointly by local neighboring communities. Farmers were free to convert the natural grassland or forest into cropland, and the land they cultivated became privately owned and used. Each farmer household used approximately 15-20 *timad*[B)], and most of the land remained as natural grassland and forest where they were free to let livestock graze and fell trees for firewood. It is said that there were many large acacia trees in the natural grassland and forest, and natural acacia groves dense enough to hide livestock herds. In some of the natural grassland and forest used by farmers of Kihen, vegetation was severely regressed and became part of the prohibited grazing and protected forest land used for eucalyptus planting in the government-led project. Once land became part of the prohibited grazing and protected forest land, firewood collection (including fallen branches) and livestock grazing were prohibited throughout the year—only cutting of herbaceous plants and bringing them back to home (cut and carry) was permitted.

Each household kept about 20-30 head of cattle in all the surveyed area, and farmers were rich both financially and nutritionally thanks to the cattle-derived resources. Livestock was basically kept by grazing. Seasonally-closed grazing lands were set up during the Imperial era—this system was established by local communities, and grazing was prohibited on natural grassland and forest from mid-July until around mid-September. This prohibition in July-September was intended to allow herbaceous plants to germinate with rainfall during the rainy season, facilitate their growth and ensure sufficient feed resources. In seasonally-closed grazing lands, only the oxen used to plow cropland were allowed to graze during the open period (i.e. except mid-July to mid-September). Cows were allowed to graze on common free-grazing land throughout the year.

Large areas of natural grassland and forest remained even in the Socialist era after 1975, with large areas for animals to graze around the communities. Although the numbers of livestock gradually decreased due to frequent droughts, each household kept a few dozen animals even during the Socialist era and people were able to consume dairy products such as raw milk, buttermilk, curd and butter oil on a daily basis. All cropland was confiscated by the government and the right to use cropland was redistributed according to family structure during the Socialist era. In principle, each household had necessary and sufficient cropland during this period. Cultivation of natural grassland and forest was prohibited upon agreement of the local communities.

Democratization started in 1991, and prohibited grazing and protected forest land expanded based on government policy. The natural grassland and forest where free grazing was allowed also decreased gradually as cropland expanded. To ensure better feed resources for oxen, areas of seasonally-closed grazing lands specified voluntarily by the local communities also increased. As a consequence, the common free grazing land where grazing was allowed throughout the year decreased dramatically after the Democratic era began. The numbers of livestock decreased due to the effects of droughts, expansion of cropland, reduction in natural grassland and forest, and decreased numbers of herd boys due to school education. Many households now keep only one or two oxen and one or two cows (Hirata *et al.*, 2018).

As described above, there was sufficient natural grassland and forest around communities during the Imperial and Socialist eras and people could collect the necessary amount of firewood and let livestock graze sufficiently. Each household kept a few dozen head of cattle and people who lived by farming and stock raising were both financially and nutritionally well-off due to the cattle-derived resources. With expansion of the prohibited grazing and protected forest land during the Democratic era and due to cultivation as cropland, only small areas now remain for natural grassland and forest where grazing is allowed throughout the year. Today, the number of livestock animals has decreased due to drought, expansion of cropland, decrease in natural grasslands and forests, and decreased numbers of herd boys, and currently the shortage of cropland happened because of population increase in Tigray.

3. Results

3.1. Types of fuel resources and amount of consumption

The survey households in the study area used dung cake, firewood, crop residue and charcoal as fuel (**Figure 2**) (**Table 2**). The average consumption per household (all in kg DM/day/household) from June 2017 until July 2018 was 8.3 (range 0.0-20.7) of dung cake, 2.3 (0.0-8.9) of firewood, 0.1 (0.0-3.5) of crop residue and 0.2 (0.0-2.0) of charcoal. Consumption of dung cake was 3.6 times higher than of firewood. Thus, it became clear that dung cake was the main fuel, and woody plants were also an important resource.

Consumption of dung cake varied greatly with a range of 0.0-20.7 kg DM/day/household (**Table 3**). The cases in which 20.7 kg DM/day/household of dung cake was used corresponded to days on which the household baked injera or bread. Household 9 said that dung cake had a greater high heating power than firewood, even though it combusted in a short period. Baking a large amount of injera or bread requires a large quantity of fuel and high heating power, and thus use of dung cake is essential. The cases in which dung cake was not used at all corresponded to days that the household did not bake injera or bread. They were days on which relatively less fuel was required, including for cooking a bean dish called *shiro*, which was cooked using mainly firewood or charcoal. Of the total 108 days in the monthly survey on nine households, dung cake was used for cooking 97 days (90%). For all households, dung cake was used throughout the year.

Fig. 2. Local farmers use dung cake and firewood mainly as fuel for daily cooking.

The average consumption of dung cake increased with a greater number of animals kept, with 2.9 kg DM/day/household in Household 5 which kept three heads of adult cattle (ox and cow), and 8.7 kg DM/day/household in Household 6 which kept seven heads of adult cattle. However, Households 1, 2 and 3 kept five or six heads of adult cattle and had average consumptions of dung cake of 10.5-11.4 kg DM/day, indicating that average consumption did not always increase with greater numbers of adult cattle. This was mainly because of different cattle feeding management practices among the households and differences in physical appearance of cattle.

The amount of firewood consumption in the survey households was 2.3 (0.0-8.9) kg DM/day/household. Local farmers are permitted to collect fallen branches for firewood throughout the year. The woody plants used as firewood were *A. etbaica* named *Seraw*, *Eucalyptus camaldulensis* named *Bahr zaf*, *Euclea racemosa* named *kuryao*, *Acacia senegal* named *Kinchib*, *Maytenus senegalensis* named *Qebqeb*, *Leucas oligocephala* named *Sewa kerni*, and *Rhus vulgaris* named *Atami* (**Table 4**). Firewood was used at 67% for cooking, corresponding to 72 out of 108 days. Of the 72 days that firewood was used in cooking, *A. etbaica* was used 69 days, *E. camaldulensis* and *E. racemosa* five days each, and others one day each. Based on the frequency of firewood use, *A. etbaica* represented 83% of the woody plants used, and this was the species mainly used as firewood. *A. etbaica* is a dominant species in forests of the southern Kilite Awlaelo district (Abebe *et al.*, 2017).

Although firewood was used throughout the year, the frequency of its use varied by household. Households 5, 7 and 9 used firewood throughout the year, but Households 1, 2 and 8 only used it 3-5 days out of the 12 days in the sur-

Table 2. The average of fuel consumption (DM kg/day) of the nine survey households from July 2017 to June 2018 in Kilite Awlaelo district.

	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Mean	(Range)
Dung cake	8.4	8.8	5.0	10.2	11.9	9.5	8.2	7.7	10.4	4.8	7.4	7.9	8.3	(0.0-20.7)
Firewood	2.3	2.9	2.0	2.4	1.9	2.2	1.8	2.3	1.7	2.2	2.6	2.8	2.3	(0.0-8.9)
Crop residue	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.1	(0.0-3.5)
Charcoal	0.4	0.4	0.1	0.0	0.2	0.2	0.0	0.0	0.0	0.5	0.0	0.2	0.2	(0.0-2.0)

Table 3. The fuel consumption (kg air DM/day) of each surveyed 9 household from July 2017 to June 2018.

Household	Dung cake												
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Mean
1	20.7	11.5	10.6	17.0	5.5	13.8	10.1	9.4	14.3	1.4	11.8	11.1	11.4
2	8.1	8.8	4.1	11.8	18.4	10.5	11.1	12.4	12.4	7.5	14.1	7.0	10.5
3	7.7	18.7	5.1	12.5	11.1	12.9	9.7	15.3	14.3	0.9	10.1	7.4	10.5
4	3.0	0.0	6.5	5.5	16.6	14.8	14.1	3.8	11.6	8.3	14.3	6.0	8.7
5	4.0	2.8	0.0	4.4	8.8	6.3	0.0	1.5	4.1	0.0	0.0	3.4	2.9
6	9.9	8.7	13.0	6.8	16.1	13.6	12.4	0.0	13.3	0.0	0.0	11.1	8.7
7	7.7	9.1	4.1	13.9	11.5	5.7	7.4	10.0	5.5	7.4	0.0	7.9	7.5
8	11.3	10.5	0.0	12.6	12.1	0.0	0.0	11.0	10.0	11.1	9.2	9.7	8.1
9	2.8	8.8	1.8	6.9	6.5	7.7	8.8	5.5	7.6	6.9	7.4	7.8	6.5
Mean	8.4	8.8	5.0	10.2	11.9	9.5	8.2	7.7	10.4	4.8	7.4	7.9	8.3

Household	Firewood												
	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Mean
1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	2.2	0.0	1.1	0.3
2	0.0	0.0	0.0	0.0	0.9	0.9	0.0	0.0	0.0	0.0	0.0	1.8	0.3
3	5.4	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.9	3.2	1.8
4	3.7	5.7	3.6	0.0	2.3	2.4	1.4	2.5	1.4	4.5	1.8	2.7	2.7
5	2.7	4.5	4.5	6.3	0.9	6.1	4.5	3.3	3.6	4.5	3.0	5.0	4.1
6	0.0	0.0	4.9	2.3	5.3	3.8	3.2	3.9	1.8	0.0	5.4	3.2	2.8
7	5.0	3.2	0.9	3.1	5.9	4.5	3.6	2.6	1.4	3.2	6.2	3.9	3.6
8	0.0	0.0	0.0	7.9	0.0	0.0	1.4	4.1	4.1	0.0	2.3	0.0	1.6
9	4.2	4.1	3.6	2.2	2.3	2.0	1.8	4.1	3.2	2.7	3.6	4.1	3.2
Mean	2.3	2.9	2.0	2.4	1.9	2.2	1.8	2.3	1.7	2.2	2.6	2.8	2.3

Table 4. Resources for fuel consumption and those use frequency of the nine survey households from July 2017 to July 2018 in Kilite Awlaelo district.

	Fuel resources	Frequency
Firewood	*Acacia etbaica* (Seraw)*	69
Firewood	*Eucalyptus camaldulensis* (Bahr zaf)	5
Firewood	*Euclea racemosa* (Kuryao)	5
Firewood	*Acacia senegal* (Kinchib)	1
Firewood	*Maytenus senegalensis* (Qebqeb)	1
Firewood	*Leucas oligocephala* (Sewa kerni)	1
Firewood	*Rhus vulgaris* (Atami)	1
Dung cake	Cattle feces	97
Crop residue	Sorghum stalk	5
Charcoal	Purchased charcoal	6

*: *Latin name* (local name)

Note) Total 108 days' survey on the 9 houseolds during the priod

vey period. The amount of firewood consumed by Households 5, 7 and 9 throughout the year was 3.2-4.1 kg DM/day/household, which was greater than the average of 2.3 kg DM/day/household for the nine survey households. Households 5, 7 and 9 consumed dung cake at 2.9-7.5 kg DM/day/household, which was less than the average of 8.3 kg DM/day/household. Conversely, firewood consumption by Households 1 and 2 which only used firewood three out of 12 days was 0.3 kg DM/day/household, and for Household 8 which used it five out of 12 days was 1.6 kg DM/day/household—indicating consumptions below the average of 2.3 kg DM/day/household. Instead of firewood, Households 1, 2 and 8 frequently used dung cake and their consumption exceeded the average of 8.3 kg DM/day/household, with 11.4, 10.5 and 9.7 kg DM/day/household, respectively.

The only crop residue used as fuel was the stem residue of sorghum known as *kancha*. The *kancha* was used only

five out of 108 days. Only Household 2 used it in July, August, February and May, and Household 4 in August. *Kancha* was used as fuel in combination either with dung cake or firewood. When used as fuel, consumption of *kancha* was 0.8-3.5 kg DM/day/household; however, it was almost no use, with an average consumption for all households of 0.1 kg DM/day.

The charcoal that people used was purchased from markets. One bag weighed approximately 20 kg and cost 250 Bill[C]. Charcoal produced in the lowlands of Afar Region is carried to Tigray and sold in the markets. Only Households 4, 6 and 8 used charcoal. Because Household 9 was located far from the market, it did not use charcoal. Charcoal was mainly used in July and August, corresponding to the rainy season. Firewood used for cooking leaves embers, which function as banked fire, burning low and long with continuing heating power. The embers were used for brewing coffee in the living room where the residents relaxed. During the rainy season of July to August, firewood did not dry well and so they could not use embers for brewing coffee but used charcoal. The charcoal was also used in December and April, corresponding to days on which cooking did not require much heating power such as for *shiro*, instead of injera or bread. On these days, only charcoal was used and no dung cake or firewood. The average charcoal consumption for all households was 0.2 kg DM/day, indicating that it was almost not consumed and that it contributed little as a fuel.

As described above, it was clarified that livestock feces was a major and essential fuel resource for local peoples in the Tigray Region, and woody plants were also an important fuel resource, with *A. etbaica* the major species frequently used. It was also confirmed that crop residue and charcoal were seldom used.

3.2. Amount of fuel resource production

Dung cake is only prepared from cattle feces. Dung cake is not prepared from sheep, goats or donkeys (Table 4). Although local farmers said that they could use the dried feces of sheep, goats or donkeys as fuel without further processing if they were too busy to prepare dung cake, this was extremely rare. Cattle are released for grazing during the day but are kept inside the house from evening until morning to be given feed and protection from predators at night. Dung cake is prepared by gathering the all feces excreted inside the house while they are kept there. Crop residue such as barley and teff stems are given inside the yard. Each household prepared dung cake by kneading together the cattle feces excreted in the yard with the crop residue spilled while animals were eating. Dung cake is dried by being placed on the stone wall surrounding the house (**Figure 3**). Dung cake is not prepared for use as fuel during the rainy season of July to August, as it does not dry well. During July to August, livestock feces is fermented and prepared as manure. Thus, dung cake is prepared during the dry season of September to June and used throughout the year including the rainy season.

Fig. 3. Preparation of dung cake.
Cattle faces inside a house are kneaded with crop residues and then dried on stone wall.

The nine survey households exhausted the total amount of dung cake produced by each household during the year, with no provision for other households or any excess. Thus, it was estimated that a household produced 10.0 kg DM/day/household of dung cake during the dry season, approximately 10 months from September to June for using the dung cake by the average of 8.3 kg DM/day/household throughout the year (8.3 DM/day/household multiplied by 12/10). According to Households 4 and 9, cattle excrete 1/3 of the feces during day grazing in rangeland, and 2/3 inside the house from evening to morning. That is, the average total amount of livestock feces produced by cattle kept by each household was estimated as 14.9 kg DM/day/household (dung cake production 10.0 kg DM/day/household multiplied by the excretion ratio 3/2 between inside and outside house).

Regarding the resources of firewood, the aboveground biomass and amount of growth for *A. etbaica* were estimated within the forests of Kihen, which was the dominant woody plant species in the study area. The aboveground biomass for *A. etbaica* was 9.9 Mg DM/ha. Since the amount of change in aboveground biomass for *A. etbaica* in 3 years was 190 kg DM/ha, average growth was cal-

culated as 63.3 kg DM/ha/year (Takenaka, 2015). Abebe *et al.* (2017) surveyed the Kilite Awlaelo district and surrounding areas and reported that forest biomass was 6.3-12.3 Mg DM/ha. Thus, our calculated forest biomass was an average value for the Tigray Region. However, Ubuy *et al.* (2014) measured the amount of growth in forests mainly comprising *A. etbaica* in the Tigray Region as 200 kg DM/ha/year; consequently, the amount of *A. etbaica* growth in Kihen was a relatively low value for the Tigray Region.

3.3. Balance between local fuel production and its consumption

An average of 14.9 kg DM/day/household of livestock feces was produced from cattle kept by each household, and they prepared 10.0 kg DM/day/household of dung cake in approximately 10 months from September to June. Since X community had a total of 1,402 households in 2017, the total amount of livestock feces produced by all households in X community was estimated at 7,645.2 Mg DM/year/community, and the dung cake production at 4,247.4 Mg DM/year/community. According to the nine survey households, each household exhausted all dung cake within the year they produced during the dry season, with no provision to others and no leftover. In X community, 4,247.4 Mg DM/year/community of dung cake was produced in approximately 10 months in the dry season of September to June, and the same amount was consumed through the year. This indicated that a good balance between the amounts of livestock feces produced and consumed in each household using all the available feces as fuel and leaving no excess dung cake.

The amount of firewood production in the entire X community was estimated by multiplying the MAI for *A. etbaica* by the total area of forests in X community. Based on the NDVI values from a satellite image taken on 17 September 2018, the area of forests and croplands with NDVI more than value 0.2 corresponded to 9,306 ha. According to variation in NDVI, calculated from the difference between 26 April and 17 September 2018, areas with more than values 0.23 were identified as croplands, which resulted in estimated cropland area of 2,933 ha/communuty. Since the forests area can be estimated by subtracting the cropland area from the area of forests and croplands, the forests area in the entire X community was estimated to be 6,373 ha/community. Hence, the annual amount of woody plant production in the entire X community was calculated as 403.4 Mg DM/year/community by multiplying the MAI 63.3 kg DM/ha/year by the total forest area 6,373 ha/community in X community.

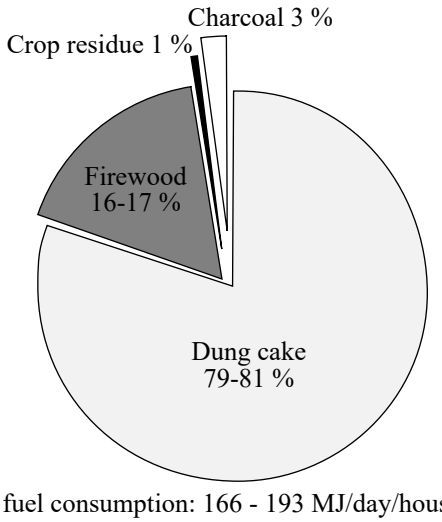

Fig. 4. Energy ratio of fuel using in the southern Kilite Awlaelo district.

Firewood consumption was 2.3 kg DM/day/household. Since there were 1402 households in X community in 2017, the woody plant consumption by the entire Kihen community was estimated as 1,177.0 Mg DM/year/community. Consumption of woody plants as firewood exceeded production by 2.9 times. This indicated that production and consumption of woody plants were not balanced in southern parts of Kilite Awlaelo distric, and that consumption was excessive. Giday (2002) also reported that consumption of woody plants exceeded production in the same Tigray Region.

4. Discussion

Average fuel consumption (all in kg DM/day/household) by local farmers in Tigray Region was 8.3 for dung cake, 2.3 for firewood, 0.1 for crop residue and 0.2 for charcoal; the corresponding conversions into energy were 131.1-156.0, 28.1-30.1, 1.5 and 5.6 MJ/day/household, respectively, making a total of 166.3-193.3 MJ/day/household. Hence, the households of Tigray Region depended on dung cake for 79-81% of their fuel (**Figure 4**) and firewood represented only 16-17%. However, the annual amount of firewood consumption by Kihen was 1,177.0 Mg DM/year/community, which far exceeded the production of woody plants of 403.2 Mg/year/community. This indicates that firewood consumption may continue to cause the forests to decrease in the future. To protect the forest ecosystems of the Tigray Region and ensure fuel for the population, it is necessary that the forest area is increased by 2.9 times or the firewood consumption be reduced to about one third.

Most of the flat land belonging to X community has already been cultivated as cropland to meet the population increase. Given the current shortage of cropland, there is no area to convert cropland into forest to increase the forest area. This is a common situation in Kilite Awlaelo Woreda. It is therefore impossible to dramatically increase the area of forests and increase the amount of firewood production including of fallen branches.

Possible methods of reducing firewood consumption include 1) developing a resource of fuel other than livestock feces and firewood, 2) increasing dependency on livestock feces as a fuel by increasing animal numbers, 3) increasing the collecting amount of livestock feces by changing livestock feeding management and 4) reducing fuel consumption. The possible fuel resources other than livestock feces and firewood are crop residue, charcoal, propane gas and solar power generation. Sorghum stems were the only crop residue used as fuel. However, sorghum requires much more water for growth than teff, wheat, barley or legumes, and cannot be grown on cropland with poor soil. Therefore, it cannot be expected that the use of sorghum stems increase in the future under rainfed farming conditions in the Eastern zone of Tigray Region. Use of charcoal or propane gas is impossible unless the village is close to a market. The Household 9 was located approximately 18 km from the market in Wukro—a journey of about 4 hours on foot. It is impossible to obtain resources purchased from markets as alternatives to firewood in farming villages located at such long distances, unless transport improvements such as a paved road are made. On the other hand, solar power generation can be produced anywhere, even if it is far from the market. In Mongolia and Tibet, solar power generation has spread to pastoral households and is used as lighting and radio powers (Baters-Bayer and Bayer, 2016; Wang *et al.*, 2011). In Tigray Province, clear and sunny days continue during the dry season, and solar power can be sustainably generated except of the rainy days in July and August. If the supply of electricity becomes possible by solar power generation, it will be possible to use an electric cooking machine for boiling and/or ingera baking. In fact, the electric injera-baking machines is popular in urban areas. Therefore, it is expected that the consumption of firewood will be greatly reduced if solar power generation becomes widespread and even a part of the power required for the cooking machine can be supplied in local households. The issues with the spread of solar power generation is the installation cost and the amount of power generation against with the consumption power amount of electric cooking machine. Therefore, solar power generation can be also expected as a new fuel resources other than firewood and animal feces in the current situation unless irrigation and transport improvements are spread.

With the current number of livestock animals kept, it is difficult for local people to consume more livestock feces than presently as a resource of fuel, because they are consuming all of the dung cake they produce. They would have access to more livestock feces if they increased the number of animals kept; however, households cannot increase animal numbers because of the decreases in grazing land, feed resources and numbers of herd boys (Hirata *et al.*, 2018). However, livestock feces is the most promising fuel resource to replace firewood, and the only way to increase its availability is to increase the animal numbers kept by each household. If the number of animals was increased to 1.27 times of the current level, it would be possible to supply all the fuel required by each household with livestock feces. This 1.27 times increase in animal numbers could be achieved by adding just one or two adult cattle to each household—if each household increased the number of livestock animals by one or two, this would reduce the amount of firewood used in the future. After the start of democratization in 1991, the local government has extremely expanded the prohibited grazing and protected forest (Ogawa *et al.*, 2018). The prohibited grazing and protected forest land is allowed for local farmers only to cut herbaceous plants and curry back to villages. Abundant herbaceous plant resources exist in the prohibited grazing and protected forest land because of the prohibition of grazing there. If the herbaceous plant resources in the prohibited grazing and protected forest land are used for animal feed by the cut and carry, each household can be expected to increase one or two adult cattles more. Therefore, each household is possibly expected to increase the number of one or two adult cattles using the herbaceous plant resources by the cut and carry in the prohibited grazing and protected forest land.

The meaning of "3) increasing the collecting amount of livestock feces by changing livestock feeding management" is that a part of livestock keeping is converted from grazing to barn feeding. The local municipality has a policy to convert from grazing to barn feeding (Shapiro *et al.*, 2015). If the herbaceous plant resources can be fed to livestock by the cut and carry, it becomes possible to change a part of livestock management from grazing to barn feeding. The testimony of households 4 and 9 was that cattle emit 1/3 of the excreta during daytime grazing and 2/3 in the mansion from the evening to the morning. If each houshold changes

the feeding management from grazing to barn feeding for one or two adult cattles, the local farmers can increase to collect animal feces, produce dung cake and then reduce the amount of firewood uses. However, the realization of barn feeding put a heavily burden on local farmers to cut and curry of herbaceous plants from the prohibited grazing and protected forest land. For the promotion of cut and carry, local government support is needed to reduce the burden on local farmers, such as the spread of mower, the development of road improvements and transport vehicles. Therefore, the conversion of a part of livestock management from grazing to barn feeding may lead to increase the animal feces collection and reduce the firewood consumption under the strong support from local government.

One possible method of reducing fuel consumption is to popularize improved cooking stoves with higher combustion efficiency as was attempted by Torres-Rojas *et al.* (2011). Mekkonnen and Köhlin (2008) also recommended the use of cooking stoves with higher combustion efficiency in order to reduce consumption of livestock feces, although they were considering converting the use of livestock feces from fuel to manure so that agricultural productivity could be improved. However, at present, no improved cooking stove has been adopted in the agricultural areas of Kihen, Agula and Debre Birhan. To protect the woody plants by reducing collection of firewood, it is desired that improved cooking stoves are popularized in agricultural regions in the future.

It was previously mentioned that the people in Tigray used firewood embers to enjoy coffee in their living room and the use of firewood will be necessary as long as they continue this habit. Firewood is also easy to use when adjusting heating power in a cooking stove, and it generates less smoke than livestock feces, indicating importance in use of firewood as fuel for health reasons (Mekkonnen and Köhlin, 2008). Thus the use of firewood as fuel is essential for people in the Tigray Region. Consequently, it is extremely important to introduce solar power generation, increase the number of livestock animals (by addition of one or two adult cattle per household), change the livestock feeding management (conversion of a part of livestock keeping from grazing to barn feeding) and to popularize improved cooking stoves in order for people of the Tigray Region to reduce the pressure on use of woody plants and protect the forest environment, while using a minimum amount of firewood.

Notes

A) The name of *gogo* originated from the black round plate on the oven called *mogogo*. Bread and injera are baked in this plate.

B) *Timad* is a unit of cropland area used in Kilite Awlaelo district, Tigray. *Timad* is an area in which two oxen can plow in one day using a cattle-driven plow. 1 *timad* is approximately 0.25 ha.

C) Birr is the unit of currency in Ethiopia. 1 Birr was 0.037 US $ in June 2018. One L of cow's milk was 20 birr.

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—原著論文—

エチオピア・ティグライ州キルテ－アウラエロ郡南部における燃料の生産と消費の視点からの森林保全の検討

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要旨：本研究では，エチオピア高地のティグライ州において，燃料の生産と消費の視点から森林地の保全を考察するために，1）燃料として利用されている資源の種類とその頻度，世帯当たりの燃料消費量を把握し，2）燃料として利用されている家畜糞ケーキと木本植物の生産量を推定することにより，燃料の消費－生産バランスを検討し，3）森林を保全するために，薪の消費量を軽減する方策について考察することを目的とした．ティグライ州の農民は，燃料として家畜糞ケーキ，薪，農耕残渣，および，木炭を利用していた．世帯当たり 1 日の平均消費量は，家畜糞ケーキが 8.3（min 0.0 ～ max 20.7）kg DM/day/household，薪が 2.3（0.0 ～ 8.9）kg DM/day/household，農耕残渣が 0.1（0.0 ～ 3.5）kg DM/day/household，木炭が 0.2（0.0 ～ 2.0）kg DM/day/household であった．家畜糞ケーキは薪の 3.6 倍も消費されていた．これらのことから，燃料は家畜糞ケーキを中心に利用しながら，木本植物も重要な資源として利用されていることが把握された．家畜糞ケーキの生産は，乾期の 9 月から 6 月までの約 10 ヶ月間で 10.0 kg DM/day/household 生産し，同量を年間を通じて消費することにより，家畜糞ケーキの余剰量を出すことなく，家畜糞を使えるだけ燃料として消費していた．木本植物の生育量と薪の消費量を計算した結果，薪の消費量は木本植物の生育量よりも 2.9 倍も消費していた．従って，Kilite Awlaelo district 南部においては，木本植物の生産と消費はバランスが取れておらず，消費過多の状況にあると判断された．今後，薪の消費量を減らして最低限度の薪を利用することにより，木本植物の利用への圧力を軽減し，森林の環境保全を図っていくには，太陽光発電の普及，家畜頭数の増加（世帯毎に飼養する成牛を 1 ～ 2 頭増加），家畜飼養管理の変更（飼養する家畜の一部を放牧から舎飼いに転換），および，改良竈の普及が極めて重要であることが示唆された．これらの薪の消費量を減らす試みには，地方自治体のサポートが不可欠である．

キーワード：燃料，薪，家畜糞ケーキ，*Acasia etbaica*，森林保全

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