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Production and reproductive performance, and egg quality of indigenous chicken in Siltie Zone, Ethiopia

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Abstract

Limited attention has been given to the performance evaluation and classification of indigenous chickens. The performance of chicken production can be influenced by genetic and non-genetic factors. Thus, the purpose of this study was to assess the production and reproductive performance as well as egg quality of indigenous chickens in highland and midland agro-ecologies in Silte Zone of Central Ethiopia. From each agro-ecology four districts were purposively selected. Three hundred twenty farm households were randomly selected for household survey representing highland and midland agro-ecologies. Data on Production and reproduction performances were collected. Additionally, 160 chicken were used for measuring the body weight and other traits. Three hundred eggs were collected and transported to Hawassa University, poultry farm laboratory, for quality analysis. The collected data were analyzed using Generalized Linear Model (GLM) procedure of SAS. Body weight of cockerels were 1271.3±89.29 and 1220±87.27 grams while body weights of laying hens were 1023.8±80.47 and 1027.5±75.19 grams in midland and highland agro-ecologies, respectively. Matured age of cockerels, pullets' age at first egg and survival of chicks in wet season were significantly better in the midland agro ecology. Pullet's ages at first egg were 28.30±1.72 weeks. Egg weight, egg length, albumen weight and yolk diameter were significantly higher in midland. In conclusion, there was variation on production and reproductive performance and egg quality of indigenous chicken under farmers' management conditions between the two agro ecologies. In some production performances, and some egg quality parameters, indigenous chickens were better in the midland agro ecology. Hence, it can be recommended that agro-ecological-based improvements in breeding and management practice (feeding, housing and health) of indigenous chickens are vital in the study area.

Key words: Hawassa University; Egg quality parameters; poultry growth parameters; highland and midland agro-ecologies

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INTRODUCTION

Chicken production is a suitable enterprise for poor and landless households, as it requires small/no land and investment to establish and manage the farm (FAO, 2019). In Ethiopia, there are approximately 57 million chicken, with 78.85% (44,940,924) indigenous, 12.02% (6,857,718) hybrid and 9.11% (5,194,345) exotic–chicken (CSA, 2021). Poultry have added importance to various socio-economic, food security, and religious contributions (Gulilat *et al*., 2021).

Local chicken productivity is very low, as compared to exotic and commercial breeds with only 40-60 eggs annual egg production, 70% hatchability rate and excessive mortality rates (Getachew, 2016; Emebet, 2015). In the traditional poultry production system, more than 90% of the national egg and meat output is from indigenous chicken (Chaimiso, 2018). Non- genetic factors such as feeding, housing, healthcare, and other management practices have a much greater impact on production than genetics under a scavenging system of production (Berhanu *et al*., 2022). Native chickens are normally kept according to an extensive or scavenging system with few or no inputs for housing, feeding and health care **(**Mtileni *et al*., 2012)**.** Indigenous chickens are properly tailored to the local climatic conditions, feed and management stresses, with better resistance to diseases **(**Iqbal and Pampori, 2008). **A**lthough efforts have been ongoing for several years to introduce more efficient, exotic and crossbred types of poultry, village chickens remain predominant throughout many African villages. This is because local farmers have been unable to deliver the high input requirements such as housing/shelter, proper balanced diets, and disease control/vaccination programs associated with more genetically efficient breeds (Tabler *et al*., 2018).

The per-capital annual poultry meat, and egg consumption in Ethiopia is only 0.12 and 0.14 kg, respectively (Tshovhote, 2015). On the other hand, Yosefe *et al*., (2016) reported a higher value with 2.85 kg of meat and 57 eggs per year, which might attribute to the production of chicken in that specific study area in Ethiopia. Still, in low earning households, both chicken meat and eggs are preferred sources of cash income.

The traditional and improved family poultry production systems target smallholder farmers who can utilize potential feed resources locally. Generally, limited attention has been given to the performance evaluation and classification of indigenous and non-descriptive chicken types in Ethiopia. Future research needs to focus on the identification, description, and evaluation of these genetic resources and their production and reproduction performance under smallholder conditions as well as quality of products. The internal and external egg quality traits were influenced by factors such as agro-ecology, breeding, and their interaction (Serkalem et al., 2023). Aberra and Tegene (2009) reported that identification and characterization of the chicken genetic resources generally require information on their adaptation to a specific environment, possession of unique traits of current or future economic value and socio-cultural importance, which are crucial inputs to decisions on conservation and utilization.

In Silte zone, little research has been conducted on characterization of the production system of indigenous chicken. Even though there were little studies performed on production and reproductive performance, husbandry practices and egg quality of indigenous chicken, there was no adequate documented information on indigenous chicken in the study area.

Egg quality is a factor that contributes to the better economic price of fertile and table eggs. In general, the characteristics of eggs have a genetic basis (Silversides and Scott, 2001). Egg production is believed to be a complex qualitative trait that is influenced by several factors such as breed, nutrition, age, the weight of birds, level of production, management practices, and environmental factors (Oluyemi and Roberts, 2000). Therefore, the study was conducted to assess production and reproductive performance and egg quality traits of indigenous chicken in the mid and high land agro-ecologies.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out in mid and highland agro-ecologies of Siltie Zone of Central Ethiopia Region, Ethiopia (figure 1).

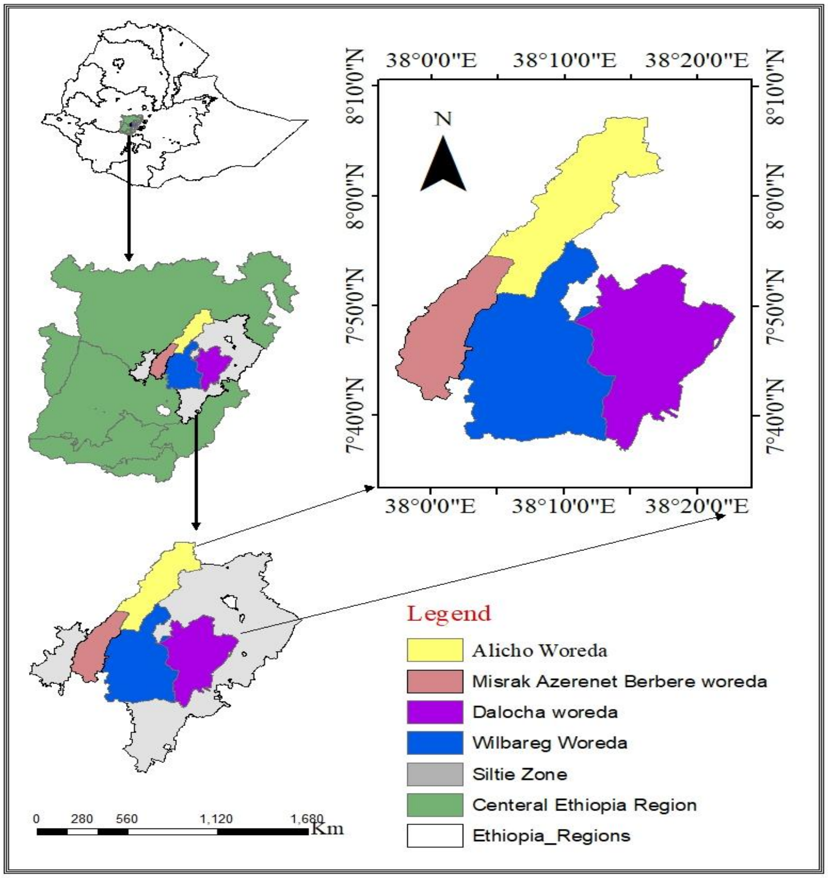

Figure 1. Map of the study area (Source: shape files from CSA, Ethiopia, 2013)

Siltie Zone is bordered by Hadiya Zone to the south, Gurage Zone to the north and north-west, Oromia to the east and Halaba Zone to the south east. Worabe is the capital town and found 172km South of Addis Ababa. Siltie Zone coordinates a Latitude of ranges 7°4'0"- 8°1'0" north and a longitude of 38°00'0" - 38°20'0" east and it is located at an elevation of 1,500-3,700 meters above sea level. There are 10 (ten) districts and 4 (four) administrative towns having two different agro-climatic zones, (Highland or Dega, 20.5%) and (Mid-land or Weyna-Dega 79.5%). The average temperature ranges from 12-26^{o}C and the average annual rainfall ranges from 780-1818mm (Tagese *et al*., 2021). In Siltie zone, there are approximately 646,525 chicken heads, with 71.43% (461,833) indigenous chicken population, 26.20% (169,452) are hybrid chicken population, and 2.36% (15,240) are exotic (CSA, 2021).

Sampling Design and Data Collection Procedures

The study had both household survey and laboratory studies. Four districts were purposively selected based on the potential of local chicken population and presence of both agro-ecologies. Two districts from each of highland and midland were selected. A total of eight (8) Kebeles, two Kebeles from each district were selected purposively based on potentiality of indigenous chicken population and accessibility for data collection. Before selecting the household for the survey, the total households having indigenous chicken in the Kebele were identified and listed.

Then from each Kebele, using simple random sampling technique, 40 households who have greater than five adult local chickens were selected. Prior to the selection of households for the survey, farmers who own exotic and their crosses have been identified with the help of extension workers in the district. Then those having exotic chicken or their crosses in the neighborhood were purposely excluded. Closely adjoining households also skipped to avoid the risk of sampling chickens sharing the same cock. Hence, a total of 320 poultry keeping smallholder households were selected from the study area.

Data Collection Procedures

The survey part was accomplished through interview using pre-tested and semi-structured questionnaires. Before the survey was started, the prepared questionnaires were provided to four households in four different districts to check whether or not it was understandable. Pre-testing the questionnaire before the actual survey had enriched the main structured questionnaire which otherwise could have been missed. The interviews were conducted at farmers' house. Data sets included chicken productivity and flock performance (number of times the hen brood in a year, number of eggs per clutch per hen, number of days per clutch, number of eggs per set of incubation, hatchability percentage of the eggs and survivability percentage of chicks).

Quantitative data such as body weight from both adult sex groups (age of chicken more than 6 months) were measured using a hanging spring balance to the nearest 0.01gram before the chickens leave for scavenging in the morning by holding the chicken systematically (without disturbing) and tie their legs. From each of the agro-ecologies, 160 chicken were used for measuring the body weight to see the effect of agro-ecology on their growth performance.

Data Collection for Egg Quality Measurements

Three hundred (300) fresh eggs that have not been stored for more than a week after being laid were directly collected (purchased), 150 eggs from each agro-ecologies.

The storage time of eggs ranged from 1-5 days since the eggs were collected from different household and it was not possible to get the same storage duration. The collected eggs were properly collected with straw bedded carton with several small holes on it for aeration and to avoid egg breaking. The eggs were labeled according to their agro-ecologies and transported to Hawassa University, college of Agriculture, poultry farm. On the next day, egg quality traits were evaluated.

External egg quality parameters include egg weight, egg length, egg width, eggshell weight, and eggshell thickness. Egg length and width were measured using stainless hardened digital caliper to the nearest of 0.01 mm. Egg shape index was calculated using the formula of Van den Brand *et al*. (2004).

$$\text{Eggshell wt. (\%)} = \frac{\text{Dry shell wt.}}{\text{Egg wt.}} * 100$$

$$\text{Egg shape index (\%)} = \frac{\text{Egg width}}{\text{Egg length}} * 100$$

The internal egg quality parameters including yolk height, yolk diameter, yolk weight, yolk color, albumen weight and albumen height were determined. Egg weight was measured using a digital sensitive balance (SF-400) to the nearest 0.1 gram precision. Each egg was broken on to a glass covered table and the albumen and yolk heights were measured using PAT.460176 Tripod micrometer to nearest 0.01mm. Yolk was carefully separated from the albumen and weighed separately. The eggshells were cleaned with tissue paper and the shell membrane was removed by hand and then dried in the open air for 24 hours and the eggshells were weighed without the shell membrane. Then, the eggshell thicknesses were measured using stainless steel hardened digital caliper to the nearest 0.01 mm. from three parts and average of the three was taken. Based on the collected data, egg shell ratio, Haugh Unit, yolk ratio, albumen ratio, and yolk index were calculated using the given formulas below .

Haugh units of the eggs were estimated based on the albumen height and egg weight according to the formula of Haugh (1937). Yolk height and diameter values were used to compute yolk index of the eggs. Yolk color was measured using Roche color fan consisting of a series of fifteen colored plastic trips which were used as a reference to determine yolk color.

$$HU = 100\log(AH - 1.7EW^{0.37} + 7.6)$$

Where: HU= Hough unit, AH= Albumen height in millimeters, and EW= Egg weight in gram

Yolk Ratio and Albumen Ratio were estimated by the following formula:

$$Yolk\ Ratio = \frac{Yolk\ weight}{Egg\ weight} * 100$$

$$\text{Albumen Ratio} = \frac{Albumen\ weight}{\text{Egg weight}} * 100$$

$$\text{Yolk index} = \frac{\text{Yolk height in (mm)}}{\text{Yolk diameter in (mm)}} * 100$$

Statistical Analysis

The data collected on production and reproductive performance, egg weight, egg quality parameters were subjected to analysis of variance (ANOVA) ($p < 0.05$). All data were analyzed using Generalized Linear Model (GLM) procedure of SAS (Version 9.0) statistical package (SAS, 2002). The statistical model used for quantitative data measurements of indigenous chicken was:

$$Y_{ijk} = \mu + Ai + eijk$$

Where: Y_{ijk}: the corresponding quantitative trait of indigenous chicken in i^{th} agro-ecology

μ: overall population mean for the corresponding quantitative trait

A_i: effect of i^{th} agro-ecology (i=2, midland and highland)

e_{ijk}: random error and

The statistical model used for Egg quality parameters was

$$Yik = \mu + Ai + eik$$

Where: Yik = response to the observed variable of egg quality

μ = overall mean

Ai = the effect of i^{th} Agro-Ecology (i = 2, Highland and Midland) and eik = random error

RESULTS AND DISCUSSION

Production and Reproductive Performance of Indigenous Chicken

Age at First Mating

Production and reproductive performance of indigenous chickens are presented in Table 1. The mean cockerels' age at first mating was 22.71±1.35 and 22.4±1.29 weeks in highland and midland agro-ecologies, respectively. The current result on cockerel age at first mating was earlier than the findings of Fisseha *et al.* (2010), who reported that average age at first mating was 24.6 ± 2.0 and 24.5 ±1.6 weeks in highland and midland respectively in Bure district, north west Ethiopia.. On the other hand earlier age at first mating 5.22±0.03 months (20.88±0.12 weeks) for local cockerels than the current study was reported by Andualem (2020) in Awei zone, Amhara region, Ethiopia. Similarly, Yadessa *et al.* (2017), also reported earlier sexual maturity of local cockerels with 20, 19.6 and 21.2 weeks of age in Mezhenger, Sheka and Benchi-Maji areas. The variations in sexual maturity or age at first mating in different areas might be due to agro-ecological factors such as environmental temperature; husbandry practices of the chickens, local breed eco-type, and the type of feed resources in and around the study areas. The sexual maturity in animals is a highly energy-consuming process, thus it is strictly regulated by the body's nutritional status and energy metabolism. Previous studies have found a correlation between the sexual maturity of animals and body weight and body composition on different animal species. Studies conducted on quails revealed that there is correlation between body weight and body composition with sexual maturity (Reddish et al., 2003; Abou Khadiga et al., 2016).

Matured Body Weight

Matured body weight of cockerels in the study area were 1271.3±89.29 grams in midland and 1220±87.27 gram in the highland agro ecology, with overall mean matured body weight of 1245.6±91.81grams. Matured body weight of laying hens was 1027.5±75.19 grams in highland and 1023.8±80.47grams in midland agro-ecologies with the overall mean matured body weight of 1025.6±77.78 grams. The matured body weight observed for both sexes in the current study area are lower than the value by Hailu and Aberra, (2018) who reported that 1.68 kg for cocks and 1.42 kg for hens with overall mean value of 1.55 kg in Sheka zone. Matured body weight of cockerels in the midland was significantly ($P<0.05$) higher than the highland agro ecology. The variation might be due to the agro-ecological effect in relation to the environmental temperature on local chicken and the husbandry practices (feed supplementation and watering management) of the chicken owners in the study area.

Non-genetic factors like feeding practices, flock management, housing, season, chick rearing, brooding and vaccination etc. have great influence on production performance (Ochieng et al., 2011; Hossen, 2010). Management intervention contributes to increase production potential of indigenous chicken and helps to support effectively the livelihood of poor rural households (Sarkar, 2012; Hossen, 2010) thus recognizing small-scale poultry production as an economically viable and sustainable enterprise for rural households in Bangladesh (Sarkar and Mustafa, 2009).

Age at First Egg Laying (AFE)

Mean age at first egg of local pullets were 28.96±1.46 and 27.63±1.69 weeks for highland and Midland agro-ecologies with overall mean of 28.30±1.715 weeks respectively. The overall mean of AFE in the current study was higher than the average values of 27.5±2.4 weeks by Fisseha *et al.* (2010), in Bure district, North West Ethiopia. In the current study AFE was significantly ($P<0.05$) earlier in Midland than Highland agro ecology. Similarly Getachew *et al*. (2021) conducted a study in Gambella region and the results revealed mean age of 24.8 weeks age at first egg which is much earlier than in the current study. The variation between the different studies might be attributed to differences in geographical location which could be related to availability of feeds and feed resources. The sexual maturity of animals is regulated by various factors, such as genetics, non-genetics (nutrition, and environment). The relationship between sexual maturity and nutritional status has been a subject of study in the field of reproductive biology. Some of the research findings were also confirmed in subsequent studies. Jambui et al. (2017) and Heijmans et al. (2023), suggested that poultry need to reach a critical threshold of body weight or fat storage to enter the egg-laying stage. Nutritional status also has an effect on the development of body frame, which was reported to be related to sexual maturity in mammals and poultry (Vargas et al., 1999; Setoguchi et al., 2011; Afrouziyeh et al., 2021).

The late maturity of pullets in the current study needs serious intervention measure to improve the situation. A different report on the age of chickens at first egg might be due to lack of proper supplementary feeds, availability of scavengable feed resources, disease outbreak, environmental temperature and provision of clean water by the households.

Egg Production Performance

Mean egg production per hen per clutch were (12.3±1.61 and 12.6±1.03 eggs) in the highland and midland with overall average egg per clutch per hen of 12.45±1.36. The result in this study for eggs per clutch per hen was lower than the result of Getachew *et al*. (2021) who reported that average egg per hen per clutch was (13.29±0.25 eggs) in Gambella region of Ethiopia. Similarly Assefa *et al.*

(2019), reported higher average egg production per hen per clutch of 13.3±2.5 eggs in two agro-ecologies (lowland and highland) than the current study. The current result egg production per hen per clutch was slightly higher than the finding by Habte *et al*. (2013), who reported 11.23 eggs per hen per clutch in Nole Kabba Woreda of western Wollega.

The current result showed that, the mean egg production of indigenous chicken per hen per year was 47.43±6.48 eggs in Highland and 48.42±6.94 eggs in the Midland agro-ecology with the overall mean egg production of 47.92±6.71 eggs in the study area. The mean egg production of indigenous chicken per hen per year (47.92 in the current study) is lower than the national average (65) of egg production per hen per year, which indicates low production performance (CSA, 2021).

Getachew et al. (2021) reported that comparable mean egg production per hen per year of indigenous hens with values (47.24, 46.0, 44.7 and 43.85 eggs) in Abobo, Gambella Ketema Zuria, Itang and Lare, areas, respectively with the overall mean egg production per hen per year of (45.48 eggs) in Gambella Region. The reason for low productive performance of indigenous chicken in the current study might be due to difference in management practices, environmental temperature, altitude, humidity and feed resource availability. The result of the current study revealed that there is a need for serious intervention in management practice, feeds and feeding situation so as to improve production and reproductive performance.

Table 1. Production and reproductive performance of indigenous chicken in the study area

Indigenous chicken performances	Agro-ecology			
	HL	ML	Overall	P-value
	N=160 Mean ±SD	N=160 Mean ±SD	N=320 Mean ±SD	
Pullets age at first egg lay in weeks	28.96±1.46	27.63±1.69	28.30±1.715	<0.0001
Cockerels age at first mating in weeks	22.71±1.35	22.4±1.288	22.56±1.324	0.0346
Matured age of cockerels(weeks)	29.63±1.114	28.96±1.732	29.2±1.493	<0.0001
cockerels matured body weight in grams	1220±87.271	1271.3±89.29	1245.6±91.81	<0.0001
Laying hen mature body weight in grams	1027.5±75.194	1023.8±80.47	1025.6±77.78	0.667
Clutch lengths in days	25.97±0.531	26.03±0.387	25.99±0.465	0.280
Number of clutches in a year	3.96±0.190	3.98±0.371	3.97±0.465	0.4899
Number of eggs/clutch/hen	12.3±1.614	12.6±1.029	12.45±1.359	0.0531
Average number of eggs lay per hen/year	47.43±6.480	48.42±6.94	47.92±6.712	0.1491

Means within row are significantly different at when (p≤0.05),
HL, refers to Highland, ML, refers to midland and N, Refers to sample size

Number of Clutch and Clutch Length

The mean number of clutch per year for local chicken was 3.96±0.19 in the highland and 3.98±0.37 in the midland agro ecology with the overall mean of number of clutch per year of 3.97±0.465. The result shows a non-significant (P>0.05) difference between two agro ecologies in the number of clutch per hen per year. The result was in agreement with the mean clutch numbers reported by Tsegaw et al. (2013) who reported 4.3 clutches per year in North Gonder, Ethiopia. The overall mean clutch length of indigenous chicken in the study area was 25.99±0.465 days and there was no significant difference (P>0.05) between the two agro ecologies The result was consistence with the report of Nebiyu et al. (2013) who reported that the average of clutch length of 26.0 days per clutch in Halaba zone of southern Ethiopia.

Brooding and Hatching Performance

The brooding and hatchability performance is presented in Table 2. The mean number of eggs set per incubation and hatching period per broody hen were 8.69±0.78 and 9.38±0.78 eggs in highland and midland agro-ecologies, respectively with overall average of 9.03±0.84 eggs. The number of eggs incubated per hen in this study was comparable with the finding of Getachew et al. (2021) who reported that, the overall mean number of eggs incubated was 9.64 eggs in Gambella Region of Ethiopia. The number of eggs set for hatching was significantly higher ($p<0.05$) in the midland than highland agro ecology in the study area The current report was inconsistent with the report of Andualem (2020) who reported greater numbers of eggs set to broody hen (12.50±0.3) in Awi Zone, Amhara Region. The mean number of chicks hatched per number of eggs set per hen per hatching was significantly higher ($p<0.05$) in the midland than highland agro ecology. The variation on the number of eggs set in the two agro-ecologies might be related to the number of egg produced per clutch in the respective agro-ecologies.

The variation on the number of hatching chicks might be due to the performance of broody hen, egg storage condition, the agro-ecological environmental temperature (seasons) and to the total number of eggs set during incubation period. The hatchability of chicks varied in dry and wet season in highland and midland agro-ecologies in the study area. In wet season higher rate of hatchability was observed in midland than highland. Highest hatchability rate was observed in dry season with values of 85.19±6.42% and 84.83±6.78% in highland and midland agro-ecologies, respectively, with overall average of 85.01±6.60%. The higher hatchability during dry season in the present study could be attributed to favorable environment for the hen to incubate her eggs for hatching than wet seasons.

Seasonal fluctuations could be one of the possible reasons for the wide variability in hatchability. In this regard, higher hatchability of chicken eggs was reported in other areas in spring than in summer (Farooq et al., 2003). On the other hand, poor hatchability was reported by North (1984) and Farooq et al. (2000) in summer hatches. Chowdhury et al. (2004) also reported highest hatchability of duck eggs in winter and lowest in summer.

Donald et al. (2002), Rashid et al. (2005) and King'ori et al. (2007) reported that performance in chickens in terms of hatchability and chick hatch-weight may be closely related to the weight of the eggs because the main effect of egg size lies in the mass of the residual yolk sac that the chick retains at hatching.

King'ori (2011) suggested that chick weight, fertility and hatchability are interrelated heritable traits that vary among breeds, variety or individuals in a breed. Asuquo and Okon (1993) studied the effects of age in lay and egg size on fertility and hatchability of eggs. The authors noticed that egg size within the intermediate range of 45–56 g would hatch better than small eggs.

Survival Rate of Local Chicks

Survival rate of chicks in dry and wet seasons are presented in Table 2. The survival rate to eight weeks of age at wet season was significantly higher ($p<0.05$) in the midland than highland agro ecology whereas in dry season, higher survival rate was obtained in highland agro-ecology. The overall mean survival rate of chicks in dry and wet seasons were 42.96±1.82 and 33.08±4.42 % respectively. The variation might be due to the environmental temperature condition, husbandry practices, season of the year and the prevalence of diseases and predators at that season in the study area. The current study was comparable with the report of Matawork et al. (2019) who reported that survival rate of local chicken ecotype in highland, midland and lowland were 38.06±2.13, 39.14±1.09 and 39.35±0.95 %, respectively. The difference in mortality or survival rate of chickens in different parts of the country might be due to the difference in environmental temperature, body weight at hatching time, chicken's health management practices, prevalence of predators in different localities, density of chicken kept and season of the year chicks' hatch. In a study conducted in other countries, significantly ($P<0.05$) higher chicks survival was recorded in summer, spring and autumn season as compared to winter season. This may be attributed to extremely harsh environmental condition during the winter season. Sankhyan et al. (2015) also recorded the higher survival of chicks during summer season.

Reproductive Life Span of Local Chicken

There was significantly higher (P<0.05) reproductive life span of hens in the midland than the highland agro ecology in the study area.

Reproductive life span of cocks shows a non-significant (P>0.05) difference between the two agro ecologies in the study area. The mean reproductive life span of cocks (1.87±0.43 years) in the current study was less than the study conducted by Zewdu et al. (2013) who reported higher reproductive life span of cocks (3.79 years) in Metekel zone. On the other hand, the same author had reported a lower mean reproductive life span of hen of 3.56±0.14 years than the mean reproductive life span in the current study. Andualem et al. (2024) reported overall average reproductive lifespans of male and female Local chickens were 4.07 ± 0.07 and 3.75 ± 0.07 years, respectively which is higher than the observed lifespan in the current study. Several factors play a role in determining how long chickens live. Genetics and breed characteristi**cs** influence their natural longevity, while the quality of care they receive and the conditions in which they live can make a substantial impact on their lifespan.

Table 2. Hatchability and survivability of indigenous chicks in the study area

Indigenous chicken performances	Agro-ecology			
	HL	ML	Overall	P-value
	N=160 Mean ±SD	N=160 Mean ±SD	N=320 Mean ±SD	
Average number of egg set/hatch/hen	8.69±0.779	9.38±0.784	9.03±0.847	<0.0001
Chicks hatched/Settled eggs/hen/hatching	7.3±0.612	8.5±1.133	7.9±1.089	<0.0001
Percentage of hatch rate in the dry season	85.19±6.418	84.83±6.799	85.01±6.603	0.6186
Percentage of hatch rate in the wet season	73.19±6.418	76.08±6.799	74.64±6.757	0.0001
Chick survival to 8 weeks (dry season %)	43.25±1.166	42.66±2.257	42.96±1.816	0.0039
Chick survival to 8 weeks (wet season %)	30.35±4.471	35.8±2.061	33.08±4.419	<0.0001
Reproductive life span of hens in (year)	4.06±0.231	4.2±0.409	4.13±0.339	0.0002
Reproductive life span of cocks in (year)	1.89±0.449	1.85±0.407	1.87±0.428	0.4343

Means within row are significantly different at when (p≤0.05), HL, refers to Highland, ML, refers to midland and N, Refers to sample size

External and Internal Egg Quality Traits

External Egg Quality Parameters

External egg quality traits, particularly egg weight, shell weight, width and length are important parameters to consider during selection for improvement in live weight of the local chicken (Parmar et al., 2006).

The different external egg quality parameters are presented in Table 3. The mean value of egg weight and egg length in the midland was significantly (p<0.05) higher than the highland agro-ecology. The average egg weight (38. 44 gram) in the current study were lower than values (39.4 gram in lowland, 40.2 gram in midland and 39.3 gram in highland) reported by Aberra et al. (2013) across different agro-ecologies of Ethiopia. Similarly, the values of egg weight in the current finding was lower than the report of Kgwatalala et al. (2016) who reported average egg weight of 49.79 gram and 48.21gram reported on necked neck and normal indigenous chicken.

The variation might be due to the environmental factors related to the agro ecology in terms of diet, water intake, temperature, humidity and management practices. Isidahomen et al. (2013) reported, environmental influences in terms of the age of chicken, body size, and type of feed, water intake, temperature, and humidity and management practices may contribute to the variability observed in their egg quality results. Alex (2001) further reported that an egg weight is proportional to body weight. Big body birds eat more feed to maintain their body size. Higher egg weight, egg volume and surface area for the egg influences its egg quality and reproductive fitness of the chicken. Thus, it plays a significant role in the process of embryo development and successful hatching while the size of the hatching egg influences body weight of chicks up to maturity as suggested by (Islam et al., 2001; Farooq et al., 2001).

Egg width had shown significant difference between the two agro-ecologies in the study area in which the midland egg width were significantly ($p<0.05$) higher than the highland agro ecology, with the overall mean egg width of (37.39±1.41mm). The width of the eggs from the indigenous chickens in the study area were in agreement with the finding of Legesse and Kefyalew (2022) who reported that the egg width of indigenous chicken of 37.37, 38.65 and 38.62 mm respectively for in highland, midland and lowland agro-ecologies of Sidama Region, Ethiopia.

Egg shell weight in the midland was significantly higher than the highland agro-ecologies at ($p<0.05$). The result of mean egg shell weight (3.42±0.567gram) in the current study was lower than the report of Matawork and Meseret (2022) who reported shell weight of 5.25 ± 0.73, 5.12 ± 0.73 and 4.76±0.73 gram respectively at highland, midland and lowland agro-ecologies in Gena Bossa district of Dawro zone.

The egg shell thickness of indigenous chicken eggs in the study area was recorded with the overall mean of 0.27±0.034 mm showing a non-significant difference between the two agro ecologies. The current finding was comparable with the report of Fisseha *et al*. (2010), who reported 0.26 mm in Northwestern Ethiopia. The result was also in line with the report of Legesse and Kefyalew (2022) who reported the egg shell thickness of 0.286, 0.234 and 0.298 mm respectively for indigenous chicken in highland, midland and lowland agro-ecologies in Sidama Region of Ethiopia. However, the result in the current study was lower than the finding of Serkalem et al., (2019), who reported 0.279±0.03 and 0.281±0.02 mm respectively for shell thickness in lowland and midland agro-ecologies in different areas of Ethiopia. The variations in egg shell thickness among indigenous chicken ecotypes reared in various parts of the country might be due to the availability of calcium mineral in the feed, type of management, type of chicken population, and environmental influence as reported by Welelaw et al. (2018). From external egg quality traits, egg shell thickness is one of the vital portion of egg quality as it measures the strength of egg shell to minimize egg shell breakages which is important for breeder flock as studied by Bekele et al. (2009).

Egg shape index of indigenous chicken in the highland was significantly ($p<0.05$) higher than the midland agro-ecologies which had the overall mean of 75.21±4.28%. The variation might be due to the agro ecological effect, the husbandry practices and age of the hens. The finding was in agreement with the study of Veena et al. (2015), who reported egg shape index values of 72.10 during winter and 71.99 during summer on indigenous chickens of Andhra Pradesh. Egg shape is an important parameter in commercial production systems. Sharp eggs and round eggs do not fit well in egg cartons; therefore, they are much more likely to be broken during transportation than eggs of normal shape (Jacob, Milles, & Mather, 2000).

Table 3. External Egg quality parameters in the study area

Egg quality parameters	Agro-ecology			
	HL	ML		
	(Mean ±SD)	(Mean ±SD)	Overall mean	P-value
Egg weight (gm.)	37.72±3.544	39.16±3.777	38.44±3.726	0.0012
Egg length (mm)	49.21±2.825	50.46±2.154	49.84±2.584	< 0.0001
Egg width (mm)	37.18±1.512	37.62±1.267	37.39±1.409	0.0088
Shell weight (gm.)	3.32±0.62	3.53±0.496	3.42±0.567	0.0025
Shell thickness (mm)	0.27±0.035	0.27±0.034	0.27±0.034	0.0977
Shell Weight (%)	8.79±1.348	8.93±1.392	8.86±1.369	0.1196
Egg shape index (%)	75.77±5.067	74.64±3.221	75.21±4.276	0.0266

Means within row are significantly different when (p≤0.05), HL, Refers to Highland, ML, Refers to midland and SD, Refers to standard deviation

Internal Egg Quality Parameters

Internal egg quality depends upon the albumen quality, yolk quality, existence of blood or meat spot and air cell size (Ketelaere et al., 2004). Internal egg quality parameters of indigenous chicken in the study area are presented in Table 4. Albumen weight was significantly (p<0.05) higher in midland agro-ecology than the highland agro-ecology. The value of the albumen weight in the current study was comparable with the study of Legesse and Kefyalew (2022) who reported albumen weight of indigenous chicken of (21.78±3.16, 25.47±3.39 and 23.49±4.25gram) respectively, in highland, midland and lowland agro-ecologies of Sidama Region, Ethiopia.

Albumen height was significantly (p<0.05) higher in highland than midland agro-ecology in the study area. There was a non-significant (p>0.05) difference in Yolk weight between the two agro-ecologies but numerically there was some difference in yolk weight of indigenous chicken (14.84±1.92 gram) in highland and (14.76±1.335 gram) in midland agro-ecology (table 3). The current study was slightly similar with the report of Matawork and Meseret (2022) who reported yolk weight of 15.21±0.27gram in Gena Bossa district of Dawro zone. The variation in different localities might be due to difference in age of the hen and difference in the feed resource (type and availability). The effects of storage period were remarkable in nearly all internal egg quality traits (Khatun et al., 2016). Among non- genetic factors affecting internal egg quality; age of hens has the most important role in determining albumen quality in fresh laid eggs. Younger hens lay eggs with good albumen quality than aged hens although an induced pause can also lead to better quality albumen in aged hens (Supral and Surya, 2022). Yolk height of indigenous chicken in the highland (15.19±0.934 mm) was significantly (p≤0.05) higher than the midland agro-ecology (14.76±1.335mm) in the study area. The variation might be due to difference in the environmental temperature difference and type of scavenging feed sources in the study area. The result was consistent with the finding of Matawork and Meseret (2022) who reported yolk height of (14.83± 0.31 millimeter) in Gena Bossa district of Dawro zone.

The yolk diameter of indigenous chicken in the current study was (36.81±2.37) millimeter in highland and (38.37±1.95 millimeter) in the midland agro-ecology which was significantly higher in midland than that of highland agro-ecology (p≤0.05). The study was in agreement with the report of Demissu (2020) who stated yolk diameter of unimproved Horro chicken of (36.6, 41.1 and 39.7 millimeter) in highland, midland and lowland agro ecologies, respectively.

The result of yolk color shows statistically a non-significant (p>0.05) difference. Albumen ratio also shows a non-significant difference between the two agro ecologies in the study area. The value of the yolk color (9.22±0.83) in the current study was comparable with the reports of Legesse and

Kefyalew (2022) who reported that the value of 9.35±1.49, 9.46±1.78 and 8.96±1.80 respectively in highland, midland and lowland agro-ecologies of Sidama Region, Ethiopia. Slightly lower yolk color was reported by Matawork and Meseret (2022) who reported average yolk color of eggs to be 8.37 ± 0.15. The variation might be due to difference in the feeds type which had an effect on the yolk color of eggs from indigenous chickens in different localities. The color of the egg yolk is mainly dependent on the type of feed and the management systems of chicken. The eggs collected from scavenging birds have a higher yolk color count because scavenging birds have free access to green plants and other feed sources rich in xanthophyll (Zaman *et al*., 2004).

Mean yolk ratio of 38.96±3.754% and Albumen ratio of 50.06±4.838% was recorded in the current study. Yolk ratio in the highland was significantly (p<≤0.05) higher than the midland agro ecology in the study area. Demissu (2020) reported average yolk ratio of 34.99% which was lower than the current study and nearly comparable average albumin ratio of 54.71% was reported and the current finding was consistent with the report of Legesse and Kefyalew (2022) who reported yolk ratio of (37.68±6.72, 36.17±3.92 and 37.30±6.28) and Albumen ratio of (51.35±9.75, 51.48±6.19 and 52.94±10.66) respectively in indigenous chicken in highland, midland and lowland agro-ecologies in Sidama Region of Ethiopia.

Both the Haugh unit and yolk index were significantly ($p \le 0.05$) higher in highland agro ecology than the midland agro ecology in the study area. However, Nuhu *et al*. (2018) reported higher Haugh Unit (100.533) in Nigerian savanna indigenous chicken.

Table 4. Internal egg quality parameters in the study area

Egg quality parameters	Agro-ecology			
	HL	ML		
	(Mean ±SD)	(Mean ±SD)	Overall Mean	P-value
Albumen weight (gm.)	18.87±2.425	19.59±2.556	19.23±2.514	0.0172
Albumen height (mm)	4.7±0.678	4.49±0.804	4.59±0.749	0.0184
Yolk weight (gm.)	14.84±1.92	15.06±1.695	14.95±0.323	0.3231
Yolk height (mm)	15.19±0.934	14.76±1.335	14.97±1.169	0.0020
Yolk diameter (mm)	36.81±2.371	38.37±1.951	37.59±2.302	<0.0001
Yolk Roche fun color	9.2±0.712	9.24±0.935	9.22±0.83	0.6666
Yolk ratio	39.43±4.470	38.49±2.805	38.96±3.754	0.0364
Albumen ratio	50.19±6.052	49.93±3.214	50.06±4.838	0.6560
Haugh unit	76.01±5.012	73.64±5.461	74.82±5.365	0.0002
Yolk index	41.41±3.542	38.59±4.199	39.99±4.127	<0.0001

Means within row are significantly different when ($p \le 0.05$), HL, Refers to Highland, ML, Refers to midland, SD refers to standard deviation

Correlation among Internal and External Egg Quality Parameters

Correlation among External Egg Quality Parameters

The result presented in Table 5 indicated that there was a strong positive correlation between egg weights and other external egg qualities such as egg width and egg length, and moderate positive correlation with shell weight and shell thickness. The current study is in good agreement with the finding of Berhanu *et al*. (2022) who reported that egg weight had a positive correlation with the external egg quality traits of egg width, egg length, and shell weight in southern Ethiopia.

There was a positive correlation between egg length with the egg width and shell weight. The finding was in line with the report of Bobbo *et al*. (2013) which found a strong positive correlation between egg length and egg width on frizzle and necked neck indigenous chickens in Yola.

There was a statistically significant positive correlation between egg shape index and egg weight ($P \leq 0.05$). This could be explained as a result of the denser part of the egg (albumen) occupying the width area, which translates to heavier weight for the egg. The result agrees with finding of Duman *et al*. (2016), but disagrees with the findings of Yilmaz *et al*. (2011). Egg length was negatively correlated with the egg shape index, but correlated positively with the egg width and egg shell weight. This indicated that when the egg becomes wider, its shape index will be larger, and it will possess a round shape that it makes it challenging to handle and pack. Similarly, a strong negative correlation between egg length and shape index but positive correlation between egg width and shape index were reported in dwarf, normal and necked neck indigenous chicken of Tswana as reported by Kgwatalala *et al*. (2016).

Shell weight indicated that a strong positive correlation with that of shell weight percentage and a positive correlation with the shell thickness (Table 5). The result was in good agreement with the Markos *et al*. (2017). Egg shell weight percentage with shell weight and shell thickness has a positive correlation but negatively correlated with egg weight.

Table 5. Pearson correlation of external egg quality parameters in the study area

	Egg weight	Egg length	Egg width	Shell weight	Shell thickness	Egg shape index (%)	Shell Wt. (%)
Egg weight	1						
Egg length	0.547	1					
Egg width	0.701	0.352	1				
Shell weight	0.435	0.285	0.342	1			
Shell thickness	0.304	0.123	0.17	0.257	1		
Egg shape index (%)	-0.05	-0.76	0.33	-0.05	-0.016	1	
Shell Weight (%)	-0.16	-0.03	-0.07	0.815	0.08	-0.02	1

Note: Wt., Refers to Weight, %, Refers to percentage

Correlation between Internal Egg Quality Parameters

There was a strong positive correlation between albumen weight with the albumen height and albumen ratio. Albumen weight was positively correlated with yolk height, yolk weight and Haugh Unit of indigenous chicken (table 6). The result was in line with the report of Markos *et al*. (2017) who reported a strong positive correlation between albumen weight and yolk weight in highland, midland and lowland agro ecology ecotypes of chicken in Tigray region. A strong positive correlation between albumen weight and yolk weight was reported in dwarf, normal and necked neck indigenous chickens of Tswana (Kgwatalala *et al*., 2016). The current result disagrees with the finding of Bertha (2013) reporting that there was a negative correlation between albumen weight and yolk weight and yolk diameter. Albumen height had a strong positive correlation with the Haugh Units (0.948) and positively correlated with the egg yolk height, albumen ratio and yolk index but negatively correlated with the yolk diameter and yolk ratio. The study was in line with the study of Bobbo *et al*. (2013) who reported positive correlation between albumen height and Haugh Units of 0.98, 0.91 and 0.90 for frizzle, necked neck and smooth feathered indigenous chickens, respectively, in Adamawa state of Yola. Albumen height is higher for fresh eggs and deteriorates with increasing storage period and storage temperature and at the same time, the Haugh Unit of eggs decreased.

There was a positive correlation between yolk weight with yolk height, yolk diameter and yolk ratio. The result was consistent with the report of Markos *et al*. (2017). Yolk height was strongly correlated with yolk index and Haugh Units of indigenous chicken eggs in the current study. The current study was in line with the study of Markos *et al*. (2017) and Bertha (2013) who reported strong correlation of yolk height with yolk index and Haugh Unit.

Correlation of yolk diameter with yolk index, Haugh units and albumen ratio were negative. It might occur when yolk height decreases due to different factors, the yolk expands, and its diameter increase. In the current study, Huagh unit showed a strong positive correlation with the albumen height and negatively correlated with egg yolk diameter and yolk ratio. The result was consistent with the report of Sinha *et al*. (2018).

Table 6. Pearson correlation of internal egg quality parameters of indigenous chicken

	Albumen Weight	Albumen Height	Yolk Weight	Yolk height	Yolk Diameter	Yolk ratio	Albumen ratio	Yolk index	Haugh unit
A/weight	1								
A/height	0.523	1							
Y/weight	0.292	0.1	1						
Y/height	0.386	0.512	0.454	1					
Y/Diameter	0.1	-0.25	0.376	-0.1	1				
Yolk ratio	-0.32	-0.25	0.62	0.11	0.208	1			
Albumen ratio	0.653	0.356	-0.25	0.074	-0.153	-0.21	1		
Yolk index	0.232	0.535	0.105	0.798	-0.674	-0.05	0.155	1	
Haugh Unit	0.321	0.948	-0.1	0.397	-0.353	-0.19	0.398	0.513	1

Correlation between Internal and External Egg Quality Parameters

Correlation between internal and external egg quality parameters of indigenous chicken is shown in Table 7. Albumen weight has a positive correlation with the egg weight, egg length and egg shape index. This result was in line with the study of Markos *et al*. (2017).

Albumen height has a positive correlation with the egg weight but negatively correlated with egg shell weight. The result was in good agreement with the study of Bertha (2013) who reported a significant negative correlation of albumen height with the egg length; egg width and shell weight but disagree with the egg weight which correlated negatively.

Yolk weight had a positive correlation with the egg weight of indigenous chicken in the current finding. The result is in agreement with the report of Markos *et al*. (2017). According to the current study, yolk weight increases with increasing of egg weight and egg length. The weight of eggs and egg length are related with different factors, such as the age of the hen, breed, nutrition and other environmental factors.

Yolk height had a positive correlation with the egg weight, egg width and egg shell thickness but had a negative correlation with the egg length, shell weight and egg shape index. The current finding is in line with the finding of Godson *et al*. (2020) who reported that a positive correlation of yolk height with egg weight, egg length and egg width. The same author reported a negative correlation of yolk height with shell weight, shell thickness and shape index.

Yolk diameter of indigenous chicken showed a positive correlation with the egg weight, egg length, shell weight and egg shape index but had a negative correlation with the egg width and egg shell thickness. Haugh Unit of the indigenous chicken eggs in the study area shows a positive correlation with the egg weight but negatively correlated with the egg length, egg width, egg shell weight, shell thickness and egg shape index. In general the egg quality of indigenous chicken at different localities might be different due to a number of factors, such as storage duration of eggs, storage temperature, age of laying hen, the chicken ecotype, the agro ecological condition, season of the year and difference in the feed type.

Table 7. Correlation between some internal and external egg quality parameters in the study area

Parameters	Egg weight	Egg length	Egg width	Shell weight	Shell thickness	Egg shape index
Albumen weight	0.551	0.176	-0.205	-0.029	-0.061	0.192
Albumen height	0.387	-0.03	-0.03	-0.159	-0.02	-0.013
Yolk weight	0.418	0.052	-0.028	-0.08	0.075	0.056
Yolk height	0.445	-0.07	0.011	-0.156	0.026	-0.045
Yolk diameter	0.033	0.078	-0.013	0.027	-0.052	0.062
Haugh units	0.215	-0.03	-0.029	-0.161	-0.016	-0.015

CONCLUSIONS

In this study, a better productive performance in terms of the number of eggs per clutch, number of chicks hatched and the number of eggs per year was observed in midland agro-ecology. Eggs from the midland agro-ecology had significantly greater weight, width and shell weight. Eggs from the midland agro-ecology had higher albumin weights and yolk diameter but lower albumen height. Eggs from highland were higher in HU and yolk index than midland. Based on the above conclusion, it can be recommended that agro-ecological-based improvements in breeding, management practice (feeding, housing and health) of indigenous chickens are vital in the study area

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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Original Research Article||

Graduate Research in Animal Sciences at Hawassa University: Scoping Review of Published Theses during 2009 to 2022

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Abstract

Hawassa University launched its first MSc programs in 2004 in various agricultural fields, including animal science specializations. In the past 20 years, the study programs diversified by fields of specializations and increased admissions. This scoping review assessed abstracts of 200 MSc theses of animal science graduates from Hawassa University produced during 2009 to 2022. The study was initiated to shed light on the trends in terms of diversity and quality of research conducted by students. The analysis focused on studies conducted on livestock species, disciplines, geographic coverage, data collection approaches and statistical methods employed by students. The study further assessed whether graduate research is orientated towards problem solving or whether it focuses on information seeking/gathering/assessments. The most frequently studied species (96%) were cattle, sheep and chicken/poultry and goats, in descending order. Of the total theses, 85% were skewed to three research themes, 1) livestock feed resources and nutrition, 2) livestock production systems and/or product characterizations and 3) livestock genetic resources, breeding systems, reproduction and genetic improvements. The majority of the graduate students (89%) combined two or more data collection approaches. Out of the total MSc theses, 77% fall under information seeking/gathering/assessment researches. Only 22% theses were orientated towards investigative and problem-solving research. This scoping review might shed lights on a further country wide study for all agricultural fields offered by the concerned Ethiopian public Universities that are running BSc, MSc and PhD programs. The results of such a study can also be used to inform the need for developing suitable strategies for improving graduate studies in Ethiopia, in order to ensure that graduate studies will contribute to societal change and economic development through quality and impactful research outputs. Revisiting the animal science graduate study programs would contribute to increasing the contributions of graduate research for livestock sector development.

Key words: Graduate study programs; Quality research; Ethiopian Universities; Problem solving research

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INTRODUCTION

Globally, the role of higher education institutions to overall development of human capital and its contributions for science, technologies and innovations as well as economic development is very well recognized (David et al., 2008; Allais, 2017; Agasisti and Bertoletti, 2022; Bing, 2023). Countries that invest more on higher education development programs have been rewarded by their continuous and sustainable economic development. For example, according to Bing (2023), China's gross enrolment rate in higher education increased from 30% in 2012 to 57.8% in 2021. In the same period, the country achieved a historic leap forward in building the world's largest higher education system which in turn led to rapid and consistent economic development in the country. However, a lot of shortcomings have been reported on the higher education systems of sub-Saharan Africa, which is identified as the only region in the world where food production per capita has decreased since 1970 (African Union, 2007). Africa's higher education system needs more investment not only to increase enrolments but also to substantially improve the quality of education and research in the existing programs. In many African universities and other academic and research institutions, quality of research is usually judged on the basis of scientific rigor including use of sound methodologies, and the communication of research results and deployment of graduates to

the wider job market and scientific community (Ochola et al., 2013). Further, it is imperative to analyze the impact of research from higher education systems, notably from graduate students, in light of its impact on societal change and overall economic development.
Countries usually review such graduate study programs and revisit their curriculums accordingly. Since agricultural sciences were introduced to Ethiopia, first at Diploma and later at Bachelor, MSc and PhD levels, there have been limited efforts to evaluate the quality of education and research outputs from universities. Few studies have been conducted to shed lights on the quality of education and thesis based research works. According to our review, the first and only scoping study was initiated by Eyasu Seifu (2005) who evaluated theses of MSc students from Haromaya University after programs were launched in the late 1980s.

Over the past three decades, Ethiopia has witnessed a rapid growth and massification of higher education at undergraduate and graduate study programs. Hawassa University (HU), as one of the first generation public Universities in Ethiopia, launched its first MSc study programs in 2005 and its PhD programs in 2012, both at the College of Agriculture. The programs included various agricultural study programs, including animal science. Until MSc programs were launched in 2005, Haromaya University was the only University in the country to run graduate study programs in animals science fields (Eyasu, 2005). During the last 20 years, the school of animal and range sciences of Hawassa University has produced over 200 MSc students in various animal science fields/specializations. This study sought to review the theses which were electronically published/deposited at the HU library, to assess the trends in terms of diversity and quality of research by graduate students. The study described the theses in terms of research focus by livestock species, discipline, geographic coverage/production system, data collection approaches, and statistical methods employed for data analysis. The study further assessed whether graduate researches have been orientated towards problem solving and investigative nature or if they rather focus on information seeking/assessments. Empirical evidences generated from this study will contribute to inform the need to revisit the graduate study programs in animal science fields to tailor them towards impactful research outputs which significantly contribute to inform responsible bodies on the development of livestock sector in the country. By taking this case study as an example, we will try to showcase how future graduate study programs in the fields of agricultural sciences should be impactful for societal change and economic development of the country.

MATERIALS AND METHODS

Data Collection Approach

Qualitative and quantitative research approaches have been used in describing and interpreting the information. The study adopted graduate thesis review methods, mainly involving systematic examination of electronic sources (Dolmaz et al., 2020). Electronic abstract of theses were used to extract both quantitative and qualitative information as used in Maxwell (2007) and Bowen (2009). The data was collected from Hawassa University Library and the detail can be accessed at http://etd.hu.edu.et(http://etd.hu.edu.et/handle/123456789/1779).

The MSc study program at Hawassa University was launched in 2004, and the first batch were admitted starting from 2005. Theses produced from the school of animal and range sciences and those deposited at the library during 2009 to 2022 GC were used. Theses that were produced in the first two years (2007 and 2008) were not considered for the current analysis as they were not readily available in electronic forms. Data were extracted from MSc thesis titles, abstracts and key words on theses published by graduate students. The main sets of data extracted from the theses include profiles of graduate students, year of graduation, sex, nationality and fields of specializations. Major geographic locations of study areas, main livestock species studied, data collection methods, as well as data analysis methods applied by graduate students were analyzed. The theses were thematically analyzed by thesis categories (i.e. whether they were information seekers or more problem solving and investigative types). Data were organized on spreadsheets for further analysis. Contents of the abstract referring to their topic, methods and main results were used for data extractions.

Working Definitions for Variables used in The Study

Study Areas: in this study all study areas of the graduate students were plotted into Ethiopian map. Students might have one or multiple Kebeles, districts or Zones in their theses. We considered a given administrative zone as a study area if there is any mention of Kebeles or districts from that zone its field experiment or social surveys.

Fields of Specializations: until this study was conducted, the school of animal and range sciences at Hawassa University had 5 MSc study programs/specializations within animal science fields. Graduate students might specialize in animal production, animal nutrition, animal breeding, dairy science and technology, animal biotechnology and range sciences (which was later named as range land ecology and management).

Data Collection Methods: In this study data collection methods were categorized into three 1) laboratory experiment/analysis, 2) field experiments and 3) social survey/house hold survey. Graduate theses were categorized based on their research unit and data sources for their primary data. Students might use only or combinations of two or three data collection methods. For example, if students used animal experiments (on farmers' fields or on stations), this study falls under category two. If students conduct formal or informal survey, or key informant surveys or group discussions or all, it falls under category 3.

Information Seeking versus Investigative/Problem Solving Thesis: in this study, theses were categorized into two as information seeking/assessment or investigative. If a given lab analysis, field experiment or social survey only assess information to describe and/or compare commodities, production systems or study areas by the given descriptors, it falls under information seeking/assessment. On the other hand, if students conduct experimental studies to test new methods, new products, new technologies, new innovations that solve a given societal problem, it falls under investigative research category. For example, if a given thesis deals with prevalence of a given diseases or nutritional contents a feed stuff, it falls under the first category. On the other hand, if the thesis deals with developing methods that minimize or control diseases on animals or developing a new feeding system, new diet formulations or introducing new products and test it, it falls under the investigative research category. Lists of MSc these titles are found as Annex 2.

Data Analysis

The data collected from graduate theses was organized in a way suitable for analysis based on the various variables categorized by thematic focuses and methodological classes. The data content includes: year of publication (submission), gender, nationality, field of specialty, study area, species under consideration, data collection methods, statistical test, data analysis methods and tools (summary found as Annex 1). The data analysis was done using R software and MS Excel tools. The result was subjected to multiple analysis and plotted using tidyverse package to plot bar, histogram and others. The diagrammatic representation of workflow is shown in Figure 1.

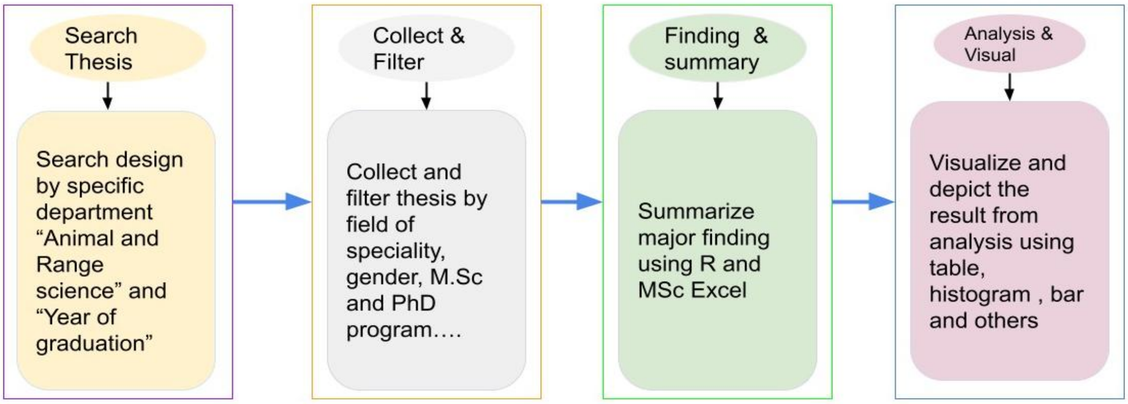

Figure 1. Workflow for thematic and methodological trend analysis from graduate theses 2009-2023

RESULTS AND DISCUSSION

Trends and Distributions of Graduate Theses by Fields of Specializations and Research Areas

Over the past three decades, Ethiopia witnessed a rapid growth of higher education and massive admissions of students in various animal science fields at undergraduate and graduate study programs. During these period, curriculums/programs for undergraduate and graduate study programs were rapidly growing and diversified. HU launched its first MSc study programs in 2005 and its PhD programs in 2012 including animal science under the College of Agriculture. By then, 4 MSc specializations, namely Animal Production, Animal Nutrition, Animal Breeding and Dairy Sciences were launched as research-based programs and begun admitting students. Between 2009 and 2022 GC, a total of 190 masters research theses were deposited at Hawassa University library (can be accessed at http://etd.hu.edu.et). Theses based on MSc research were produced since 2007, but electronic versions were available beginning from 2009.

Numbers of graduate theses documented under HU library system is presented in Figure 2 below. The result showed an increasing trend in the number of graduate theses published except the sharp decline during 2014 and 2015 resulting from the admission of students only in two programs in 2012 and 2013. The highest number of MSc theses were produced during 2016 to 2021 as a result of the initiatives taken by the school to revise curriculums of existing programs, launching of more specialized fields followed by successive promotion of the study programs. After 2021, the number of graduate theses again started to decline, which might attributed to the increasing number of graduate study programs launched in various public Universities in the country in general and in southern region in particular. The national graduate admission test (GAT), which was introduced and implemented since 2023, significantly affected further admissions. For instance, no graduate student was admitted to HU during 2023/24 academic year). This policy might continue to affect admissions of graduate students and number of theses to be produced in the following years, as very few students have been able to pass the GAT. The first MSc thesis in animal science fields was produced in 1981 from Haromaya University which was the only University running MSc programs in animal science fields until 2004 (Eyasu, 2005). Today, over 50 public Universities in Ethiopia have animal science programs, at least at Bachelor level and most of them have also launched MSc and PhD programs. This will on the one hand increase the total number of graduate students in the country, but have affected and may continue to affect admission rates per university including HU as the students are tending to attend their graduate studies in relatively nearby Universities.

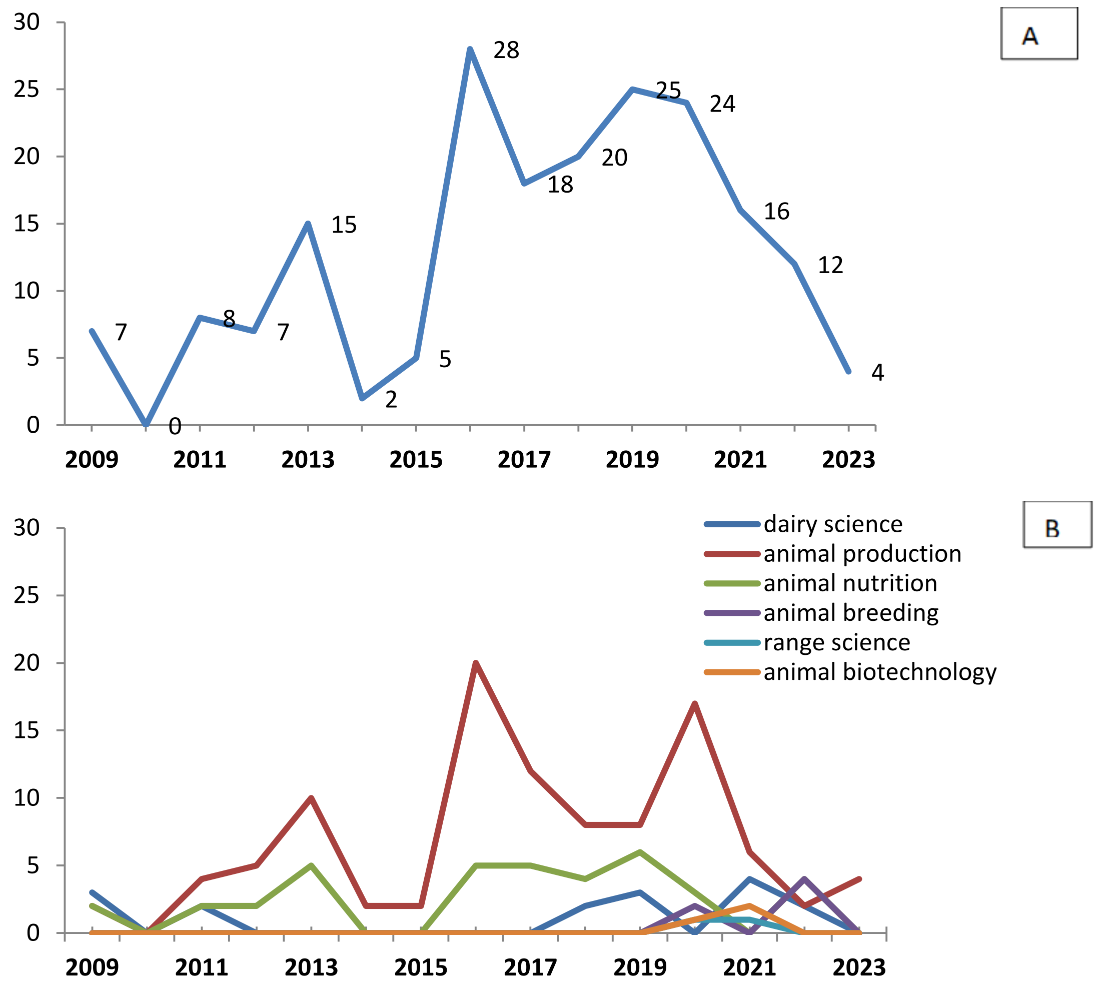

Figure 2. Overall trends on the number of graduate theses produced annually (A) and the corresponding specializations (B)

Figures 3 shows the profiles of graduate students by fields of specializations as disaggregated by sex of the graduates. The number of female graduates admitted during 2009-2022 were low and account only about 13% of the total graduates. Among the female graduates, 21% and 10.8% have attended animal nutrition and animal production programs, respectively. The overall proportion of female graduates in HU is low. However, it is higher than the reported 4.4% for Haromaya University (Eaysu, 2005). Inadequate physical infrastructure, equipment, and communication facilities; limited teaching and research capabilities; poor incentives for the academic staff; and limited funding for research have affected quality of research by graduate students in African Universities (Kristin et al., 2008), which also applies to Ethiopian public universities including HU. The proportion of international students in animal science study programs at HU were only 1%. Moreover, the graduate programs could not attract international students even from neighbouring countries. Should the capacities of African Universities improve and contribute substantially to advancing science, internationalizing graduate study programs is highly recommended (Kristin et al., 2008). Low-income African nations were not succeeding well with internationalizing their graduate programs (Mohammad and Alireza, 2024). Lack of clear policies and guidelines; inefficient organizational structure; finance, infrastructure, and equipment problems; weaknesses in scientific skill, and language competences as well as cultural differences were mentioned as important barriers. Internationalization is not a goal by itself but a means to excel and advance science and scientific outputs. More efforts should be made by the education stakeholders including the Ministry of Education and Ethiopian Universities to ensure quality of the graduate programs.

The highest number of theses were produced from graduates of animal production, which accounts for 53.7% of the total theses generated under animal science (Figure 3A). The number of students specialized in animal biotechnology and range sciences were low, as the two programs were launched only since 2018. Overall, the peak years by the number of theses produced were 2013, 2016 and 2020, while animal production and animal nutrition programs were dominating the graduate thesis research works. In 2016, the school re-launched an MSc program in dairy sciences, which was later renamed as dairy science and technology. In 2018, most of the MSc curriculums were revised and new programs such as animal biotechnology were launched.

As shown in Figure 3 (B), the majority of graduate theses addressed three major thematic areas including, 1) livestock feed resources and nutrition, 2) livestock production systems and/or product characterizations and 3) livestock genetic resources, breeding systems, reproduction and genetic improvements in descending order (34.4%, 30.4%% and 19.8%), respectively. Overall, the above thematic accounted for 85% of the total graduate theses produced under animal science during the indicated period. The remaining 15% of the graduate theses focused on topics related to animal products safety and health, range and pastoralism, as well as other issues (such as wool, hide and skin, honey bees, draft animals, and biotechnology). The current study is supported by the unique study conducted at Haromaya University which studied graduate research topics during 1981-2005; which also showed that the highest proportion of students at Haromaya University focused on research topics related to feeds and nutrition (Eyasu, 2005). This could also be attributed to better availability of subject matter specialists in animal nutrition at the school, which was reflected over longer periods of time. The choices of fields of specializations as well as research topics/areas selected by graduate students may not necessarily reflect the country's/regional state's needs and priorities, but might be a reflection of multiple factors including the student interests and their supervisors. This entails the need for a strategy by which graduate research focuses should be guided in a demand driven manner. We observed that students who come from development and livestock extension have shown to join animal production programs while those coming from academic and research institutions prefer to specialize in highly specific fields such as animal nutrition, animal breeding, dairy science and animal biotechnology.

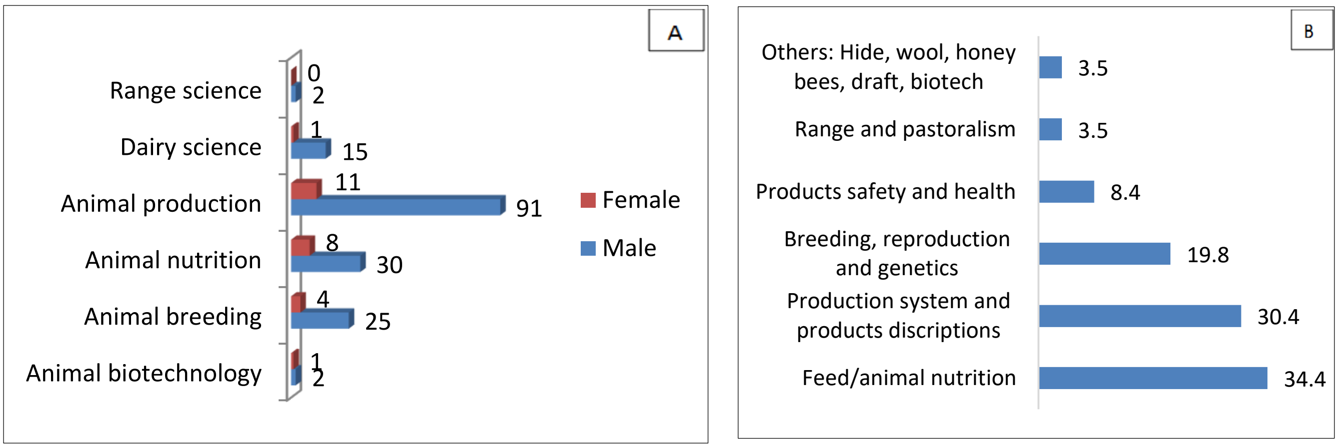

Figure 3. Number of MSc theses by fields of specializations and gender (A), and proportion (%) of theses by research thematic areas (B)

The result shows that the MSc theses were skewed to few thematic areas. This might have been due to lack of sufficient experts/supervisors, or lack of the necessary courses to encourage graduate students to diversify their study areas. Some research areas, such as livestock products quality (animal source foods), by-products utilization (such as wool, hair, hide and skin or other by products) were almost neglected in the graduate research undertakings. Feed is one of the most important inputs to livestock, and the major bottle neck for the country's livestock development, but graduate research works have not focused on developing/testing different feed processing technologies. Vibeke et al. (2008) showed that graduate students in the developed world are criticized for their low focus on spatial scale and lack of broader perspectives at systems levels (farm, landscape, and regional levels), whereas our graduate students researches lack rigor and do not address more specific livestock problems.

Distributions of Theses by Geographic Locations/Study Areas

Figure 4 shows the major study areas covered by the graduate research theses. It shows that graduates of Hawassa University have a wide coverage of study areas within Ethiopia. No student did his/her study outside Ethiopia. Almost all regional states of Ethiopia were covered in the thesis research works of graduate students at Hawassa University. Mixed crop-livestock production systems in the mid-and highlands of Ethiopia have been mostly covered in the graduate research works. The Eastern, Western and South-Eastern low lands of Ethiopia were less covered by the graduate research works. In the past, graduate students usually cover wide areas (comparing multiple districts, zones or regions). In recent years, students have shown a tendency to reduce the spatial scale to the lowest administrative structures, covering only a small part of a given district/Kebele due to its proximity to the University, their workplace or even their home/residence. This could be attributed mainly to the declining research funds and the need to avert associated risks.

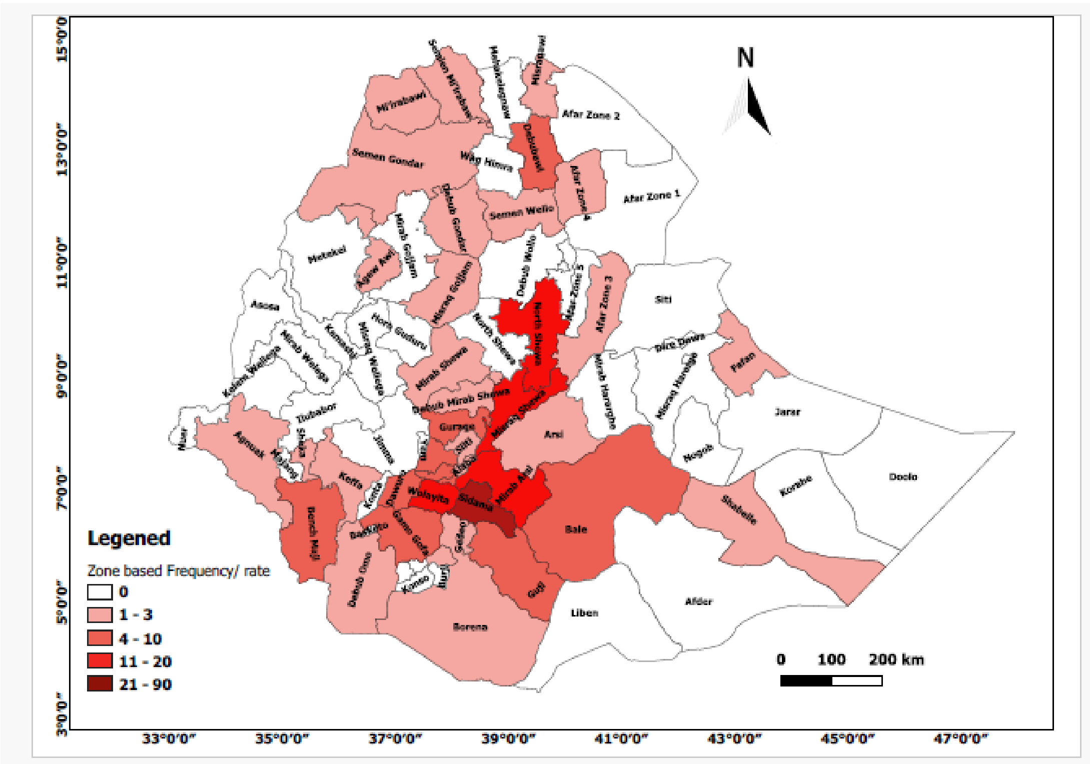

Figure 4. Geographic coverage of graduate research works at HU

Distributions of Graduate Theses by Studied Livestock Species

Figure 5 shows the major livestock species studied by the graduate students. Cattle, sheep, poultry and goats, in descending order, were the most frequently studied livestock species. Graduate students specializing in animal production mostly did their thesis research on poultry followed by cattle and sheep. Honey bees, fish, equines/draft animals and other non-conventional livestock species (such as Guinea fowls) were not covered in the graduate research works. Ethiopia is known for plant and animal diversity. In view of this, the country would benefit much from diversifying studies on the commonly used as well as those neglected but important farm and non-farm animals. Hence, graduate students in animal science should not neglect camels, donkeys, horses, mules, and other poultry species besides chicken. This is possible only if the University/School could develop a research strategy for guiding graduate thesis, encompassing such aspects as well. Undergraduate animal science programs have courses on swine production, camel production, honey bees (including the non-conventional ones). However, these have not been well captured in the MSc programs. This calls for the need to revisit curriculums and develop expertise on those areas and encourage graduate students to conduct their thesis researches on such neglected livestock species.

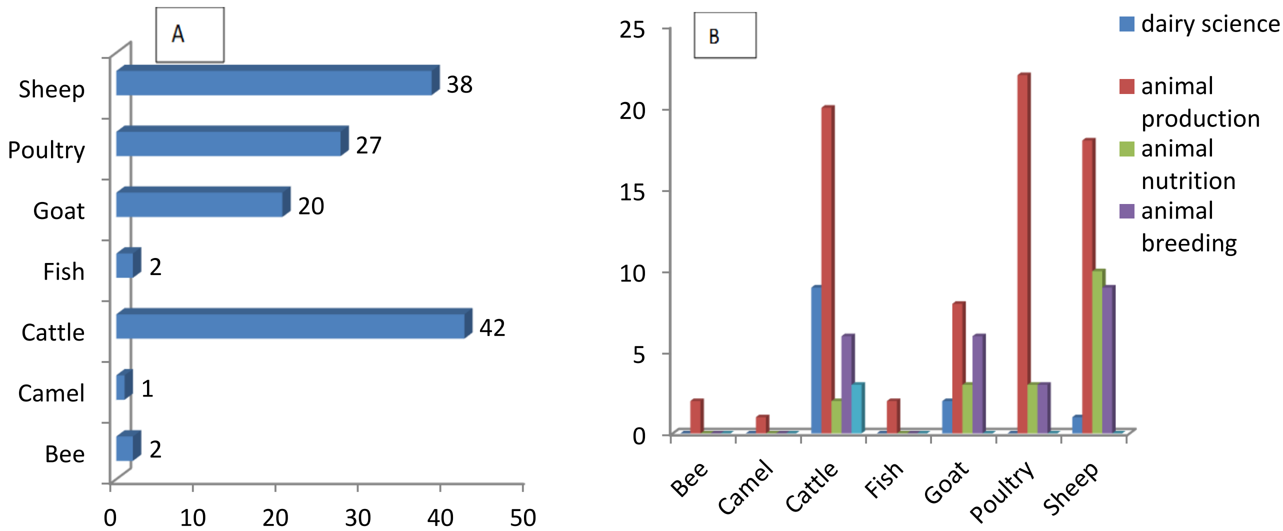

Figure 5. Overall frequencies of livestock species targeted in the graduate research (A), and also by fields of specializations (B)

Methodological Approaches and Data Analysis Techniques Applied by Graduate Students

Designing of experiments and conducting good data/statistical analysis are critical aspects of the education programs at graduate levels (Nick et al., 2021). Figure 6 below shows data collection approaches followed by the graduate students at HU. According to our assessment, graduate students applied three main data collection approaches: social assessments/farm-household survey, laboratory analysis/experiments, field experiments and/or combinations of the two or the three data collection approaches. Majority of the graduate students (89%) combined two or more of data collection approaches like social/household survey plus laboratory experiments, social/household survey plus field experiments, field experiments plus laboratory experiments, as well the combinations of the three approaches. The most predominant approach, however, was the field experiment followed by laboratory analysis.

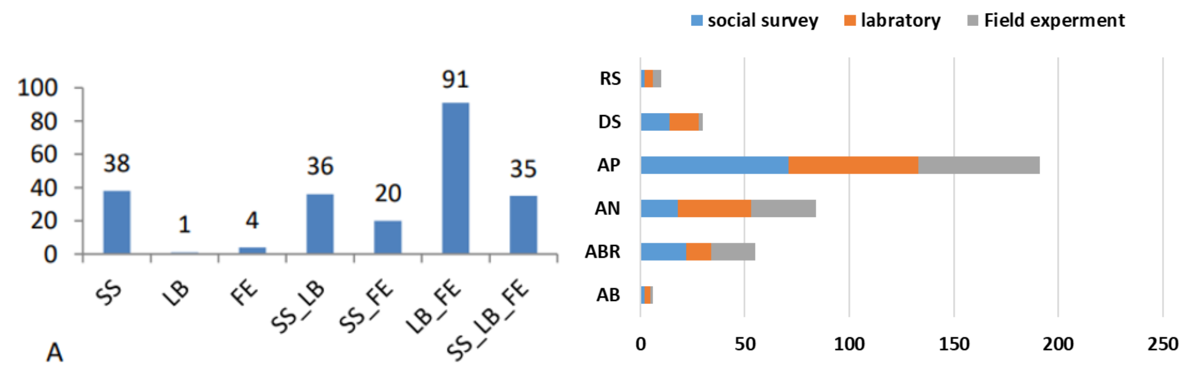

Figure 6. Data collection approaches followed by graduate students - SS (Social Survey), LB (Laboratory Analysis/experiment), and FE (Field Experiment), RS(Range Science), DS (Dairy Sciences), AP (Animal Production), AN (Animal Nutrition), ABR (Animal Breeding), AB(Animal Breeding)

Figure 7 shows sample sizes most graduate students used during household/farm assessment studies. Regardless of the research subjects/units, the most frequently mentioned sample size by the graduate students ranges between 100 and 200, accounting for over 75% of the cases.

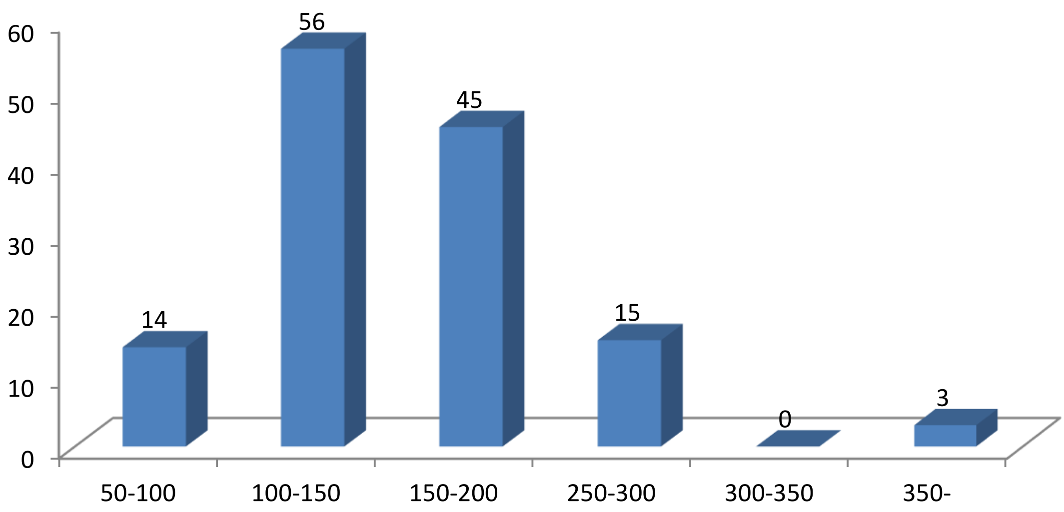

Figure 7. Sample sizes used by graduate students for collecting social survey data

Field experiments on areas such as forage agronomy, range/pastureland management and on-farm/on-station animal experiments have been shown to have very variable sample sizes depending on experimental designs and treatments to be tested. It was observed that sample sizes for laboratory assessments and controlled experiments were highly variable; ranging from one composite sample to tens of samples of feeds, milk, carcasses, blood, urine, feces, and hair/wool. Such studies usually duplicate/triplicate samples to avoid sampling errors in their results.

Statistical Methods Employed by Graduate Students

Figure 8 illustrates the major types of statistical methods used for data analysis and testing treatment means employed by graduate students specializing in different fields. The heat-map on figure 9, further depicts the magnitude of test statistics applied by graduate students and the associated preferences for the respective fields of specializations. Non-parametric tests like Chi-square, and mean comparisons using Duncan, Tukey and LCD tests were mostly used by the students specializing in animal production. Statistical packages for social sciences (SPSS), followed by SAS, were widely used by those specializing in animal production and animal nutrition fields. Most students specializing in animal nutrition and those who conduct animal experiments use one-way ANOVA while those specializing in animal breeding and genetics use more advanced inferential statistics such as regressions using more specific statistical models.

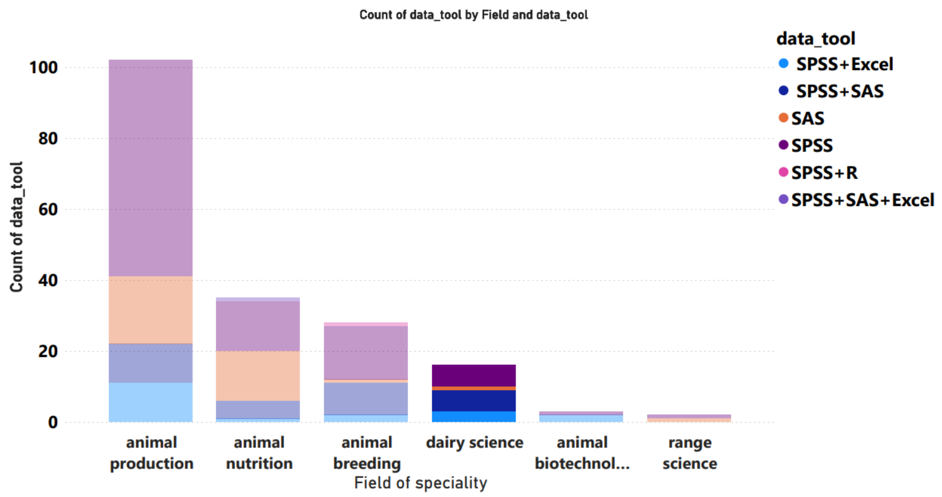

Figure 8. Statistical analysis tools used by graduate students specilizing in different fields

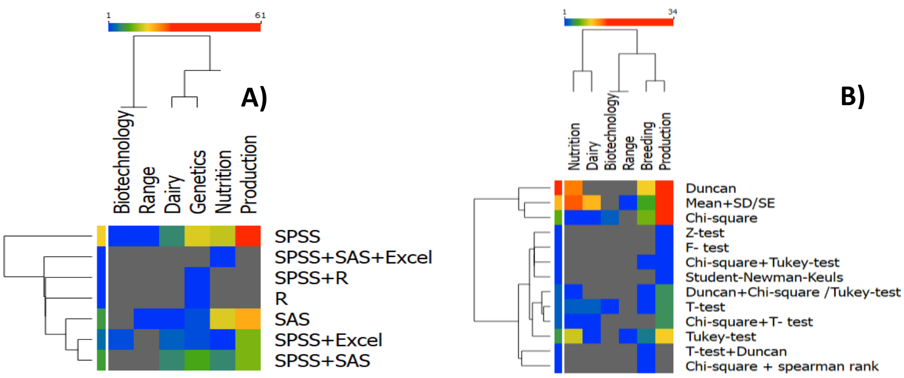

Figure 9. Heat map that shows softwares (A) and statistical tests (B) applied by graduate students (hint: frequency of the uses increases from the blue to red colors).

Information Seeking versus Investigative Research

Figure 10 shows the proportions of theses on the basis of graduate research orientation, i.e. information seeking Vs investigative and problem solving type of research. The result showed investigative and problem-solving research accounts for about 23.6% of the graduate thesis research at HU. The rest 77.6% of the theses were tending towards information seeking types of research. Students tend to generate the types of data used to describe their study subjects (production system, livestock species, functions or performance of animals, morphometric and genetic traits, feed resources, quality and safety levels of animal products) through household surveys, field experiments or laboratory analysis. Kristin et al., (2008) reported that one of the key challenges of sub-Saharan African nations is the failure to make the best out of their universities as centers of innovations and problem-solving research institutions. The problem was mainly attributed to lack of well-established research infrastructures, experienced faculty members and funding.

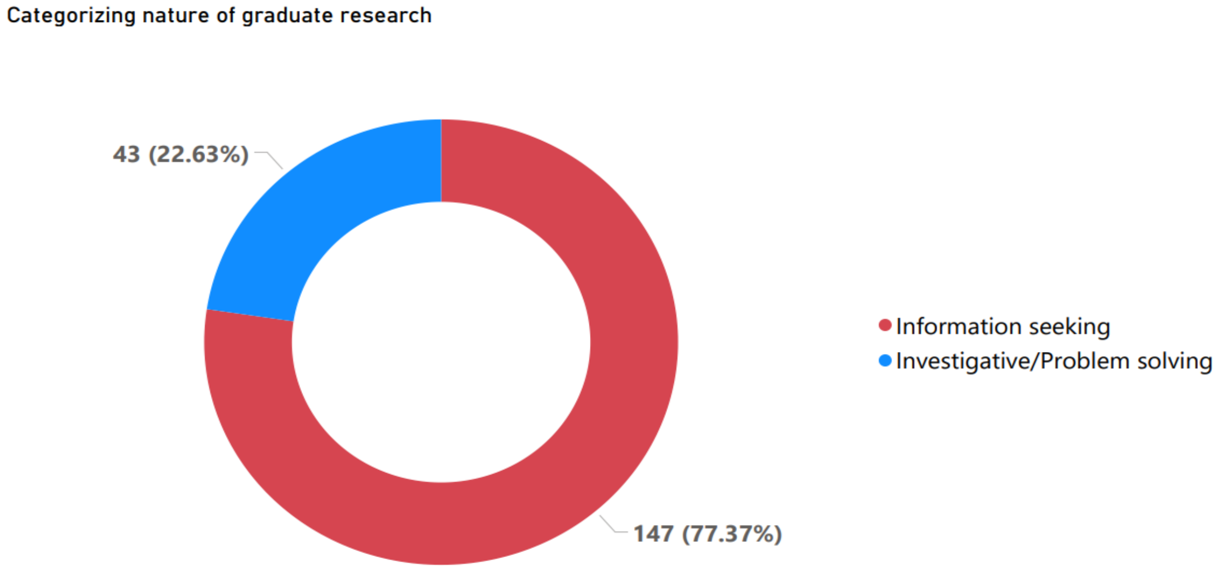

Figure 10. Proportion of graduate theses by the nature of research (information seeking Vs instigative/problem-solving)

Overall Implications of the Findings and Future Directions

Formal degree training in agricultural sciences in sub-Saharan African universities is largely discipline-based (Ochola et al., 2013). Graduates are equipped with the skills to design, manage and report on research projects, but are rarely able to deal with 'real life' situations related to empowering smallholder farmers and reducing poverty.

Agricultural education and training in sub-Saharan Africa can contribute to agricultural development by strengthening the capacity to innovate and introduce new products and processes, relevant to the major farming communities-smallholder farmers and allied actors. This intern would contribute to societal and economic developments (David et al., 2008). For this, not only curriculums and training approaches, but also researches conducted by graduate students should be orientated towards identifying more researchable problems, and generate problem-solving research outputs.

Little attention is given to the relevance of these graduates and their research findings in spurring innovation at different levels. Graduates should develop skills to design, implement and report on research and innovation processes, drawing on the scientific rigour that gives credibility to agricultural development. Further, quality of research by graduate students should be assessed on the basis of its contribution to reducing poverty through problem solving research, innovations and the use of new knowledge and practices. This has been largely lacking in graduate research programs of many universities (Ochola et al., 2013).

A study conducted on graduate research focus in the West, notably in the USA, Canada and Denmark has shown how graduate studies have advanced science and are becoming more rigor over time, However, the focus is still on lower levels of spatial scale, where graduate research is lacking the broader perspectives at the systems level (farm, landscape, and regional levels) (Vibeke et al., 2008). On the other hand, graduate research in Africa is blamed for its rigor and its contributions to bringing change to societal development. Should the research outputs be used to solve societal problems, graduate students should be encouraged and well supported technically and logistically.

Considering the life of research by MSc studies, which is usually less than 1 year of course works, MSc research might be well designed/integrated as part of bigger thematic projects. Graduate students could, on one hand, learn how to design rigorous research; on the other hand contribute to answering research questions faculty members are addressing as a long-term research that solves societal problems. Graduate research theses may be accessed only by certain segments of society, mainly the scientific community. More communication documents, such as policy briefs, need to be emanated from MSc theses for the benefit of the wider end users.

Professional societies like the Ethiopian Society of Animal Production (ESAP) and the Ministry of Agriculture should not neglect the human resource development efforts of Ethiopian Universities, and should organize platforms and forums to review the overall teaching programs of the universities at all levels and accordingly identify intervention areas for improvement. These kinds of studies may help to provoke discussions/debates to assess the overall education system in the country. According to Erickson et al (2020), the role of the American Society of Animal Sciences (ASAS) centennial review of animal sciences teaching was immense in transforming animal science education programs in the USA. It resulted in a nationwide re-evaluation of the learning outcomes, course experiences, and re-assessment of the undergraduate programs in animal sciences. Given this, ESAP could play a pivotal role in assessing the animal science education programs being implemented by the different Ethiopian Universities and outline suitable directions for policy actions.

CONCLUSIONS

This study made scoping review on graduate research in terms of the study programs, fields of specialization, geographic focus of the research, most studied livestock species, approaches of data collection and statistical methods/tools used for data analysis. The findings in this work may help to provoke discussions among the different stakeholders, and also further detail studies on graduate programs in the country at large, as part of improving quality of graduate research in animal science fields. Such discussions and further studies would increase the contributions of Ethiopian Universities and their graduate study programs to scientific outputs, human resource development and their respective sectoral economic developments. This case study might shed lights on a further country wide scoping review for all agricultural fields offered by the concerned universities at BSc, MSc and PhD levels. The results of such study can also be used to inform the need for devising suitable strategies in order to ensure that graduate studies will contribute to societal change and economic development through quality and impactful research outputs. Revisiting the programs would contribute to increasing the contributions of such graduate study programs to livestock sector development.

The following issues might require due attention for further studies:

- Tracer studies on graduate students and their employees may help to revisit the study programs, for instance if a thesis-based MSc is always required or else
- The current study could not address the scientific outputs from the theses/graduate students. Hence, further studies should consider assessing graduate research outputs in terms of their contribution to scientific publications in peer reviewed journals
- There is a need to extract applicable results from graduate theses and make them available in a way that can be utilized by different clients, including the grass root users-smallholder farmers. The recent initiative by HU to make abstracts public, is one encouraging step
- Universities may need to have strategies by which graduate research will be guided. Extending the study to more universities and various graduate programs at both MSc and PhD levels is recommended.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

ACKNOWLEDGEMENT

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Annex 1: Statistical Test Used by Graduate Thesis

Table 1: Statistical data analysis summery

Study approach	Description	characteristics features
Experimental design	Completely Randomized Design and Randomized Complete Block Design	
Social survey	Random sampling, Purposive random sampling, Multi- stage purposive sampling, Systematic stratified random sampling	
Qualitative	Descriptive and interpretive analysis	
Inferential	Apply inferential approach	ANOVA, Chi-square, t-test, p-value
Descriptive	Summarize data features	mean, median, Standard deviation,
Combined	Multiple statistical approach used for both qualitative and quantitative dataset	

Annex 2: List of graduate theses

2009

1. Alewi, Musa (2009-04-10) Characterization Of Smallholder Dairy Production Systems In Enemor And Ener Wereda Of Gurage Zone Of The Southern Nations Nationalities And Peoples Regional State, Ethiopia
2. Belay, Beshaw (2009-04-10) The Importance Of Small Ruminants To The Socio-Economic Well-Being Of People
3. Belete Shenkute (2009-04) Production And Marketing Systems Of Small Ruminants In Goma District Of Jimma Zone, Western Ethiopia
4. Mekonnen, Semira (2009-04-10) Effect Of Grazing Land Exclosure And Feeding Strategy On Livestock Water Productivity In Lencha Dima Watershed, Guba Lafto Woreda, Amhara Region
5. Tesfaye, Mulugeta (2009-06-10) Cattle Milk And Meat Production Systems In Arsi-Negelle Town, Oromia, Ethiopia
6. Tezera, Workneh (2009-06-10) Goat Husbandry Practices And Comparative Performance Of Amato And Introduced Begait Goats In Amaro Special Woreda, Southern Ethiopia
7. Zelalem, Tikunesh (2009-07-10) Assessment Of Livestock Production And Feed Resources In Gondar Zuria Woreda, Amhara Region

2011

8. Abebe, Almaz (2011-04-10) Dairy Production, Mastitis Prevalence And Milk Compositional Quality In Sebeta–Hawas Woreda Oromia Regional State, Ethiopia
9. Abie, Meseret (2011-02-10) The Effect Of Urea Treated Teff And Millet Straws Ongrowth Performance Of Sheep In Awi Zone, Northern Ethiopia
10. Alewi, Misba (2011-06-10) On-Farm Performance Evaluation Of Local Chickens And Their F1 Crosses With Rhode Island Red And Fayoumi Breeds In Beresa Watershed In Guraghe Zone, Southern Ethiopia

11. Bereda, Abebe (2011-02-10) Handling And Utilization Of Milk And Milk Products In Ezha District Gurage Zone, Snnrps
12. Bino, Gashahun (2011-05-10) Smallholder Goat Husbandery Practices And On-Farm Evaluation Enset Leaf Supplementation On Milk Yield And Composition By Lactating Does In Umbulo Wacho Watershed, Sidama Zone, Southern Ethiopia
13. Netsere Teklehaimanot Zewdea (2011-09) Pastoralists’ Perceptions On Rangeland Degradation And Effect Of Prosopis Juliflora Canopy On Herbaceous Species In Goden District, Somali Regionland, Eastern Ethiopia
14. Thomas, Mesfin (2011-05-10) Evaluation Of Farmer’s Perception, Chemical Compositin And Degradability Of Enset (Enset Ventricosum) As Animal Feed In Wolaitta, Southern Ethiopia
15. Worku, Zemene (2011-06-10) Investigating Village Chicken Production System, Consumption Pattern And Egg Quality Parametre In Goncha Siso Enesie Woreda Of Amhara Region

2012

16. Abiy Fisseha (2012-09) Effect Of Supplementation Of Effective Microbes On Growth, Serum Biochemical Parameters And Carcass Traits Of Bovans Brown Chicks
17. Akuri Alemu (2012-09) The Effect Of Feeding Different Proportions Of Enset Leaf And Whole Sugarcane On Intake And Growth Of Goat And Dry Matter Degradability Of Enset Leaf And Whole Sugarcane
18. Ayele Abebe (2012-11) Small-Holder Farms Livestock Management Practices And Their Implications On Livestock Water Productivity In Mixed Crop-Livestock Systems In The Highlands Of Blue Nile Basin: A Case Study From Fogera, Diga And Jeldu Districts (Ethiopia).
19. Aynalem Teshome Demissie (2012-03) Characterization Of Smallholder Chicken Production System In Sinana District Of Bale Zone, Southern Oromia
20. Dinku Getu (2012-09) Nutritive Value Of Natural Pasture From Grazing Land, Two Varieties Of Sweet Potato Morphological Fractions, And Effect Of Feeding Sweet Potato Vine To Grazing Sheep
21. Fsahatsion Hailemariam Baragaber (2012-02) Production System And Morphological Characterizations Of Indigenous Sheep Populations Found In Gamogofa Zone, Southern Ethiopia
22. Teshome Gedefa (2012-11) Evaluation Of Production and Reproduction Performances Of Arsi-Holstein Friesian Crossbred Dairy Cattle: A Case Of Assela Model Agricultural Enterprise, Arsi Zone, Oromia Region

2013

23. Amare Abera (2013-12) Livestock Feed Resource Assessment, Growth Performance And Blood Biochemistry Of Grazing Local Goats Supplemented With Graded Levels Of Sweet Potato (Ipomoea Batatas) Silage In Loma Woreda, Southern Ethiopia.
24. Asdesach Churfo (2013-06) The Effect Of Substituting Noug Seed Cake With Pigeon Pea Leaf On Feed Intake, Digestibility, Nitrogen Utilization And Growth In Sheep Fed A Basal Diet Of Rhodes Grass Hay
25. Biruk Bogale (2013-01) Assessment Of Feed Availability And Effect Of Processing Techniques Of Sweet Potato (Ipomoea Batatas) Vine On Growth Performance And Serum Biochemistry Of Lambs In Damot Gale Woreda Of Wolaita Zone, Snnpr.
26. Churfo, Asdesach (2013-06-10) The Effect Of Substituting Noug Seed Cake With Pigeon Pea Leaf On Feed Intake, Digestibility, Nitrogen Utilization And Growth In Sheep Fed A Basal Diet Of Rhodes Grass Hay
27. Deneke Negassa Sima (2013-05) Production System And Morphological Characterization Of Indigenous Chicken In Tiyo, Hetossa And Dodota Woredas Of Arsi Zone, Oromia, Ethiopia
28. Gebreegziabher Zereu (2013-03) Chemical Composition And In Vitro Dry Matter Digestibility Of Fresh, Dried And Ensiled Vines Of Sweet Potato (Ipomoea Batatas) Cultivars
29. Girma Terefe Kokobe (2013-04) Estimation Of Body Weight Of Native Cattle Using Some Morphological Measurements At Maki District

30. Hiwot Bekele Hailu (2013-06) Assessment Of Indigenous Knowledge In Livestock Rearing Practices At Arbegona And Lokabaya Woreda Of Sidama Zone, Southern Ethiopia
31. Kassa Demo (2013-02) Performance Of Local Sheep Fed Natural Grass Hay Supplemented With Different Levels Of Millettia Ferruginea Leaf Meal
32. Kassahun Habtegiorgis (2013-02) Evaluating Poultry Production System And Egg Quality Parameters Of Village Chickens At Hawassa Zuria Woreda, Southern Ethiopia
33. Lijalem, Tsegay (2013-03-10) Assessment Of Consumption, Some Nutritive Parameters And Marketing Of Ruminant Meat And Meat Animals In Hawassa City, Southern Nations, Nationalities And Peoples Regional State, Ethiopia
34. Roman Alemayehu Gibe (2013-03) Effect Of Drying Methods And Plant Fraction On Chemical Composition And Nutrient Degradability Of Sweet Potato (Ipomoea Batatas) Leaves And Vines With And Without Rhodes Grass (Chloris Gayana) Hay
35. Seyoum Debebe (2013-12) Effect Of Feeding Different Levels Of Furfurame Replacing Maize On Growth Performance And Carcass Characterstics Of Hubbard Chickens
36. Tsegaye, Meseret (2013-06-10) Effects Of Substituting Maize With Kocho On Intake, Digestibility, Nitrogen Utilization And Weight Gain In Sheep Fed A Basal Diet Of Rhodes Grass Hay
37. Yared Fanta (2013-06) Studies On Some Wool Quality Parameter Sheep, Arsi-Bale Locations 1 Some Wool Quality Parameters Of Dorper Bale Sheep And Their Crosses Reared In Two Locations Of Southern Ethiopia

2014

38. Aman Getiso (2014-01) Effect Of Substitution Of Kocho For Maize On Feed Intake, Digestibility, And Body Weight Gain Of Sheep Fed Rhodes Grass Hay As Basal Diet
39. Deginet H/Meskel (2014-04) The Effect Of Feeding Graded Levels Of Moringa Stenopetala Leaf Meal On Feed Intake, Growth And Carcass Characteristics Of Arsi- Bale Goats

2015

40. Chiemela Peter Nwogwugwu (2015-06) Some Morphometric Traits And Structural Indices Of Boer, South Wollo And Their F1 Crossbred Goats Reared At Ataye Farm, Ethiopia
41. Gelaye Gebisa (2015-06) Effects Of Non – Genetic Factors On Wool Quality Parameters Of Menz Sheep At Debre Birhan, Ethiopia
42. Metsafe Mamiru Mamo (2015-01) On-Farm Performance Evaluation And Community Based Traditional Selection Methods Of Bonga Sheep In Adiyo Kaka Woreda, Southern Ethiopia
43. Mitiku Yohannes (2015-01) Comparative Studies Of On-Farm And On-Station Performance Of Crossbred (Dorper X Arsi-Bale) And Arsibale Sheep Reared In Southern Ethiopia
44. Temesgen Alemu (2015-01) Evaluating The Effect Of Feeding Different Levels Of Sweet Potato (Ipomoea Batatas) Leaf Meal On Feed Intake, Growth Performance And Carcass Characterstics Of Broilers

2016

45. Abiyu Tadele Alene (2016-06) Phenotypic Characterization Of Indigenous Chicken Populations And Their Productio N Systems In Kaffa Zone, South Western Ethiopia
46. Abule Guye Wodeso (2016-06) Traditional Husbandry Practices With Some Productive And Reproductive Performance Traits Of Gumuz Goat In Nuer Zone, South Western Ethiopia
47. Ahmed Hussein Gobena (2016-06) The Potential Of Coarsely Ground, Gelatinized And Soaked Maize Grain And Wheat Bran As Energy Supplements To Arsi-Bale Sheep Fed A Basal Diet Of Native Grass Hay
48. Asemahegn Mersha (2016-01) Determination Of Cultivar-Dependent Variation In Food-Feed Traits In Lentil (Lens Culinaris)

49. Behailu Samuel (2016-03) Husbandry Practices And Productivity Of Arsi-Bale Goats In Agarfa District Of Oromia Regional State, Ethiopia
50. Belete Kuraz Abebe (2016-11) The Role Of Bole (Lake Soil) As A Mineral Supplement To Arsi-Bale Sheep Fed Native Grass Hay And Concentrate Supplement
51. Debir Legesse (2016-01) Assessment Of Breeding Practices And Evaluation Of Estrus Synchronization Of Dairy Cattle In Sidama Zone, Southern Ethiopia
52. Dereje Andualem Gellaw (2016-06) Nutritional Evaluation And Supplementary Value Of Stinging Nettle (Urtica Simensis S) On Milk Yield And Composition Of Lactating Arsi-Bale Goats And Growthperformance Of Their Suckling Kids
53. Eyob Marufa Wobisa (2016-03) On-Farm Performance Evaluation Of Abera Sheep Under Community Based Breeding Practices In Dara Woreda, Southern Ethiopia
54. Feleke Tadesse Froche (2016-06) Growth Performance And Nutritive Quality Of Tree Lucerne (Chamaecytisus Palmensis) Fodder Under Different Management Conditions In The Highlands Of Ethiopia
55. Fisahaye Abraha Woldu (2016-01) Indigenous Knowledge Of Livestock Husbandry And Ethno Veterinary Practices In Endamohoni District Of Tigray Region, Ethiopia
56. Gashu Geremew (2016-06) Assessment O F Availability And Nutritive Values Of Feed Resources And Their Nutrient Contribution To The Livestock In Chire Woreda, Southern Ethiopia
57. Gebregiorgis Gebrehiwot Hailu (2016-11) Effect Of Feeding Leucaena Leucocephala Leaves And Pods On Feed Intake, Digestibility, Body Weight Change And Carcass Characteristic Of Tigray Highland Sheep Fed Basal Diet Wheat Bran And Grass Hay
58. Hailu Assefa Getahun (2016-11) Production System And Phenotypic Characterizations Of Indigenous Chicken Populations In Sheka Zone, South Western Ethiopia
59. Kedir Abdurahman Terie (2016-06) Studies On Poultry Management Practices, Marketingsystem And Effect Of Feeding Fish Meal On Growth Performance And Carcass Characteristics Of Koekoekchickens In Bora District, East Shoa Zone
60. Mastewal Asfaw Defar (2016-11) Effect Of Including Graded Level Of Silkworm (Bombyx Mori) Feces In The Diets Of Nile Tilapia (Oreochromis Niloticus) On Their Growth Performance In Ziway, Ethiopia
61. Mekete Girma Asfaw (2016-01) Morphological Traits And Structural Indices Of Woyito-Guji Goats Reared At Nyangatom And Malle Woredas Of Snnprs, Ethiopia
62. Mengistu Lemma Lebena (2016-02). Assessment Of Feed Resource Availability And Quality In Kedida Gamela Woreda, Southern Ethiopia
63. Merga Bayssa Becho (2016-09) Nutritional Evaluation Of Major Browse Species From Afar And Borana Rangelands And Supplementary Values Of Acacia Tortilis Leaves To Arsi-Bale Goats
64. Mulugeta Gudisa Goro (2016-03) Assessment Of Grazing Land Condition, Herbaceous Biomass Species And Chemical Composition In Adami-Tullu Jido-Kombolcha And Arsinegelle Woredas, Southern Ethiopia
65. Nebiyu Chalew (2016-06) The Effects Of Sweet Potato (Ipomoea Batatas) Leaf Supplementation On Nutrient Intake, Growth Performance, Digestibility And Nitrogen Utilization Of Arsi-Bale Sheep Fed Natural Grass Hay As A Basal Diet
66. Nigatu Wolde (2016-11) Assessment Of Feed Resource Availablity, Feeding System And Nutritional Quality Of Some Feedstuffs Used For Dairy Farms In Sodo Town And Sodo Zuria Woreda, Southern Ethiopia
67. Simachew Fetene Ayenew (2016-11) Effect Of Nitrogen Fertilizer Rates And Harvesting Days On Yield And Quality Of Blue Panic Grass (Panicum Antidotale Retz) Under Irrigation At Gewane District, North Eastern
68. Tamene Tadesse Tessema (2016-02) Effect Of Faba Bean (Vicia Faba L.) -Forage Inter-Cropping: Benefits And Trade-Offs To Improve Feed Resources In Lemo Woreda, Southern Ethiopia

69. Tesema Tego (2016-01) Effect Of Supplementing Different Proportionof Enset(Ensete Ventricosum) And Sesbania (Sesbania Sesban) Leaf Meals On Feed Intake,Digestibility,Nitrogen Utilization, And Growth On Sheep Fed On Natural Grass Hay As Basal Diet
70. Tewelde Gebru (2016-01) Studies On Morphometric Characteristics, Performance And Farmers’ Perceptions On Begait Cattle Reared In Western Tigray,
71. Welelaw Edmew Worku (2016-11) Assessment Of Production System, Egg Quality And Carcass Characteristics Of Village Chicken In Bench Maji Zone, South Western Ethiopia
72. Zerihun Janje Boroje (2016-11) Assessment Of Livestock Feed Resources And Nutritional Qualities Of Major Livestock Feeds In Aleta Chuko Woreda, Southern Ethiopia

2017

73. Abebayehu Demeke Alagaw (2017-03) Physiomorphological Parameters Of Semen Obtained From Selected Bulls Raised At National Artificial Insemination Center And Its Effect On Conception Rate Of Cows Reared At North Shoa, Amhara Region, Ethiopia
74. Addisu Abera Wondimie (2017-02) Effect Of Poultry Litter Supplementation On Feed Intake, Digestibility, Weight Gain And Carcass Characteristics Of Arsi- Bale Sheep Fed Natural Pasture Hay
75. Amine Mustefa (2017-10) Genetic And Non-Genetic Factors Affecting Survivability, Growth And Reproductive Performance Of Boer And Central Highland Goats And Their Crosses Reared At Ataye Farm, North Shoa, Ethiopia
76. Askale Dubale (2017-06) Assessment Of The Utilization Practices Of Banana And Mango Residues, And Effect Of Ensiling On Silage Quality And Performance Of Indigenous Sheep Grazing Natural Pasture In Arba Minch Zuria District Of Gamo Gofa Zone
77. G/Hiwot W/Ananya Yigzaw (2017-01) Effect Of Urea Fertilization Rate And Harvesting Stage On Yield And Nutritive Value Of Buffel Grass (Cenchrus Ciliaris Linn) Under Irrigation At Gewane District, North Eastern Ethiopia
78. Galaye Ganebo (2017-11) Effect Of Partial Substitution Of Noug Seed Cake With Stinging Nettle (Urtica Simensis S.) Leaf Meal On Egg Quality Parameters Of Commercial Layer Hens
79. Gezahegn Shirmeka Hemecho (2017-06) Bovine Tuberculosis In Crossbred Dairy Cattle In Wolaita Sodo Town, South-Western Ethiopia: Prevalence, Associated Risk Factors And Its Effect On Milk Production
80. Hussein Abduku Worku (2017-09) Farming System And Traditional Grassland Management Practices: The Case Of Kofele District, Western Arsi Zone, Ethiopia
81. Kaangundue Brian (2017-02) Assessment Of Feed Resources Availability, Quality And Livestock Production In Mixed Crop-Livestock System In Loka Abaya District Of Sidama Zone, Southern Ethiopia
82. Mengistu Masebo Lambebo (2017-03) The Effect Of Partial Substitution Of Noug Seed Cake With Cassava (Manihot Escutulata C.) Leaf Meal On Feed Intake, Growth Performance And Carcass Traits Of Ross 308 Broiler Chickens
83. Moges Demilie Temesgen (2017-02) The Effect Of Growing Niche, Management System And Season On Yield And Quality Of Desho (Pennisetum Pedicellatum)Grass In Jeldu District, West Shewaethiopia.
84. Mosebework Kassa (2017-10) Effect Of Replacing Maize (Zea Mays L.) With Partially Cooked Orange Fleshed Sweet Potato Tuber (Ipomoea Batatas) On Feed Intake, Body Weight Gain And Carcass Characteristics Of Cobb 500 Chickens
85. Nigatu Dejene Deneke (2017-03) Assessment Of Production And Marketing Systems, And On-Farm Evaluation Of The Effect Of Supplementing The Leaves Of Balanites Aegyptiaca And Maize Grain On Growth Performance And Economic Return Of Indigenous Goats In Gamogofa Zone
86. Serkalem Assefa (2017-11) Management Practices, Egg Production And Linear Body Measurment Traits Of Local And Exotic Chickens Reared Under Traditional Production System In Boricha Woreda, Sidama Zone

87. Tadesse Bokore (2017-01) The Effect Of Feeding Itacha (Dodonaea Angustifolia) Leaf Meal On Parasite Load And Growth Performance Ofgoats Infected With Hemonchus Contortus Larvae
88. Tamirat Negash Gure (2017-01) Detection Of Virulences And Evaluation Of Wheat Lines (Triticum Spp.) For Resistant To Stripe , Leaf And Stem Rust (Puccinia Spp.) In Central And South-East Ethiopia
89. Yaregal Melak (2017-04) Effects Of Distance From Water Points On Grassland Condition, Biomass Production And Nutritional Quality Of Grasses In Chagni Ranch, North-West Ethiopia
90. Yitatekush Fidel (2017-11) Production And Reproductionpotentialof Native And Crossbreed Cattle And Their Milk Qualityr Eared In Selected Woredas Of Gurage Zonesouthern, Ethiopia
91. Yonas Kejela (2017-11) Urban Poultry Production Systems And Egg Quality Parameters Of Local And Exotic Chickens Reared In Yirgalem And Hawassa Towns

2018

92. Abdi Abdilahi (2018-11) Study On Management Practices And Constraints Of Black Head Somali Sheep Reared In Awbarre Distirict Of Fafen Zone, Somali Region, Ethiopia
93. Abdulahi Mahamed (2018-11) Assessment Of Management Practices, Performance And Constraints Of Camel In Kebri Dahar District, Somali Region, Ethiopia
94. Aman Gudeto (2018-05) Studies On Structural, Fuctional Traits Traditional Breeding Practices Of Arsi Cattle In East Shoa And West Arsi Zones Oromia Regional State, Ethiopia
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Original Research Article||

Characteristics of Soils Types along the Toposequence in Central Highlands of Ethiopia

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Abstract

It is imperative to understand and predict the nature and distribution of soils along a given physiographic condition. However, the hitherto practices of collecting basic soil information at a site-specific level seem inadequate to ensure sustainable agricultural production via proper utilization and effective management of soil resources. Therefore, this research was conducted to characterize, classify, and map soils along the toposequence of the Qenberenaweti sub-watershed, Central Highlands of Ethiopia. A total of 91 auger inspections were made up to a 120 cm depth to define soil mapping units with their boundaries. Then, six pedons were opened at typical slope positions along the toposequence. The depth of the pedons varied between 135 and 200+ cm, whereas the thickness of A-horizons showed an increasing trend down the slope by excluding the back-slope position. All the soils at the surface and subsurface horizons had clayey texture with pH ranging from 5.59 to 6.23 and 5.31 to 7.65, respectively. The OC contents throughout the entire horizons varied from 0.22 to 2.03%. The highest CEC values were found at the middle slope position followed by pedons at the upper and bottom parts. The exchangeable cations of most pedons were in declining order of Ca, Mg, K, and Na except for the Mg dominance over Ca at the back slope and bottom depression. Hereby, six soil types were identified; and their distribution was mapped. The results of this research revealed that the extent of variations in key topographic features resulted in the formation, development, and distribution of diversified soils along the toposequence. Consequently, such detailed soil characterization, classification, and mapping work is vital for proper planning, management, and utilization of the soil resources at local topographic conditions. However, further research should be done to ensure sustainable agricultural production in the study area.

Key words: Topography, Soil Mapping Unit, Pedon, Horizon, Soil Properties.

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INTRODUCTION

Soil is a gradually renewable dynamic natural resource (Jenny, 2012) whose extents of proper utilization and effective management determine the sustainability of agricultural production (Adugna, 2016). Generally, soil is classified as natural body on the basis of its characteristics (Nikiforova et al., 2019), and soils in a given group are believed to be homogeneous (Tursina, 2012). Characterization of soils deals with the assessment of their morphological, physical, chemical, and mineralogical properties (Schaetzl and Thompson, 2015) while classification is the systematic categorization of soils into different groups at varying levels of generalization based on their overall properties (Ditzler, 2017; Buol et al., 2011). Besides, soil mapping is a process of creating a visual representation of the different soil types and their distribution within a specific geographic area (Wimalasiri et al., 2020; Kienast-Brown et al., 2017).

The action of characterization and classification is ultimate to all soil studies as it is a vital tool to reflect the real diversity of soils (Brevik et al., 2016; Buol et al., 2011). It also links research results and their beneficial extension with field applications (Ayalew et al., 2015) by providing key information about soil properties and environmental conditions (Lufega and Msanya, 2017). Hence, it helps in organizing of knowledge, ease of remembering of soil properties and understanding of relationships, having clear communication, and the best of technology transfer (Lufega and Msanya, 2017; Hartemink, 2015). According to Brevik et al.

(2016), characterization and classification of soils are done in the application of proper management practices, rehabilitation of degraded soils, and provision of a ready-made map legend for soil surveyors. Whereas, soil mapping aims to unravel deficiencies in our understanding of soil properties and processes both in time and space (Taha et al., 2019; Minasny and McBratney, 2016).

Toposequence is series of soils that vary primarily due to the topography as soil forming factor (Alves et al., 2024). This means each soil type in a toposequence exhibit distinctive characteristics that are directly related with the slope at typical components (crest, shoulder, back slope, foot slope, and toe slope) of a topography (Omokaro, 2023; Seifu and Elias, 2018). Moreover, topography is important in pedologic processes via determining the extent of water drainage and runoff, soil thickness and erosion potential, particle size distribution, reaction, and OM content (Omokaro, 2023; Begna, 2020). However, any patterns of soil association along a toposequence is not necessarily repeated with the topography in the landscape (Bonfatti et al., 2020; Ogban et al., 2019). Because soils with identical parent material, existing within a uniform climatic condition, and affected by similar soil-forming factors may still have varied characteristics due to local relief, internal drainage, and/or geomorphic attributes (Tunçay and Dengiz, 2020; Gruber et al., 2019). Hence, the concept of toposequence is a useful analytical tool in describing the outline of soil characterization, classification, and mapping for sustainable agricultural production and land use management (Seifu and Elias, 2018; Brevik et al., 2016).

Soil genesis and distribution in Ethiopia are influenced by agro-ecological zones accompanied by geology, topography, vegetation, and climatic variability (Weldegerima, 2024; Regassa et al., 2023). For instance, different soil units like Acrisols, Cambisols, Fluvisols, Leptosols, Luvisols, Nitisols, Vertisols, and Umbrisols with various qualifiers have been identified in the country (Ali et al., 2024; Tufa et al., 2021). The country has a long history of collecting basic information on soil characterization which is either limited to some selected potential areas or done with shallow observations and wider generalizations (Megarsa, 2023; Nyssen et al., 2019). Furthermore, the available soil maps in the country are dominantly small-scale and represent scattered areas which hinder site-specific soil interpretation and utilization (Seifu et al., 2023; Debele, 2018). Accordingly, detailed soil survey and mapping are imperative for better understanding and prediction of soil types and distribution at local physiographic variability level (Abdu et al., 2023; Megarsa, 2023; Fekadu et al., 2018).

Variation in the physiography of agricultural lands has an enormous influence on soil properties and plant production (Abdu et al., 2023; Laekemariam et al., 2016). Consequently, the absence of inclusive evidence on the nature of soils at the level of local variability is often a key factor limiting the development of Ethiopian agriculture (Seifu and Elias, 2018; Tamene et al., 2017), as it does particularly around the study area (Cherinet, 2017). Acquiring comprehensive soil information while doing an in-depth characterization and classification at local topographic condition or watershed level is important to make proper utilization and management of soils for sustaining food production, rehabilitating degraded land, and tackling site-specific soil related problems (Mathewos and Mesfin, 2024; Bedadi et al., 2023). Therefore, this study was conducted to characterize, classify, and map the soils along a toposequence of Qenberenaweti sub-watershed, Central highlands of Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Qenberenaweti sub-watershed which is located between 09° 33′ 50″ and 09° 35′ 03″ N latitude and 39° 32′ 50″ and 39° 33′ 54″ E longitude (Figure 1). It is found at about 120 km northeast of Addis Ababa on the way to Debre Berhan and 18 km from the Chacha town of Angolelana Tera district, North Shewa zone of Amhara National Region State. The site covers a total area of 317 hectares on a plateau of the central Ethiopian highland system with elevations ranging between 2808 and 2960 meters above sea level (m.a.s.l).

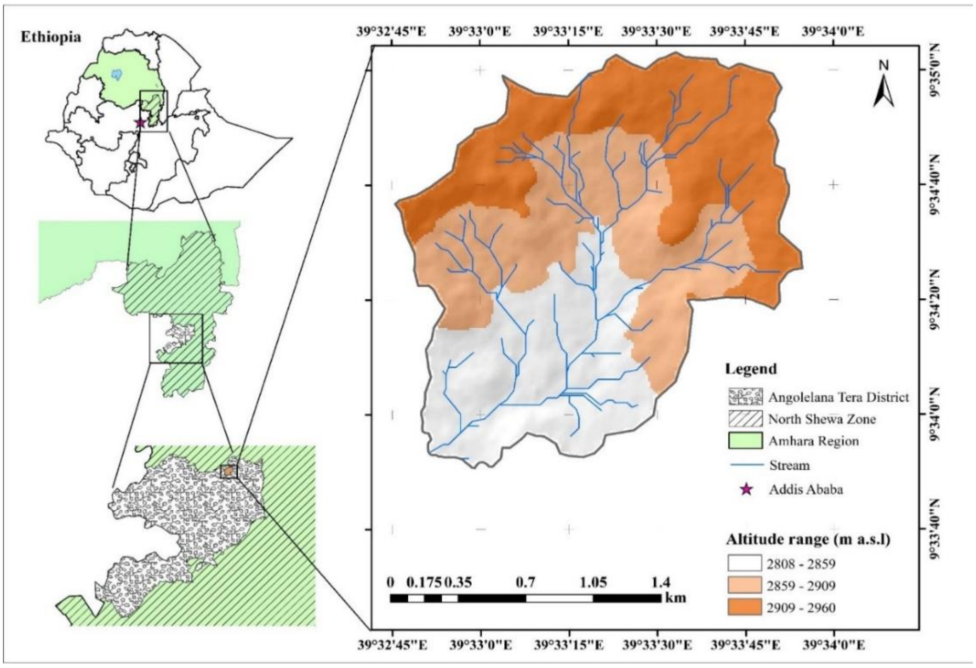

Figure 1. Location and altitude map of the study area

The rainfall distribution is bimodal, short (March to April) and long (June to September) rainy seasons, with mean annual precipitation of 928.5 mm. The mean annual temperature is 14.2 ℃ having monthly averages of 15.6 ℃ in May and 12.9 ℃ in October, respectively (Figure 2). Generally, the area falls under the Tepid to Cool Sub-Moist Mid-Highland agro-ecological zone (MoARD, 2005); and has Cambisols, Leptosols, and Vertisols as major soil types (ATDAO, 2017).

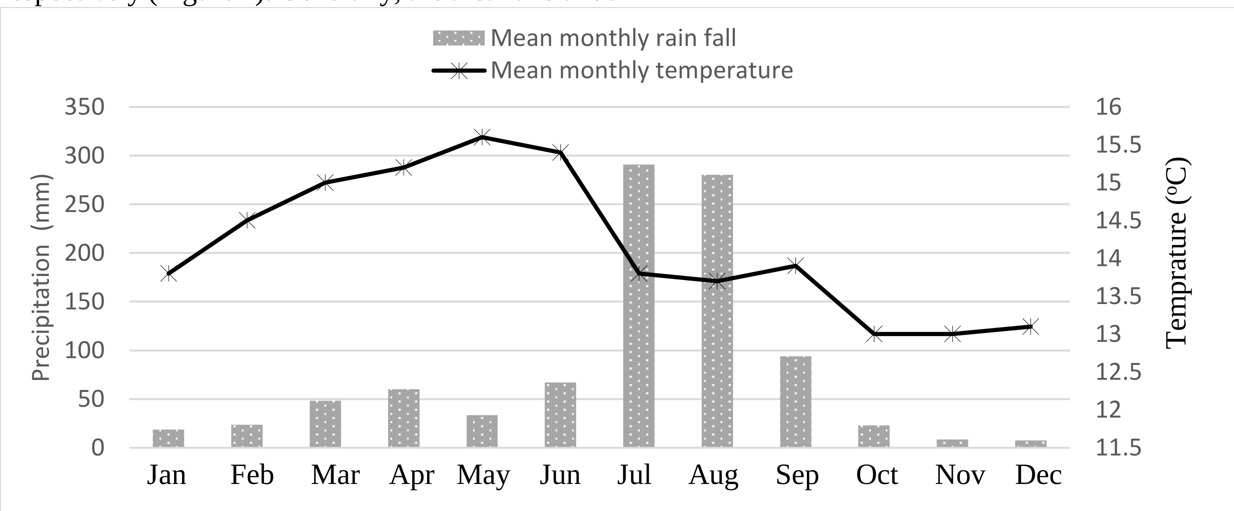

Figure 2. Mean monthly rainfall and temperature of the study area

Selection of Soil Sampling Sites and Identification of Mapping Units

Before the field survey, the topographic map (1:50,000) and areal image (Google Earth Pro) of the study area were interpreted to organize the vital site and land information: slope, altitude, drainage patterns, and land configurations. The overall topographic configuration and exact outlet point of the area were recognized during the field visit. Delineation of the sub-watershed and determination of its hydrological components were done using spatial analysis tools of Arc GIS 10.5 software after retrieving a 12.5 m digital elevation model (DEM) data from the United States Geological Survey (http://www.USGS.gov).

The free-soil survey (Driessen et al., 2000) method that followed a systematic sampling approach was employed across the north-south facing landscape configuration to identify the soil mapping units (SMU) with their boundaries. A given SMU was defined on the basis of similarity and/or closeness in key topographic and morphological (slope gradient, soil depth, and texture of surface soils) features of each augur sampling points. A total of 91 auger samples to 120 cm depth were collected using 'Edleman auger' unless limited by the stoniness or compactness of the soils. A toposequence along the major stream flow directions which have all the typical topographic components and represent the upper, middle, and lower positions was considered for excavation of a representative pit (1.5 m width by length and up to 2 m depth) and collection of peripheral surface soil samples. Coordinate points of all auger and profile inspections were taken by a handheld geographic positioning system (GPS) apparatus (Garmin-60) and digitized on the topographic map produced using Arc GIS 10.5 software.

Soil Sampling and Analysis

Both disturbed and undisturbed soils were sampled from every identified genetic horizon of the opened profiles. Additionally, twelve disturbed surface (0-20 cm) soil sub-samples were randomly collected within 15 m radius surrounding of each pedon. Then, the sub-samples were thoroughly mixed and made into three composites per pedon.

The disturbed soil samples were air-dried and ground to pass through a 2 mm sieve for analyses of most physicochemical properties except for the organic carbon (OC) and total nitrogen (TN) contents in which case soils were sieved by a 0.5 mm mesh size. The undisturbed samples were oven-dried at 105 ℃ for 24 hours to determine bulk density using the core-sampling method (BSI, 1975) while particle density with the pycnometer method (Tan, 1995). Soil particle size distribution was analyzed by the modified sedimentation hydrometer procedure (Bouyoucos, 1951).

The pH of the soils was determined in 1:2.5 soil-to-water suspension using a pH meter (Van Reeuwijk, 1995); and the suspension was also used to measure the EC of the soils with a conductivity meter. The organic carbon (OC) content was determined using the wet digestion method of Walkley and Black (Van Ranst et al., 1999). The total nitrogen (TN) content was analyzed by a wet-oxidation procedure of the Kjeldahl method (Bremner and Mulvany, 1982). The soil available phosphorus (Av. P) content was extracted following Olsen method (Van Reeuwijk, 1995) and the concentrations were measured using spectrophotometer at 882 nm. The exchangeable base cations (Ca, Mg, K and Na) and cation exchange capacity (CEC) of the soils were determined using 1M ammonium acetate (pH 7) method according to the percolation tube procedure (Van Reeuwijk, 1995). The concentrations of exchangeable Ca and Mg in the leachate were determined by Atomic Absorption Spectrophotometer (AAS); whereas the exchangeable K and Na contents were measured by a flame photometer. Available micronutrients (Fe, Mn, Zn, and Cu) were extracted using the diethylene-triamine-pentaacetic-acid (DTPA) method (Tan, 1995), and their concentrations were determined by AAS. The CEC due to the clay fraction (CEC clay) was computed by subtracting the CEC value of OM from CEC of soil (equation 1) with assumption of OC has a CEC of 200 cmolc kg-1 (Landon, 2014):

$$CECclay = \frac{CEC\ soil - (\%\ OM * 200)}{\%\ Clay} \quad \text{…Equation1}$$

Description of the Pedons and Classification of the Soils

The in-situ description of soil properties was carried out following the guideline for soil profile description (FAO, 2006). Furthermore, the soils of the study area were classified according to the World Reference Base (WRB) for soil resources classification system (IUSS, 2022).

Statistical Analysis

The data on selected physicochemical properties of the surface soils were interpreted by descriptive statistics. Besides, Pearson's correlation matrix was used to explain the relationship pattern among all the variables. All statistical analyses were performed using the Statistical Package for Social Science (SPSS) software version 26.0 (IBM, 2020).

RESULTS AND DISCUSSION

Description of Soil Mapping Units and Site Characteristics

After the detailed in-situ detection of each soil augering point, 32 different soil mapping units (SMU) were identified in the sub-watershed (Figure 3). The upper topographic position occupied SMU-01, 02, 03, 04, 05, 06, 07, 08, 10, and 19 while the middle position had SMU-09, 11, 12, 15, 16, 17, 18, 20, 22, and 23. The rest (SMU-13, 14, 21, 24, 25, 26, 27, 28, 29, 30, 31, and 32) were found at the lower topographic position. A representative pit was dug on SMU-06, 05, 16, 17, 32, and 30 in lieu for the summit, shoulder, back slope, foot slope, toe slope, and bottom depression positions, respectively.

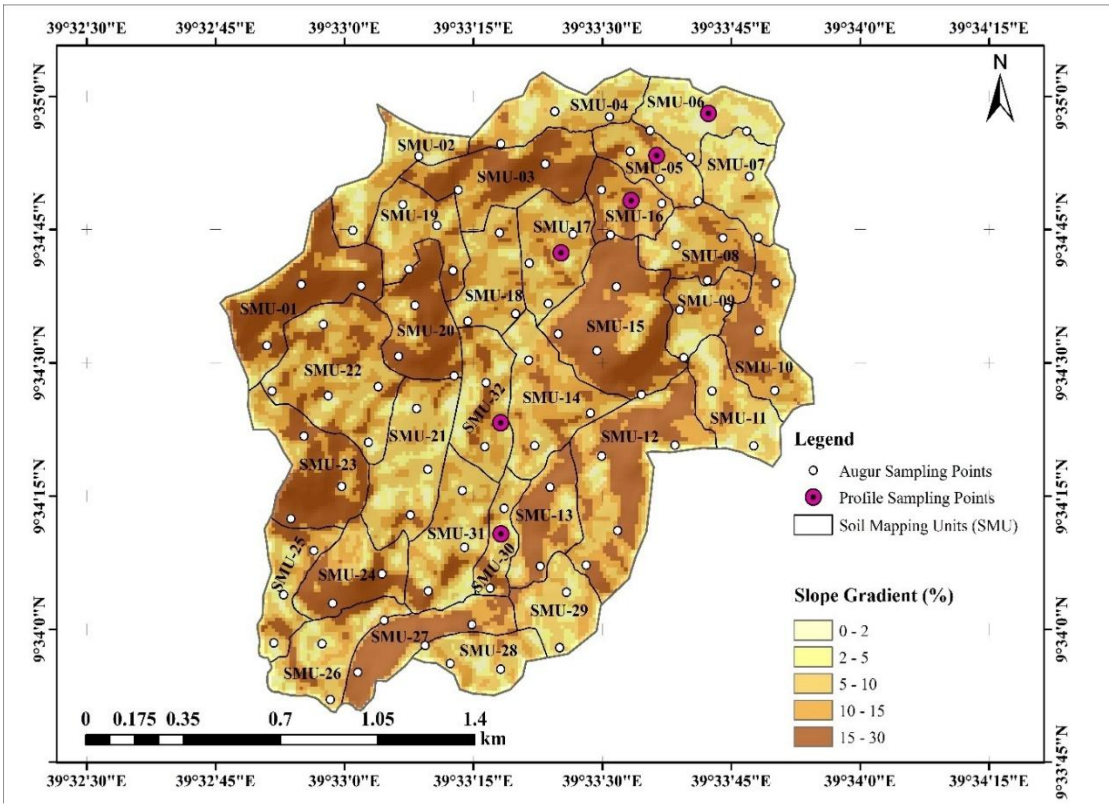

Figure 3. Topographic map of the study area

As shown in Appendix Table 1, the SMU-06, 07 and 30 were very deep soils (>120 cm) with clayey texture (feel method) at the surface of level (0-2 %) and gently level (2-5 %) lands. Amongst SMUs found on sloping lands (5-10 %), SMU-04, 21, 28, 31, and 32 had very deep profiles while SMU-02, 18, 26, and 29 were categorized as deep soil (100-120 cm). The soils of SMU-02, 04, 18, 26, 29, 31, and 32 were clayey while that of SMU-21 and 28 were clay loam in texture. The strongly sloping land (10-15 %) was occupied by SMU-05, 14, 17, 22 and 25 with soils having deep solum and clay loam texture. They were also partly covered by very deep SMU-11 and 19 and deep SMU-08 and 09 solum with clay textured soils at the surface. Although many of the SMUs (01, 03, 10, 15, 20, 23, 24, and 27) existing on moderately steep slope land (15-30 %) had a moderately deep (50-100 cm) solum with clay loam textured surface soils, the few (SMU-12, 13, and 16) were deep soils with a clay texture.

The variations in the depth of the solum and soil texture at the surface might be related to the shape and length of the slope which determine the degree of soil material translocation and accumulation via the action of water flowing down the slope. Depth of the solum and soil texture at the surface are ascribed to slope features (Mwendwa, 2021; Subhatu et al., 2018) that erode, move, and depose finer soil materials via the action of the running water from upper to bottom topographic positions (Debele et al., 2018). Consequently, the nature of slope in a given landscape can influence the rate of soil formation and development at different topographic positions (Deressa et al., 2018; Mulugeta and Sheleme, 2010). All the pedons were opened on grazing and fallow land uses that had distinctive parent materials of basaltic igneous rock (Table 1). The pedons have existed on different landforms and slope gradients with straight slope forms and straight plus concave surface flow pathways. Rill and sheet soil erosions were observed at shoulder, back-slope, and foot-slope positions, whereas soil deposition was prevalent on the toe-slope and bottom depression areas. Also, the surface of the eroded topographic components was covered by different amounts and sizes of coarse fragments. However, there was no rock outcrop and sign of surface sealing in the area. The data gathered from auger inspection and site characteristics of the study area revealed the presence of variations in key topographic features that determine the nature (morphological, physical, and chemical properties) and distribution of soils along the toposequence.

Table 1. Selected site characteristics of pedons along the toposequence

Basic information	Profiles					
	Summit	Shoulder	Back-slope	Foot-slope	Toe-slope	Depression
Coordinates (Latitude/Longitude)	09°34’58’’N 39°33’42’’E	09°34’53’’N 39°33’36’’E	09°34’48’’N 39°33’33’’E	09°34’42’’N 39°33’25’’E	09°34’23’’N 39°33’18’’E	09°34’11’’N 39°33’18’’E
Altitude (masl)	2957	2946	2927	2894	2859	2845
Major landform	Level land, plain	Sloping land, medium-gradient escarpment	Sloping land, medium-gradient hill	Sloping land, dissected plain	Level land, depression	Level land, depression
Slope gradient (%)	Level (0.5)	Strongly sloping (10)	Moderately steep (17)	Strongly sloping (12)	Sloping (5)	Gently sloping (2)
Slope form and surface flow pathway	Straight-Straight	Straight-Concave	Straight-Concave	Straight-Straight	Straight-Straight	Straight-Straight
Land use	Grazing	Fallowing	Fallowing	Fallowing	Grazing	Grazing
Geologic materials	Basic Igneous rock (Basalt)	Basic Igneous rock (Basalt)	Basic Igneous rock (Basalt)	Basic Igneous rock (Basalt)	Basic Igneous rock (Basalt)	Basic Igneous rock (Basalt)
Parent materials	Weathered products of rocks with a high amount of a 2:1 expanding clay type (smectite)	Saprolite	Saprolite	Variety of fine to medium textured unconsolidated materials from alluvial and colluvial deposits	Fine-textured materials (clay and silt fractions) derived from alluvial deposit	Fine-textured materials (clay and silt fractions) derived from alluvial deposit
Rock outcrops	None	None	None	None	None	None
Surface cover (%) and size dimension (cm) of coarse fragments	None	Many (15-40) stones (6-20)	Common (5-15) boulders (20-60)	Few (2-5) stones (6-20)	None	None
Category, affected area (%), and degree of erosion or material deposition	No evidence	Rill erosion, 10-25, moderate	Rill erosion, 10-25, moderate	Sheet erosion, 5-10, slight	Deposition by water	Deposition by water
Surface sealings	None	None	None	None	None	None
Width (cm), depth (cm) and distance between (m) surface cracks	Very wide (5-10), very deep (>20) and moderately wide spaced (0.5-2)	Wide (2-5), very deep (>20) and widely spaced (2-5)	None	Medium (<1), medium (2-10) and widely spaced (2-5)	None	None
Soil type (WRB)	Vertisol	Cambisol	Leptosol	Luvisol	Cambisol	Cambisol
Local soil name	*Mererie*	*Areda*	*Ajara*	*Bodda*	*Abolsie*	*Abolsie*

Soil Morphological Properties

The pedons had A and B sequence of horizons with their depth varying from 135 to 200+ cm (Table 2). In general, the thickness of A-horizons showed an increasing trend down the slope with the exception of the horizon at the back-slope. The shallowest (20 cm) and deepest (70 cm) A horizons existed at the back slope and toe slope, respectively (Table 2). The disparity in surface horizon thickness might be attributed to slope steepness and form at a particular topographic position which determine soil formation and development by influencing horizontal (erosion and deposition) and vertical (eluviation and illuviation) translocations of soil material. An increase in the depth of surface horizon along toposequences largely occurs due to water erosion that takes soil materials from summit to bottom depression (Sheleme, 2017; Alemayehu et al., 2016; Dessalegn et al., 2014). The relatively gentler slope at the lower topographic locations aids the deposition of materials eroded from the upper part (Chaplot, 2013; Ali et al., 2010). In line with the present findings, (Mulugeta and Sheleme, 2010) also found a reduction in the depth of surface soils with increasing slope along the toposequences of Kindo Koye sub-watershed in southern Ethiopia, whereby the thinner and thicker A-horizons appeared at the steep (shoulder and back) and gentle (foot and toe) slopes, respectively.

The distinctness and topography of horizon boundaries between the surface and sub-surface horizons were abrupt and smooth, except for the clear-wavy and abrupt-wavy boundaries for the pedons at the summit and bottom depression areas (Table 2). The variations in the appearance of horizon boundaries indicate that the soils were formed through different soil-forming processes (Ayalew et al., 2015) while they partly reflect anthropogenic impacts (Cools and De Vos, 2010). The boundary changes between surface and sub-surface horizons of cultivated land-use occurred because of repeated human activities like plowing (Hailu et al., 2015). Moreover, the changes in grazing land use could be due to gradual transformation, homogenization, and/or erosional-depositional processes (Ande, 2010). The color of the surface soils was very dark brown (7.5YR 2.5/2 or /3) at the upper while it was dark reddish brown at the middle (5YR 3/3) and lower (5YR 2.5/2) slope positions (Table 2). The surface soil colors of the pedons were darker than their subsurface counterparts except for the pedons at the summit and shoulder (Table 2). The color variations within and among the pedons might be the reflection of differences in chemical and mineralogical composition, topographic positions, OM content, and moisture regimes. (Dengiz et al., 2012) confirmed that soil color was related to OM and carbonate accumulations, redoximorphic features, drainage condition, and physiographic position. Similarly, several authors reported that the surface horizons have darker colors than the corresponding subsurface horizons as a result of relatively higher soil OM contents in the surface layers (Dessalegn et al., 2014; Ali et al., 2010; Mulugeta and Sheleme, 2010). Mulugeta and Sheleme (2010) also reported that soils on slopes that have never been saturated with water had reddish and brownish subsoil colors while soils on poorly drained locations tended to have grey-colored B-horizons. However, the greyish subsurface soils color at the summit could be due to the limited weathering of smectite clays that remain stable as long as the pH is above neutral and result in subsoils with a lower red hue and weaker chroma because of the less free ferric ions (Driessen et al., 2001). Besides, the blackish/greyish sub-surfaces at the shoulder could be due to the leaching accumulation of weathered smectitic clays that impede internal drainage upon cementation of subsoil particles while providing reddish soil color owing to Fe^{3+} compounds left behind in the surface horizon (Driessen et al., 2001).

The structures of soils at the surface layers were granular and sub-angular blocky with grades ranging from moderate and moderate to strong and fine to coarse sizes (Table 2). On the other hand, the subsurface horizons had different structures (angular blocky, sub-angular blocky, prismatic, columnar, platy, and crumbly) weak to moderate and strong grades, and fine to very coarse sizes. The presence of granular structure at the surface could be attributed to the OM content (Gebrekidan and Negassa, 2006), whereas the well-developed structure in the subsurface is due to increasing clay content (Khormali et al., 2003). The results corroborate with Fekadu et al. (2018); Mesfin et al. (2017); Teshome et al. (2016) who found granular soil structure in the surface horizons that changed to angular and sub-angular structures in the sub-surface horizons of the pedons.

Table 2. Morphological properties of soils along the toposequence of Qenberenaweti sub-watershed

Profile	Horizon	Depth (cm)	Boundary	Soil Color (Munsell Code)		Soil Structure (Grade/ Size/ Shape)	Soil Consistency				Texture (Feel)
				Dry	Moist		Dry	Moist	Wet		
									Plasticity	Stickiness	
Summit	A	0-25	CW	10YR 3/3	7.5YR 2.5/2	Mo/ Me/ Gr	HA	VFR	PL	VST	Clay
	Bt1	25-70	AS	10YR 4/1	7.5YR 3/1	St/ Co/ Ab	VHA	FI	VPL	VST	Clay
	Bt2	70-105	CW	10YR 4/2	10YR 3/2	St/ Co/ Pr	EHA	FI	VPL	VST	Clay
	Btk1	105-135	AS	10YR 4/3	7.5YR 3/3	MS/ Co/ Ab	VHA	VFI	PL	VST	Clay
	Btk2	135-165	AW	10YR 4/3	7.5YR 3/2	MS/ Me/ Sb	HA	FI	VPL	ST	Clay
	Btkm	165-200	-	10YR 4/4	7.5YR 4/2	MS/ Me/ Cr	HA	FR	PL	ST	Clay
Shoulder	A	0-30	AS	10YR 3/4	7.5YR 2.5/3	MS/ Me/ Gr	SHA	VFR	VPL	ST	Clay loam
	AB	30-65	CS	10YR 3/3	7.5YR 2.5/2	Mo/ Fi/ Cr	SHA	VFR	VPL	VST	Clay loam
	Bt1	65-100	AW	10YR 3/1	7.5YR 2.5/1	St/ Me/ Pr	VHA	FR	VPL	VST	Clay
	Bt2	100-120	GW	10YR 4/1	7.5YR 3/1	St/ Me/ Pl	HA	VFI	VPL	VST	Clay
	BC	120-135	-	10YR 4/2	7.5YR 3/2	MS/ Fi/ Cr	SHA	FR	PL	ST	Clay loam
Back slope	Ac1	0-20	AS	7.5YR 3/3	5YR 3/3	Mo/ Me/ Sb	SHA	VFR	PL	ST	Loam
	Ac2	20-40	CW	7.5YR 3/4	5YR 3/3	Mo/ Me/ Sb	HA	FR	PL	ST	Loam
	Bwv	40-60	CS	7.5YR 3/2	5YR 3/2	MS/ Me/ Sb	VHA	FI	PL	ST	Clay loam
	Bhsm	60-110	CW	7.5YR 3/2	7.5YR 2.5/2	St/ Me/ Ab	VHA	VFI	VPL	VST	Clay loam
	Btx	110-125	AW	7.5YR 4/4	7.5YR 3/3	MS/ Me/ Cr	HA	FI	VPL	VST	Clay loam
	B/C	125-155	-	7.5YR 4/3	7.5YR 3/3	St/ Me/ Cr	HA	FR	PL	ST	Clay loam
Foot slope	Ac1	0-35	AS	7.5YR 3/4	5YR 3/3	Mo/ Co/ Sb	SHA	VFR	PL	ST	Clay loam
	ABc2	35-70	CS	7.5YR 3/2	5YR 3/2	Mo/ Me/ Sb	HA	FR	PL	ST	Clay
	Btc3	70-95	CW	7.5YR 3/3	7.5YR 2.5/2	Mo/ Me/ Ab	HA	FR	PL	VST	Clay
	2Bti1	95-150	AS	10YR 3/1	7.5YR 2.5/1	St/ VC/ Cl	SHA	VFR	VPL	VST	Clay
	2Bti2	150-200+	-	10YR 2/1	7.5YR 2.5/1	St/ Co/ Cl	VHA	FI	VPL	VST	Clay
Toe slope	Ac1	0-20	AS	7.5YR 3/3	5YR 2.5/2	Mo/ Me/ Gr	SHA	VFR	PL	ST	Clay loam
	Ac2	20-45	AS	7.5YR 3/4	5YR 3/2	Mo/ Fi/ Gr	SHA	FR	PL	ST	Clay loam
	Ac3	45-70	CS	7.5YR 4/4	5YR 3/2	Mo/ Fi/ Cr	HA	FI	VPL	ST	Clay
	Bhc4	70-105	CW	7.5YR 3/2	7.5YR 2.5/2	Mo/ Me/ Cr	HA	VFI	VPL	VST	Clay
	B/C	105-165+	-	7.5YR 4/2	5YR 2.5/2	WM/ Me/ Cr	HA	FR	PL	ST	Clay loam
Bottom depression	Ag1	0-30	AW	7.5YR 3/4	5YR 2.5/2	Mo/ Fi/ Gr	HA	FR	VPL	ST	Clay loam
	Aqg2	30-65	GW	7.5YR 3/3	5YR 3/2	Mo/ Me/ Sb	SHA	VFR	VPL	VST	Clay loam
	Bg3	65-110	CW	7.5YR 3/3	5YR 3/2	Mo/ Me/ Ab	HA	FR	VPL	ST	Clay
	Bhg4	110-140	CW	7.5YR 3/2	5YR 3/2	Mo/ Fi/ Ab	SHA	FR	VPL	VST	Clay
	BCg5	140-190	-	7.5YR 4/3	7.5YR 2.5/2	WM/ Fi/ Cr	HA	FR	PL	ST	Clay loam

Where: AS-Abrupt Smooth; CS-Clear Smooth; AW-Abrupt Wavy; CW-Clear Wavy; GW- Gradual Wavy; St-strong; Mo-moderate; We-weak; MS-moderate to strong; WM-weak to moderate; VC-very coarse; Co-coarse; Me-medium; Fi-fine; Cr-crumbly; Ab-angular blocky; Sb-subangular blocky; Gr-granular; Pr-prismatic; Cl-columnar; Pl-platy; HA-hard; VHA-very hard; SHA-Slightly hard; FI-firm; FR-friable; VFR-very friable; PL-plastic; VPL-very plastic; ST-sticky; VST-very sticky

The soils along the toposequence had consistence ranging from hard to slightly hard, friable to very friable, and plastic/sticky to very plastic/very sticky at the surface horizons while the soil consistence in the subsurface horizons varied from hard to extremely hard, very friable to firm and plastic/sticky to very plastic/very sticky (Table 2). The variations in soil consistence could be resulted from the differences in particle size distribution, texture, OM content, and amount and nature of clay particles (Paltseva, 2024; Ayalew et al., 2015; Moradi, 2013). Very friable and friable consistencies were observed in the surface soils as a result of higher OM contents compared to their subsurface counterparts (Debele et al., 2018; Mulugeta and Sheleme, 2010) and impacted better workability of clayey soils by reducing their stickiness (Ali et al., 2010). In contrast, sticky/very sticky and plastic/very plastic consistencies show the existence of high clay and low organic carbon contents with difficulty to till (Ayalew et al., 2015). Furthermore, (Ali et al., 2010) pointed out that very sticky and very plastic appearances could be best indicative of the presence of smectitic clays in the soils.

Soil Physical Properties

The textural class of all soils at the surface and subsurface horizons was clay with different distribution of the three soil separates (Table 3). The proportion of the separates is determined by slope steepness, form, and topographic laying position of the excavated pedons (Ofori et al., 2013). The sand fraction in the surface layer increased from 18% at the summit to 32% at the back-slope, and then decreased to 24% at the bottom depression position, whereas the clay decreased from 48% to 40%, and then increased to 48% at the respective topographic positions (Table 3). The coarser soil texture in the surface horizons at the middle part of the toposequences might be due to the selective removal of fine (clay) and medium (silt) sized soil particles by the action of erosion from steeper slope at this topographic position and their deposition at lower parts. It is likely that silt proportion would be raised on foot and toe slopes as compared to the surface soils on the shoulder and back slopes when erosion left coarse particles on the hill part (Mulugeta and Sheleme, 2010). The highest amount of clay particles at the surface of the bottom depression position could be attributed to their translocation and deposition from the upper and adjacent profiles (Babalola et al., 2007).

On the other hand, the subsurface horizons of most pedons were finer in texture than their respective surface horizons due to the downward translocation of clay particles (Table 3). The presence of clay illuviation is the main factor in the formation of the argillic horizon in the subsurface soils of the upper and middle slope profiles (Mulugeta and Sheleme, 2010). In line with this finding, Adhanom and Toshome (2016); Mulugeta and Sheleme (2010) found an increasing trend of clay contents while sands showed a decreasing trend down the slope gradient due to selective movement of finer soil particles laterally from the upper slopes and/or adjacent areas and subsequent accumulation in the lower topographic position. Accordingly, the higher clay content in the B horizon of soils was reported as a result of illuviation, predominant *in-situ* pedogenetic formation in the subsoil, destruction in the surface horizon, upward movement of coarser particles due to swelling and shrinking, biological activity, and a combination of two or more of these different processes (Fekadu et al., 2018; Yitbarek et al., 2018; Mesfin et al., 2017). The very high significant ($P \leq 0.01$) correlations between clay and sand ($r = -0.82$) and silt ($r = -0.80$) also confirm the translocation and illuvial accumulation of clay in the subsurface horizons (Appendix Table 2).

The silt to clay ratio of the soils across the profiles ranged from 0.19 to 1.00 (Table 3); hence, implying that the soils are at a relatively better rate of weathering with significant leaching of clay particles. Soils having silt to clay ratio below a unity are considered to be at an advanced stage of development and had undergone feralitic pedogenesis process (Debele et al., 2018; Abayneh, 2005). The lower silt to clay ratios in the subsoil layers as compared to their surface counterparts also confirm the existence of clay migration in the pedons (Nahusenay et al., 2014; Beyene, 2011). The presence of an appreciable amount of silt fraction in the surface soils could increase the water-absorbing ability of the soils, and facilitate longer soil-water retention for plant use (Saha et al., 2020; Beyene, 2011)

Table 3. Physical properties of soils along the toposequence of Qenberenaweti sub-watershed

Profile	Horizon	Depth (cm)	Particle Size (%)			Silt to Clay	Textural	Density (g cm^{-1})		Total
			Sand	Silt	Clay	Ratio	Class	Bulk	Particle	Porosity (%)
Summit	A	0-25	18	34	48	0.71	Clay	1.22	2.35	47.97
	Bt1	25-70	14	14	72	0.19	Clay	1.24	2.39	48.33
	Bt2	70-105	12	14	74	0.19	Clay	1.30	2.43	46.50
	Btk1	105-135	18	14	68	0.21	Clay	1.35	2.42	44.10
	Btk2	135-165	14	24	62	0.39	Clay	1.29	2.51	48.50
	Btkm	165-200	10	18	72	0.25	Clay	1.41	2.56	45.12
Shoulder	A	0-30	26	28	46	0.61	Clay	1.19	2.43	51.03
	AB	30-65	22	26	52	0.50	Clay	1.21	2.42	50.00
	Bt1	65-100	18	16	66	0.24	Clay	1.29	2.50	48.30
	Bt2	100-120	12	16	72	0.22	Clay	1.40	2.58	45.63
	BC	120-135	26	22	52	0.42	Clay	1.31	2.56	48.73
Back slope	Ac1	0-20	32	28	40	0.70	Clay	1.19	2.41	50.62
	Ac2	20-40	28	28	44	0.64	Clay	1.23	2.44	49.59
	Bwv	40-60	30	24	46	0.52	Clay	1.28	2.56	49.90
	Bhsm	60-110	20	34	46	0.74	Clay	1.30	2.53	48.62
	Btx	110-125	18	20	62	0.32	Clay	1.29	2.47	47.87
	B/C	125-155	24	28	48	0.58	Clay	1.40	2.57	45.72
Foot slope	Ac1	0-35	30	28	42	0.67	Clay	1.19	2.35	49.36
	ABc2	35-70	24	38	38	1.00	Clay Loam	1.16	2.39	51.67
	Btc3	70-95	18	26	56	0.43	Clay	1.26	2.49	49.40
	2Bti1	95-150	14	16	70	0.23	Clay	1.36	2.64	48.39
	2Bti2	150-200+	14	16	70	0.23	Clay	1.42	2.60	45.58
Toe slope	Ac1	0-20	26	32	42	0.76	Clay	1.15	2.37	51.37
	Ac2	20-45	26	30	44	0.68	Clay	1.20	2.43	50.82
	Ac3	45-70	24	32	44	0.73	Clay	1.19	2.41	50.62
	Bhc4	70-105	22	28	50	0.56	Clay	1.24	2.48	50.10
	B/C	105-165+	36	18	46	0.39	Clay	1.28	2.61	50.96
Bottom depression	Ag1	0-30	24	28	48	0.58	Clay	1.18	2.43	51.34
	Aqg2	30-65	34	16	50	0.32	Clay	1.20	2.50	51.90
	Bg3	65-110	20	26	54	0.48	Clay	1.19	2.45	51.33
	Bhg4	110-140	20	28	52	0.54	Clay	1.23	2.59	52.51
	BCg5	140-190	34	20	46	0.43	Clay	1.29	2.55	49.31

The bulk and particle densities of the surface horizons ranged from 1.15 to 1.22 and 2.35 to 2.43 g cm^{-3}, respectively, whereas their corresponding values in the subsurface horizons ranged from 1.16 to 1.42 and 2.39 to 2.64 g cm^{-3} (Table 3). The bulk density values of the soils in the surface horizons were under the usual ranges (1.0-1.5 g cm^{-3}) for fine-textured soils (Wogi et al., 2021). Both the particle and bulk densities of the soils increased with soil depth at all topographic positions which could be due to the relatively higher OM content in the surface than the subsurface soils; while the increase in bulk density could also result from natural compaction of the subsurface soils by a load of surface soils (Abayneh, 2005). According to Mulugeta and Sheleme (2010), soils that are loose, porous, or well-aggregated may have lower bulk densities than soils that are compacted or non-aggregated.

The total pore space in the surface layers was between 47.97 and 51.37% showing a decreasing trend with soil depth (Table 3). According to Michael (2009), the total pore spaces in the clayey textured soils may vary between 40 and 60 %. Besides, Shahab et al. (2013) also stated that the optimum total pore space value for crop production is about 50 %. Hence, the studied soils could be considered convenient for better crop production as there is a conducive situation for free aeration and water movement within the soil structure that is also capable of determining the number, diversity, and activity of important soil organisms (Mulugeta et al., 2019).

Table 4. Mean values of particle-size distribution of the soils around excavated pedons

	Percent sand			Percent silt			Percent clay			Textural class
Pedon	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)	
Summit	19	1	5.26	33	1	3.03	49	1	2.04	Clay
Shoulder	23	3	13.04	29	1	3.45	49	3	6.12	Clay
Back-slope	30	2	6.67	31	3	9.68	39	1	2.57	Clay loam
Foot-slope	28	2	7.14	31	2	6.45	41	1	2.40	Clay
Toe-slope	27	1	3.71	29	1	3.45	43	1	2.33	Clay
Bottom depression	25	1	0.04	29	1	3.45	46	2	4.35	Clay

The surface soil samples collected from all directions of the opened pedon had more or less similar texture with that of the corresponding soils of the surface horizons, except for a slight difference at the back-slope pedon. However, the proportion of clay, silt, and sand fractions at a given physiographic position deviated by ±1 to 3 % between the soils of the surface horizons of the pedons and the respective surface soils around the pedons (Table 4). In general, the descriptive statistics analysis reviled the presence of very closeness (CV < 15 %) within each of the three soil separates of the samples around the opened pedons (Wilding and Drees, 1978).

Soil Chemical Properties

The pH values of surface and sub-surface soils ranged from 5.59 to 6.23 and from 5.31 to 7.65, respectively (Table 5). According to Wogi et al. (2021), the surface soils at the shoulder and toe slope parts were slightly acidic while the others were moderately acidic. Apart from the toe slope, the pH values in the subsurface horizons were higher than the surface horizons of the rest pedons (Table 5). The escalations in pH values in the subsoils could be due to the illuvial accumulation of basic cations i.e., leaching and downward translocation of basic cations (Fekadu et al., 2018; Nahusenay et al., 2014). Additionally, it might be due to less H^+ released from the poor decomposition of the lower OM content in the subsoils (Ayalew and Beyene, 2012). The higher pH at the surface of the toe-slope position could also be related to the effects of water moving down the slope of the toposequence causing erosion and deposition of materials rich in basic cations. Generally, the low topographic positions had higher pH values than the upper positions, which might be due to the excessive accumulation of exchangeable bases that were laterally removed from uphills and subsequently deposited at lower slopes (Hailu et al., 2015; Nahusenay et al., 2014). However, the high pH value at the surface of the shoulder site could be associated with the substantial deposition of dust particles that blown-up from the nearby main paved road of magnesitic ($MgCO_3$), dolomitic [$CaMg(CO_3)_2$], and/or serpentine [$Mg_3Si_2O_5(OH)_4$] limestone sources.

On the other hand, the lower pH values at the sub-surface horizon of the toe-slope could probably be due to infiltration and percolation of water deep into the soil. The soil water saturation might have removed basic cations from the subsoil horizon and contributed to the lowering of soil pH (Damene et al., 2007). In addition to the release of H^+ from its numerous acid functional groups, OM facilitates leaching loss of Ca^{2+} and Mg^{2+} by forming soluble complexes (Jalali and Arfania, 2010; Brady and Weil, 2008). This finding agreed with the work of Fekadu et al. (2018) and Ali et al. (2010) whereby the pH-H_2O showed a general rise with soil depth in the pedons at upper and middle slope positions compared to those at the bottom and toe slope positions. The correlation analysis also revealed that the soil pH was caused negatively due to the OC ($r = -0.45$, $P \leq 0.01$), av. Fe ($r = -0.69$, $P \leq 0.001$) and av. Mn ($r = -0.50$, $P \leq 0.01$) contents while positively from the ex. Na ($r = 0.71$, $P \leq 0.001$), ex. K ($r = 0.39$, $P \leq 0.05$) and ex. Ca ($r = 0.39$, $P \leq 0.05$) concentrations (Appendix Table 2).

Irrespective of the topographic positions, the surface horizons of all pedons had relatively low soil electrical conductivity (EC) values (0.087 to 0.273 dS m^{-1}). The soils of the study area were non-saline (Havlin et al., 2017; Richards et al., 1954) with a very low rated EC value (Shaw, 1999) at which the existing amounts of soluble salts cannot affect the growth and productivity of most crops (Landon, 2014; Richards et al., 1954).

The organic carbon (OC) and total nitrogen (TN) contents across the horizons varied from 0.22 to 2.03% and from 0.02 to 0.18%, respectively (Table 5) while the carbon to nitrogen (C: N) ratio was between 6.0 and 20.0. In general, the OC and TN contents decreased with the soil depth, except for a substantial accumulation of illuviated OM in some subsurface horizons of the back slope and bottom depression parts. Additionally, the OC and TN contents of surface soils declined from the summit to the back slope, increased at the foot slope and toe slope, and then decreased at the bottom depression (Table 5). The surface soils were rated as medium (1.5-3.0 %) in OC and high (0.12-0.25 %) in TN contents (Wogi et al., 2021), whereby their C: N ratio falls under the low (10-15) category (Newey, 2006). According to (Hartz, 2007), soils with less than 0.07 % TN are believed to have a limited N mineralization potential while those having above 0.15 % are expected to mineralize a significant amount of N during the next crop cycle, showing that most of the studied soils have a good potential of N mineralization. In most cases, the C: N ratios of soils were within the common range (8:1 to 15:1) for arable soils (Brady and Weil, 2008) implying that OM was fully decomposed and N loss was apprehended.

The variations in OC and TN contents might be due to repeated tillage with poor management practices including complete removal of crop residues and/or reduced usage of organic amendments (Sheleme, 2023). The low content of OC in the surface layers could be attributed to the rapid decomposition and mineralization of OM under cultivation practices (Beyene, 2011; Dengiz, 2010) and then resulting in a reduction of TN (Adhanom and Toshome, 2016). The relatively better level of OC in the surface horizon of the summit, toe-slope and bottom depression parts might have been due to biomass turnover of grasses on the grazing land use (Fekadu et al., 2018). The similar distribution pattern of OC and TN with soil depth was also evident from the positive ($r = 0.93$) and very highly significant ($P \leq 0.001$) correlation between the two parameters (Appendix Table 2).

The available P (av. P) concentrations in surface soils ranged from 8.43 to 23.96 mg kg^{-1}, while they ranged from 0.48 to 24.27 mg kg^{-1} in the subsurface soils (Table 5). According to Wogi et al. (2021), the surface soils had low to high av. P contents while the subsoils were under very low to high ranges. The content of av. P was increased from the surface to the immediate subsurface horizon and declined with depth then after except for the pedon at the toe-slope probably due to leaching accumulation. Though its availability is determined by the P adsorption capacity (Deressa et al., 2018), soils with a near-neutral pH have the highest av. P than those under acidic reaction (Yitbarek et al., 2018; Beyene, 2011). The extent of microbially mediated P mineralization and immobilization processes could also determine its availability to plants (Zhu et al., 2018). Generally, there were variations in the availability of P along the toposequence with an alternative decrease-increase trend from the summit to bottom depression perhaps due to differences in the soil types, topography, level of inherent P content, use of P-containing fertilizers, and soil management practice in the area (Debele et al., 2018; Mulugeta and Sheleme, 2010). The lowest av. P in the surface soil of the bottom depression could be evidence of the soils with Fe mottling and concretions had low labile P fraction (Deressa et al., 2018) which become less available because of its bound to oxides of Fe and Al (Gérard, 2016).

Similar to this finding, different scholars confirmed that the av. P content decreases with increasing soil depth because of a decline in soil OM and/or a rise in clay contents (Yitbarek et al., 2018; Nahusenay et al., 2014; Mulugeta and Sheleme, 2010). Besides, Deressa et al. (2018) reported differential P distribution along a toposequence in mountainous topography and undulating landforms of humid western Ethiopia due to lateral and vertical movements of soil materials via the action of water. Mulugeta and Sheleme (2010) found a general increase in the distribution of av. P down the slope because of the strong association between slope position and soil properties. This was also confirmed by the positive correlations of av. P with OC ($r = 0.42$, $P \leq 0.05$), av. Fe ($r= 0.54$, $P \leq 0.01$) and av. Mn ($r = 0.44$, $P \leq 0.001$) contents, whereas it was negatively correlated with pH ($r = -0.42$, $P \leq 0.05$) and clay ($r = -0.51$, $P \leq 0.01$) content (Appendix Table 2).

The amounts of exchangeable Ca, Mg, K, and Na ranged from 10.80 to 32.26, 2.86 to 26.84 0.36 to 0.92, and 0.14 to 0.37 $cmol_c$ kg^{-1} (Table 5) that were under high to very high, medium to very high, medium to high, and low to medium ranges, respectively (Wogi et al., 2021). All the cations had an irregular pattern across the soil depth; but both the divalent cations showed systematic trends of increase-decrease along the toposequence. Moreover, Ca was the abundant cation on exchange sites which accordingly followed by Mg, K, and Na except for the Mg dominance over Ca at the surface layer of the back slope and depression pedons. The cationic swarming of soil colloidal surface often reported as $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ (Fekadu et al., 2018; Yitbarek et al., 2018; Adhanom and Toshome, 2016); and thought as an ideal for normal plant growth and development (Havlin et al., 2017).

Apart from the soils in the summit position, the surface soils of all pedons had Ca: Mg ratios below the approximate optimum (3:1 to 4:1) range for most crops to face a Mg-induced Ca deficiency (Landon, 2014). Besides, the Ca: Mg ratios of the surface soils at the back slope and bottom depression positions were below the suggested lowest acceptable (1:1) limit, whereby Ca availability is curtained (Landon, 2014). The existing variabilities in amount and distribution of the basic cations could be attributed to differences in the soil type (parent material), stage of weathering and development, erosion and deposition, translocation and leaching, and mining by cropping systems (Hailu et al., 2015; Nahusenay et al., 2014; Ali et al., 2010). In addition to the presence Mg bearing minerals, the dominance of Mg over Ca could be ascribed to its primal release after a relatively more weathering; strong adsorption at lower pH; and better occluding into clay minerals for smaller atomic size (Tardif et al., 2019; Senbayram et al., 2015; Gransee and Führs, 2013).

The overall cation exchange capacity (CEC) of soils in the study area ranged between 29.07 and 48.84 cmolc kg^{-1} (Table 5), which is under high and very high categories (Wogi et al., 2021). The CEC of surface horizons varied inconsistently along the toposequence whereby the highest CEC value was obtained from the bottom depression part followed by the foot slope, summit, back slope, shoulder, and toe slope positions. Though the CEC of the soils did not show any regular pattern with soil depth, higher CEC values were recorded in the subsurface horizons of the pedons than their surface counterparts.

The varying values of CEC down the soil depth and topographic positions could be linked with soil OC and clay contents (Debele et al., 2018). The highest CEC in the bottom layers of pedons at the lower (bottom depression) and middle (foot slope) topographic positions could be the result of the higher clay accumulation, whilst the lowest CEC at the surface layers of the pedon at the upper (shoulder) topographic position could be due to lateral and/or vertical movements of clay particles (Deekor et al., 2012; Nega and Heluf, 2009). In line with the present findings, Abate and Kibret (2016) found higher CEC in subsurface layers as compared to the surface layers in pedons at different topographic positions.

With respect to the decreasing trend of CEC along the slope, (Debele et al., 2018) also reported that pedons at upper and middle slope positions relatively had higher CEC than the lower part. The CEC had a highly significant positive relation with clay ($r = 0.46$) and pH ($r = 0.48$) while its correlation with OC ($r = -0.21$) was non-significant and negative (Appendix Table 2). The non-significant correlation of CEC with OM as compared to the highly significant with clay implies that the release of permanent (pH-independent) charges due to the isomorphous substitution of cations on clay minerals of the study soils contributed to the CEC than OM (Van Ranst, 2006).

The CEC clay varied between 52.23 and 99.47 cmolc kg^{-1} whereby higher results were recorded on subsurface horizons of all pedons except for the surface horizons at summit and shoulder. Moreover, the values increased from summit to foot slope; then failed and rose at toe slope and bottom depression pedons, respectively (Table 5). Since CEC depends on the nature and amount of soil colloids (Brady and Weil, 2008), the CEC of clay fraction can be used as a sign for the type of clay mineralogy (Buol et al., 2011). Thus, all soils are assumed to have smectite (60-100 cmolc kg^{-1}) clay group (Fekadu et al., 2018). Soils with high proportion of 2:1 expanding clay mineral, dominantly the montmorillonite (80-100 cmolc kg^{-1}), are also expected to reserve more Mg, K, and Fe nutrients (Landon, 2014). The percent base saturation (PBS) of the soils throughout the profiles ranged between 87.52 and 97.42 (Table 5). As per the rating of (Hazelton and Murphy, 2021), the PBS is under a very high (>80 %) category. The PBS values were higher in subsurface horizons than the surface, and the values in the surface horizons showed inconsistent decreasing and increasing trends along the toposequence. High values of PBS are in line with the high amount of Ca^{2+} occupying the exchange sites on the colloidal sites (Sekhar et al., 2014). The variation in PBS also indicates the degree of leaching which could be used as a diagnostic character for classifying soils (Meena et al., 2014).

The concentrations of DTPA extractable Fe, Mn, Zn, and Cu in the whole horizons varied from 0.1 to 5.36, 0.27 to 6.55, 0.01 to 0.95, and 0.05 to 0.25 mg kg^{-1} with inconsistent patter along the toposequence and with soil depth (Table 5). Generally, the highest concentrations of Fe, Mn, Zn, and Cu were recorded at the back-slope, bottom depression, foot-slope, and summit positions, respectively. Whereas, the lowest contents of the rest micro-nutrients existed at the summit position, except for Zn at the shoulder. Mn was followed by Fe, and both were the dominant cations in the surface soils of the profiles, except for the summit position (Table 5). As per the rating set by Wogi et al. (2021), the surface soils of the study area are under low to medium and medium to very high ranges in available Fe and Mn contents, respectively; but very low to low in available Zn and Cu contents.

The quantities of soil Fe, Mn, Zn, and Cu could be attributed to the vital factors like soil pH, OM content, clay amount and type, cation proportion, and drainage condition (Havlin et al., 2017). For instance, solubility and availability of Fe^{+3} in soil solution decreases a thousand-fold while that of Fe^{+2} and Mn^{+2} decreased by a hundred-fold for each unit increase in soil pH. Solution Fe and Mn ions are complexed by organic compounds in the soil solution which improves their availability through chelation reactions. Besides, soluble Fe and Mn concentrations could be increased under fine-textured and/or waterlogged soils that exhibit reduced O_2 and redox potential especially in lower pH condition. Havlin et al. (2017) also stated that Cu concentration is usually low at which most of the soluble Cu^{+2} in surface soils is organically complexed and strongly bound to OM than any other micronutrient. For soils with similar clay and OM contents, the role of OM to complexing of Cu is the highest with 1:1 versus 2:1 clays. The adsorption mechanism with oxides is unlike electrostatic attraction of Cu^{+2} on the CEC of clay particles, and involves in the formation of Cu-O-Fe/Al surface bonds (Havlin et al., 2017). A significant fraction of soil Cu is also occluded in various mineral structures, such as clay minerals and Fe, Al, and Mn oxides.

Table 5. Chemical properties of soils along the toposequence of Qenberenaweti sub-watershed

Profile	Horizon	Depth (cm)	pH (H_2O)	EC (ds/m)	OC	TN	Av. P	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	CEC	CEC clay	BS	Av. Fe	Av. Mn	Av. Zn	Av. Cu
					%		$Mgkg^{-1}$	(cmol$_c$ kg^{-1})						(%)	(mg kg^{-1})			
Summit	A	0-25	5.59	0.155	1.83	0.17	18.82	29.38	6.14	0.91	0.16	41.20	72.72	90.27	2.17	1.63	0.41	0.08
	Bt1	25-70	6.23	0.358	0.43	0.07	22.74	23.08	11.92	0.84	0.21	40.76	54.55	90.28	1.45	1.36	0.19	0.11
	Bt2	70-105	7.17	0.293	0.51	0.08	15.32	23.14	11.76	0.81	0.25	40.80	52.74	90.29	0.18	0.57	0.33	0.08
	Btk1	105-135	7.18	0.391	0.38	0.04	4.24	28.40	13.02	0.78	0.32	48.59	70.05	89.90	0.10	0.36	0.45	0.05
	Btk2	135-165	6.97	0.452	0.76	0.04	10.39	32.26	7.50	0.73	0.36	46.84	71.29	89.97	0.17	0.37	0.01	0.13
	Btkm	165-200	7.65	0.280	0.29	0.03	6.33	18.46	21.30	0.86	0.37	47.03	64.96	89.99	0.17	0.27	0.23	0.05
Shoulder	A	0-30	6.23	0.087	1.67	0.16	15.69	22.72	11.08	0.66	0.15	39.45	73.26	89.05	3.22	5.95	0.12	0.17
	AB	30-65	6.52	0.096	1.04	0.12	20.62	19.78	11.12	0.92	0.17	36.55	63.42	89.25	3.82	2.00	0.36	0.12
	Bt1	65-100	6.06	0.287	0.78	0.09	13.25	18.63	12.67	0.91	0.20	37.15	52.23	89.21	1.28	1.56	0.30	0.09
	Bt2	100-120	6.38	0.395	0.27	0.03	4.92	22.15	12.26	0.81	0.24	40.82	55.42	89.00	0.37	1.03	0.18	0.07
	BC	120-135	6.77	0.145	0.31	0.02	3.35	23.55	7.62	0.54	0.28	36.99	69.10	89.24	0.48	1.01	0.16	0.08
Back slope	Ac1	0-20	5.97	0.259	1.69	0.14	22.89	14.37	23.14	0.41	0.19	40.77	83.16	95.14	4.50	5.92	0.22	0.16
	Ac2	20-40	5.95	0.198	1.52	0.13	24.27	13.01	24.46	0.37	0.17	40.59	80.30	95.15	3.99	1.55	0.03	0.14
	Bwv	40-60	5.31	0.409	0.22	0.02	12.28	11.35	20.81	0.52	0.20	35.19	74.83	95.51	4.53	2.16	0.40	0.12
	Bhsm	60-110	6.35	0.117	1.46	0.17	18.46	13.62	21.19	0.51	0.19	37.99	71.64	95.31	3.31	2.59	0.10	0.16
	Btx	110-125	5.93	0.346	0.86	0.08	10.08	19.24	21.57	0.60	0.19	44.56	67.07	94.93	1.84	1.81	0.27	0.12
	B/C	125-155	6.17	0.363	0.40	0.02	16.73	20.93	20.85	0.46	0.24	45.69	92.30	94.88	2.29	4.56	0.43	0.10
Foot slope	Ac1	0-35	5.63	0.143	1.80	0.18	11.49	19.78	18.58	0.42	0.16	42.44	86.30	93.07	2.89	4.32	0.18	0.18
	ABc2	35-70	6.41	0.187	1.71	0.17	13.57	20.94	19.36	0.41	0.18	43.71	99.47	95.08	5.09	3.86	0.64	0.15
	Btc3	70-95	5.94	0.165	1.56	0.15	11.61	19.64	18.12	0.54	0.21	42.17	65.72	93.10	4.27	3.30	0.95	0.14
	2Bti1	95-150	6.51	0.249	1.19	0.09	1.86	22.26	21.79	0.36	0.16	48.69	63.71	92.77	1.18	1.31	0.53	0.12
	2Bti2	150-200+	7.24	0.374	0.88	0.05	0.48	26.13	17.08	0.68	0.31	48.84	65.46	92.75	0.34	0.56	0.70	0.12
Toe slope	Ac1	0-20	6.32	0.143	2.03	0.18	23.96	20.96	8.04	0.72	0.18	31.45	58.24	97.14	3.37	5.82	0.21	0.15
	Ac2	20-45	5.61	0.091	1.53	0.13	16.38	28.01	2.86	0.45	0.16	33.07	63.17	97.01	3.42	5.51	0.75	0.11
	Ac3	45-70	5.87	0.243	1.69	0.17	19.20	10.80	16.20	0.58	0.16	29.07	52.80	97.42	5.36	4.58	0.01	0.25
	Bhc4	70-105	5.42	0.435	1.47	0.17	16.43	23.34	5.56	0.66	0.22	31.47	52.80	97.11	5.33	2.49	0.27	0.13
	B/C	105-165+	5.73	0.457	1.04	0.08	12.82	12.70	26.84	0.78	0.19	42.78	85.20	96.28	2.97	1.76	0.01	0.14
Bottom depression	Ag1	0-30	5.61	0.273	1.98	0.17	8.43	13.46	22.98	0.58	0.15	42.99	75.34	87.67	2.91	6.55	0.28	0.13
	Aqg2	30-65	6.69	0.119	1.43	0.16	8.53	21.78	17.44	0.72	0.14	46.38	82.93	87.52	2.24	4.94	0.38	0.15
	Bg3	65-110	6.16	0.058	0.84	0.14	15.64	26.12	5.86	0.49	0.18	37.86	64.73	88.01	3.82	2.71	0.21	0.11
	Bhg4	110-140	5.31	0.218	1.56	0.15	15.79	21.26	17.14	0.46	0.16	45.25	76.70	87.56	3.83	3.71	0.42	0.11
	BCg5	140-190	5.49	0.356	0.81	0.06	11.77	14.70	12.38	0.47	0.17	32.05	63.59	88.46	2.71	3.19	0.36	0.09

Similar to Cu^{+2}, soil solution Zn^{+2} is low as more than half of it creates stable complexes with high molecular weight organic compounds (lignin, humic acid and fulvic acid) that exist as soluble or insoluble forms. Typically, thirty-fold declines in solution Zn^{+2} due to complexation with organic matter have been observed for every unit pH increase between 5 and 7 (Havlin et al., 2017). Zn is also strongly adsorbed by magnesite, dolomite, and/or serpentine via getting into the crystal surface at sites normally occupied by Mg atoms (Havlin et al., 2017). Although the soils of the study area are not deficient in Fe and Mn, the low levels of available Zn and Cu indicate the potential deficiency of the elements. This finding is in line with Abayneh (2005) who reported Fe and Mn were at adequate levels across Ethiopian soils. Previous findings also indicated Zn and Cu deficiency in Ethiopian soils as a widespread problem (Ali et al., 2024; Karltun et al., 2013; Abayneh, 2005). All the micro-nutrients were positively correlated with OC content while they acquired negative correlations with soil pH. However, they were negatively related with clay particles and CEC except for the available Zn (Appendix Table 2).

Table 6. Values of selected soil chemical properties around excavated pedons

Pedons	Values	Properties								
		pH (H_2O)	OC (%)	TN (%)	Av.P (ppm)	Ex. K	Ex. Na	Ex. Ca	Ex. Mg	CEC
						($cmol_c\ kg^{-1}$)				
Summit	Mean	5.60	1.85	0.20	18.63	0.91	0.16	29.23	6.12	41.18
	SD	0.04	0.04	0.04	0.05	0.03	0.03	0.04	0.03	0.04
	CV (%)	0.71	2.16	20.00	0.27	3.30	18.75	0.14	0.49	0.10
Shoulder	Mean	6.22	1.67	0.14	15.82	0.68	0.14	22.67	11.13	39.46
	SD	0.05	0.06	0.05	0.13	0.07	0.03	0.10	0.12	0.11
	CV (%)	0.80	3.59	35.00	0.82	10.29	21.43	0.44	1.08	0.28
Back slope	Mean	5.94	1.71	0.13	22.79	0.44	0.18	14.35	23.18	40.91
	SD	0.06	0.08	0.04	0.15	0.03	0.04	0.10	0.12	0.12
	CV (%)	1.01	4.68	30.77	0.66	6.82	22.22	0.70	0.52	0.29
Foot slope	Mean	5.63	1.81	0.18	11.50	0.43	0.15	19.76	18.51	42.49
	SD	0.05	0.05	0.06	0.10	0.03	0.04	0.08	0.09	0.10
	CV (%)	0.89	2.76	33.33	0.87	6.98	26.67	0.40	0.49	0.24
Toe slope	Mean	6.20	2.01	0.16	23.98	0.75	0.19	20.97	8.04	31.41
	SD	0.04	0.04	0.03	0.04	0.03	0.03	0.02	0.03	0.03
	CV (%)	0.65	1.99	18.75	0.17	4.00	15.79	0.10	0.37	0.10
Depression	Mean	5.60	1.98	0.18	8.42	0.55	0.13	13.49	22.98	42.97
	SD	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.03
	CV (%)	0.54	1.52	16.67	0.36	5.45	15.39	0.22	0.13	0.07

Despite the higher SD value obtained at the back-slope position, there was low SD between the results in chemical properties of the surface soils of the horizons and their surrounding surface soils (Table 6). Apart from the intermediate variabilities (15 % < CV ≤ 35 %) in TN and exchangeable Na contents for surface horizons of the pedons and the corresponding surface soils around the pedons, the other chemical parameters showed similarities (CV < 15 %) among themselves at particular topographic positions (Wilding and Drees, 1978). Consequently, the soils of the surface horizons of the profile at a given topographic position represent the soils of their surrounding area.

Classification and Mapping of the Soils

Generally, the morphological and physicochemical properties of all the surface horizons were found within or very nearby the range of their concerned adjacent surface soil samples at a typical position of the toposequence. Similar to the pedons excavated and their surrounding surface soils, those SMUs having uniform/nearly closer results of common morphological (color, structure, consistence and texture-feel) and selected physicochemical properties (texture, pH, OC, basic cations and CEC) were considered and mapped as a similar soil group (Figure 4).

The soils of SMU 06 (the summit pedon), 09, 13, 18, and 29 were heavy textured blackish soils having a high proportion of alternatively shrink-swell clays which form wide deep cracks extending inward to ≥ 50 cm from the surface upon drying. The surface soils (≤ 30 cm) were evidenced by dusty appearance having a moist Munsell color value of ≤ 3 and chroma of ≤ 2. Besides, they had wedge-shaped aggregates with signs of frequent internal turnover (churning) of the soil materials below the upper 20 cm. Specifically, the summit pedon had thick (≥ 25 cm) subsurface horizons having more than 30 % clay and 80 % effective base saturation in 20-100 cm from the soil surface. About 80 % volume of the subsurface horizon between 25 and 70 cm depth was occupied by periodically broken wedge-shaped structural elements having an average horizontal length of < 10 cm. These properties qualify the soils for vertic diagnostic horizon. Moreover, there was a brownish subsurface horizon beyond the depth of 100 cm that has a clayey (≥ 30 %) texture with very firm and extremely hard consistencies when moist and dry, respectively, and produces effervescence when adding 1 M HCl due to its cementation by micro-crystalline forms of $CaCO_3$. Thus, such soils are classified as Pellic Bathypetroduric Vertisols (Hypereutric, Amphifractic) abbreviated as VR-pe-pdd-je-fcm.

Conversely, soils of SMU 02, 04, 05, 07, 08, 11, 12, 19, 26, and 28 exhibited wedge-shaped aggregates with a high proportion of alternatively shrink-swell clays that broke when dried, hence, qualified for vertic diagnostic horizons. However, these soils were at incipient stages of horizon differentiation which are evident from the changes in soil structure and color (mostly brownish discoloration) in their subsurface like that of the SMU 01, 03, 10, 14, 15, 16, 20, 21, 23, 24, 27, 30, 31, and 32. The soils were also characterized by slightly to moderately weathered medium and fine-textured materials, and the absence of considerable amounts of illuviated clay, organic matter, or Fe/Mn compounds within 100 cm from the soil surface. The shoulder pedon (SMU 05) was examined for the presence of ≥ 1 % soil organic carbon in the fine earth fraction of the upper two horizons to a weighted average depth of 65 cm with some noticeable soil structure and color changes from 30 to 65 cm because of a moderate pedogenetic alteration and wedge-shaped structural elements between a depth of 65 and 100 cm. Additionally, there were ≥ 30 % clay and 80 % effective base saturation throughout all horizons, hence, they are classified as Hypereutric Vertic Cambisols (Pantoclayic, Humic) abbreviated as CM-vr.je-cle-hu.

The soils of SMU 16 (the back-slope pedon), 01, 03, 10, 15, 20, 23, 24, and 27 were situated in human-made terraces, whereby ≥ 40 % of their soil surface was covered by fragments of ≥ 6 cm (stones and boulders) dimension. Also, their subsoils starting ≤ 100 cm from the soil surface had very to extremely hard and broken layer of indurated yellowish-brown materials which were cemented by Fe/Mn (hydr-) oxides with insignificant amount of organic matter. Particularly, the back-slope pedon was characterized by more than 40 % of interconnected yellowish-brown concretions and/or nodules of Fe/Mn (hydr-) oxides in reticulate patterns at which roots are only passing through vertical fractures of sheets having about 10 cm horizontal length at a depth of 40 to 60 cm. An illuvial accumulation of OM in the subsurface horizon was evident between the depths of 60 to 110 cm while having an iron-caused nearly continuous cementation. Besides, there was an illuvial accumulation of silicate clays with fragipan characteristics that developed a structure with a brittleness nature between 110 and 125 cm depth. All of the horizons throughout the pedon had clay content ≥ 30 %; with an effective base saturation (1 M

NH$_4$OAc, pH 7) of ≥ 80 %; soil organic carbon of ≥ 1 % in the fine earth fraction to a depth of 50 cm from the mineral soil surface; and an exchangeable Ca to Mg ratio of below 1 in the major part within 100 cm of the soil surface. Thus, all the diagnostic criteria qualified the soils for Hypereutric Akroskeletic Plinthofractic Cambisols (Pantoclayic, Escalic, Humic, Magnesic) abbreviated as CM-px.kk.je-cle.ec.hu.mg.

Although there was no evidence of advanced pedogenesis, appreciable signs of incipient weathering of primary minerals upon free internal and external drainages indicated the soils of SMU 32 (the toe-slope pedon), 14, 21, and 31 were at an early stage of soil formation. For instance, hydrolysis of iron-containing minerals (biotite, olivine, pyroxenes, and amphiboles) in a weakly acid environment produces ferrous iron that is oxidized to ferric oxides and hydroxides (goethite and haematite). This 'free iron' coated sand and silt particles and cemented clay, silt and sand into aggregates of yellowish-brown to reddish. There was some evidence of leaching of basic cations but no clear migration of Fe, organic matter, or clay was noted. The oxidative weathering process was not limited to the cambic horizon; rather, it also occurred in the surface A-horizon as the accumulated soil OM obscures its appearance. Explicitly, all horizons of the toe-slope pedon to a depth of 100 cm contained a pea-like yellowish, reddish, and/or blackish concretions or nodules of ≥ 2 mm diameter that were strongly cemented to indurated with Fe/Mn (hydr-) oxides in their ≥ 40 % volume. Moreover, all horizons throughout the pedon had clay contents higher than 30 % with an effective base saturation (1 M NH$_4$OAc, pH 7) of ≥ 80 % and soil organic carbon of ≥ 1.4 % in the fine earth fraction to a depth of 100 cm from the mineral soil surface. Consequently, the soils are grouped as Hypereutric Pisoplinthic Cambisols (Pantoclayic, Profundihumic) abbreviated as CM-px.je-cle.dh.

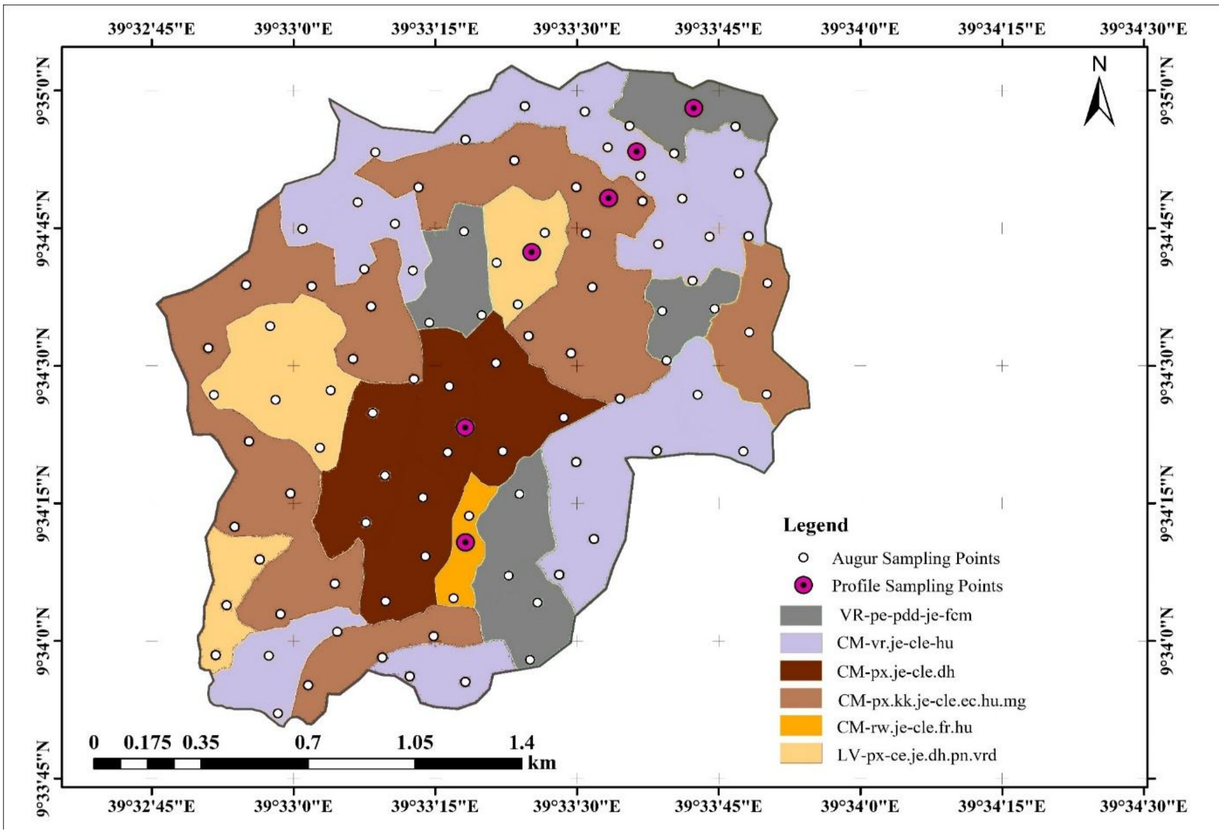

Figure 4. Soil map of the study area

The soils in the bottom depression pedon (SMU 30) had a layer ≥ 25 cm thick starting ≤ 75 cm from the mineral soil surface characterized by stagnic properties in which the area of reductimorphic colors plus the area of oximorphic colors are ≥ 25 % of the total layer area, and no reducing conditions. The segregation of ≥ 5 % reddish to blackish Fe and Mn oxides with a diameter of ≥ 2 mm in the subsurface horizon at a depth of 65 to 110 cm has taken place to such an extent that large mottles or discrete concretions or nodules were formed and the matrix between mottles, concretions or nodules were largely depleted of Fe and Mn. They did not have enhanced Fe and Mn contents, but Fe and Mn were concentrated in mottles or concretions, or nodules. Such segregation led to the poor aggregation of the soil particles in Fe- and Mn-depleted zones and compaction of the horizon. All horizons throughout the pedon had clay contents higher than 30 % with an effective base saturation (1 M NH_4OAc, pH 7) of ≥ 80 %; and soil organic carbon of ≥ 1 % in the fine earth fraction to a depth of 50 cm from the mineral soil surface. Hence, these soils are considered as Hypereutric Relictistagnic Cambisols (Pantoclayic, Ferric, Humic) abbreviated as CM-rw.je-cle.fr.hu.

The soils of SMU 17 (Foot-slope pedon), 22 and 25 had parent materials from colluvial deposition of different unconsolidated materials whereby higher clay content was noticed in the subsurface horizon that directly overlying coarser textured subsoil as a result of pedogenetic processes (especially clay migration) within the upper 100 cm. This condition made them satisfy the Argic principal qualifier listed under Luvisols. Principally, the foot-slope pedon was characterized by a pedogenetic clay differentiation with a lower clay content in the topsoil than in the subsoil without marked leaching of basic cations or advanced weathering of high-activity clays. The argic subsurface horizon existed directly below a coarser textured horizon, not separated by a lithic discontinuity between 70 and 95 cm deep at which its clay content did not decrease by ≥ 20 % (relative) from its maximum within 150 cm of the soil surface. The ratio of clay in the argic horizon to that of the coarser textured horizon was 1.47. In addition, more than 40 % of the subsurface soil volume was occupied by strongly cemented to indurated reddish and blackish pea-like concretions of Fe/Mn (hydr-) oxides with a diameter of ≥ 2 mm. The amount of OC in the fine earth fraction as a weighted average to a depth of 100 cm from the mineral soil surface was ≥ 1.4 % with an effective base saturation (1 M NH_4OAc, pH 7) of ≥ 80 % in layers between 20 and 100 cm from the mineral soil surface. The pedon had a texture class of clay, in a layer ≥ 30 cm thick within 100 cm of the mineral soil surface while the depth beyond a meter was attained by shiny-faced (slickensides) structures. Thus, these soils are grouped as Pisoplinthic Luvisols (Clayic, Hypereutric, Profundihumic, Profondic, Bathyvertic) abbreviated as LV-px-ce.je.dh.pn.vrd.

CONCLUSIONS

This study revealed that the nature and distribution of diversified soil types along the toposequence of the Qenberenaweti sub-watershed were influenced by the degree of variations in typical topographic positions and key slope features (steepness, aspect, and form). Because these pedogenesis factors directly affect the erosion-deposition and eluviation-illuviation of soil materials via controlling the action of water moving laterally across the surface and percolating vertically into the subsoils, respectively. Generally, the absence of inclusive evidence on the formation, development, and distribution of soils at a site-specific physiographic condition is often a constraint to the improvement of agriculture. Thus, the outputs of such detailed soil characterization, classification, and mapping work would give a vital clue for proper planning, management, and utilization of the soil resources at local topographic variability level. However, further research should be done to ensure sustainable agricultural production in the study area.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest.

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APPENDIXES

Appendix Table 1. On-field topographic, physical and morphological properties of identified soil map units

SMU Id.	Slope (%)	Soil Depth (cm)	Soil Color (Munsell Code)		Surface Soil Texture (Feel)	Soil Consistency			
			Dry	Moist		Dry	Moist	Plasticity	Stickiness
SMU 01	15-30	50-100	Dark yellowish brown (10YR 3/6)	Very dark brown (7.5 YR 2.5/3)	Clay loam	SHA	VFR	SPL	SST
SMU 02	5-10	100-120	Very dark grayish brown (10YR 3/2)	Very dark gray (7.5 YR 3/1)	Clay	HA	FR	VPL	VST
SMU 03	15-30	50-100	Dark yellowish brown (10YR 3/4)	Very dark brown (7.5 YR 2.5/2)	Clay loam	SHA	VFR	PL	ST
SMU 04	5-10	>120	Dark brown (10YR 3/3)	Very dark brown (7.5 YR 2.5/2)	Clay loam	SHA	FR	PL	ST
SMU 05	10-15	100-120	Dark brown (10YR 3/3)	Very dark brown (7.5 YR 2.5/3)	Clay loam	SHA	VFR	VPL	ST
SMU 06	0-2	>120	Very dark grayish brown (10YR 3/2)	Very dark gray (7.5 YR 3/1)	Clay	VHA	VFR	PL	VST
SMU 07	2-5	>120	Dark yellowish brown (10YR 4/4)	Dark brown (7.5 YR 3/2)	Clay	SHA	VFR	PL	ST
SMU 08	10-15	100-120	Dark brown (10YR 3/3)	Very dark brown (7.5 YR 2.5/2)	Clay	SHA	FR	PL	ST
SMU 09	10-15	100-120	Dark yellowish brown (10YR 3/6)	Dark brown (7.5 YR 3/2)	Clay	HA	FR	VPL	VST
SMU 10	15-30	50-100	Dark yellowish brown (10YR 3/6)	Very dark brown (7.5 YR 2.5/2)	Clay loam	HA	FR	PL	ST
SMU 11	10-15	>120	Dark brown (10YR 3/3)	Very dark gray (7.5 YR 3/1)	Clay	VHA	FI	SPL	SST
SMU 12	15-30	100-120	Very dark grayish brown (10YR 3/2)	Very dark gray (7.5 YR 3/1)	Clay	VHA	FI	VPL	VST
SMU 13	15-30	100-120	Very dark brown (10YR 2/2)	Very dark brown (7.5 YR 2.5/2)	Clay	VHA	FR	VPL	VST
SMU 14	10-15	100-120	Dark yellowish brown (10YR 4/4)	Very dark brown (7.5 YR 2.5/2)	Clay loam	HA	FR	VPL	VST
SMU 15	15-30	50-100	Dark yellowish brown (10YR 3/4)	Very dark brown (7.5 YR 2.5/3)	Clay loam	HA	FR	PL	ST
SMU 16	15-30	100-120	Dark yellowish brown (10YR 3/4)	Very dark brown (7.5 YR 2.5/2)	Clay	SHA	VFR	PL	ST
SMU 17	10-15	100-120	Dark yellowish brown (10YR 4/4)	Dark brown (7.5 YR 3/3)	Clay loam	SHA	VFR	PL	ST
SMU 18	5-10	100-120	Dark yellowish brown (10YR 3/4)	Very dark brown (7.5 YR 2.5/3)	Clay	VHA	FI	VPL	VST
SMU 19	10-15	>120	Dark yellowish brown (10YR 3/4)	Dark brown (7.5 YR 3/2)	Clay	HA	FR	VPL	VST
SMU 20	15-30	50-100	Dark yellowish brown (10YR 3/6)	Very dark brown (7.5 YR 2.5/2)	Clay loam	SHA	VFR	SPL	SST
SMU 21	5-10	>120	Dark brown (10YR 3/3)	Dark brown (7.5 YR 3/2)	Clay loam	SHA	VFR	PL	ST
SMU 22	10-15	100-120	Dark brown (10YR 3/3)	Very dark brown (7.5 YR 2.5/2)	Clay loam	SHA	FR	PL	ST
SMU 23	15-30	50-100	Dark yellowish brown (10YR 4/4)	Dark brown (7.5 YR 3/2)	Clay loam	SHA	FR	PL	ST
SMU 24	15-30	50-100	Dark yellowish brown (10YR 4/4)	Dark brown (7.5 YR 3/2)	Clay loam	SHA	FR	PL	ST
SMU 25	10-15	100-120	Dark brown (10YR 3/3)	Dark brown (7.5 YR 3/3)	Clay loam	SHA	VFR	SPL	SST
SMU 26	5-10	100-120	Very dark grayish brown (10YR 3/2)	Very dark gray (7.5 YR 3/1)	Clay	HA	VFR	VPL	VST
SMU 27	15-30	50-100	Dark yellowish brown (10YR 3/4)	Dark brown (7.5 YR 3/2)	Clay loam	SHA	FR	PL	ST
SMU 28	5-10	>120	Dark yellowish brown (10YR 4/4)	Very dark brown (7.5 YR 2.5/2)	Clay loam	SHA	VFR	SPL	SST
SMU 29	5-10	100-120	Very dark grayish brown (10YR 3/2)	Very dark gray (7.5 YR 3/1)	Clay	VHA	FI	VPL	VST
SMU 30	2-5	>120	Dark yellowish brown (10YR 3/4)	Dark brown (7.5 YR 3/3)	Clay	HA	FR	VPL	ST
SMU 31	5-10	>120	Dark yellowish brown (10YR 4/4)	Very dark brown (7.5 YR 2.5/2)	Clay	SHA	VFR	PL	ST
SMU 32	5-10	>120	Dark yellowish brown (10YR 3/4)	Very dark brown (7.5 YR 2.5/3)	Clay	SHA	VFR	PL	ST

Appendix table 2. Correlation matrix for linear relationships between soil parameters

	Sand	Silt	Clay	pH	EC	OC	TN	Av.P	Ex. Na	Ex. K	Ex. Ca	Ex. Mg	CEC	Av. Fe	Av. Mn	Av. Cu	Av. Zn
Sand	1.00																
Silt	0.31	1.00															
Clay	-0.82***	-0.80***	1.00														
pH	-0.53**	-0.46**	0.61***	1.00													
EC	-0.18	-0.48**	0.40*	0.04	1.00												
OC	0.37*	0.69***	-0.65***	-0.45**	-0.52**	1.00											
TN	0.29	0.66***	-0.59***	-0.42*	-0.62***	0.93***	1.00										
Av.P	0.28	0.55**	-0.51**	-0.42*	-0.29	0.42*	0.50**	1.00									
Ex. Na	-0.55**	-0.42*	0.60***	0.71***	0.49**	-0.66***	-0.70***	-0.46**	1.00								
Ex. K	-0.40*	-0.42*	0.51**	0.39*	0.22	-0.32	-0.22	-0.04	0.34	1.00							
Ex. Ca	-0.48**	-0.15	0.39*	0.39*	-0.06	-0.16	-0.14	-0.25	0.40*	0.28	1.00						
Ex. Mg	0.22	-0.06	-0.10	-0.05	0.22	0.06	-0.05	-0.11	-0.11	-0.33	-0.70***	1.00					
CEC	-0.36*	-0.39*	0.46**	0.48**	0.21	-0.21	-0.30	-0.53**	0.39*	0.04	0.31	0.44*	1.00				
Av. Fe	0.61***	0.65***	-0.78***	-0.69***	-0.34	0.64***	0.67***	0.54**	-0.65***	-0.54**	-0.51**	0.16	-0.52**	1.00			
Av. Mn	0.61***	0.54**	-0.71***	-0.50**	-0.37*	0.65***	0.57***	0.44***	-0.60***	-0.57***	-0.44*	0.24	-0.30	0.70***	1.00		
Av. Cu	0.44*	0.52**	-0.59***	-0.34	-0.28	0.66***	0.64***	0.39	-0.53**	-0.38*	-0.42*	0.24	-0.31	0.71***	0.52**	1.00	
Av. Zn	-0.12	0.05	0.04	-0.08	-0.18	0.08	0.06	-0.20	-0.09	-0.19	0.26	-0.08	0.16	-0.01	0.11	-0.25	1.00

*** Very highly significant ($P \leq 0.001$), ** Highly significant ($P \leq 0.01$), * Significant ($P \leq 0.05$)

Note: The pair(s) of variables with positive correlation coefficients and P values below 0.05 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.05, one variable tends to decrease while the other increases. For pairs with P values greater than 0.05, there is no significant relationship between the two variables.

Original Research Article||

Evaluation of Nutritive Values of Cactus (Oputinia ficus-indica L.) Cultivars and other Browse Species in Eastern Tigray, Ethiopia

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Abstract

Seasonal feed shortage is one of the major constraints for livestock production in Ethiopia. This study evaluated the nutritive value of five cactus cultivars (Dekik, Korem, Lematse, Tsaeda, and Keyh) and other browse species (Acacia saligna, Eculea schimperi, Olea europea, Carisa edulis and Dodonaea viscosa) in Eastern Tigray, Ethiopia for their potential to address the constraint. These plants were chosen for their abundance and utilization as animal feed by local community. The plants were characterized in terms of chemical composition and nutritive values and compared by seasons. The cactus cultivars and browse species differed significantly in chemical composition and nutritive values. Among the browse species, D. viscosa had the highest crude protein (CP) content (17.73%) during the wet season and O. europea and C. edulis had the lowest. Eculea schimperi had the lowest in vitro dry matter digestibility (IVDMD) (44.23%) during the wet season and D. viscosa had the highest value with 70.47%. This plant also showed higher dry matter digestibility (DMD) (80.97%) and relative feed value (309.27) compared to the other browse species. Among cactus cultivars, the lowest CP content was recorded in Korem and Dekik in the dry season (7.8%), while the highest was recorded for Lematse in wet season (11.17%). The highest IVDMD was recorded in Keyh during the wet season (70.59%) while the lowest was in Tsaeda and Dekik in dry season (61%). In this study plant samples harvested in wet season showed higher CP, IVDMD, relative feed value and energy content than those samples harvested during the dry season. Plants harvested in the dry season showed higher fiber contents. The finding signaled that the cactus cultivars Lematse and Keyh and the browse species A. saligna and D. viscosa can be promoted as valuable feed resources for ruminants in the stud area. However, feeding trials are needed to affirm the results of this study further.

Key words: Acacia saligna, Crude Protein, Dodonaea viscosa, Lematse, nutritive value

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INTRODUCTION

Mixed crop-livestock production system in which livestock play a key role in the national economy and rural livelihoods predominate in Ethiopian rain-fed agriculture (FAO, 2018; Mekuria and Mekonnen, 2018). Livestock production in Ethiopia is however, constrained by inadequate supply of quality animal feeds (Balehegn et al., 2020). The problem is even more severe in areas, where erratic and unreliable rainfall results in seasonal fluctuations in feed supply.

Multipurpose browse species, either native or introduced, or both offer considerable potential for use in mixed crop-livestock systems in dry areas to alleviate and complement the low quality forages from communal grazing lands and crop residues in Ethiopia (Bezabih et al., 2014; Sisay et al., 2017). For a large part of the dry season the browse species could maintain higher CP levels that could partly help solve the shortage of energy and protein during the dry season and supplement low quality forages grazed by ruminant livestock (Sisay et al., 2017; Feyisa et al., 2022). Browse species are useful sources of animal feeds, as these plants remain green during the dry season and also provide vegetation with better nutritive value than other annual grasses and herbaceous species that declined in abundance (Aregawi et al., 2008; Mangara, 2018; Belachew et al., 2020). Multipurpose browse species can also complement crop production by maintaining soil fertility by fixing nitrogen or by using it as mulch (Murmu, 2018). Hence, the use of these forage plants can be potentially efficient way to improve sustainable feeding in smallholder farming systems. It would thus be justifiable to look for locally available alternative feed resources that are easily accessible to smallholder farming communities.

The cactus plant is grown abundantly in many dry land areas of northern Ethiopia and can be used to address livestock feed shortages. It can maintain its greenness and nutritive value through the dry season. This plant can grow in areas receiving as little as 200 mm of rainfall (Georgis et al., 2010). Its importance increases as it has been introduced in the marginal lands of Ethiopia to combat feed and food insecurity, support household income, and prevent land degradation (Tegegne, 2007; Georgis et al., 2010 ; Belay et al., 2011; Ziadat & Bayu, 2015; Meaza et al., 2024). Cactus is widely grown in dry land areas because it can tolerate water-limited conditions, high temperatures, and poor soils (Sipango et al., 2022). In Tigray region alone, wild cactus covered about 32,000 ha of land (Belay et al., 2011). It is also increasingly cultivated by smallholder farmers. and is reported to be important livestock feeds, especially in moisture deficient or drought prone areas like in Tigray in Ethiopia (Tegegne, 2007; Georgis et al., 2010; Gebretsadik et al., 2013;; Lijalem and Kebede, 2024). Cactus remains green throughout the year, rich in water and water soluble carbohydrates and therefore it is suitable as a supplement to crop residue when other feeds are scarce. However, it is low to moderate in CP content (Tegegne, 2007; Nipane et al., 2021) suggesting the need to search for alternative fodder plants that can be combined with this species.

There are several indigenous browse species that are untapped and can help to ease some of the problems associated with low feed quality and partly address the major problems of long-term sustainability of crop-livestock systems in Ethiopia. These feed resources in Tigray region, for instance, are widely used by the farmers in conjunction with cactus and crop residues (Georgis et al., 2010; Tegegne, 2007). Although a number of works—on the nutritional values (e.g., in terms of their digestibility and chemical composition) of browse species including cactus are available in different parts of Ethiopia (e.g. Fentahun et al., 2020; Gebreegziabher & Tsegay, 2015; Hassen et al., 2017; Bazie et al., 2019; Teklu et al., 2023), such studies are still scarce in Tigray region, northern Ethiopia. Such studies are essential to identify—from a pool of observed species—a few promising species (that is those that are consistently better performing in at least two seasons in the same year) in the area where they are identified (in the present study case, the eastern Tigray region). These studies are also vital for predicting the production performance of the grazing/browsing animals in the study area, identifying limiting nutrients for target production, and for prioritizing individual species or pasturelands for management or development (Bezabih et al., 2014). Hence, the present study was conducted to evaluate (and compare over seasons) the nutritive value of five cactus cultivars (Lematse, Tsaeda, Dekik, Korem, and Keyh) and selected tree/shrub species (Eculea schimperi, Dodoneae viscosa, Olea europea, Acacia saligna, and Carisa edulis) identified from the eastern Tigray zone, northern Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

This study was carried out in the Eastern zone of Tigray region located in northern Ethiopia. It is located between 13°33′ to 14°40′ N and 39°11′ to 39°59′ E. The total area of the zone is 561,000 ha, which is divided in to seven districts: Erob, Hawzen, Wukro, Atsbi-Womberta, Ganta-Afeshum, Gulo-Mekeda, and Saesie-Tsaeda-Emba. The altitude ranges from 1500 to 3280 m above sea level. The study zone has three traditional agro-ecological zones: (i) highland, with areas over 2,300 m above sea level; (ii) midland, between 1,500 and 2,300 m above sea level; and (iii) lowland, with areas less than 1,500 m above sea level (Meles et al., 1997). Most of the districts are categorized as Highland or Dry Dega, followed by Midland or Dry Weinadega. The area has a semi-arid climate and receives bimodal rainfall: the main rainy season (June–September), locally known as Kiremt and a small rainy season (February–May), locally known as Belg The rainfall is highly variable due to the complex influences of topography (Meles et al. 1997). The mean annual rainfall ranges from 520 to 680 mm, and the mean annual temperature varies between 16 and 20 °C (Kahsay et al., 2019).

Sample Collection

Samples were collected from Ganta-Afeshum, Saesie-Tsaeda Emba and Atsbi-Womberta districts of the study zone. These districts were selected purposively based on the abundance and utilization of the below-mentioned browse species and cactus plants. These districts are relatively homogenous in terms of agroecology, farming systems and natural vegetation though the former two districts are relatively rich in cactus plants. Five commonly grown, multipurpose cactus cultivars namely Dekik, Keyh, Korem, Lematse, and Tsaeda and five tree/shrub species (*A. saligna, C. edulis, O.europea, E.schimperi, and D.viscosa/angustifolia*) were selected based on the abundance of the species and their broader utilization by the farmers in the study area (Gebretsadik et al., 2013 ; Mengistu, 2017; Atsbha & Wayu, 2020). Species selection was also based on extension agents' opinion and farmers' knowledge of the tree forages preferred by animals. Samples of cactus cultivars were collected from two randomly selected (one each from Ganta-Afeshum (i.e. Kokob Tsibah) and Saesie-Tsaeda Emba (i.e. Emba-Esmena) kebeles, while samples of the tree/shrub species were collected from a randomly selected kebele of Kelisha from the Atsbi-Womberta district where the above-listed trees/shrubs are dominantly found. For trees/shrubs, sampling was conducted in an enclosed land. Samples were harvested from cladodes or young leaves of cactus and the leaf part of the tree/shrub species during the wet season (August/September) and in the dry season (January/ February). The samples of tree/shrub were collected at the same time during the early growth stage (before flowering) from 5 to 10 plants in three replicates per species. The samples from cactus cultivars were harvested before they started to produce fruits from 2 to 5 plants in three replicates per cultivar. The samples were oven-dried for 72 hours at 65 ºC and reweighed to determine the DM content. The dried samples were ground separately and passed through a 1-mm sieve. The nutritive quality of plants collected from the study area during the wet and dry seasons was evaluated on the basis of chemical composition, IVDMD, dry matter intake, dry matter digestibility, and relative feed value. Samples were analyzed at the Animal Science Laboratory of Mekelle University and Holleta Agricultural Research Center, Ethiopia.

Chemical Analysis and *in vitro* Dry Matter Digestibility

The ground samples were analyzed for chemical composition on a dry matter basis. The nitrogen (N) concentration was determined based on AOAChemists (1990). Crude protein (CP) content was calculated as 6.25 x N concentration. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were determined according to Van Soest (1994). The in vitro dry matter digestibility was determined using the two-stage (Tilley & Terry, 1963) method. Rumen liquor was collected and transported to the laboratory using thermos flasks and pre-warmed to 39 ºC before the daily meal of the three cannulated Boran-Friesian steers. The steers were 40 months old, weighed 490 kg and were fed natural pasture hay (6% CP on a DM basis) ad libitum supplemented with a 22 kg concentrate mixture (20% CP on a DM basis) per day per head. The sample (0.5 g) was incubated in a test tube at 39 ºC for 48 h with 10 ml of rumen fluid and 50 ml of buffer solution. After microbial digestion, enzymatic digestion with an acid pepsin solution (i.e., 5 ml per tube) was continued for another 48 h.

Determination of Relative Feed Value (RFV) Index

Dry matter intake (DMI), digestible dry matter (DDM), and relative feed value (RFV) were estimated using the following equations:

DDM (%) = 88.9 - (0.779 * % ADF); DMI (% of BW) = 120 / % NDF (Mertens, 2002) and

RFV = (% DDM × % DMI) /1.29 (Jeranyama & Garcia, 2004)
Metabolizable energy (ME) was computed following the formula recommended in Australian Agricultural Council (1990) as:

$$ME(\text{MJ kg-1 DM}) = (0.17 * \% \text{ IVDMD}) - 2.0$$

Where, DDM is the dry matter digestibility; ADF is the acid detergent fiber (% of DM); DMI is the dry matter intake (% of BW) and RFV is the relative feed value. The forage quality grading standard assigned by the Hay Marketing Task Force of the American Forage and Grassland Council, the RFV, was assessed as roughages based on prime (>151), premium (151–125), good (124–103), fair (102–87), poor (86–75), and reject (<75) (Rohweder et al., 1978).

Data Analysis

The data on chemical compositions, IVDMD and DMI, DDM, and RFV were analyzed using factorial analysis of variance (ANOVA) using the general linear model procedure of SPSS (version 16.0). In addition, Pearson's correlation coefficient (r) was used to decide whether there was a linear relationship between IVDMD, CP, ash, NDF, ADL and ADF. The statistical model included the effects of plant species, season and their interactions. Tukey's significance difference (HSD) was used to compare means ($P < 0.05$). The significance level was set at 5%.

The following model was used for data analysis:
$Y_{ijk} = \mu + A_i + B_j + (AB)_{ijk} + e_{ijkl}$,

Where Y_{ij} = response variable, μ = overall mean, A_i = effect of plant species/cultivars, B_j = effect of season, $(AB)_{ijk}$= interaction effect of season with species/cultivar, and e_{ijkl} = random error.

RESULTS AND DISCUSSION

Chemical Composition and *in vitro* Dry Matter Digestibility of Tree/Shrub Species

The chemical composition and *in vitro* dry matter digestibility of the tree/shrub species are shown in Table 1. Among the tree/shrub species, the highest DM content was recorded in *O.europaea* in the dry (93.60%) and the wet (92.81%) seasons; followed by *C. edulis* and *D.viscosa*. in the dry and wet seasons. The lowest DM content was recorded in *E. schimperi* in the wet season (85.22%). The total ash content of the tree/shrub species ranged from 2.62% in *A. saligna* in the wet season to 9.48% in *C. edulis* in the dry season. Factors such as soil, climate, stage of maturity and season contribute to variations in the nutritive values of forages. The DM, for example, increases as the plant matures and as the dry season advances (Mueller-Harvey, 2006) in line with what we observed in the current study. The ash value of *A. saligna* was lower than the ash value 7.9%-14.1% reported by Gebremeskel et al. (2019). The ash value of *C.edulis* and *O.europea* was similar to the value 8.39% and 7.09% reported by Girma et al. (2015). But, the ash value of *C.edulis* was higher than the value 6.2% reported by Fentahun et al. (2020).The ash content of tree/shrub species reported in this study were higher than the reported data by Ali et al. (2020).

Overall, the CP ranged from 8.2 to 17.73%. *Dodonaea viscosa* had the highest CP content (17.73%) followed by *A.saligna* (15.92%) in the wet season. In dry season *A. saligna* (14.25%) followed by *D. viscosa* (12.43%) had the highest CP content and *O. europea* had the lowest CP content. As expected a wide variation in CP content was recorded in this study between the species in both seasons; the amount of CP increased from dry to wet season. The CP values reported in this study were comparable to the results of other studies (Yayneshet et al., 2009; (Girma et al., 2015; Hassen et al., 2017; Flores et al., 2020) reported values (10.3%–24.4% for wet season and 7.6%–20.2% for dry season). The CP value reported for *D.viscosa* in this study was lower than the value of 14% reported by Yisehak & Janssens (2013) but similar to the value (17.43%) reported by Ali et al. (2020). Similarly, the CP value reported for *C. edulis* and *O.europea* in this study was similar to the value reported by Ali et al.(2020). The CP value reported for *C. edulis* (8.12%) in the dry season and 10.32% in the wet season was similar to the CP values 10.8% and 8.15% reported by Girma et al. (2015). However, it was lower than the CP value 13.6% reported by Yisehak & Janssens (2013).The CP value reported for *O. europea* 12.2% in the wet season and 11.6% in the dry season was lower than the value reported by Girma et al. (2015). The lower CP content of tree/shrub species during the dry season compared to the wet season may be attributed to a higher percentage of fiber fractions (NDF,ADF, ADL), lower soil moisture content, a higher age of the plant linked to leaf maturity, and less nitrogen availability (Anele et al., 2008; Anele et al., 2009; Belachew et al., 2013; Yayneshet et al., 2009;Yu et al., 2022) and translocation of nutrients especially nitrogen from leaf to stem (Hagen-Thorn et al., 2006).

The CP content is a very important criteria for nutritional quality assessments in animal feed resources. In our study, the tree/shrub species tended to have higher CP content (range: 8–18%) which is above the recommended crude protein levels of 7% which supply the microbial requirements of nitrogenous compounds; below which ruminal fermentation of forages (digestibility) may be limited and NDF is not used adequately and feed intake decreases (Van Soest, 1994). Crude protein content of three of tree species was adequate for recommended minimum CP requirements (11-12%) for moderate level of production (ARC, 1980) and CP content of *A. saligna* and *D.viscosa* was above the recommended minimum requirement for early finishing lambs (14.5%CP) (NRC, 1985). The results showed the CP content of the tree/shrub species was adequate to sufficiently high to warrant consideration of their use as protein supplement to low quality diets except for *C. edulis* and *O.europaea* in the dry season; which showed less promising potential than the other tree/shrub species.

The fiber content of tree/shrub species in this study increases from the wet to dry season. This might be due to the low moisture content of soil, advanced maturity of plants, and low rainfall, harvesting season (Hassen et al., 2007; Camacho et al., 2010; Arigbede et al., 2012). The NDF content was lowest in *D. viscosa* in both seasons and while highest in *O. europaea* in *E. schimperi* in the dry season. The NDF content of tree/shrub species in this study ranged from 24.40% to 57.80%. The studied tree/shrub species had NDF content below 45% on dry matter basis with the exception of *E. schimperi* and can be classified as high-quality forages (Singh & Oosting, 1992). Their NDF content was below the threshold level of 60% (Meissner et al., 1991), beyond which the DM intake by the animal is negatively affected.

The ADF content was lowest in *D. viscosa* in both seasons and highest in *O. europaea* in the wet season. The ADF comprises of proteins, cellulose, and lignin, which prevents the cell wall's carbohydrates from breaking down at the rumen stage (Harper & McNeill, 2015). It is used to indicate the forage species' potential for consumption, energy availability, and diet digestibility i.e. thus, the lower the ADF content of the forage, the higher its nutritional quality and energy levels (Tambara et al., 2017). All the tree/shrub species in this study had ADF content below 40% and can thus be classified as high-quality forages (Kellems & Church, 2002).

The ADL content was lowest in *D. viscosa* in both seasons and highest in *C. edulis* in the wet season and *E.schimperi* in the wet and dry seasons. Despite wide variations between seasons, with the exception of *E. schimperi*, in both seasons in this study, tree/shrub species had lignin contents below the maximum threshold of 10%, which is expected to restrict the amount of DM consumed (Reed[1] et al., 1988). Consequently, none of the tree/shrub species in this study were likely to have an effect on the animals' DM consumption. The higher fiber (NDF, ADF and ADL) content of tree/shrub species in the dry season was due to advanced stage of maturity and lignification (Hussain & Durrani, 2009) and higher temperature which promotes the development of structural fibers in plants (Bismarck et al., 2005 ; Goudenhooft et al., 2019).

Dodonaea viscosa in the wet season had the highest *in vitro* dry matter digestibility (70.47%) compared to the other tree/shrub species. The lowest IVDMD was recorded in *E.schimperi* in dry season (44.24%). *In vitro* dry matter digestibility did not vary due to the interaction effect of season and species. However, it varied among species and between seasons. It was higher in the wet season than in the dry season and its value ranges from 44.24% to 70.47%. This coincides with the values of previous studies (Hassen et al., 2017; Fentahun et al., 2020; Ravhuhali et al., 2022) which reported (62.3%–67.8%, 64.78%, and 49.61% for the wet season) and (50.8–65.8%, 57.35%, and 44.69% for the dry season), respectively. Due to the negative correlation between feed digestibility and ADF content, tree/shrub species with high ADF content may have low digestibility (McDonald et al., 2002). There is a physical restriction on eating when IVDMD is less than 550 g/kg. Additionally, the rate of digestion and transit through the gastrointestinal system implies that intake is limited; therefore weight loss is inevitable (Dynes & Schlink, 2002).

Table 1. Chemical composition and *in vitro* dry matter digestibility (in %DM) of tree/shrub species

Season	Chemical composition						
	DM%	Ash	CP	NDF	ADF	ADL	IVDMD
Wet	89.18^{b}	6.55^{b}	13.53^{a}	39.61^{b}	18.00^{b}	9.30	58.00^{a}
Dry	90.00^{a}	7.42^{a}	10.75^{b}	41.59^{a}	19.15^{a}	8.88	53.62^{b}
SEM	0.206	0.084	0.23	0.33	0.28	0.203	0.55
P-value	0.011	<0.0001	<0.0001	<0.0001	0.009	0.304	<0.0001
Species *Season							
Wet Season							
A.saligna	88.93^{bc}	2.62^{e}	15.92^{ab}	34.38^{f}	16.92^{cd}	8.86^{c}	59.50^{bc}
C. edulis	89.76^{bc}	8.36^{b}	10.32^{e}	39.83^{de}	17.24^{d}	11.29^{b}	51.50^{cd}
O.europaea	92.81^{a}	6.47^{c}	10.56^{de}	46.28^{c}	25.6^{a}	8.66^{bc}	58.74^{bc}
E. schimperi	85.22d	8.75^{ab}	13.13^{bc}	53.16^{b}	20.08^{c}	11.94^{b}	49.79^{d}
D. viscosa	89.19^{bc}	6.57^{c}	17.73^{a}	24.40^{h}	10.17^{f}	5.74^{de}	70.47^{a}
Dry season							
A.saligna	88.30^{bc}	4.84^{d}	14.25^{b}	37.99^{e}	18.94^{c}	10.08^{bc}	56.00^{c}
C. edulis	90.44^{b}	9.48^{a}	8.2^{e}	42.01^{d}	19.94^{c}	9.68^{bc}	49.48^{d}
O. europaea	93.60^{a}	8.05^{bc}	8.12^{ef}	41.46^{d}	21.36^{bc}	6.24^{d}	55.46^{c}
E. schimperi	87.36^{c}	6.12^{c}	10.76^{d}	57.80^{a}	23.41^{b}	14.34^{a}	44.23^{e}
D. viscosa	90.33^{b}	8.6b	12.43^{cd}	28.69^{g}	12.09^{e}	4.64^{e}	62.92^{b}
SEM	0.46	0.189	0.514	0.75	0.626	0.45	0.87
P-value	0.093	<0.0001	0.017	<0.0001	<0.0001	<0.0001	0.229
Species							
A.saligna	88.62^{c}	3.73^{c}	15.08^{a}	36.18^{d}	17.97^{b}	9.47^{b}	57.75^{b}
C. edulis	90.10^{b}	8.92^{a}	9.26^{c}	40.92^{c}	18.59b	10.49^{b}	50.49^{c}
O. europaea	93.20^{a}	7.26^{b}	9.34^{c}	43.83^{b}	23.48^{a}	7.45^{c}	57.10^{b}
E. schimperi	86.29^{d}	7.43^{b}	11.94^{b}	55.48^{a}	21.74^{a}	13.14^{a}	47.01^{c}
D. viscosa	89.75^{bc}	7.58^{b}	15.08^{a}	26.54^{e}	11.13^{c}	5.19^{d}	66.69^{a}
SEM	0.326	0.134	0.36	0.53	0.44	0.32	0.87
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means with different superscripts (a, b, c, d, e. f, g, h) in the same column are significantly different (P<0.05), SEM=standard error of mean, IVDMD=Invitro dry matter digestibility, NDF=neutral detergent fiber, ADF=acid detergent fiber, ADL= acid detergent lignin, DM=dry matter

Dry Matter Intake, Digestibility and Relative Feed Values of Tree/Shrub Species

Dry matter intake, dry matter digestibility and relative feed value of tree/shrub species are shown in Table 2. The values for dry matter intake, DMDigt and relative feed value were varied due to season, species and the interaction of species and season. However, there is no significant difference in metabolizable energy of tree/shrub species due to the interaction of species and season. Overall among the tree/shrub species dry matter intake, dry matter digestibility (DMDigt) and relative feed value (RFV) were significantly (p<0.05) higher for *D. viscosa* and lowest for *E. schimperi*. The dry matter digestibility was higher in the wet season than in the dry season except in *O. europea* and its value ranges from 68.95% to 80.97% in the wet season and 70.66% to 79.48% in the dry season. This was similar to the value of 52.5% to 76.3% in the wet season and 43.1%–67.2% in the dry season reported by Ravhuhali et al., (2022) but it was higher than the value 64.75- 72.54 and 62.5-125.7

reported by Kazemi et al. (2012) and Geleti et al. (2013) respectively. Metabolizable energy of tree/shrub species was higher in wet season than in dry season and its value ranges from 7.11-7.86MJ. Metabolizable energy (ME) were significantly (p<0.05) higher for *D.viscosa* and lowest for *E. schimperi* (ranges from 5.99 to 9.3MJ/kg). This is similar to the value (8.3MJ/kg) reported by Belete et al. (2024). The relative feed value of browse species in this study was similar to the value of 100.94-246.88 reported by Kazemi et al. (2012) and Mayouf & Arbouche (2014). The studied tree/shrub species had relative feed value above the 151 value quality standard and could be classified in to quality standard of prime forage (high quality standard) except for *E. schimperi* in both seasons and *O.eurpoea* in the wet season which are classified into the quality standard premium (1) and good (2) quality forages.

Table 2. Dry Matter Intake, Digestibility and Relative Feed Values of Tree/Shrub Species

Season	Estimated parameters			
	DMI(%LW)	DMDigst (%)	RFV	ME(MJ/kg)
Wet	3.259^{a}	74.87^{a}	191.59^{a}	7.86^{a}
Dry	3.035^{b}	73.98^{b}	175.61^{b}	7.11^{b}
SEM	0.035	0.218	2.25	0.094
P-value	0.0001	0.0001	0.0001	0.0001
Species *Season				
Wet season				
A. saligna	3.49^{b}	75.71^{c}	205.32^{c}	8.11^{bc}
C. edulis	3.01^{c}	75.46^{c}	176.35^{e}	6.75^{d}
O.europea	2.59^{d}	68.95^{g}	138.84^{gh}	7.98^{b}
E. schimperi	2.25^{f}	73.25^{d}	128.18^{h}	6.46^{de}
D. viscosa	4.92^{a}	80.97^{a}	309.27^{a}	9.98^{a}
Dry season				
A. saligna	3.16^{bc}	74.14^{cd}	181.6^{d}	7.52^{c}
C. edulis	2.85^{d}	73.36^{d}	162.46^{f}	6.41^{de}
O.europea	2.89^{e}	72.25^{e}	162.17^{f}	7.42^{cd}
E.schimperi	2.07^{g}	70.66^{f}	113.78^{i}	5.51^{f}
D. viscosa	4.19^{a}	79.48^{b}	258.12^{b}	8.69^{ab}
SEM	0.078	0.488	5.03	0.211
P value	0.0001	0.0001	0.0001	0.229
Species				
A. saligna	3.33^{b}	74.93^{b}	193.46^{b}	7.81^{b}
C. edulis	2.93^{c}	74.41^{b}	169.41^{c}	6.58^{c}
O.europea	2.74^{c}	70.60^{c}	150.47^{d}	7.70^{b}
E.schimperi	2.16^{d}	71.96^{c}	120.98^{e}	5.99^{c}
D.viscosa	4.55^{a}	80.22^{a}	283.70^{a}	9.33^{a}
SEM	0.055	0.34	3.55	0.15
P-value	0.0001	0.0001	0.0001	0.0001

Means with different superscripts (a, b, c, d, e. f, g, h) in the same column are significantly different (P<0.05), SEM=standard error of mean, DMI = Dry matter intake; DDM = Digestibility of dry matter; RFV = Relative feed value.

Chemical Composition and *in vitro* Dry Matter Digestibility of Cactus Cultivars

The chemical composition and *in vitro* dry matter digestibility of cactus cultivars are shown in Table 3. Cactus cultivars' chemical composition and *in vitro* dry matter digestibility differed according to season, species, and the interaction of season and species. The DM content of Keyh in the wet season and Lematse in the dry season was significantly ($p<0.05$) higher than the other cactus cultivars. Cactus cultivars in this study ranged in dry matter content from 88.31% to 90.89%. This was comparable to the results of earlier findings (Negussie et al., 2015; Teklu et al., 2023) that reported DM content in the 89.38%–90.3% range. The DM content of Keyh, Lematse, and Tsaeda's DM was similar to the findings of Teklu et al. (2023) who reported values of 91.88%, 91.02%, and 89.35% for Keyh, Lematse, and Tsaeda, respectively.

Keyh in the dry season had significantly ($p<0.05$) higher ash content than Dekik and Lematse. The cultivars with the lowest ash content during the wet season were Korem and Tsaeda. The ash content of cactus in this study was consistent with the previous studies (Amogne et al., 2006; Bazie et al., 2019) who reported a range value of 7.22%-26%. The ash and mineral concentrations of spineless cacti can be greatly affected by variables like the moisture and mineral contents of the soil. Cacti are prone to accumulating calcium in their cladodes when they experience water scarcity and high soil Ca compound levels (Nobel, 2002). Ben Salem (2014) and Salem et al, (2010) suggested that forage's high ash content also indicates its comparatively low energy content.

In the wet season (11.17%), cultivar Lematse had the highest CP content, followed by Keyh (10.72%), Lematse (10.13%), and Dekik (10.26%) in the dry season. The CP content of cactus cultivars was higher in the wet season than in the dry season. This was similar to the findings of Amogne et al. (2006) and Hassen et al. (2017), who reported, 7.3% and 5.24% for wet season and 4.3% and 3.24% for dry season respectively. The CP content of cultivars ranged from 7.8% to 11.17%, which is above the CP minimum maintenance requirement of ruminant animals. Sanon et al. (2008) concluded that forage consumed by goats that have CP content greater than 10 g/100 of DM has the ability to increase ruminant N levels. Thus, based on CP results of the studied cultivars, to increase N in ruminant animals, Lematse in the dry and the wet seasons and Keyh and Dekik in the wet season should be used. As suggested by Misra et al.(2006) diets containing cactus cladodes should be supplemented with protein source feeds like *A.saligna* in order to satisfy production requirements of ruminant animals.

In the dry season Lematse had significantly ($p<0.05$), the highest NDF content (24.86%) followed by Korem (24.16%) then Keyh (23.72%). The NDF content of cactus is higher in the dry season than in the wet season. Consistent with this study, Hassen et al. (2017), reported a higher NDF content of cactus cladodes in the dry season than in the wet season 58.5% and 55.2%, respectively. However, Dias et al. (2023) reported a higher NDF content of cactus in the wet season (33.12%) than in the dry season (19.75%), respectively. The higher NDF content of cactus cladodes in the dry season might be due to sunlight exposure, and low moisture content and maturity stage of cactus (Retamal et al., 1987).The variation in NDF content between different studies may be due to the site of sample collection, season, age of cactus cladodes, soil fertility, and other climate-related conditions. Jafari et al. (2015) and Kholif et al. (2016), stated that an NDF content in forage feeds above the critical level of 60% decreases voluntary feed intake, feed conversion efficiency, and the retention time of feeds in the gastrointestinal tract in livestock. Based on this justification, the studied cultivars might not affect feed intake or feed conversion efficiency of animals.

Cactus cultivars' ADF content was not significantly affected by interaction of cultivar and season. Nonetheless, the ADF content of Dekik during the dry season was significantly ($p<0.05$) higher than that of the other cactus cultivars. Lematse, had the lowest ADF content (12.12%) in the wet season. The dry season's lowest ADF content, was recorded in Lematse (12.12%). Acid detergent fiber content of cultivars varied from 12.12% to 19.66% .This was similar to the values range of 15% to 25%, reported in previous studies (Batista et al., 2009; Negussie et al., 2015; Teklu et al., 2023). The ADF content of cactus cladodes was higher in the dry season than in the wet season. This coincides with the findings of Hassen et al. (2017) and Dias et al. (2023), which reported higher ADF content in the dry season (49.5% and 14.8%) than in the wet season (43.3% and 12.46%), respectively.

The acid detergent lignin content of cactus cladodes ranged from 2.45% to 4.26%. This is similar to the value of 3.06% reported by Amogne et al. (2006). The acid detergent lignin content of cactus cladodes in this study was higher in dry season (3.81%) than in the wet season (3.54%). This was similar to the finding of Hassen et al. (2017), who reported higher ADL contents in the dry season (17.2%) than in the wet season (15.4%).

The *in vitro* dry matter digestibility (IVDMD) of cactus was significantly higher in Keyh in the wet season then followed by Lematse and Korem in the wet season. The *in vitro* dry matter digestibility (IVDMD) of cactus in this study was within the range of 57-78.61% reported by previous studies (Hassen et al., 2017; Teklu et al., 2023; Bazie et al., 2019; Silva et al., 2022). The variation in digestibility might be due to the age of cactus cladodes, the fertility of the soil and its management, and the climatic conditions of the area. Cactus cultivars have a greater IVDMD during the wet season than in the dry season. The results of Hassen et al.(2017), who reported 50.8% in the dry season and 63.2% in the wet season, are consistent with the results of this study. Cactus cladodes' nutritional quality varies due to plant type (variety), cladode age, sampling season, soil type, climate, growth stage and portion of the plant (Retamal et al., 1987; Mondragón-Jacobo & Pérez-González, 2001; Scalisi et al., 2016; Mounir et al., 2020; Kumar et al., 2021). Based on the Standard assigned by Hay Market Task Force of American Forage and Grassland Council all cactus cultivars are classified under quality standard 4 (based on NDF and ADF value) and standard quality prime(1)(based on relative feed value)

Table 3. Chemical Composition in % DM and *in vitro* Dry Matter Digestibility of Cactus cladodes Cultivars

Season	Chemical Composition						
	DM%	Ash	CP	NDF	ADF	ADL	IVDMD
Wet season	89.05^{b}	17.02^{b}	10.077^{a}	19.72^{b}	15.36^{b}	3.52^{b}	67.83^{a}
Dry season	89.26^{a}	19.60^{a}	8.61^{b}	23.10^{a}	17.34^{a}	3.80^{a}	62.99^{b}
SEM	0.05	0.096	0.055	0.044	0.118	0.049	0.119
P-value	0.012	<0.0001	<0.0001	<0.001	<0.0001	<0.0001	<0.0001
Cultivar*Season							
Wet season							
Dekik	88.54^{cd}	18.22^{c}	10.26^{b}	18.44^{f}	17.63^{b}	3.09^{c}	65.78^{c}
Keyh	90.89^{a}	17.16^{d}	10.72^{ab}	21.30^{d}	14.97^{d}	3.60^{b}	70.59^{a}
Korem	89.27^{bc}	16.41^{e}	9.38^{c}	21.70^{d}	15.88^{c}	3.14^{c}	67.84^{b}
Lematse	89.057^{c}	17.10^{d}	11.17^{a}	19.06^{e}	12.12^{f}	2.45^{d}	68.76^{b}
Tsaeda	88.31^{d}	16.18^{e}	8.84d	18.09^{g}	16.18^{c}	3.72^{b}	66.20^{c}
Dry season							
Dekik	88.87^{c}	20.13^{b}	7.87^{e}	21.67^{d}	19.66^{a}	4.26^{a}	61.61^{e}
Keyh	89.54^{b}	21.43^{a}	9.17^{c}	23.72^{c}	16.83^{bc}	4.19^{a}	63.20^{d}
Korem	89.75^{b}	17.40^{c}	7.8^{e}	24.16^{b}	18.24^{b}	3.52^{b}	63.64^{d}
Lematse	89.78^{a}	20.0^{b}	10.13^{b}	24.86^{a}	14.11^{e}	3.63^{b}	65.19^{c}
Tsaeda	88.35^{d}	19.05^{c}	8.06^{e}	21.07^{d}	17.84^{b}	4.137^{a}	61.32^{e}
SEM	0.119	0.215	0.122	0.099	0.26	0.07	0.26
P-value	<0.0001	0.0001	<0.0001	<0.0001	0.76	<0.0001	<0.0001
Cultivar							
Dekik	88.70^{c}	19.18^{ab}	9.06^{c}	20.05^{c}	13.11^{d}	3.82^{b}	63.70^{c}
Keyh	89.81^{a}	19.29^{a}	9.94^{b}	22.51^{b}	15.90^{c}	4.04^{a}	66.90^{a}
Korem	89.51^{ab}	16.91^{d}	8.59^{d}	22.93^{a}	17.01^{b}	3.48^{c}	65.74^{b}
Lematse	89.42^{b}	18.55^{b}	10.65^{a}	21.96^{d}	17.05^{b}	3.04^{d}	66.97^{a}
Tsaeda	88.33^{d}	17.61^{c}	8.45^{d}	19.58^{e}	18.64^{a}	3.92^{ab}	63.76^{c}
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SEM	0.08	0.15	0.08	0.07	0.18	0.05	0.19

Means with different superscripts (a, b, c, d, e. f, g, h) in the same column are significantly different (P<0.05), SEM=standard error of mean, IVDMD=Invitro dry matter digestibility, NDF=neutral detergent fiber, ADF=acid detergent fiber, ADL= acid detergent lignin, DM=dry matter

Dry Matter Intake, Digestibility and Relative Feed Values of Cactus Cultivars

Dry matter intake, dry matter digestibility and relative feed value of cactus cultivars are shown in Table 4. Dry matter intake and relative feed value of cactus cultivars varied due to season, cultivar and interaction of season and cultivar. But, there was no interaction effect of season and cultivar on dry matter digestibility of cactus cultivars. Dry matter intake and relative feed value were significantly (p<0.05) higher for cultivar Tsaeda in the wet season than the rest of the cultivars. Dry matter digestibility of Lematse (78.68%) was significantly (p<0.05) higher than the other cultivars and followed by Keyh (76.52%). Metabolizable energy of cactus cultivars was significantly higher in Keyh in the wet season than in the other cactus cultivars. The lowest metabolized energy was recorded in Tsaeda and Dekik in the dry season. The relative feed value for all cultivars was higher than the 151 value standard quality and classified as prime standard quality (high quality) forages.

Table 4. Dry Matter Intake, Digestibility and Relative Feed Values of Cactus Cultivars

Season	Parameters			
	DMI	DMDigst	RFV	ME(MJ/kg)
Wet season	6.119[a]	76.93[a]	364.88[a]	9.53[a]
Dry season	5.216[b]	75.39[b]	304.60[b]	8.71[b]
SEM	0.11	0.092	0.81	0.02
p-value	0.0001	0.0001	0.0001	0.0001
Species *Season				
Wet season				
Dekik	6.50[b]	75.16[c]	379.20c	9.18[e]
Keyh	5.63[d]	77.23[b]	337.31[d]	10.00[a]
Korem	5.53[e]	76.52[c]	328.0[e]	9.53[c]
Lematse	6.29[c]	79.45[a]	387.69[b]	9.68[bc]
Tsaeda	6.63[a]	76.29[c]	392.19[a]	9.25[d]
Dry season				
Dekik	5.53[e]	73.15[e]	315.82[f]	8.47[h]
Keyh	5.05[f]	75.78[c]	297.16[g]	8.74[f]
Korem	4.96[g]	74.68[d]	287.56[h]	8.81[f]
Lematse	4.82[h]	77.9[b]	291.43[h]	9.08[e]
Tsaeda	5.69[d]	74.99[d]	331.06[d]	8.42[h]
SEM	0.025	0.206	1.82	0.045
P-value	0.0001	0.76	0.0001	0.0001
Cultivar				
Dekik	6.022[b]	74.37[d]	347.51[b]	8.82[c]
Keyh	5.346[d]	76.51[b]	317.23[d]	9.37[a]
Korem	5.248[e]	75.60[c]	307.78[e]	9.17[b]
Lematse	5.56[c]	78.68[a]	339.56[c]	9.38[a]
Tsaeda	6.16[a]	75.64[c]	361.62[a]	8.84[c]
SEM	0.18	0.145	1.82	0.032
P-value	0.0001	0.0001	0.0001	0.0001

Means with different superscripts (a, b, c, d, e. f, g, h) in the same column are significantly different (P<0.05), SEM=standard error of mean, DMI = Dry matter intake; DDM = Digestibility of dry matter; RFV = Relative feed value.

Relationship between Chemical Components and *in vitro* Dry Matter Digestibility of Cactus Cultivars and Tree/Shrub Species

The relationship of chemical components and *in vitro* dry matter digestibility in cactus cultivars and tree/shrub species are shown in Tables 5 and 6, respectively. The CP content and IVDMD of the studied plants (among cultivars and species) were positively correlated. However, their CP content and IVDMD were negatively correlated with the fiber content (NDF, ADF and ADL). This coincides with the findings of Melaku et al. (2010); Mokoboki et al. (2019); Teklu et al. (2023); Mahyuddin (2008) who reported *in vitro* dry matter digestibility was positively correlated with crude protein and negatively correlated with fiber content. The CP content of tree/shrub species was negatively correlated with ash content of tree/shrub species. In line with this finding of Oko et al. (2016), the reported crude protein content was negatively correlated with ash (r = -0.680; p<0.01) and ADF (r= -0.497; p<0.05).

Table.5. Correlation Coefficient(r) of the Relationship between Chemical Components and IVDMD of Cactus Cultivars

	DM	Ash	CP	NDF	ADF	ADL	IVDMD
DM							
ASH	0.11						
CP	0.27	-0.225					
NDF	0.69***	0.53**	-0.27				
ADF	-0.26	-0.29	-0.81***	0.12			
ADL	-0.25	0.25	-0.12***	-0.12	0.49**		
IVDMD	0.35	-0.65***	0.80***	-0.33	-0.70***	-0.41*	

Table.6. Correlation Coefficient(r) of the Relationship between Chemical Components and IVDMD of Tree/Shrub Species

	DM	Ash	CP	NDF	ADF	ADL	IVDMD
DM	1						
ASH	0.11						
CP	-0.47**	-0.57***					
NDF	-0.27	0.14	-0.50**				
ADF	0.138	-0.022	-0.59***	0.83***			
ADL	-0.56**	-0.078	-0.18	0.79***	0.55***		
IVDMD	0.27	-0.24	0.61***	-0.84***	-0.66***	0.79***	1

Notice: astrix in superscripts of the numbers indicates that significance of the correlated parameters: (*level of significance: p<0.05,**level of significance: p<0.01, ***level of significance: p<0.001).

CONCLUSIONS

In conclusion, all tree/shrub species have CP level above the maintenance requirement for ruminant animals, especially A. saligna and D. viscosa have good potential as livestock feed and particularly as protein supplement for low quality roughages during the dry season. Based on relative feed value and fiber contents, they are also categorized as high quality forages. Cactus cultivars are better in metabolizable energy when compared to tree/shrub species. With the exception of some tree /shrub species they were also shown to have potential in terms of their IVDMD and energy contents. However, these results need to be further confirmed using animal feeding trial experiments to examine whether the potential could be translated into animal performance. Further research is also needed on mineral and ant- nutritional contents of the studied browse species.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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Original Research Article||

Physico-chemical Characterization of Domestic Sludge of Hawassa Industry Park and Evaluation of its Potential Use as Fertilizer

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Abstract

Using domestic sewage sludge on cultivated soils may increase agricultural yield in developing countries; nevertheless, the environmental damages must be properly examined and addressed before application. This research was undertaken to determine the physical and chemical characteristics of domestic sludge from Hawassa Industrial Park in Ethiopia and assess its potential applicability as organic fertilizer for crop production and hence to reduce environmental problems related to their disposal. For this purpose, five domestic sewage sludge samples were collected over five consecutive days in a week and the samples were then analyzed at the College of Agriculture soil laboratory of Hawassa University for physical and chemical properties. Descriptive statistics were conducted to describe the physico-chemical properties of the domestic sewage sludge. The results revealed that organic carbon, total nitrogen, and available phosphorus contents were higher in all domestic sludge samples than conventional organic fertilizers. The bulk density of the sludge samples was low and the water holding capacities were high. These results indicated that the domestic sludge could improve the soil's physical and chemical properties. The analyses also revealed that the sludge is slightly alkaline (pH>7.4) and with low electrical conductivity (EC, 2.06 mS/cm). The analyses of concentrations of heavy metals (Zn, Cu, Cd, Pb, Ni, and Cr) showed that concentrations in the domestic sewage sludge are below the Ethiopian standard and FAO limits. In general, the majority of the physical and chemical properties revealed that the sewage sludge is potentially suitable for use as a fertilizer. However, further research should be conducted on the effect of the sewage sludge on crop growth. Also, the biological characteristics of sludge and the content of polychlorinated byphenyls (PCB) should be studied for a solid recommendation.

Key words: brewery dried grain, egg mass, egg production, egg quality, egg weight, feed conversion ratio

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INTRODUCTION

Domestic sludge, commonly referred to as sewage sludge, is a processed organic residue produced by residential wastewater treatment facilities. The byproduct produced after sewage treatment is denoted as bio-solid or sewage sludge (Jatav et al., 2021). Currently, industrial waste materials are rising in volume and might potentially be a source of organic materials for soils (Moreno-Barriga et al., 2017). Sewage sludge has been used in developed nations for horticulture and agriculture to increase soil fertility since it contains different quantities of plant nutrients and organic matter (Jamil et al., 2006; Rodríguez-morgado et al., 2015).

Domestic sludge could be potentially used as fertilizer to enrich agricultural soils and might replace/supplement synthetic fertilizers since it could contain high levels of nitrogen and phosphorus (Iticescu et al., 2018; Suanon et al., 2016) and trace elements that are beneficial for plant growth (Aggelides and Londra, 2000; Mtshali et al., 2014). For example, 200 kg of organic matter, 6 kg of nitrogen, 8 kg of phosphorus, and 10 kg of various soluble salts are typically found in one ton of dry sludge (Iticescu et al., 2018). Adding sewage sludge to the soil can improve its physical, chemical, and biological qualities, fostering a more sustainable soil ecosystem and promoting plant growth (Jatav et al., 2018).

Currently, some of the industrial parks, in Ethiopia particularly the Zero Liquid Discharge (ZLD) Hawassa Industry Park (HIP) have deployed innovative wastewater treatment technologies consisting of screening, equalization, and an up-low anaerobic sludge blanket process to minimize negative effects on the environment. The domestic sludge, which comes from the disposal of the pit latrine of the HIP is passed through the sewage treatment plant (STP), and its accumulation has created environmental concern. Ethiopia is a low-income country that invests a huge amount of foreign currency in the purchase of synthetic fertilizer every year. Organic fertilization options should be explored as a replacement or supplement to mineral fertilizer use.

The use of sewage sludge as fertilizer reduces the cost of commercial fertilizers and could be a viable option (Pengcheng et al., 2008; Roca-Pérez et al., 2009). At present, the global production of sewage sludge is estimated at 45 Mg of dry matter per year (Zhang et al., 2017), and this figure is expected to double in the coming years (Wang et al., 2017), which calls for immediate interventions since the growing sludge production could lead to environmental problems. Sewage sludge often has high organic carbon, nitrogen, phosphorus, porosity, and water holding capacity, implying its potential for use as fertilizer (Delibacak et al., 2009; Poykio et al., 2019; Suanon et al., 2016).

Sludge properties could modify the soil's physical chemical, and biological properties, which could enhance its capacity to support plant growth. As a result, changes in soil quality induced by sewage sludge usage could have a positive impact on agricultural productivity (Baloch et al., 2023).

When compared to soil supplemented with inorganic fertilizers, the amount of organic carbon in sludge-amended soil can rise by as much as three times (Nyamangara and Mzezewa, 2001). In situations where sewage sludge does not contain the optimum nutrient ratio for plant growth, it can be applied combined with mineral fertilizers (Mtshali et al., 2014).

The majority of research findings indicated that using sludge from agro-industrial wastewater treatment plants for agricultural applications as a soil conditioner is the best possible disposal mechanism without affecting the ecosystem (Babel et al., 2009; Latare et al., 2014; López-Mosquera et al., 2000; Poykio et al., 2019; Suanon et al., 2016). Due to its high organic carbon content, sewage sludge has the potential to enhance soil's physical properties (Khaleel et al., 1981). This could include reducing bulk density, improving aggregate stability, and soils' ability to retain water, and encourages greater water infiltration (Kladivko and Nelson, 1979). Due to the potential for recycling, domestic sludge's features make it an interesting material for agricultural reuse, particularly in farmland and wooded regions, instead of direct disposal (Erdem and Sözüdoğru, 2002; Garg and Kumar, 2015; Mondal et al., 2015).

Sludge management has grown in importance as a result of the possible environmental risk and higher disposal costs (Suanon et al., 2016). Sewage sludge's potential use as a fertilizer offers a practical and affordable disposal option. However, the knowledge of heavy metal and other contaminants concentration in the sludge is needed to ensure that national limit values are not exceeded if the sludge is to be used for agriculture (Poykio et al., 2019). Moreover, there are insufficient scientific pieces of evidence in Ethiopia on the potential of application of domestic sludge as fertilizer on soils. Therefore, managing a considerable and steadily rising amount of sewage sludge is the top priority for both developed and emerging countries (Ghorbani et al., 2022). For the safe use of sewage sludge, it must be characterized in terms of its composition, as this residue may contain toxic compounds, causing environmental pollution. Several scholars have attempted to describe the brewery sludges that may be utilized in Ethiopia to produce crops among other agricultural uses (Alayu et al., 2018; Merga et al. 2021), Nevertheless, little attempt was made to conduct additional research for the characterization of effluents from the emerging Ethiopia's industrial parks.

The purpose of this study was, therefore, to evaluate the physico-chemical properties of sewage sludge produced from zero liquid discharge (ZLD) at HIP in Ethiopia, to look into its nutrient contents and potential use as fertilizer and to determine whether it can be recommended for soil amendment.

MATERIALS AND METHODS

Description of the Study Area

This study was carried out at Ethiopia's Sidama National Regional State's Hawassa Industrial Park (HIP), in the city of Hawassa. HIP, which started operation in July 2016 and has been referred to as the "flagship" industrial park of the Ethiopian government (Figure 1). It is situated in Hawassa City, which is roughly 275 kilometers from Ethiopia's capital Addis Abeba. The park has a total area of 1.3 million m2, of which a manufacturing shed build-up constitutes an area of 300,000 m2. Currently, the park is home to 22 top worldwide garment and textile enterprises from the USA, China, India, and Sri Lanka, as well as many local manufacturers (Xiaodi et al., 2018). Currently, HIP has a total of 13,700 workers across 52 shades and around 80% of the employees are female.

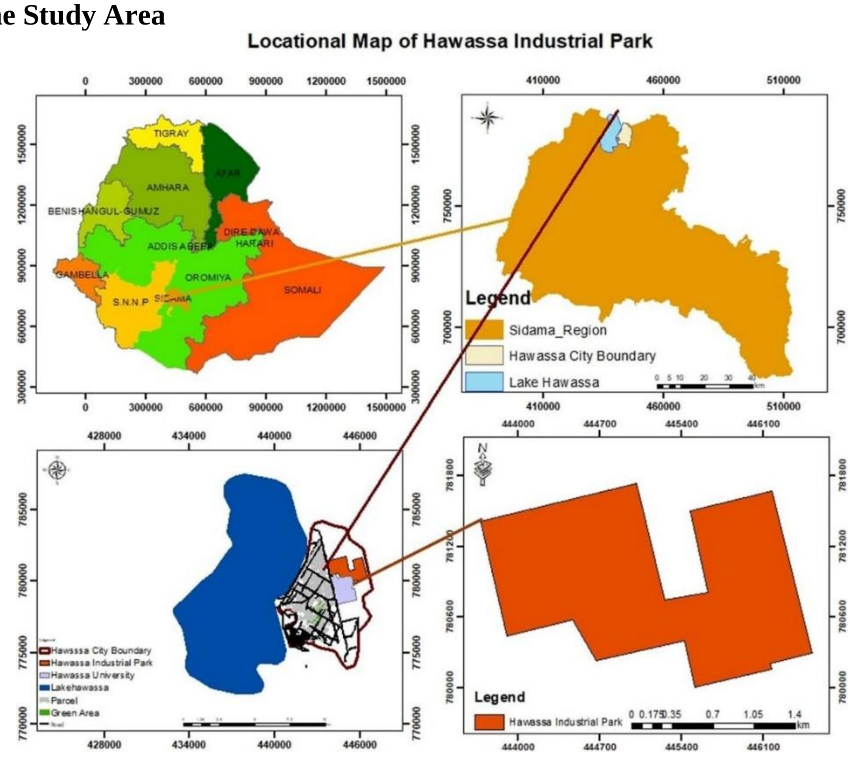

Figure 1. Hawassa Industrial Park location map

The park has a zero-liquid discharge (ZLD) plant that treats and recycles wastewater to reduce environmental impact. This is supposed to help businesses to satisfy the environmental requirements needed by global markets, allowing them to concentrate on exports.

Domestic Sludge Sampling and Preparation for Analysis

The source of the domestic sludge for this study is the ZLD wastewater treatment plant at Hawassa Industry Park. The HIP has sewage treatment plant (STP) which treats three million litres per day. This domestic wastewater is discharged from toilets of the different sheds. The sludge samples were collected from semisolid obtained from STP based on the environmental standards of the Environmental Protection Agency (EPA) (EPA, 1983). Five domestic sludge samples were collected from the sedimentation tank daily for consecutive five days. The domestic sludge was collected, carefully mixed, dried and then passed through a 2 mm sieve and stored in a plastic bag for further analysis in the laboratory. The prepared samples were then analyzed for different physical and chemical properties including content of heavy metals in the soil laboratory of the college of agriculture, Hawassa University.

The bulk density (BD) of the domestic sludge was ascertained by using the core sampler technique as described in Blake (1965). Using the pressure plate apparatus technique, the water retention at field capacity (FC) and permanent wilting point (PWP) were determined at water potentials of -1/3 bar and -15 bar, respectively (Richards, 1965). The available water content (AWC) of the domestic sludge (mm/m) was calculated using Equation 1 described below:

$$AWC = 10 \times [FC - PWP] \times BD \qquad (1)$$

Where AWC= available water content, FC = moisture content at field capacity, and PWP= moisture content at the permanent wilting point
The pH of the sludge was measured in 1:2.5 sludge and water suspension, electrochemically using a pH meter (Jackson, 1958). The amount of organic carbon (OC) in the domestic sludge was determined with the aid of a rapid titration approach (Walkley and Black, 1934) whereas in a sludge water extract (1:2.5), the electrical conductivity (EC) was measured using a conductivity meter (Okalebo et al., 2002). Kjeldahl method was employed to estimate the amount of total nitrogen (TN) in the sludge as described by Jackson (1958). The available phosphorus content was determined using the Olsen extraction process as described by Olsen et al. (1954). The ammonium acetate method was used to determine the exchangeable bases and cation exchange capacity (Van Reeuwijk, 2002). Atomic absorption spectrophotometer was used to measure Ca^{2+} and Mg^{2+}, whereas flame photometer was employed to measure Na^{+} and K^{+}.

Analyses of Sludge Samples for Heavy Metals

The heavy metal test was carried out at Horticoop Ethiopia (Horticulture) PLC, soil, water and plant analysis laboratory which is found at Debreziet city. Cu, Zn, Mn, Cr, Mo, Co, Pb, Se, and Cd, were extracted using the DTPA extraction technique (Lindsay and Norvell, 1978), and their concentrations were all determined using inductively coupled plasma-optical emission spectrophotometer (ICP-OES). The apparatus was set up properly to analyze the sample, including the wavelength selector, plasma, auxiliary, nebulizer, and gas settings (Dilebo et al., 2023).

Data Analysis

The domestic sludge samples' physical and chemical characteristics and heavy metal concentration were determined and the data were analyzed with the help of Microsoft Excel for descriptive statistics.

RESULTS AND DISCUSSION

Physico-Chemical Properties of Domestic Sludge (DS)

Physical Characteristics of the Domestic Sludge at HIP

The data of the physical properties of the domestic sludge samples are presented in Table 1.

Table 1. Physical properties of domestic sludge (n=5).

Physical properties	Unit	Mean±SD	Minimum	Maximum	CV
BD	g cm^{-3}	0.85±0.02	0.82	0.87	1.91
FC	%	92.06±5.88	86.00	99.30	6.39
PWP	%	47.40±11.55	35.00	65.00	24.36
AWC	%	44.66±8.93	30.00	52.00	19.99

BD= bulk density; FC=field capacity; PWP=permanent wilting point; AWC= available water content; SD=standard deviation; CV=coefficient of variation

The results in Table 1 clearly show that the domestic sludge has favorable physical characteristics that may be useful to enhance its potential use as a soil amendment. The mean bulk density value is 0.85 g/cm^3, and ranges from 0.82 to 0.87 g cm^{-3}. Higher values of BD (1.19 g cm^{-3}) were reported by Jatav et al. (2021), 1.18 gm cm^{-3} by EI-Nahhal et al. (2014), and 1.05 gm cm^{-3} by Hu et al. (2012) which is essential to improve soil BD. The domestic sludge also has a good water holding capacity of 44.6%, which is an excellent signal as it can be useful in enhancing the soil's water holding capacity, and this finding is similar to the finding by Jatav et al. (2021) who found higher moisture content in Bhagwanpur STP, India in sludge amended soils. Similarly, Alayu et al. (2018) found a mean water holding capacity (WHC) of 54% for bio-solid from the Kombolcha Brewery sewage treatment facility of Amhara regional state. The greater water holding capacity of the sewage might be due to the elevated organic matter content. El-Nahhal et al. (2014) showed that the moisture retention capacity of sludge can be 2 times higher than that of a sandy soil, and they explained that the lesser permeability and higher porosity in the sludge could be responsible for the higher water holding capacity.

The analyses of the physical properties of the domestic sludge (DS) at HIP indicated that it could be a great supplement to enhance the bulk density of soils as suggested by various authors (Jatav et al., 2018; Latare et al., 2014). Similarly, various studies revealed that DS has advantageous physical characteristics that can enhance soils' physical attributes (Jatav et al., 2021). Application of waste sludge results in an increase in porosity, moisture content at field capacity, and permanent wilting point (Delibacak et al., 2009). Sludge would also help to activate the various microbes in the soil (Jatav et al., 2021).

Chemical Properties of the Domestic Sludge at HIP

The domestic sludge samples were also analyzed for their chemical properties and the results are presented in Table 2. The pH of the domestic sludge at HIP was found to be slightly alkaline and had values ranging from 7.48 to 7.98 (Table 2). The chemical, and biological features of the soil are significantly influenced by the sewage sludge's alkalinity and acidity, which also impacts the likelihood of nutrients being available for plant growth (Alayu et al., 2018; Obasi et al., 2012). The reported sludge pH values are optimum for the majority of crops (Mcconnell et al., 1993). Comparable results were reported by Alayu et al. (2018) in Kombolcha Brewery Factory with a mean pH value of 7.85. For soils that had been sewage sludge treated, it is advised keep the soil pH above 6.5 (Henning et al., 2001).

Table 2. Chemical properties of domestic sludge (n=5).

Chemical properties	Unit	Mean±SD	minimum	maximum	CV
pH (H_2O)		7.74±0.21	7.48	7.98	2.70
EC	$mScm^{-1}$	2.06±0.37	1.74	2.65	17.80
P	mg/kg	911.80±225.52	739.20	1300.20	0.25
Ca^{2+}	meq. $100g^{-1}$ soil	33.23±11.87	16.79	43.91	35.73
K^+	meq. $100g^{-1}$ soil	6.02±1.56	4.78	8.38	25.98
Mg^{2+}	meq. $100g^{-1}$ soil	18.68±1.34	16.89	20.35	7.15
Na^+	meq. $100g^{-1}$ soil	14.32±1.64	11.88	16.10	11.46
S	meq. $100g^{-1}$ soil	1.31±0.60	0.51	1.85	45.75
CEC	meq. $100g^{-1}$ soil	36.57±2.33	33.46	38.81	6.37
OC	%	14.35±2.92	10.33	17.80	20.37
TN	%	2.95±0.71	2.34	3.99	24.16
C/N	-	5.25±2.54	2.59	7.51	38.83

EC= electrical conductivity; P=phosphorus; S=Sulphur; CEC=cation exchange capacity; OC=organic carbon; TN=total nitrogen; C/N= carbon to nitrogen ratio; SD= standard deviation; CV=coefficient variation

The mean value of electrical conductivity (EC) of the domestic sludge was 2.06 mS/cm. This EC result is consistent with the waste sludges' reported EC values, which ranged from 1.38 to 2.12 $mScm^{-1}$ (Obasi et al., 2012). According to Soumaré et al. (2003), the EC value in this study is within the range required to be utilized as a good fertilizer, which is 3 mS/cm, and this range is suitable for plant growth in Ethiopian conditions.

As shown in Table 2, the domestic sludge had an average organic carbon (OC) content of 14.35%, with a range of 10.33 to 17.80%. Sharma et al. (2022) disclosed that the amount of organic matter in dewatered sludge can be as high as 50 to 70%. Other researchers also found a high amount of organic matter, 70.5% (Wang et al., 2022) and 51.5% (Hurley et al., 2018). Domestic sludge's high OC content makes it a potential soil fertilizer that could significantly increase the amount of essential nutrients required by crops, improve the physical characteristics of the soil, and contribute more to an increase in crop production if used as soil amendment (Alayu et al., 2018).

The total nitrogen (TN) content in the domestic sludge was found to be 2.95% with a range from 2.34 to 3.99 % (Table 2). The amount of total nitrogen found in this domestic sludge indicates that it can potentially be a good source of nitrogen if applied to soils (Alayu et al., 2018, Mtshali et al., 2014).). Another study conducted by Singh et al. (2022) showed that dry sludge may contain 2.35–4.2% nitrogen, 2.46–3.2% phosphorus, and 0.83–1.24% potassium making it an excellent organic fertilizer for growing crops.

The mean value of C/N of the sewage sludge in this study is 5.25. This value is lower than reported C/N ratio of brewery sludge, malting sludge, compost, and brewery spent grain, were 12.78, 7.47, 11.2, and 7.1, respectively, (Alayu et al., 2018; Mtshali et al., 2014; Sampson, 2016). The result is in line with the allowable range of C/N for organic fertilizers for agricultural use of <35:1 (Meghari and Omar, 2017).

The available phosphorus (911.80 $mgkg^{-1}$) satisfies the Ethiopian standard established (ESA, 2021), and the value is higher than that obtained by the Environmental Qualifications Authority for the country of Israel for the fertilizer value of sludge for agricultural application (Meghari and Omar, 2017). Therefore, the amount of available phosphorus found in the DS samples is optimum for its potential use as fertilizer. In general, the high OM and nutrient (nitrogen and phosphorus) contents found in this domestic sludge potentially makes it a valuable organic fertilizer.

The Calcium content of the domestic sludge was found to be 33.23 meq. 100g^{-1} soil. This value is higher than values obtained by Alayu et al. (2018) and Dolgen et al. (2004) with Ca values in brewery sludge of 3.19 and 28.81 meq. 100g^{-1} soil, respectively. The mean concentration of Magnesium was found to be 18.68meq/100g soil. This result is higher than brewery sludge contents reported for other sludge materials (Alayu et al., 2018; Campaña et al., 2014). The mean value of potassium in domestic sludge was found to be 6.02 meq. 100g^{-1} soil, whereas other studies reported a value of 5 meq. 100 g^{-1} soil (Alayu et al., 2018). This domestic sewage sludge contains potassium, which suggests that it may be available for plants. The measured value of sodium (14.32 meq.100g^{-1} soil in the domestic sludge was lower than the one in the study by Campana et al. (2014) for a brewery sludge of 21.30 meq. 100g^{-1}, it offers the benefit of avoiding issues with salt buildup in soil and plant roots. In general, the HIP domestic sewage sludge was found to be suitable in terms of secondary plant nutrients such as sulfur calcium, and magnesium so that if this DS is applied to soils, these nutrients will be available for crop growth.

The mean value of CEC of domestic sludge is 36.57 meq. 100 g^{-1} which is high. Domestic sludge application could modestly improve the cation exchange capacity (CEC) of soils. This is most likely because of the high organic matter content in the sludge (Erdem and Sözüdoğru, 2002).

Heavy Metal Concentration in the Domestic Sludge at HIP

The analysis results of heavy metals in the domestic sludge (Table 3) indicated that the sludge could potentially be used as fertilizer since the values fall below the Ethiopian standard and FAO limits (ESA, 2021; Council of the European Communities, 1986).

Table 3. Heavy metals contents of domestic sludge in the HIP and recommended standards (n=5)

Chemical properties	Unit	Mean±standard deviation	minimum	maximum	Permissible limits	Source
Manganese	mg kg^{-1}	255.11±34.86	215.56	292.49	2000	(Council of the European Communities, 1986)
Zinc	mg kg^{-1}	399.79±37.37	357.26	451.63	2500	(ESA, 2021)
Boron	mg kg^{-1}	34.77±3.82	29.48	39.42		
Copper	mg kg^{-1}	71.61±5.28	64.24	78.93	800	(ESA, 2021)
Arsenic	mg kg^{-1}	12.10±0.32	11.64	12.42	40	ESA, 2021
Lead	mg kg^{-1}	41.57±2.21	38.66	44.55	900	(ESA, 2021)
Chromium	mg kg^{-1}	24.97±3.54	20.38	29.77	900	(ESA, 2021)
Cadmium	mg kg^{-1}	3.71±0.34	3.31	4.11	10	(ESA, 2021)
Cobalt	mg kg^{-1}	17.88±2.44	14.67	20.46	100	(Water Research Commission, 1997)
Nickel	mg kg^{-1}	16.83±0.73	15.78	17.52	200	(ESA, 2021)
Mercury	mg kg^{-1}	3.54+0.14	3.39	3.74	8	(ESA, 2021)
Selenium	mg kg^{-1}	19.40±0.72	18.18	20.06	15	(Water Research Commission, 1997)

The allowable limits for possible toxicity levels of Zn, Cu, Cd, Pb, Ni, and Cr in sewage that can be applied in agricultural soils are 2500, 800, 10, 900, 200, and 900 mg/kg, respectively, as presented in Table 3 (ESA, 2021). However, the mean concentration of lead, zinc, and copper in the sludge were found to be 41.57, 399.79, and 71.61 mg/kg, respectively. Similarly, the levels of cadmium, chromium, cobalt, manganese, and nickel were also below the thresholds recommended for sludge used in agriculture (Alayu et al., 2018; Khanal et al., 2014; ESA, 2021). In addition, the concentration of Manganese ranged from 215.56 to 292.49 mg/kg, which was lower than the FAO/WHO (2001) recommendation (a maximum of 2000 mg/kg). The mean concentration of Nickel was 16.83 mg/kg, which was lower than the values reported for sludges in China and the UK, which were 214.29 mg/kg and 58.5 mg/kg, respectively (Hua et al., 2008; Milik et al., 2017). The level of Nickel was also found to be lower than the limit of FAO recommendations.

The mean value of arsenic was 12.10 m/kg and this is lower than the standard set, which is 40 mg/kg (ESA, 2021). Heavy metals are needed in suitable concentrations for the structural and catalytic components of proteins and enzymes as co-factors and essential for optimal plant development (Mahdi et al., 2007). Moreover, the mean value of Cobalt was 17.88 mg/kg, which was much less than the threshold set by scholars from South Africa and Ethiopia which were 100 mg/kg (DWAF, 1997; ESA, 2021).

Generally, the heavy metal concentrations were found to be much lower than the Ethiopian standard for sludge management for the majority of the heavy metals (ESA, 2021). On the contrary, the content of selenium in the sludge was found to be 19.40 mg/kg which was a bit higher than the recommended limit of 15 mg/kg (Taylor et al., 2021). On the other hand, Alemu et al. (2017) found a lower selenium content in sludge (12.56 mg/kg) in Harari Regional State, eastern Ethiopia.

CONCLUSIONS

Characterization of sewage sludge is important before application of sewage sludge to soil as fertilizer. Such characterization helps to determine the potential of sewage sludge for nutrient supplementation and for increasing crop yields. The high water-holding capacity of domestic sludge has the potential to enhance the water retention capacity soils if used as fertilizer.

The domestic sludge in the study area showed high contents of organic matter, nitrogen, and phosphorus. The concentrations of heavy metals (Zn, Cu, Cd, Pb, Ni, and Cr) in the domestic sludge are below the Ethiopian standard and FAO limits.

Analysis of domestic sludge also revealed that it contains significant amounts of secondary nutrients like sulfur, calcium, magnesium, as well as macro nutrients like nitrogen and phosphorus. The majority of physical and chemical properties revealed that it is potentially suitable for agricultural purposes. It is advisable to conduct soil testing when sludge is applied for proper risk management, especially for sensitive crops at the field level.

The use of sewage sludge for agricultural land could lead to lower production costs as reduced amounts of inorganic fertilizers will be used and also reduce the risk of problems created by the accumulation of increasing amounts of domestic sludge in the environment. Further research on analysis of the content of polychlorinated byphenyls (PCB) before the domestic sludge can be used for agricultural purposes is recommended.

CONFLICTS OF INTEREST

Authors declare that they have no conflicts of interest regarding the publication of this paper with the Journal of Science and Development.

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Journal of Science and Development

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For details of manuscript preparation, please refer to the guide below, or visit the above website

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Books

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Conference/workshop/seminar proceedings

Demel Teketay 2001. Ecological effects of eucalyptus: ground for making wise and informed decision. Proceedings of a national workshop on the eucalyptus dilemma, 15 November 2000, Part II: 1-45, Addis Ababa.

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