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The journal provides a formal platform for researchers, academics, development practitioners, and policymakers to publish scientific findings, promote innovation, preserve indigenous knowledge, and enhance the visibility and impact of research conducted in pastoral regions of Ethiopia and beyond.

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- Strengthening the link between **research, education, and community development**.
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Research Article

Northern Kenya Decadal Droughts: Livestock Population and Wealth Dynamics and Impacts of Intervention Scenarios

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Abstract
Pastoral livestock systems are highly vulnerable to recurrent drought, particularly in the arid and semi-arid lands of East Africa, where livestock serve as the primary source of food, income, assets, and social security. Increasing drought frequency and severity, driven by climate variability and climate change, can cause substantial livestock mortality, disrupt herd recovery, and progressively erode household wealth. This study investigates the long-term impacts of recurrent droughts on livestock demographics and household wealth in Northern Kenya's Obbu region. Drawing on a 34-year household panel dataset (1982–2011, revisited 2018–2025), we analyze herd dynamics, wealth transitions, and intervention scenarios across varying drought frequencies. Results show cattle as the most vulnerable species, with mortality exceeding 80–90% and recovery periods spanning two decades, whereas small stock and camels demonstrate greater resilience and faster rebound rates. Repeated drought cycles eroded wealth stratification, driving formerly affluent households into poverty or destitution and increasing dropout rates, with 44% of households exiting pastoralism by 2025. Scenario modelling reveals that high-frequency droughts (every two years) eliminate wealthy households and accelerate dropout, while moderate (every three years) and low-frequency droughts (every six years) still undermine recovery. Targeted interventions—restocking grants, feed subsidies, and improved water infrastructure—significantly reduce mortality, stabilize wealth categories, and prevent dropout, with combined measures delivering the highest impact. Findings underscore the urgent need for bundled interventions to sustain pastoral economies under intensifying climate pressures.

Keywords: Drought frequency scenarios, drought intervention strategies, livestock mortality, recovery, wealth transition modelling.

1. Introduction

There is limited research on how multi-decadal droughts (lasting more than 10-year cycles) affect livestock population dynamics and influence shifts in household wealth in Northern Kenya (Oba, 2024). Repeated drought cycles within the same community can lead to cumulative livestock losses (Mauerman et al., 2023). In this context, demographic

resilience – the ability of livestock species to recover after significant mortality – is a crucial parameter for assessing the effects of aftershocks. Resilience, as a measure of recovery potential, encompasses the time required and the annual growth rate needed to restore herds to pre-drought population levels (Lesnoff et al., 2012). Impacts may vary with drought frequency and intensity, with some lasting a single season and the most severe extending over several years (Loukas et al., 2008), influencing differences in birth rates among livestock species (Angasa & Oba, 2007; Oba, 2024).

Drought frequency has a greater influence on post-drought livestock population recovery rates, ranging from high (every 2 years) to moderate (every 3 years or more) to low (every 6 years or more). This might be mitigated through development interventions, such as offering financial grants to help households at risk of dropping out of pastoralism to restock, providing feed subsidies, and developing water infrastructure (This study). The challenge is the availability of longitudinal panel data to monitor livestock mortality and recovery patterns over extended periods (Oba, 2024; Desta & Coppock, 2002; Mengistu et al., 2013; Angasa & Oba, 2007; Oba, 2001). We used a 34-year panel dataset on livestock demographics, and household wealth dynamics, covering 16 drought cycles in Northern Kenya.

We had the following objectives: first, to analyze livestock demographic trends (separately for cattle, small stock and camels); second, to examine wealth dynamics using Borana criteria; third, to use 2018-2025 data on individual livestock species to simulate 'what-if' scenarios with high drought frequency (every 2 years), moderate (every 3 years), and low (every 6 years); and fourth, to investigate how interventions such as restocking grants, feed subsidies, and water infrastructure development influence herd mortalities under scenarios with different drought frequencies.

Background analysis

Drought is a climate-change-driven disaster that has affected pastoral and agro-pastoral economies in the drylands over the years (Huho & Mugalavai, 2010; Shibiru et al., 2022). These areas face a higher risk of water and grazing shortages, which negatively affect livestock population (Jokoby et al., 2015), forcing households to take many years to rebuild their herds (Theodory & Malipula,2014). Failure to rebuild stock during recovery will ultimately halt herd growth (Mwambi et al., 2015). Therefore, understanding the impact of droughts on livestock population dynamics and wealth requires access to

long-term data series (Oba, 2024; Desta & Coppock, 2002; Mengistu et al., 2013; Angasa & Oba, 2007). Another factor is how droughts affect per capita adult equivalents in subsistence economies, a direct measure of household wealth (Oba, 2001, 2024). The outcome is that individual households either run out of stock or, as reported here, drop out as ex-pastoralists. Households with more surviving livestock species may be able to climb the wealth ladder (Kirui et al., 2022)—through natural regeneration, market-based replacements, and gifts from friends and clans (Wangai et al., 2013). Herd losses and gains can be estimated through simulation scenarios of drought frequency and development interventions (Lesnoff et al., 2012)—a practice often undertaken by development agencies (Namatsi, 2016).

2. Materials and Methods

2.1. Study area

This study was conducted in the Obbu region in northern Kenya, which borders the southern edge of the Gorro escarpment, forming a steep ecological gradient from southern Ethiopia into northern Kenya. This gradient spans semi-arid, arid, and very arid zones, each with distinct grazing resources and varying levels of drought risk. The semi-arid zone (includes the sub-locations of Waye Godha, Anona, Sololo-Ramata, and Uran); the arid zone (Madho Adhi, Golole, Mukutano, and Damballa Fachana); and the very arid zone (Ambalo and Walda) (Figure 1) are settled by about 30,000 Obbu Borana residents (6,000 households). Human population densities varied across the locations.

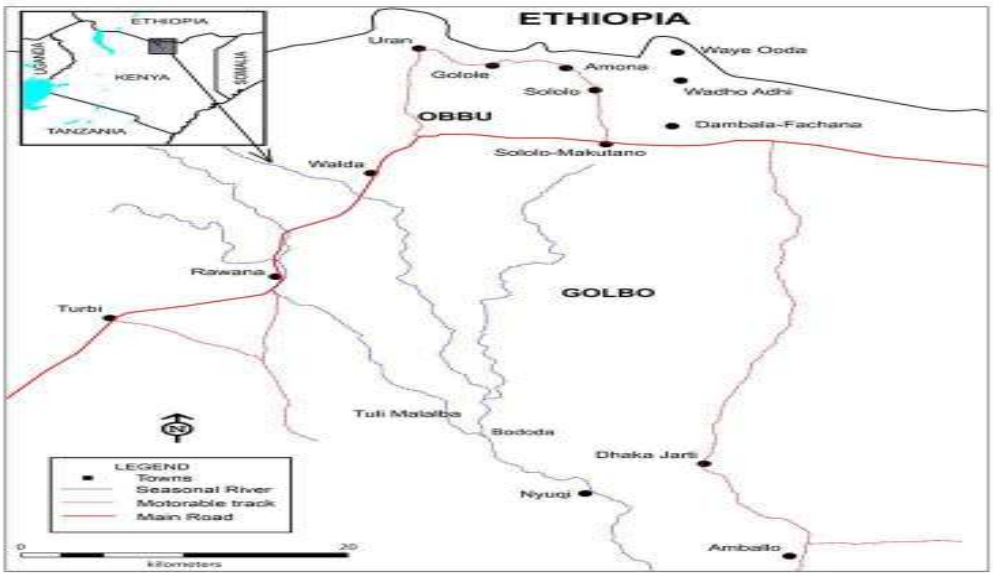


Figure 1: Map of the study area

The Obbu region receives bimodal rainfall –the short rains between October and December and the long rains between March and May. Drought is frequent, with consequent impacts on livestock demography and household wealth. Over the past 34 years, there have been six major droughts—1983/84, 1991/92, 2000–2002, 2004–2005, 2010–2011, and 2019-2022—and an equal number of minor droughts (Ochieng et al., 2022).

2.2. Study Design

Across eight locations (Mukutano, Sololo-Ramata, Waye, Madho Adhi, Anona, Dambala Fachana, Golole and Uran), 164 households were randomly selected in the 1983 drought (*oola diima sugha*), and repeatedly surveyed annually to track changes in livestock (initially, only cattle were monitored) up to 2011. The survey had gaps between 2012 and 2017. Monitoring was then repeated between 2018 and 2025 to coincide with the 2019-2022 drought, and again during the recovery period of 2023-2025, when, in addition to the historical households, 64 additional households from Ambalo and 10 from Walda were randomly selected and included in the surveys. From 2018 to 2025, livestock household data included cattle, small stock (sheep/goats) and camels. The types of data collected included livestock holdings in terms of calves, immatures, females and males before and after droughts (1983-2011 data only) and for the later periods, total cattle, small stock and camel holdings by individual households. For the 2018-2025 data series, we recorded lost herds and herd replacements by species.

Among the Obbu Borana, livestock is regarded as investment capital, and individual wealth is measured by the total number of livestock (traditionally only cattle, but now all livestock species are included). To assess wealth dynamics, we categorized household as: wealthy (>100 heads), medium (30-70 heads), self-reliant (>20 heads), poor (5–10 heads), very poor (<5 heads), destitute (<2 heads), or those who dropped out (0 heads) of livestock owned, and tracked these categories over time. For scenario modelling, we applied two approaches. (a) We simulated drought frequencies under three scenarios: high (two-year intervals), moderate (three-year intervals), and low (six-year intervals), then analyzed how livestock populations and wealth categories shifted. (b) We examined three drought mitigation strategies: providing restocking grants, offering feed subsidies, and improving water access. The wealth transition

probability matrix (tabulated) was used to evaluate the likelihood that a household shifts between wealth categories due to drought impacts.

2.3. Data analysis

We analyzed how livestock species' populations shifted during normal periods and during droughts. We then analyzed corresponding shifts in the populations of different livestock species under scenarios of frequent, moderate, and low-frequency droughts. We developed 'what-if' scenarios for future drought interventions by development agencies to assess whether effective mitigation measures will reduce drought impacts on livestock population changes and wealth-class shifts using 2018-2025 data to estimate periods up to 2036. We used two approaches to assess shifts in household wealth across wealth categories. In the first, we constructed a wealth transition probability matrix (Jappelli & Pistaferri, 2000) from the longitudinal data by tabulating the likelihood that households moved between wealth categories after drought shocks. Second, we assessed how interventions, including restocking, livestock feed subsidies, and the development of water structures, influenced shifts in wealth ranks. We then refined this into scenario-specific matrices (e.g., high-frequency drought vs moderate vs low) to directly compare how transition probabilities shift under different drought frequencies and interventions. For example, a probability of 0.10 represents a 10% chance of the rank transitioning to the given wealth category, while 0.25 means a 25% chance of moving into that category. Once households reach dropout (0 heads), they remain at that level (probability = 1.00).

2.4. Scenario Modelling equations

To model responses of small stock, cattle, and camels to different drought frequencies (high, moderate, low), we employed a set of parametric equations that simulate herd mortality, recovery, and replacement processes over time, reflecting patterns seen in longitudinal data and suitable for scenario analysis.

1. Mortality Rate (MR)

Defined as the proportion of animals lost during a drought event

$$MR_{(s,z,f)} = (L_{(s,z,f)} / H_{(s,z,f)}) \times 100$$

Where:

s: species (cattle, small stock, camels)
z: ecological zone (semi-arid, arid, very arid)

f: drought frequency (high, moderate, low)

L_{s,z,f}: number of animals lost during the drought

2. Recovery Rate (RR)

Annualized percentage of herd regained during post-drought

$$RR_{s,z,f} = ((R_{s,z,f} + P_{s,z,f}) / L_{s,z,f}) / Y_r \times 100$$

Where:

R_{s,z,f}: number of animals recovered (natural growth)

P_{s,z,f}: number of animals replaced (restocking)

Y_{r}: number of recovery years

3. Net Herd Change (NHC)

Overall change in herd size over a drought-recovery cycle

$$NHC_{s,z,f} = H_{s,z,f} - L_{s,z,f} + R_{s,z,f} + P_{s,z,f}$$

This was used to assess whether herds return to pre-drought levels or remain below subsistence thresholds.

4. Wealth Transition Probability (WTP)

Probability of a household shifting between wealth categories due to drought impact

$$WTP_{w \rightarrow w'} = N_{w \rightarrow w'} / N_w$$

Where:

w: initial wealth category

w': post-drought wealth category

N_ {w \right arrow w'}: number of households transitioning from w to w'
N_{w}: total households in category w pre-drought

5. Economic Loss Estimation (ELE)

Loss per household based on the market value of livestock

$ELE_s = L_s \times V_s$ Where: L_{s}: number of animals
lost V_{s}: average market value per head (species-specific)

6. Intervention Impact Factor (IIF)

This facilitates the comparison of the effectiveness of interventions in reducing losses of scenarios involving restocking grants, feed subsidies, or water infrastructure.

$$IIF_{s,z,f} = ((NHC_{with\ intervention} - NHC_{without\ intervention}) / NHC_{without\ intervention}) \times 100$$

3. Results and Discussion

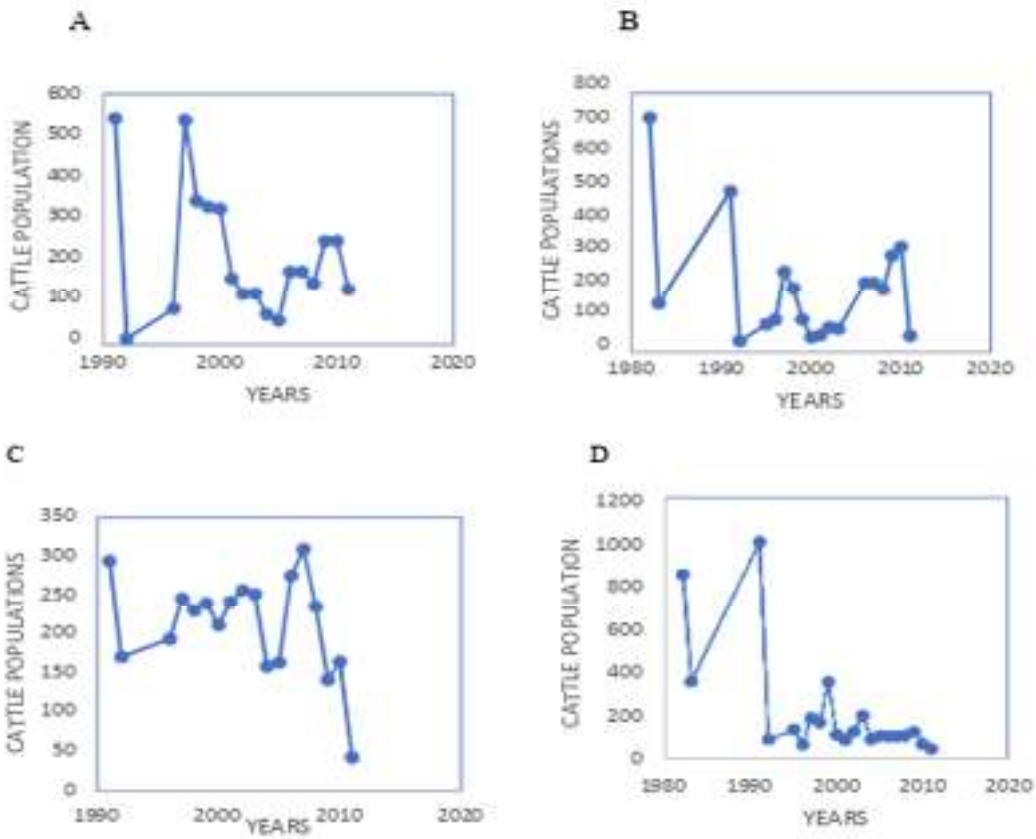
3.1. Livestock Demographic Fluctuations

Droughts have severely affected cattle herds. The most severe declines occurred during the 1983/84, 1991/92, 2010–2011, and 2019–2022 droughts, when herd mortality exceeded 90% in some areas. Reproductive females generally survived droughts at higher rates than calves and juveniles (Figures 2A, B, C, and D, and Figures 3A, B, and C).

Mortality altered the age structure of cattle (Oba, 2001; Oba, 2024; Mwanyumba et al., 2015) and was particularly severe among

calves and immatures during droughts, with mortality rates of 40% to 90%. Droughts from 2000 to 2005 caused repeated losses among younger cattle, leading to a cumulative decline in herd size, while the 2010–2011 drought resulted in a catastrophic collapse across all cattle age and sex classes. Mature males remained chronically low due to mortality and off-take (sales/slaughter). In southern Ethiopia, droughts lasting five to seven years led to cattle losses of 45% to 70% (Mengistu & Haji, 2015). Over 21 years of monitoring in southern Ethiopia, a 54% reduction in the cattle population was observed (Angasa & Oba, 2007).

Different droughts lead to distinct die-off patterns (Oba, 2013; Catley et al., 2014). Herd die-offs influence herd structure (Oba, 2001; Angassa & Oba, 2007). In relatively wetter areas in southern Ethiopia, long-term data also show variable herd die-offs with drought frequency (Desta & Coppock, 2002; Tache & Oba, 2010). The increase in mortality observed during some droughts was a combination of feed scarcity and animal diseases (Desta & Coppock, 2004). Mortality varied across locations and agro-ecological zones (Table 1).



Figures 2: The total cattle population dynamics between different droughts in (A) Sololo –Ramata, (B) Anona, (C) Golole and (D) Mukutano. The four sites are in different ecological zones.

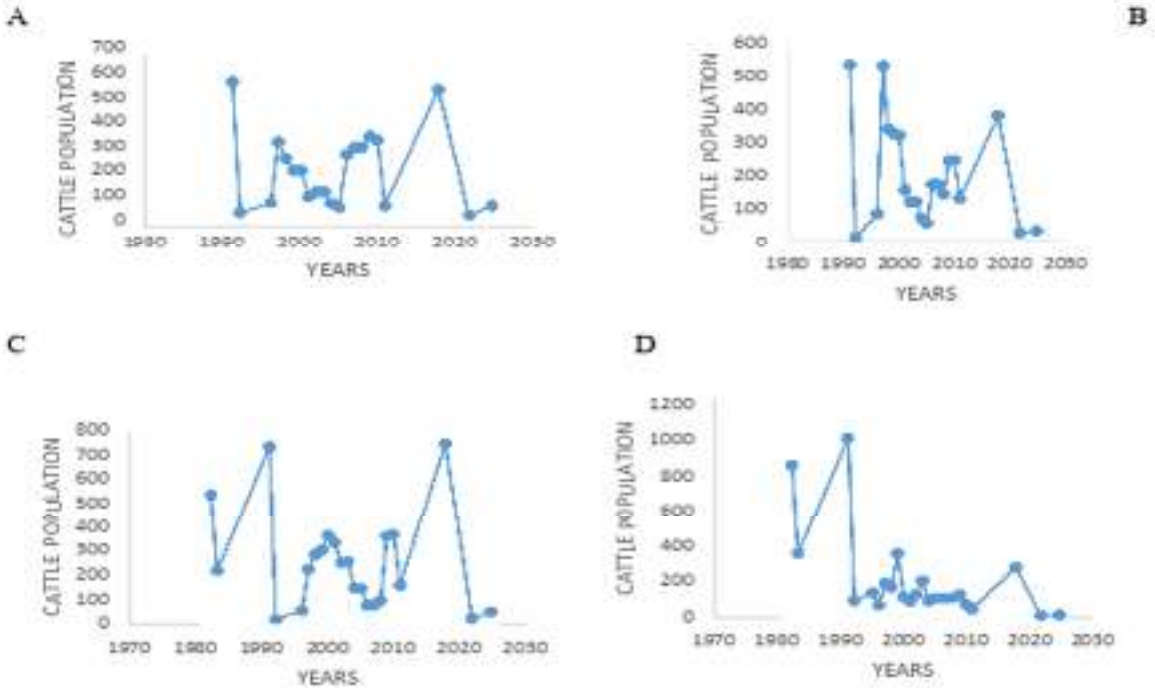


Figure 3: Cattle population trends in the locations of (A) Golole, (B) Uran, (C) Damballa Fachana, and (D) Mukutano from 1982 to 2025.

Table 1: % changes in wealth ranks of the Obbu Borana households by total livestock heads between 2018 and 2025

Wealth rank	% households (initial herd)	% of households (current herd	% Change
Wealthy (> 100 heads)	12.6	6.2	-6.4
Medium (30-70 heads	18.3	13.1	-5.2
Self-reliant (> 20 heads)	14.6	13.4	-1.2
Poor (5-10 heads)	14.9	13.9	-0.5
Very poor (< 5 heads)	2.3	3.4	+0.8
Destitute (< 2 heads)	3.2	6.7	+3.5
Drop out (0 heads)	34.6	43.6	+9.0

Source: Household survey data

Population recovery depends on whether droughts occur at 3–5 year intervals (Oba, 2001) or 10–15 year intervals (Coppock, 1994). During a rapid succession of drought events, the impacts can be very dramatic (Kreyling et al., 2011). From the end of the drought in 2023 through 2025, the cattle recovery rate was 11.7%, approximately 2.3% per year. Herd replacement, meaning self- restocking, showed considerable variability. Cattle replacements (22%) were notable but more limited, likely due to higher costs and slower recovery rates. Herd replacements, particularly for cattle, depended largely on the financial capacity of individual households (Doye et al., 2013). In southern Ethiopia, Cossins and

Upton (1988) noted that after severe droughts, cattle populations recovered in ~15 years, whereas in Turkana ecosystem, recovery took 3 years (McCabe, 1987).

For the 2018-2025 data sets, the mortality rate among small stock was 73.6%. Among small stock, recovery was 41.1% (13.7% annually) between 2023 and 2025 following the return of rainfall. This is crucial, as small stock is the backbone of herd recovery, accounting for 74% of replacements (Figure 4C-D). Greater small-stock replacement emphasised their vital role in herd recovery and possibly their greater affordability. In a southern Ethiopian study, sheep and goats showed mortality patterns similar to those observed in northern Kenya (Shibiru et al., 2022). Conversely, evidence shows that camels are better adapted to drought crises, which might explain the recent (40%) increase in acquisitions by the Obbu families (Figure 4E). For camels, recovery underscores the need for long-term breeding rather than short-term restocking. In southern Ethiopia, Wako and colleagues (2017) and in northern Kenya, Watson and colleagues (2016) report that the adoption of camels was attributable to their better drought adaptations. This is a common trend in other drylands (Josef et al., 2013).

At high drought frequency (every 2 years), cattle and sheep herds decline by over 70%, while goat and camel herds fall by 50–60% (Figure 5). Conversely, with moderate frequency (every 3 years), herds decrease gradually. Goats and camels demonstrate resilience, retaining 60–70% of their original numbers, while at low frequency (every 6 years), herds sustain 80–90% of their initial size. Recovery intervals between droughts allow herd regeneration, particularly for goats and camels. Camels are the least affected.

3.2. Changing Dynamics in Wealth Ranks

Recurrent droughts in Northern Kenya have profoundly reshaped household wealth structures among pastoralist communities (Fratkin & Roth, 1990). This is evident in the Obbu households, where recurrent droughts transformed households' wealth landscape from stratified pastoral prosperity to widespread impoverishment and dropout. During the 1983/84 drought, cattle per capita were around 6 per adult equivalent, falling to roughly 1.5 per adult equivalent after 1984 (a 75% decline). By 1996, five years after the drought, cattle per capita had fallen to fewer than 4 per adult equivalent. Destitution doubled, with more households falling below the 2-adult-equivalent threshold. This trend signals a weakened buffer capacity, reduced

resilience, and a flattening of wealth stratification (Table 1). Although some households recovered during the post-drought phases, overall wealth stratification decreased, as households that were once wealthy or middle- wealthy either moved to lower categories or dropped out entirely. By 2011, households labelled as "poor," "impoverished," or "destitute" accounted for over 70% of all households, and only a few remained in the top wealth brackets undermining traditional Borana social redistributive mechanisms (Berhanu et al., 2017). By the 1990s and 2000s, especially after the 2010–2011 drought, these groups shrank dramatically. By 2011, dropout households accounted for a significant share of the population. This marks a structural transformation - pastoralism was no longer viable for many families, forcing them into alternative livelihoods. Formerly affluent households lost herds and slipped into lower categories, showing that wealth was not durable under repeated drought shocks. This reflects cumulative herd losses: repeated calf and juvenile mortality, slow recovery rates, and an inability to rebuild before the next drought. Destitution became a common outcome, eroding traditional safety nets and weakening community resilience (Berhanu,2011).

Between 2018 and 2025, wealth rankings show a significant rise in destitution and dropout rates, alongside a decline in the number of households classified as wealthy or in the middle-wealth category. Here is a breakdown of the percentage change in household wealth ranks, based on total herd size, comparing initial to current herd figures (Table 1). The share of wealthy households fell from 12.6% to 6.2%, indicating substantial herd losses among previously affluent families. Dropout rates rose by 9 percentage points, accounting for nearly 44% of households without livestock. Destitution doubled, with more households falling below the 2-head adult equivalent (i.e. a 50% decline below the subsistence level). The middle and self-reliant groups shrank, signaling downward social mobility and a weakening of buffer capacity. The ranks of poor and very poor remained relatively stable, but the slight rise in impoverished households suggests marginal survival. Dropout rates rose across all zones, particularly in the arid (+8.6%) and very arid (+8.9%) zones. These changes indicate significant increases in poverty, a pattern similar to that reported in Borana, southern Ethiopia (Tache, 2008; Tache & Oba, 2010).

3.3. Wealth Transition Probability Matrices

The wealthy-to-dropout probability reflects the collapse of affluent households during high- frequency droughts. The destitute-to-dropout probability is highest (40%), consistent with the finding that destitution doubled and dropout rose to 44% of households. The three-phase wealth transition matrices for high, moderate, and low drought frequencies are presented in Tables 2, 3 , and 4, respectively.

Table 2: Wealth transition probability matrix under scenarios of high drought frequency (every 2 years)1

From/to	Wealthy	Medium	Self-reliant	Poor	V. poor	Destitute	Dropout
Wealthy	0.00	0.10	0.15	0.2	0.15	0.20	0.00
Medium	0.00	0.15	0.20	0.20	0.15	0.15	0.15
Self-reliant	0.00	0.10	0.15	0.15	0.20	0.15	0.15
Poor	0.00	0.05	0.10	0.25	0.20	0.20	0.20
V. poor	0.00	0.05	0.05	0.15	0.20	0.25	0.30
Destitute	0.00	0.00	0.05	0.10	0.15	0.30	0.40
Dropout	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Source: Survey data

1The key to probability matrix is as follows: Rows = Starting Wealth Category. Each row represents households beginning in a given wealth category (e.g., Wealthy, Medium, Poor). Columns = Ending Wealth Category, each column shows the probability that households move into that category after a drought cycle. Cell Values = Transition Probabilities (0–1). A value of 0.25 means a 25% chance of moving into that category. Each row sums to 1.00, since households must end up in one of the categories. Dropout = Absorbing State. Once households reach Dropout (0 heads), they remain there (probability = 1.00). This reflects the difficulty of re-entering pastoralism without external intervention

Table 3: Wealth transition probability matrix under scenarios of moderate drought frequency (every 3 years)

From/to	Wealthy	Medium	Self-reliant	Poor	V. poor	Destitute	Dropout
Wealth	0.15	0.25	0.20	0.20	0.10	0.10	0.00
Mediu	0.10	0.30	0.25	0.20	0.10	0.05	0.00
Self-	0.05	0.20	0.25	0.25	0.15	0.10	0.00
Poor	0.02	0.10	0.20	0.30	0.20	0.10	0.08
V.	0.01	0.05	0.10	0.20	0.30	0.20	0.14
Destitu	0.00	0.05	0.10	0.20	0.25	0.30	0.10
Dropo	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Source: Survey data

Table 4: Wealth transition probability matrix under scenarios of low drought frequency (6 or more years)

From/to	Wealthy	Medium	Self-reliant	Poor	V. poor	Destitute	Dropout
Wealthy	0.35	0.25	0.20	0.15	0.05	0.00	0.00
Medium	0.15	0.35	0.25	0.15	0.05	0.05	0.00
Self-reliant	0.10	0.20	0.30	0.25	0.10	0.05	0.00
Poor	0.15	0.10	0.20	0.35	0.20	0.10	0.00
V. poor	0.02	0.05	0.10	0.20	0.30	0.20	0.13
Destitute	0.01	0.05	0.10	0.20	0.25	0.30	0.10
Dropout	0.00	0.00	0.00	0.00	0.00	0.00	1.0

Source: Survey data

Under high drought frequency (every 2 years) before the intervention, wealthy households collapse to 0%, while dropout rises to 39%. The population is dominated by destitute households. In the high-frequency drought matrix, a household starting at medium has a 15% chance of remaining medium, a 20% chance of becoming self-reliant, a 15% chance of falling to destitute, and a 15% chance of dropping out (Table 2). The matrix captures the probability of moving from

one category (rows) to another (columns), highlighting the fragility of pastoral wealth. In these baseline scenarios (no development intervention), wealthy households have a high probability of sliding into the medium, poor, or even destitute categories. The chance of remaining wealthy is very low, while middle-wealth and self-reliant households are most vulnerable to downward mobility, with significant probabilities of becoming poor or destitute. Following intervention (combined grants + feed + water), restocking grants rebuild medium wealth, while feed subsidies reduce mortality by ~25%. Access to water development boosts wealth recovery by ~20% and nearly eliminates dropout.

Under moderate drought frequency (every 3 years), wealthy households shrank to ~3%, while poor and destithouseholds (Doye et al., 2013). In southern Ethiopia, Cossins and Upton (1988) noted that after severe droughts, cattle populations recovered in ~15 years, whereas in Turkana ecosystem, recovery took 3 years (McCabe, 1987).

For the 2018-2025 data sets, the mortality rate among small stock was 73.6%. Among small stock, recovery was 41.1% (13.7% annually) between 2023 and 2025 following the return of rainfall. This is crucial, as small stock is the backbone of herd recovery, accounting for 74% of replacements (Figure 4C-D). Greater small-stock replacement emphasised their vital role in herd recovery and possibly their greater affordability. In a southern Ethiopian study, sheep and goats showed mortality patterns similar to those observed in northern Kenya (Shibiru et al., 2022). Conversely, evidence shows that camels are better adapted to drought crises, which might explain the recent (40%) increase in acquisitions by the Obbu families (Figure 4E).

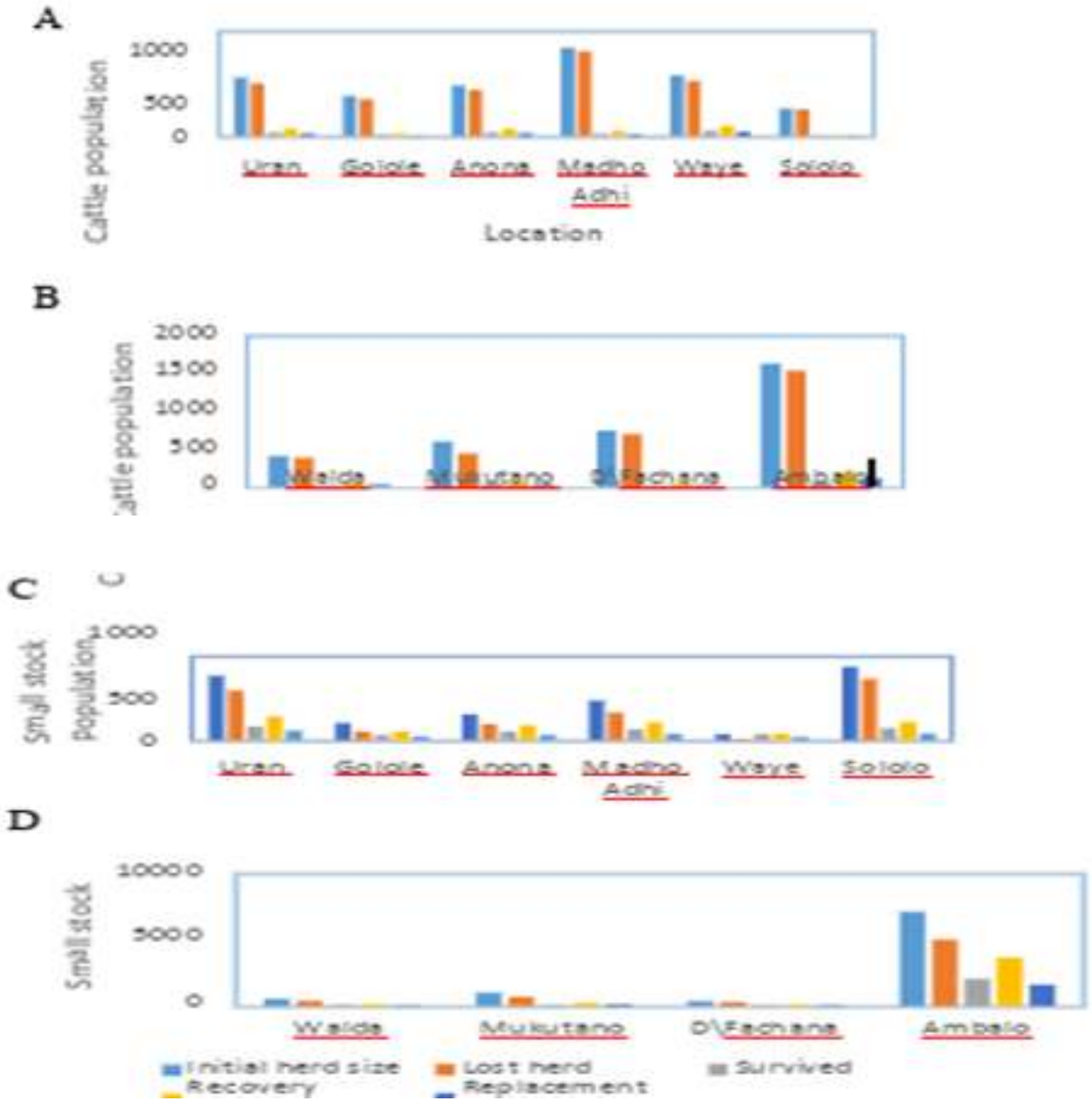


Figure 4: Initial herd size, lost herds, surviving herds, recovery and replacement of (A-B) Cattle, (C-D) small stock populations across the ten sub-locations in the Obbu region of Northern Kenya between 2018 and 2025



Figure 4E: *Camels' population dynamics across the ten sub-locations in the Obbu region of Northern Kenya between 2018 and 2025*

For camels, recovery underscores the need for long-term breeding rather than short-term restocking. In southern Ethiopia, Wako and colleagues (2017) and in northern Kenya, Watson and colleagues (2016) report that the adoption of camels was attributable to their better drought adaptations. This is a common trend in other drylands (Josef et al., 2013).

At high drought frequency (every 2 years), cattle and sheep herds decline by over 70%, while goat and camel herds fall by 50–60% (Figure 5). Conversely, with moderate frequency (every 3 years), herds decrease gradually. Goats and camels demonstrate resilience, retaining 60–70% of their original numbers, while at low frequency (every 6 years), herds sustain 80–90% of their initial size. Recovery intervals between droughts allow herd regeneration, particularly for goats and camels. Camels are the least affected.

3.4. Changing Dynamics in Wealth Ranks

Recurrent droughts in Northern Kenya have profoundly reshaped household wealth structures among pastoralist communities (Fratkin & Roth, 1990). This is evident in the Obbu households, where recurrent droughts transformed households' wealth landscape from stratified pastoral prosperity to widespread impoverishment and dropout. During the 1983/84 drought, cattle per capita were around 6 per adult equivalent, falling to roughly 1.5 per adult equivalent after 1984 (a 75% decline). By 1996, five years after the drought, cattle per capita had fallen to fewer than 4 per adult equivalent. Destitution doubled, with more households falling below the 2-adult-equivalent threshold. This trend signals a weakened buffer capacity, reduced resilience, and a flattening of wealth stratification (Table 1). Although some households recovered during the post-drought phases, overall wealth stratification decreased, as households that were once wealthy or middle- wealthy either moved to lower categories or dropped out entirely. By 2011, households labelled as "poor," "impoverished," or "destitute" accounted for over 70% of all households, and only a few remained in the top wealth brackets undermining traditional Borana social redistributive mechanisms (Berhanu et al., 2017). By the 1990s and 2000s, especially after the 2010–2011 drought, these groups shrank dramatically. By 2011, dropout households accounted for a significant share of the population. This marks a structural transformation - pastoralism was no longer viable for many families, forcing them into alternative livelihoods. Formerly affluent households lost herds

and slipped into lower categories, showing that wealth was not durable under repeated drought shocks. This reflects cumulative herd losses: repeated calf and juvenile mortality, slow recovery rates, and an inability to rebuild before the next drought. Destitution became a common outcome, eroding traditional safety nets and weakening community resilience (Berhanu,2011).

Between 2018 and 2025, wealth rankings show a significant rise in destitution and dropout rates, alongside a decline in the number of households classified as wealthy or in the middle-wealth category. Here is a breakdown of the percentage change in household wealth ranks, based on total herd size, comparing initial to current herd figures (Table 1). The share of wealthy households fell from 12.6% to 6.2%, indicating substantial herd losses among previously affluent families.

Dropout rates rose by 9 percentage points, accounting for nearly 44% of households without livestock. Destitution doubled, with more households falling below the 2-head adult equivalent (i.e. a 50% decline below the subsistence level). The middle and self-reliant groups shrank, signaling downward social mobility and a weakening of buffer capacity. The ranks of poor and very poor remained relatively stable, but the slight rise in impoverished households suggests marginal survival. Dropout rates rose across all zones, particularly in the arid (+8.6%) and very arid (+8.9%) zones. These changes indicate significant increases in poverty, a pattern similar to that reported in Boraute categories expand, and dropout increases to ~20% before interventions (Table 3). With interventions, wealthy households would stabilize at ~15%, and dropouts would be halved. Feed subsidies prevent collapse into destitution. Following interventions, wealthy and medium households have higher probabilities of retaining their status or moving upward, while the probability of households falling into dropout is significantly lower, especially for poor and destitute groups. Indeed, self-reliant and poor households have a greater chance of moving into the medium or wealthy categories, reflecting the impact of restocking grants.

Household wealth transitions with and without development intervention under low frequency droughts (Table 4)**.** This scenario is less destructive than high- or moderate-frequency droughts, but the matrix still reveals important dynamics. Without development intervention, wealthy households retain a ~25% probability of staying wealthy, with moderate chances of sliding into medium

or self-reliant categories. Poor and very poor households still face significant probabilities of falling into destitution, though dropout rates remain low. With development intervention, wealthy households rise to ~35% probability of retaining their status, showing consolidation of herd capital. Interventions (restocking, feed subsidies, water access) sharply reduce the probability that households fall into the destitute or dropout categories. Medium and self-reliant households show higher probabilities of moving upward into wealthy or medium ranks, reflecting effective herd recovery.

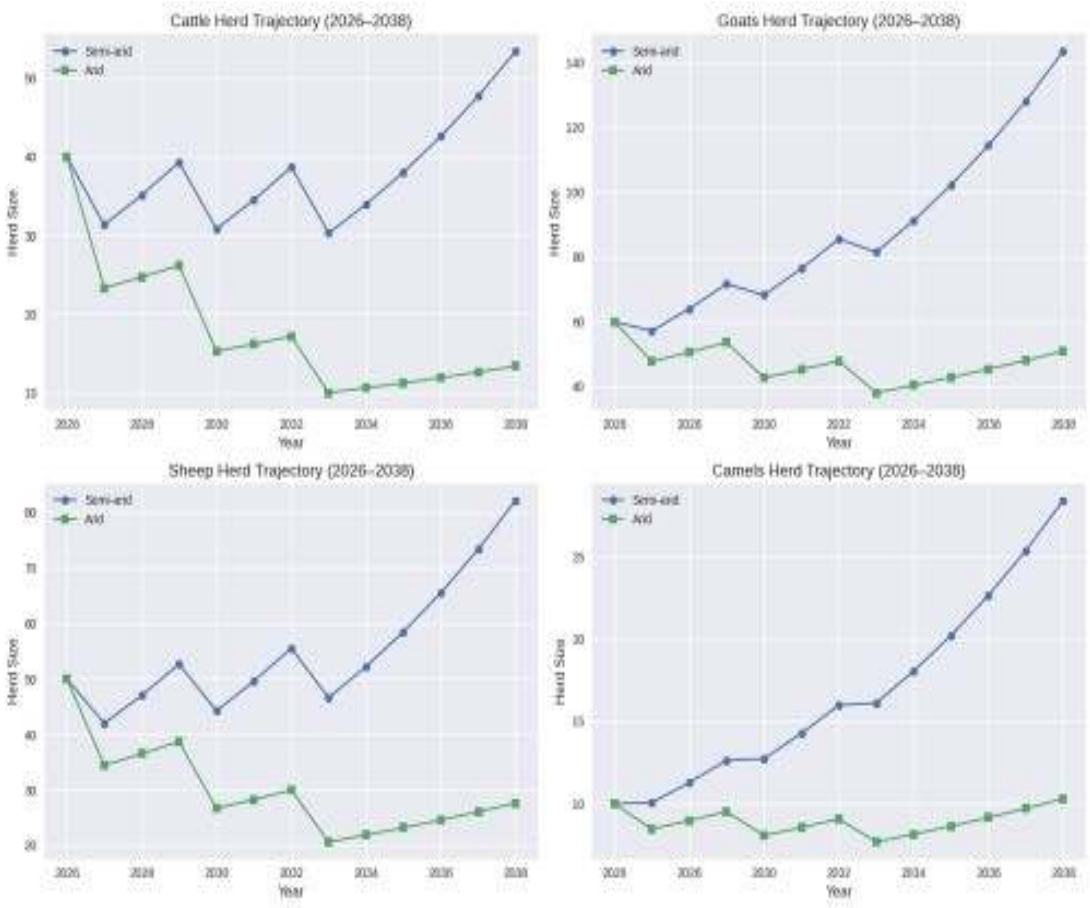


Figure 5: Simulated herd dynamics by species across the agro-ecological zones for the periods 2026-2038 using the 2018-2025 data series

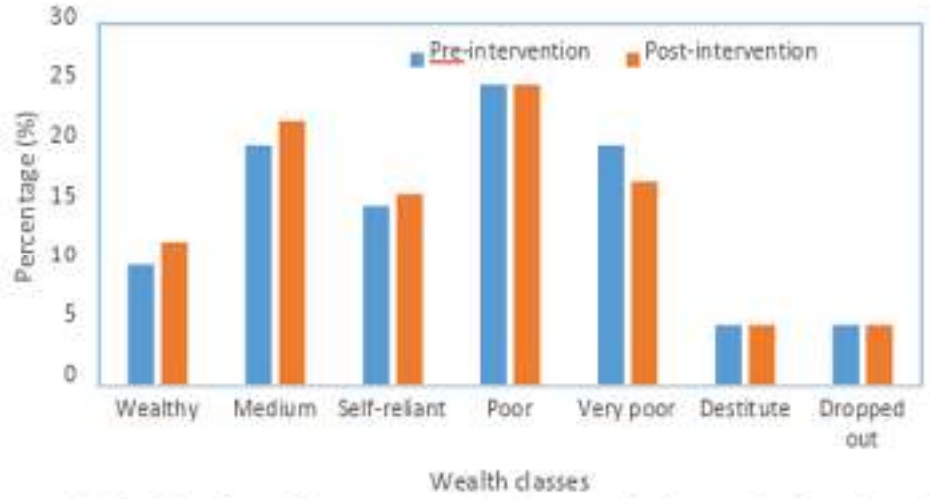


Figure 6: Simulated wealth category distributions before and after drought interventions

The restocking grant program (30% replacement of lost stock) is most effective at rebuilding medium-level wealth and halving dropout rates, delivering benefits that would support communities. Restocking grants help rebuild herd capital, but are not sufficient on their own. Conversely, feed subsidies (which reduce mortality by 25%) would have the greatest impact on preventing destitution by maintaining more households in viable pastoralism. Improved water access (a 20% increase in recovery) slightly enhances recovery across all wealth levels. Combining restocking grants, feed subsidies, and improved water access during drought cycles completely prevents household dropout. It delivers the highest impact per shilling invested – up to 3.5 times that of individual interventions (Figure 6).

Without these measures, all households will lose viability by 3036. These measures could reduce household drought losses by up to 86%. With bundled interventions, dropout nearly disappears, preventing irreversible exits from pastoralism. Thus, development support transforms low-frequency droughts into opportunities for resilience building, stabilizing stratification and sustaining pastoral livelihoods. It means that wealth stratification is preserved, upward mobility is possible, and dropout is nearly eliminated.

4. Conclusion

This study provides critical insights into how recurrent droughts reshape pastoralism in Northern Kenya's Obbu region. Drawing on a 34-year household panel dataset, the findings highlight cattle as the most vulnerable species, with

mortality rates exceeding 80–90% during severe droughts and recovery periods stretching over two decades. In contrast, small stock and camels demonstrate greater resilience, rebounding more quickly and increasingly forming the backbone of herd recovery. Despite these adaptive shifts, repeated drought cycles erode household wealth, collapsing stratification and driving formerly affluent families into poverty or destitution. By 2025, nearly 44% of households had exited pastoralism altogether, underscoring the structural transformation of livelihoods under intensifying climate pressures. Scenario modelling reveals that drought frequency is decisive in shaping household trajectories. High-frequency droughts (every two years) eliminate wealthy households and accelerate dropout rates, while moderate and low-frequency droughts still undermine recovery, as households lack sufficient time to rebuild before the next shock. Importantly, targeted interventions—restocking grants, feed subsidies, and improved water infrastructure—significantly reduce mortality, stabilize wealth categories, and prevent dropout. When combined, these measures deliver the highest impact, up to 3.5 times greater than single interventions.

Author Contributions: Gufu Oba, Hussien Tadhicha Wario, and Hassan Guyo Roba discussed the research design. Gufu Oba conducted a field study and availed longitudinal household data from earlier research (1983-2011), complemented by data from 2018-2025. Gufu Oba conducted data analysis and initial write-up. Hussien Tadhicha and Hassan Guyo participated in writing and commented on the work.

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Declaration: All the authors have read through the final document and approved its content.

Data Availability: Household longitudinal data on livestock populations and livelihoods are available on request.

Declarations: We declare that the research adhered to all ethical standards and customs of the community partners.

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Research Article

Climate-Resilient Conservation Farming Improves Crop Productivity and Food Security in Loka Abaya District, Sidama Region, Ethiopia

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Abstract

Conservation farming project was implemented at Loka Abaya district for two consecutive years (2013-2014) to conserve soil moisture, improve soil fertility, and enhance crop productivity and food security of the farming community using participatory action research and extension approach. The treatments involved include (1) ripper + fertilizer (R+F), (2) ridger + fertilizer (Rg+F), (3) conventional + fertilizer (C+F), (4) conventional without fertilizer (C–F), (5) ridger + fertilizer + intercropping (Rg+F+I) and (6) ridger + intercropping without fertilizer (Rg+I–F), using randomized complete block design (RCBD), replicated three times. The objective was to determine effects of conservation tillage practices on maize and haricot bean yields. The collected data were subjected to analysis of variance (ANOVA) using MINITAB software. After harvesting, a minimum of 30% of crop residues were retained on conservation plots. Maize growth performance under conservation farming was not attractive during the first implementation year as expected. During the second year, conservation tillage practices resulted in significantly ($P < 0.05$) higher maize grain and biomass yields as compared to conventional tillage. Interestingly, R+F supply improved maize grain by 50.0% and 29.4% as compared to C-F and C+F practices, respectively; correspondingly biomass yields increased by 157% and 76.3%. Similarly, Rg+F improved maize grain and biomass yields compared to conventional tillage. In addition to yield benefits, farmers reported that soil health had been already improved, soil moisture conserved and erosion reduced. Furthermore, conservation tillage practices saved farmers more labour, time and money investment for repeated tillage and weeding. The results demonstrate that household food security improved through increased maize grain yield by adopting conservation tillage practices. Therefore, we suggest the scaling up of these conservation tillage practices to wider farming community of similar agro-ecologies.

Keywords: crop residue retention, herbicides, micro dose fertilizer, soil health, soil moisture

1. Introduction

Agriculture is a leading sector in the economy of Ethiopia; employing over 80% of population, contributing more than 40% to national GDP and 90% of export, and provides basic needs and income to more than 90% of the poor (Diao, 2010). Currently, Ethiopia is under rapid economic growth and transformation. Consequently, the number of populations under extreme poverty was reduced from 38% to 29% during the last decade (WFP, 2014).

Despite the positive advances, Ethiopia remains one of the world's most food insecure countries, where approximately one in three people live below the poverty line (WFP, 2014). This happened due to severe land degradation, recent trends of climate change and lack of balance between food production and population growth. Shrinking farm sizes and land degradation have become worse in areas of ever growing population pressure, like in southern Ethiopia, partly attributed to existing traditional methods of land preparation, complete removal of crop residue, and low supply of manure and chemical fertilizers (DCG-Norway, 2015). According to Berry (2003), land degradation results in 3-4% annual GDP loss in Ethiopia. It is believed that soil fertility degradation in Ethiopia is mainly related with twin problems, which include economic limitation and lack of awareness by the farming community. Moreover, mismanagement of agricultural lands, complete removal of crop residues and minimal or no fertilizer inputs are considered as some of the factors that aggravate soil fertility depletion in Ethiopia (Wakene et al., 2012).

The continuous intensive soil preparation by hoe or plow leaves the soil exposed to rain, wind and sun. Soil organisms are destroyed by exposure to solar radiation and rapid drying of the soil. Soil inversion enhances the decomposition of organic matter in the soil through oxidation and leads to soil compaction, and increased water evaporation. Although in the short term, soil pores temporarily increase through tillage, they collapse once the soil settles leading to soil crusting and surface sealing which impedes rainfall infiltration (Thierfelder et al., 2013).

Maize (Zea mays L.) ranks third after wheat and rice in the world food grain production. It is grown extensively with equal success in temperate, sub-tropical and tropical regions of the world (FAO, 2011; Jaliya et al., 2014). Maize is consumed mainly as second-cycle produce in developed countries in the form of meat, eggs and dairy products, while in developing countries, maize is

consumed directly and serves as staple diet for some 200 million people (Plessis, 2003). Ethiopia is the fourth largest maize producing country in Africa, and first in the East African region (FAO, 2012). Maize is most productive and bulk of it is produced under rain fed condition, ranging from moisture stress to high rainfall areas.The total annual production and productivity of maize exceed all other cereals, except for tef (*Eragrostis tef*) in terms of total area (Benti et al., 1997). Maize has immense potential and a yield of up to 7.5 ha^{-1} can be harvested if properly managed (FAO, 2007). However, Ethiopia's average national maize grain yield is about 3.2 t ha^{-1} (CSA, 2015). Loka Abaya of Sidama Zone is one of the potential maize producing district in Ethipia. The maize production contribution of Loka Abaya could be further enhanced through appropriate tillage and agronomic management practices and use of improved seeds. This is because maize is the main staple food crop for the poor rural and urban dwellers of Ethiopia. Legumes also constitute important dietary protein source for the rural poor. Most legumes are traditionally grow in association with maize due to their similar environmental requirements (Girma et el., 2013).

Yield potential of any crop mainly depends up on its genetic makeup and environment. Both properties can be manipulated by application of modern technologies such breeding, biotechnology and agronomic management of the production conditions. Among these, conservation farming (CF) practice is a sustainable farming option that enhances soil fertility and structure, conserve moisture, and improve organic matter and soil health or address the problems of land degradation in general (Giller et al., 2009). In addition, conservation agriculture is an approach to farming that seeks to increase food security, alleviate poverty, conserve biodiversity and safeguard ecosystem services. Conservation agriculture practices can also contribute to making agricultural systems more resilient to climate change; proven to reduce farming systems' greenhouse gas emissions and enhance their role as carbon sinks (Greenhouse Gas Working Group, 2010). Conservation farming was begun to enhance the concerns about sustainability in agricultural systems that center on the need to develop technologies and practices that do not have adverse effects on environmental goods and services, are accessible to and effective for farmers, and lead to improvements in food productivity (Pretty, 2008). Moreover, it purports to address the problem of intensive labor requirements in smallholder agriculture (African Conservation Tillage Network, 2008). To

this effect, the study was designed to assess the effects of different conservation tillage treatments on maize growth performance, biomass and grain yields on farmers' field at Loka Abaya district, Sidama Zone, Ethiopia.

2. Materials and Methods

2.1. Site and cropping systems description

The study was conducted in Loka Abaya district, which is one of the 17 districts in Sidama Zone (Figure 1). The study area of the district is located in the great rift valley of Ethiopia with elevation ranges of 1580-1680 m, at $6^{O}42'04.3"$ to $6^{O}42'59.3"$ N and $38^{O}18'00.9"$ to $38^{O}18'33.0"$ E coordinates. It is characterized by intense heat and high evapo-transpiration, and with intermittent dry spells. Land degradation and water-logging problems are some of the features of Loka Abaya district. Originally, the conservation farming (CF) project was started at Borecha district in 2012, with finger millet and haricot bean, but was not successful. Hence the activities at Borecha was discontinued and transferred to Loka Abaya in 2013. Conservation farming project was carried out for two consecutive years (2013-2014) in three kebeles: Dessie, Jirmancho and Sala Kebado of Loka Abaya district, Sidama Zone of Southern Nations, Nationalities and Peoples Region (SNNPR).



Figure 1. Conservation farming implementation sites in Loka Abaya district, Sidama zone

Farmers in Loka Abaya practice mixed crop-livestock production along with diverse cropping systems. The majority of crops that are produced in the district are maize (Zea

mays), haricot bean (*Phaseouls vuligaris* L.), teff (*Eragrotis teff*), coffee (*Coeffa arabica*), enset (*Ensete ventircosum*), sweet potato (*Ipomoea batatas* L.), cow pea (*Vigna unguiculata* L.) etc. Indeed, farmers of Loka Abaya have good experiences in practicing inter-cropping, double and multiple cropping of cereals and legumes, to efficiently utilize the available land resources. Commonly maize and haricot bean are produced as inter crops in two cycles. During the first cycle, maize is often inter-cropped with haricot bean at planting or haricot bean inter-cropped immediately after maize planting. When the first cycle haricot bean matures, a second cycle haricot bean will be relay inter-cropped or during the second cycle teff may be cropped after removing the maize biomass. This is due to the fact that haricot bean and teff are short season crops.

2.2. Experimental Design and Treatments Set Up

Composite soil samples were taken randomly from each farmer plot before execution of the field experiments and baseline soil physical and chemical properties were analyzed in the laboratory. The experimental treatments were set up as Mother-Baby Trial and Baby Trial in randomized complete block design (RCBD). The treatments for Baby Trial were selected based on the preceding year performance of the Mother-Baby Trial design. The Mother-Baby Trial set up consists of six treatments (1) ripper with micro dose fertilizer (R+F), (2) ridger with micro dose fertilizer (Rg+F), (3) conventional with fertilizer (C+F), (4) conventional without fertilizer (C–F), (5) ridger with intercropping and with fertilizer (Rg+I+ F) and (6) ridger with intercropping and without fertilizer (Rg+I–F). Whereas Baby Trial experiments consisted of three treatments: R+F, Rg+F and C+F. On all conservation practices treated plots, at least 30% of crop residues retained, while crop residues were completely removed from conventional tillage plots except the root stalk. The weeds on the conservation plots were killed by spraying 2-4-D herbicide a month before plating. The herbicide was treated at the rate indicated on the product label. Manual weeding was also performed after planting.

All plots were prepared according to the treatments envisaged. For example, a plot that received R+F treatment was simply ripped and fertilizer was placed at the two sides of the maize seeds. Hybrid maize variety BH540 was used as a test crop being planted as spacing of 75 x 25 cm between rows and plants. Two seeds were planted per hole. Each treatment was planted on 10 x 10 m plot and then a total of six treatments were planted on a 600 m^2 plot of land.

Therefore, each farmer was considered as replicate having all the three or the six treatments. The blanket recommended fertilizers, 200 kg ha^{-1} Urea and 100 kg ha^{-1} DAP were applied in micro dose at sides of maize seeds. In plots that received treatments 5 and 6, haricot bean was late planted as inter-cropping and hence its establishment and growth performance was not satisfactory. Therefore, the biomass and grain yield of haricot bean was not considered in this report.

2.3. Statistical Analyses

The effects of conservation and conventional treatments on maize growth performance, grain and straw yields of maize were subject to analyses of variance using a general linear model (GLM) of MINITAB software packages. The mean value differences were separated by least significant difference and declared at the 5% level of significance.

3. Results And Discussions

3.1. Soil characteristics

The results revealed that the sampled soil texture, where conservation farming project was conducted varied from farm to farm. It appears that the majority of sampled soil texture ranged from clay to sandy clay across the farms (Table 1). These soil textures are expected to suffer water logging and aeration problems during excess rainfall conditions and moisture stress during dry spell, implying that there is a need for appropriate soil moisture management. The clay to silt ratio of the study site soils ranged from 1.0-2.9%, suggesting low to high level of weathering. Thus, clay to silt ratio has been used as an index of stage of soil development by many investigators, and high clay content showed complete alteration of weatherable minerals into secondary clays and oxides (Buol & Mc-Danie, 2003; Girma & Endalkachew, 2013). Organic carbon and total nitrogen contents of the studied soils ranged from low to high, i.e. from 1.09-2.49% and 0.07-0.20%, respectively, and OC/TN ranges from 9.8-22 across the kebeles. The soil pH of studied soils ranged from 5.4-6.9, while its electrical conductivity ranged from 0.04-0.12 ds cm^{-1}. These values are normal and indicators of good soil health condition for sustainable crop production potential, provided that appropriate management and crop residue retention are performed.

Table 1. Soil characteristics of participatory on-farm Mother-Baby and Baby Trial sites of Loka Abaya district of Sidama Zone, SNNPR collected during 2013

Village	Farm	OC	OM	TN	C/N	Sand	Silt	Clay
Desse	Farm 1	2.33	4.01	0.13	17.3	28	35	37
	Farm 2	2.49	4.30	0.14	18.1	40	23	37
	Farm 3	1.88	3.29	0.18	9.8	31	29	40
	Farm 4	1.09	1.88	0.08	13.8	26	36	38
	Farm 5	1.42	2.44	0.09	15.3	22	38	40
	Farm 6	2.36	4.07	0.15	18.2	42	21	37
Jirmancho	Farm 7	1.59	2.47	0.12	13.5	42	22	36
	Farm 8	0.57	0.99	0.11	5.3	42	16	42
	Farm 9	2.17	3.74	0.15	14.6	26	19	55
	Farm 10	1.90	3.22	0.13	10.4	31	33	38
	Farm 11	1.55	2.67	0.07	22.0	44	28	28
Sala Kebado	Farm 12	1.86	3.20	0.11	12.9	32	26	42
	Farm 13	2.27	3.92	0.14	16.5	38	26	36
	Farm 14	1.58	2.6	0.07	11.9	32	28	40
	Farm 15	2.13	3.66	0.15	14.2	42	18	40
	Farm 16	2.31	3.98	0.20	11.8	36	28	36
	Farm 17	1.71	2.99	0.11	14.7	50	14	36
	Farm 18	1.86	3.20	0.11	16.7	36	25	29
	Farm 19	2.27	3.92	0.14	16.8	32	26	42

Key: OC = organic carbon, OM = organic matter, TN = total nitrogen and C/N = carbon to nitrogen ratio

3.2. Effect of CF on growth performance, grain and biomass yield

The results revealed that maize performance was not attractive enough under conservation farming treatments during the first implementation year (2013). Indeed, conservation farming treatments mostly resulted in comparable grain and biomass yields to the fertilized conventional tillage practices. However, maize-haricot bean intercropping without fertilizer under tie-ridging displayed exceptionlly low yield than conventional tillage (Table 2). The poor perfomance under tie-ridger during the fisrt year was attributed to low fertilizer supply, weed infestation, high knowdge demand of the practices and waterlogging problems. This finding complies with several earlier results as minmim tillage precludes the proper aeration, leads to poor root growth and weed infestation (Thierfelder et al., 2013). Furthermore, as common to most projects in Sub-Saharan Africa, implementation of conservation agriculture faced difficulties in the first year (FAO, 2009).

Table 2. Effects of different conservation tillage practices on farmers' fields in mother-baby trial at Loka Abaya district of Sidama Zone, SNNPR during 2013

Treatments	Grain yield (t ha^{-1})	100 seed weight (g)	Plant height (cm)	Biomass yield (t ha^{-1})
Ripper + Fertilizer	2.35^{ab}	27.3	142.1^{b}	7.07
Tie-ridge + Fertilizer	2.15^{ab}	26.2	148.2^{ab}	7.01
Conventional + Fertilizer	2.38^{ab}	25.6	167.8^{a}	9.96
Conventional – Fertilizer	2.02^{ab}	26.8	157.1^{ab}	-
Tie-ridge +Int. + Fertilizer	2.20^{ab}	28.4	138.2^{b}	7.0
Tie-ridge + Int. –Fertilizer	1.72^{b}	25.2	150.1^{ab}	7.49
LSD (5%)	0.65	NS	23.4	NS
CV (%)	26.2	22.7	16.8	13.7

Key : Int.= intercropping. Means followed by the same letter in a column are not significantly different.

During the second year, conservation farming treatments along with micro dose fertilizer tested significantly ($P < 0.05$) affected plant height, cob weight, seed weight and biomass yield of maize (Tables 3 and 4). In R+F treated plots, maize seed weight was increased by 12.7% and 21.0% as compared to C+F and C-F, respectively. Similarly, R+F improved maize stover (biomass) yields by 29.4% and 76.3%, as compared to C+F and C-F practices, respectively. Furthermore, ridger with micro dose fertilizer application (Rg+F) improved maize biomass yield over conventional tillages. This implies that ripper and ridger resulted in minimum soil disturbance only along the row line. Results from Zambia showed maize yields increase by 78% in a direct seeded conservation agriculture treatment, using cowpea in a full rotation after four cropping seasons (Thierfelder et al., 2013). The present findings confirm the advantages of conservation farming over conventional tillage that resulted in conservation of soil moisture through enhancing drainage and reducing erosion, low soil disturbance and mulching of crop residues (Pretty, 2008; Giller et al., 2009). Besides, we claim that CF could increase organic matter, microbial biomass and activity via crop residue retention that are crucial for improvement of soil structure and soil health. We further claim that micro dose fertilizer application could have played substantial role in enhancing both N and P fertilizer use, through fostering access of nutrients to plant and restricting leaching, volatilization and fixation of nutrients. Therefore, further studies should be conducted to disaggregate the effects of tillage, residue retention and micro dose fertilizer application in CF. In general the benefit of conservation farming practices observed here confirmed the earlier findings that stated plowing (repeated plowing) in the long term destroys soil structure and

contributes to declining fertility and organic matter levels (FAO, 2009).

In the present study, farmers reported that conservation farming revealed many benefit to their soils that attribute to higher grain and biomass yields than conventional tillage. These benefits include biomass retention (a minimum of 30%), soil organic matter and fertility improvement, and soil moisture conservation as dry spells are common problems to the study areas. Farmers also reported that the soil biota that are observable by naked eyes were revived that they claim to be only available in highly fertile soil and good indicators of soil health.

Conservation farming practices significantly ($P < 0.001$) affected maize grain yield (Tables 3 and 4). Ripper with micro dose fertilizer supply (R+F) improved maize grain yield by 50.0% as compared to conventional tillage with fertilizer supply (C+F). Likewise, ripper with micro dose fertilizer (R+F) increased maize grain yield by 157% over conventional without fertilizer (C-F). Furthermore, ridger with micro dose fertilizer supply (Rg+F) improved maize grain yields relative to C+F and C-F (Tables 3 and 4). Interestingly, conservation farming practices at Loka Abaya kebeles revealed a yield increase over national average maize grain yield (3.2 t ha^{-1}; CSA, 2015), but comparable with that of the world average yield, 5.1 t ha^{-1} (FAO, 2008). The high yield response of CF treatments in the present study could be attributed to high rates of N and P fertilizer supply, in compliance with that of 73% of the meta data that showed conservation agriculture practices require high inputs especially N for improved yield (Rusinamhodzi et al., 2011).

The present findings revealed a yield benefits of both grain and biomass within two years of experimentation (Tables 3 and 4) as opposed to many earlier reports that stated crop yield benefits from CF usually occur in the long term, while associated costs are immediate (Corbeels et al., 2011; Rusinamhodzi et al., 2011). These disparities may be attributed to many factors, including climate, soil and management. Indeed, this finding complies with the statement that indicates CF is undoubtedly an option that can result in substantial benefits for certain types of farmers in certain locations (Giller et al., 2009). Although economic benefit of CF was not assessed in the present study, yield benefits and the labour saved due to reduction of repeated tillage could plausibly result in profitable CF. Nevertheless, it is important to document the increased amount of labour required for weeding in CF and or the cost of herbicides for weeds control in

order to estimate the economic profitability of CF relative to conventional tillage in the future. It is obvious that CF promotes weed infestation and hence increased amount of labour required for weeding.

In all treated plots of conservation practices, a minimum of 30% (average of 4.1t ha^{-1}) crop residues were retained. Indeed, few highly interested farmers retained 100% of the biomass on the fields of conservation farming plots. It is remarkable to note that on-farm retention of crop residue has immense contributions towards soil management. It improves soil organic matter, increases soil fertility and water holding capacity, improves soil microbial biomass and activity (Hossner & Juo, 1999; Omotayo & Chukwuka, 2009). In addition, the conservation tillage practices along with crop residue mulching inadvertently promote farmers adaptation to climate change. Therefore, raising farmers' awareness through engaging them in the process of implementation and evaluation of new technologies, particularly conservation farming practices have paramount importance in restoration of degraded lands and fostering climate change adaptation and mitigation. Some of these are long term benefits, as contrary to what most smallholder farmers of Africa unusually value, i.e. immediate costs and benefits due to their immediate economic and food security constrains (Rusinamhodzi et al., 2010; Corbeels et al., 2011).

Table 3. Effects of different conservation tillage practices on farmers' field in Mother-Baby Trial at Loka Abaya district of Sidama Zone, SNNPR during 2014

Treatments	Plant height (cm)	Cob yield (t ha^{-1})	Biomass yield (t ha^{-1})	100 Seed weigh (g)	Grain yield (t ha^{-1})
Ripper + fertilizer	207.3a	6.2a	14.1a	48.9a	5.4a
Ridger + Fertilizer	219.7a	6.0a	12.9ab	50.6a	4.1b
Conventional + Fertilizer	203.0a	5.2a	10.9b	43.4b	3.6b
Conventional – Fertilizer	179.4b	3.1b	8.0c	40.4b	2.1c
Ridger + Intercropping + F	181.1b	5.1a	10.9b	43.8b	3.7b
Ridger + Intercropping – F	174.4b	3.7b	8.3c	39.0b	2.4c
LSD (5%)	13.2	2.2	1.8	1.9	1.1
CV (%)	16.0	10.2	13.7	11.9	12.1

Key: +F = fertilizer supplied and –F = fertilizer not supplied.

Table 4. Effects of different conservation tillage practices of maize agronomic parameters on farmers' field under baby trial at Loka Abaya district of Sidama Zone, SNNPR during 2014

Treatments	Plant height (cm)	Cob yield (t ha^{-1})	Biomass yield (t ha^{-1})	100 Seed weigh (g)	Grain yield (t ha^{-1})
Ripper + Fertilizer	181.8	6.6	19.5	45.1	6.0a
Ridger + Fertilizer	183.0	5.8	16.7	44.3	5.0b
Conventional + Fertilizer	183.9	5.3	15.1	40.6	4.5b
LSD (5%)	NS	NS	NS	NS	1.5
CV (%)	15.1	14.0	11.9	9.4	10.0

3.3. Effect of landscape on maize grain and biomass yield

Maize grain and biomass yields were significantly ($p < 0.0001$) varied among kebeles related with the differences in inherent soil characteristics and history of management practices rendered by farmers. According to the present findings, in Dessie, Jirmancho and Sala Kebado PAs (kebeles) grain yields of 5.2, 4.2 and 2.4 t ha^{-1} were recorded, respectively (Table 5). The yield differences among the three study kebeles correlate with topography of the areas. Dessie and Jirmancho PAs are relatively gentle in slope than Sala Kebado; consequently soil depth and level of erosion of soil in the kebeles might greatly vary. Soils respond differently to management depending on the inherent properties of the soil and the surrounding landscape. Therefore, conservation agriculture aims to address the problems of soil degradation resulting from agricultural practices that deplete the organic matter and nutrient content of the soil (Giller et al., 2009).

Table 5. Effects of kebeles or landscape on agronomic parameters of maize under different conservation tillage practices at Loka Abaya district of Sidama Zone, SNNPR during 2014

Kebeles	PH	CY	ABY	100 SW	GY
Dessie	190.8b	6.9a	18.8a	45.1a	5.2a
Jirmancho	228.6a	6.8a	14.5b	44.3a	4.2b
Sala Kebado	172.4c	3.6b	8.0c	40.6a	2.4c
LSD (5%)	20.0	3.0	4.1	3.0	0.8
CV (%)	11.5	7.0	11.8	16.3	13.0

Key: PH= plant height (m), CY = cob yield (t ha-1), ABY = above ground biomass yield (t ha-1), 100 SW = 100 seed weight (g) and GY = grain yield (t ha-1)

In addition to the economic yield benefits, farmers reported that their soil's health has been already improved, moisture conserved and erosion reduced across the landscape. Furthermore, host farmers reported that the CF practices saved farmers from investing more labour, time and money in repeated tillage and weeding. This finding confirmed the claim that CF addresses the problem of intensive labour requirements in smallholder agriculture (African Conservation Tillage Network, 2008). The results demonstrate farmers' food security improvement by increasing yield from a unit plot of land through adopting conservation tillage practices. Therefore, we recommend scaling up conservation farming practices and enhancing farmers' capacity through continuous training and field demonstrations for wider adoption. It is also essential to document soil fertility and soil organic carbon dynamics for assessment of carbon sequestration potential of conservation farming. Furthermore, it is vital to point out

that despite the fact that herbicide was treated to CF plots over the two study years, it was not as effective as expected in killing weeds perhaps due to adulteration. This calls for appropriate regulatory policy to be in place for agricultural inputs supply.

3.4. Effect of conservation farming on weed infestation and labor requirement

Although weed infestation was reported to be high during first year (2013) of conservation farming implementation, no record was made. However, the effect of treatments on weed infestation was assessed in three kebeles during the second year (2014). Weeds were removed three times during the cropping season and their weight were registered (Table 6). Non-significant ($p < 0.05$) differences were observed among treatments in affecting weed infestation (weed weight plot^{-1}) across the three cycle of weeding across the study areas. This implies that labor demand for conservation farming was comparable with that of conventional tillage across the three cycle of weeds removal (Table 6). Weed infestation tended to be slightly higher in ripper treated plots than ridger and conventional tillage, due to the fact that under ripper soil disturbance was minimal than others. More weed infestation was observed in Dessie than other study areas (Sala Kebado and Jirmancho), attributed to its higher soil fertility than others. Therefore, based on yield and economic benefits, we suggest the scaling up of conservation farming practices to wider farming community of similar agro-ecologies.

Table 6. Effect of conservation farming practices on weed weight (kg plot^{-1}) and labour requirement for weeding (man day plot^{-1}) at Loka Abaya district of Sidama Zone, SNNPR during 2014

Kebele	1st cycle weed weight	2nd cycle weed weight	3rd cycle weed weight	Labor for 1st cycle	Labor for 2nd cycle	Labor for 3rd cycle
Dessie	164.65	96.36	92.62	0.372	0.309	0.225
Jirmancho	102.31	92.88	87.53	0.368	0.304	0.204
Sala Kebado	88.67	82.17	76.16	0.333	0.275	0.199
LSD (5%)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**27.83**	**26.44**	**28.06**	**22.20**	**24.07**	**27.24**

3.5. Effect of farmers' capacity building on achievements

Given the complexity and the knowledge intensive nature of CF systems and the need to tailor CF practices to local conditions, a strong capacity building work is crucial in problem-solving around CF among farmers, development agents and researchers (Corbeels et al., 2011). In view of this, the capacity of farmers was enhanced through action research and extension approach, which includes demonstration and field days during field preparation, planting and weeding through crop physiological maturity. In addition, the project annually organized trainings during the project implementation periods for male and female farmers, development agents and experts. It is simple to imagine that the success of CF in terms of yield gain over the national average maize grain yield was highly significant achievements. This is attributed to farmers' capacity building, good field management and recommended input supply. However, there have been arguments that CF adoption in Sub-Saharan Africa (SSA) is low due to the socio-economic conditions and the knowledge-intensive nature of implementing CF (Giller et al., 2009). Furthermore, others also reported that CF can only improve food security in SSA if farmers have access to herbicides and fertilizers (Gowing & Palmer, 2008). The present findings share the same view that crop performances under CF would be superior with use of appropriate inputs (N and P fertilizers) and with well-trained farmers. If the conservation farming practices implemented by the input support of the project continue, the farming systems at Loka Abaya will become climate-resilient and sustainable. Nevertheless, the issue of wider adoption and expansion of the CF technologies still needs more capacity building, besides making inputs- seeds, fertilizers and herbicides- available at affordable price.

4. Conclusion

Conservation farming (ripper and ridger) significantly improved maize biomass and grain yields relative to conventional tillage practices. The improved biomass serve as organic fertilizer and animal feeds during the dry season, while the grain yield increase consequently enhance food security of smallholder farmers. In addition, the present conservation farming achievements are the combined effects of minimum soil disturbance, micro dose fertilizer supply and crop residue retention that need to be disaggregated in the future through separate experiments. Farmers' capacity building via use of participatory action-research and extension approach remarkably fostered the adoption of improved conservation farming

technologies. Nevertheless, it was observed that communal grazing would negatively impact the sustainability of conservation farming technologies. Therefore, we recommend important intervention that introduces forage crops (grass and legume) to restrict communal grazing in the district.

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Research Article

Ethical Considerations and Animal Rights in the *Borana Gadaa* System: A Comparative Analysis with Western Philosophical Perspectives

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Abstract

This study examines the guiding ethical principles and customary rights regarding animals within the context of the Gadaa system of the Borana Oromo people of Ethiopia. A comparative analysis is undertaken with the Western philosophical conservationist approach which often reflects anthropocentrism and utilization of animals as mere natural resources for economic benefits. The study employed an ethnographic research design including interviews and focus group discussions to gather rich information and living evidences from selected knowledgeable elders, Abbaa Gadaa (community leaders), Haadha Siiqqoo (women in customary political power), herders, and park officials located in the study area. Observations also were carried out in and surrounding the Borana National Parks, wildlife sanctuaries, and grazing landscapes to gain an understanding of how the Borana people protect and preserve animals through the established rights and moral obligations induced by the Gadaa system in their daily lives. The study reveals that customary laws, morals, and taboos enshrined in the Borana Gadaa system grants rights to survival, safe passage, access to water, pasture and reproduction rights to non human animals, practiced since time immemorial. This symbolizes an indigenous model of environmental stewardship and harmonious relations between animals and non animals, contrasting with Western or modern paradigms that prioritize human needs and also separate human and animal reciprocal relations in the natural environment. The article concludes that the Borana Oromo Gadaa system contributes in animal well-being mitigates extinction by and through the established customary laws and ethical protocols through maintaining mutual inter dependence between animals and non-animal humans.

Keywords: *Gadaa*, animal rights, Western perspective, *Borana Oromo* people

1. Introduction

Mismanagement of animals and their landscape is a pressing problem in contemporary world (Bradshaw, 2018). Animal rights, conceptually, are legal or cultures induced moral frameworks grounded in the belief and/or premise that non-human animals deserve the right to life and should not be subjected to death and extinction. For this, the animal rights movement often focuses on protection of wildlife, livestock, and so on (Bradshaw, 2018). In fact, human beings have the power

to affect animals either positively by creating a conducive environment or negatively by posing existential threats (Fraser & MacRae, 2011). Animal law and ethical code has developed for the well-being of animals (Peters, 2016). In exceptional cases, however, there may be moments when animal life could be deprived (Bryant, 2020). From an ethical Within the *Gadaa* system of the *Borana Oromo* people, which has been in practice for centuries, ethical considerations and customary laws have been applied in relation to animal rights and relations with non-humans in a shared natural environment. Despite this, there has been limited attention from scholars in one hand and there has been state intervention by establishing multiple National Parks and Wildlife Sanctuaries that are part of animal conservation policy in the study area on the other. No one denies that such modernist interventionist approach is the value Western philosophical notion that promotes separation of animal and non-animal relations. In this case, Regassa et al. (2017) indicated that disruptions of human and animal relations, for instance, with wildlife, forests, spirits and so on is often perceived that it would displease *Waaqa* (sky God) and cause punishment in the form of drought, death, disease and conflicts.

The objective of this paper is to comparatively analyze the animal rights and

standpoint, this raises moral and legal questions regarding how and in what ways such action could be acceptable or not across multi-cultural settings. This illustrates the absence of 'universal' moral principles and legal system that govern human-animal relationships and protect animals from harm (Cederholm et al., 2014).

ethical guidelines coded in the *Borana Gadaa* system, alongside Western or modern knowledge. Western environmental ethics, are traditionally rooted in the dialectic between anthropocentrism and biocentric individualism, often frame animal rights through the lens of human utilitarianism (Bernet, 2025). This sharply contrasts with the *Borana Oromo* indigenous philosophical approach where animals are not merely subjects with rights-bearing status but they are integral components of *woyyuu/safuu* (spiritual and moral values) that maintains balance between the Creator (*Waaqa*), nature, and humanity. In this case, for instance, the mistreatment of animals (livestock or wildlife) is regarded as a breach of *ayyana* (spiritual essence) (Kelbessa, 2023). What is understandable as a 'conflicting epistemology' in this case is that the Western model often relies 'only' on the legalistic enforcement of animal rights and separation from people, while the *Gadaa* system embeds animal well-being within an

internal ethical framework that sees the flourishing of non-humans as inseparable entities from the people.

2. Materials and Methods

Ethnographic filed work was employed in this study. In this case, purposive and snow ball sampling was used as tools for collecting deep and rich information, including from *Abbaa Gadaa* (community leaders), *Haadha Siinqqoe* (women in indigenous political power), herders, and also park officials—from Yaballo, Dirre, and Arero areas located in the study area. These localities were chosen due to the presence of relevant participants in one hand and National parks and wildlife sanctuaries that exemplify the modernist idea of animal protection approach on the other. In addition, as a technique of gathering information from the field, observation was used in *Borana* National Park, Yabello Wildlife Sanctuary, and pastureland in Arero District. Musante & DeWalt (2010) noted observation enables to witness firsthand information within various settings including in daily activities. The above-mentioned methods collectively ensure that data collection captures from multiple. In this article, twenty key informants for in-depth interviews and two focus group discussions each containing eight members, and four park officials totaling forty participants were included. The collected data is qualitatively comparatively analyzed. Smelser (2013) notes comparative analysis essential in the social sciences. This study, the field work was done in 2024 and 2025.

Research sources show that the start of modern animal right issue traces back to the early 1970s that started in England by intellectuals and philosophers (Kean, 1998). In this contemporary world, animal right is remained as a subject of debate that emerge from different perspectives of multidisciplinary lenses extending from cultural, moral, legal and political matters (Moore, 2005). Such debates include in what ways animals should be protected and whether or not animals possess inherent legal rights. Animal rights advocates the basic interests confer moral rights to animals (Franklin, 2004). In line with this, today, there are countries that have developed animal rights (Garner, 2019). The author further noted that the United Kingdom's Act of Zoo prohibits keeping primates with and without a license. Garner further noted that the law established basic guidelines for sale, transport and handling animals. The Canadian legal frameworks grant suitable food, water, shelter and care to animals (Hughes & Meyer, 2000) while the Australian Animal Welfare Act of 2004 states causing 'malicious' harm to animals that range from penalties in thousands of dollars to imprisonment (Chen, 2016).

Denmark's Animal Welfare Act of 2021 also suggests that animals should be treated properly and protected from suffering including psychological pain. Rodriguez et al. (2021) argued that human animal relation has plagued with mixed results that promote animal well-being and the opposite on the other. Abebe (2021) argues that animal's worth inherent right including not to suffer from unwise human actions.

Evidences show that around 80 billion animals are slaughtered for food in each year on our planet earth (Garber, 2016). Other scholars indicate that individual economic interests toward animals deserve recognition, and at the same time, protection for animal well-being (Feinberg, 2017). Villanueva (2018) proposes a justifiable moral principles for animals like non-human animals is essential. The above notions of animal rights are emerged from the modern or Western philosophical approaches that promote separation human animal relations. This article contributes to the indigenous notion of harmonious relationships between animal and non-animal humans.

3. Description of the Study Area

The *Borana Oromo* people inhabit South Eastern part of Ethiopia and also in Northern Kenya in the natural environment classified as arid and semi-arid, that grow savanna grasses perceived as conducive for livestock production. In fact, the *Borana Oromo* are predominantly pastoralists who rely heavily on livestock herding as their main livelihood and have a deep connection to the local ecology (Abebe, 2021). They are characterized by mobility, nature of adapting to seasonal changes and resource availability, crucial in arid and semi-arid regions. They often rear goats,camels, and cattle. Recently, they have adapted semi-agriculture activities including wheat production (Yadeta, 2013).

The state has established National Parks and wildlife sanctuaries in the area (Oromia Tourism and Culture Bureau, 2024). These include the Chelbi Wildlife Reserve, Geraille National Park, Yabelo Wildlife Sanctuary and Arero natural forest. From 2019 – 2023, the *Borana* parks and the *Borana* people faced a tremendous drought that caused losses of livestock and wildlife like Zebra, wolf, lion, elephant and birds like ostrich and others migrated and others died (OBN, 2022).

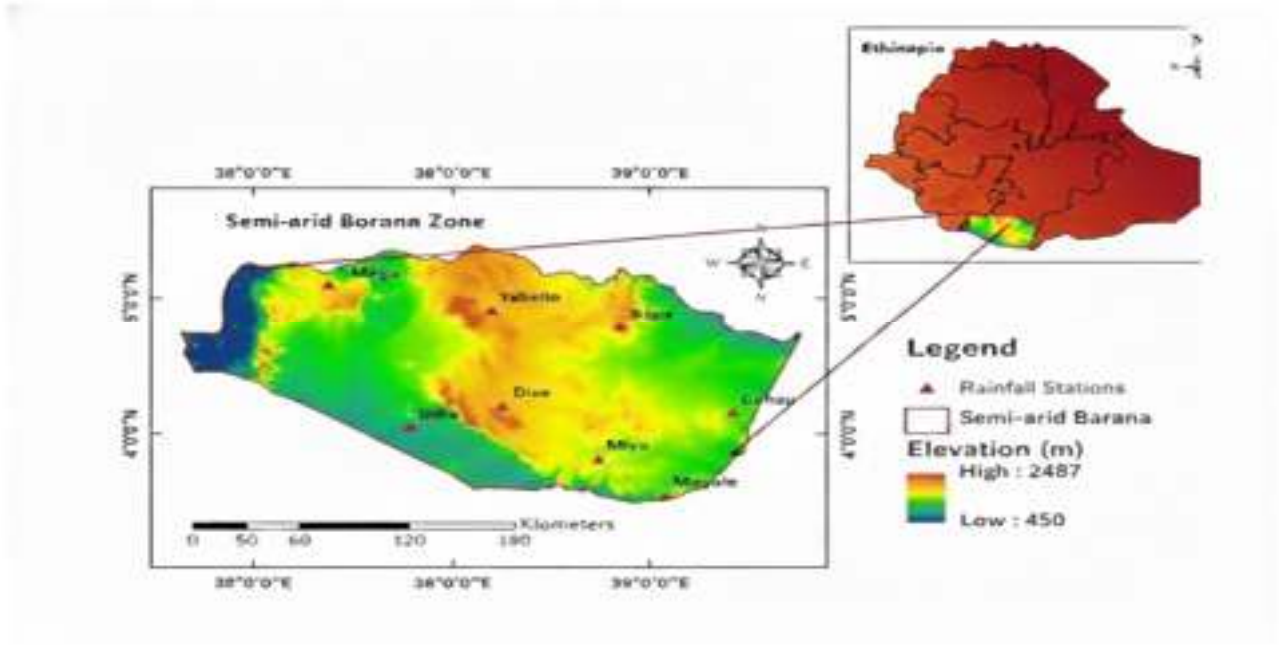


Fig 1: Study area map adapted from Gallinaro et al. (2018).

4. Results And Discussions

4.1. Sacred Spaces As Safe Refuge For Wildlife in *Borana Gadaa* Law

The concept of sacred land is common among many peoples worldwide (Mangena, 2013). The *Gadaa* system, a sophisticated indigenous institution of the *Borana Oromo* people possesses hundreds of sacred sites that serve as destinations for pilgrimages traversing across various traditional lands of the *Borana Oromo* for governance, military, and ritual purposes.

These sites are regarded as *woyyuu(sacred),* having miraculous spiritual powers. Consequently, such sites are honored more or equal to Christian chapels and mosques within the *Borana Gadaa* culture. The *Gadaa* laws forbid cutting down trees, killing, or inflicting any harm on wildlife within these sacred territories. Consequently, for instance, a person who kills an animal in any sacred land is often subjected to face justice, as per the *Gadaa* laws, which range from giving advice, warning, to confiscation of cows and corporal punishment, depending on the severity of the case committed. Concerning this, one of our respondents stated his experience as follows:

> *Wildlife is protected in the sacred lands equally as respectful ritual elements. The Borana men and women understand this very well. Even if someone kills an animal in such lands secretly, he may escape punishment under the Gadaa system, but he is in the eyes of Waaqa (the sky God). In our culture, it is believed that such a person will face bad luck in life including early death*

and animals such as lions may seek revenge by killing his cattle.

This notion illustrates that the *Borana Gadaa* system designates sacred sites for cultural practices, community gatherings, and beyond serving as a "safe haven" for wild animals. And the shared legal value of animal protection across generations provides a framework for animals to live in harmony among the *Borana*. The *Borana* customary laws exist in unwritten form, sometimes amended by *Gumii Gaayyo* assembly, proclaimed and interpreted by the *Hayyuu* (traditional legal experts). In this case, the customary laws stemming from the *Gadaa* system have legal characteristics on the one hand and spiritual dimensions on the other hand, making the system more effective concerning animal protection compared to modern statutory or modern secular legal systems.

In relation to the spiritual perspective, there is a belief that killing an animal in the sacred lands leads to negative repercussions for the perpetrator of this immoral act. In fact, *Borana Oromo*'s sacred shrines are integral to *Gadaa* that encompasses rituals, religion and the myths surrounding their formation. Scared lands are communal property of the *Borana* people, encompassing extensive areas of land that are collectively safeguarded by *Gadaa* laws. This institution is developed for the well-being of ecosystems (Abebe, 2021). The author acknowledges the *Gadaa* as a living example of an African indigenous institution that manages and utilizes natural resources wisely. Regassa (2017) indicated that the indigenous laws of the *Oromo* society promote harmonious ties between *Waaqa* (sky God and humans and animals. On the other hand, the human-animal relationship in the non-Western world is built on the principle of human superiority (Ingold, 2012). Hosey & Melfi (2014) examined the peaceful connection between people and animals, highlighting that behaviors influencing this relationship are essential for the mental, physical, and social health and well-being of both parties.

4.2. Ethical Stewardship Concerning Animals

The ethical guidelines (for example, concerning wildlife protection and extinction mitigation) derived from the *Gadaa* system of the *Borana Oromo* promote the well-being of non-human animals. These ethical codes are internalized in the form of cosmic values, for instance, what is acceptable and what is not related to animal stewardship in the *Borana* tradition and worldviews. The focus group discussants indicated that even during hunting days, it is unethical or taboo to kill pregnant and young animals for food consumption in accordance with the *Borana Gadaa* culture. Instead, hunting the older

animal is allowed in this case.

Another respondent from the study area told us the following:

> *During the past drought seasons, many wildlife died, and many of them left the forest, and many of them lost their stamina as a result and scattered into villages and residential areas in searchfor water and food for survival. In that condition, I know the Borana people who saved cubs of lions and tigers, as well as calves of ibex and antelope, by assisting them with meat, milk, and water.*

This evidence shows how the caregiving practices as part of the moral codes mitigate wildlife extinction in a harsh environment, especially during dry seasons among the *Borana*.

4.3. How *Ayyaana* /spiritual/ dimensions of animal rights are manifested in *Borana* culture?

Several indigenous peoples regard animals as sacred, which is conceptually connected to spirituality (McGinnis et al., 2019). In this case, the author indicated that 'spirituality' indicates belief that the natural world contains both material and spiritual entities, in which the material world can be visible while the spiritual world is allied to the invisible powers that direct events in the course of life. Within the context of the *Borana Gadaa* system, both human and non-human animals have spirits and relations. In this case, different animals convey spiritual powers, categorized into two types, namely fortune (*danbooba*) and evil spirit (*farra*). In line with this indigenous notion, it is conceived that animal movements, voices, deaths, and so on signal messages and new updates within the *Borana Oromo* cultural setting. Such symbolization is often defined by *Borana* elders for the local community. Concerning this, one experienced person said the following:

> *A big lion killed camels and cows in different villages in one of the Districts of the Borana Zone in 2016. The owners of the livestock reported to a knowledgeable elder in the area and asked him what the lion conveyed by killing livestock. The elder told them that the lion indicated armed men would come seeking to grab the ancestral lands of Borana and fight the Borana people. The elder warned not to kill that lion in Borana lands as it would have spiritual consequences on the local people. We respected his advice because it is a sacred warning. Later on, that lion left the area after a few weeks, and conflicts arose between the Somali and Borana over land claims a few*

months later.

Another key informant narrated:

> *Our ancestors did not have modern communication tools like mobile phones and radios to gather and transfer news. They taught us that animals are messengers of information on a daily basis. For example, when we plan to go on a long journey, initially we listen to the sounds of birds and watch animal movements, often in the afternoon and early morning. If the signals we received are good, we proceed and reach our destination safely. But, if the message discouraged us, we would cancel the plan and postpone the journey. We believe animals are reliable in conveying information. Additionally, we don't have books to read and understand, as most of our elders are not formally educated. Our books are the intestines of animals. We interpret and understand what will happen by examining the intestines. This is the reason why we respect animals laws in our tradition (key interview, June 2015.*

The *Borana* elders are more experienced than the younger generation in possessing customary laws and interpreting meanings related to animal movements and spiritual messages they are carrying and transferring. In relation to this, it is also perceived that certain birds are viewed as messengers between heaven and earth to humans according to *Borana* culture. *Borana* elders' carefully analyse the definitions for the movement or voice of an animal in a specified circumstance and follow up from day to day. The information collected in this way enables the *Borana* elders to make decisions, provide early warning advice and solutions to upcoming challenges, for example, through well-preparedness, prayers, rituals, and so forth. This indicates that wildlife protection is an integral part of the *Borana* belief system and worldviews aimed at a better life. In fact, the relationship between humans and other animals is culturally constructed (Stibbe, 2005). And ritual performances through sacrificial slaughter constitute a widespread practice on the African continent as well as in all world religions and several cultural ceremonies (Horsthemke, 2019)**.**

4.4. Ethical Protocols For Animals During Parturition And While Consuming Drinking Water

The social, political, spiritual, and lifestyle practices of the *Borana* people, along with their deep attachment to the local ecology, are governed by their indigenous *Gadaa* system. In fact, animals are source of food and medicine, and also have physical and spiritual ties with humans (McGinnis et al.,

2019). The author further noted that many traditional societies possess local knowledge that enables them to 'understand' animals. Horsthemke (2017) indicated that African ethics is connected with the community's harmonious communal relationships with nature (Horsthemke, 2017). Unlike the West, African people did not regard themselves as superior to nature, including animals, birds, fish, or trees (Horsthemke, 2019). According to our respondents, the *Borana Oromo* possess a rich cultural heritage that emphasizes ethical codes for protecting animals, especially during critical times such as during giving birth and while consuming drinking water. It is considered taboo to kill any wildlife or cattle during these moments, as doing so is viewed as a sinful act leading to unfavorable consequences, including sterility and premature death for the individual responsible for the act. This indigenous moral philosophy of the *Borana Oromo* enforces respect for and protection of wildlife, viewing the life of animals as the sole sacred property of *Waaqaa* (Sky God) and natural cycles of mating and thirst among animals as part of natural law (*seera Waaqaa*). Culture and religion is the main markers of African morality (Mangena, 2013). That is why animal-human relationships are often physical and spiritual in nature in many African people (McGinnis et al., 2019). This notion is part of a broader moral framework that grants animals the 'freedom' to survive and access water, to be free from psychological disruptions during reproduction and while drinking water, all this within the context of *Borana* indigenous *Gadaa* culture.

We also observed that the *Borana Oromo* pastoralists fetched water from wells for their livestock. They noted that various wild animals, such as antelopes and warthogs, come at night to drink the remaining water from the watering places. In this case, cattle herders utilize a local tool called *faccina* to draw water from deep traditional wells. This practice, through the moral obligation of providing water, reflecting the *Borana* people's deep-rooted indigenous ecological stewardship for a better life is essential for animals, especially during challenging seasons such as drought that often negatively affect wildlife and livestock.

In fact, many wild animals usually drink water in secure spaces. Besides, the *Gadaa* laws mandate the protection of water wells for the well-being of both the *Borana* people and the ecosystem. According to our informants, in *Borana* culture, persons referred to as *Abba Herrega* are responsible for monitoring activities related to the traditional wells to prevent misuse. Failure to comply with this responsibility can result

in customary punishment. Furthermore, we observed that zebras and ostriches, along with cattle, were in the grazing land around the *Yabello* Wildlife Sanctuary, symbolizing harmonious relations with non-human animals and domesticated animals in that natural environment, which reflects the values stemming from the *Borana Gadaa* system practiced for centuries.

4.5. The Right to Safe Passage

Wild animals prefer a safe place to survive. In fact, wild animals can be "sovereign" through human culture (Papadopoulos, 2022). Wild animals migrate seasonally to different parts of the lands of *Borana* in Ethiopia and also to Kenya and vice versa. Such journeys to their preferred destinations are often safe both day and night through the villages and residential areas. It is prohibited for the *Borana* people to hinder or kill while they are on their way home. This safe passage is due to the presence of the customary laws of the *Gadaa* system. In line with this, the informant who had surpassed 100 years of age during the interview explained that allowing animals to pass safely implies a sacred action and influence, while hindering their movement is considered morally wrong (*aadmale*) and a sinful action (*daba*).

Today, the younger generations of the *Borana* are less familiar with indigenous knowledge related to animals compared to the elders, primarily due to modern education and the introduction of Christian denominations, which often marginalize local knowledge and ways of knowing. This highlights the presence of an inter-generational gap regarding the indigenous knowledge of the *Borana Oromo* in relation to animal rights and indigenous ontology.

5. Comparative Analysis: *Gadaa* System versus Western Perspectives

From its philosophical foundation and perspectives, the *Oromo Gadaa* system treats animal rights as an inherent component of both customary and natural laws (*Seera Waaqaa*), making them inseparable from people (*seera Uumaa*) (Biratu & Kosa, 2020). In contrast, from a Western perspective, animal rights differ in that it separates animals from humans and view animals as mere property or resources to be exploited for economic benefits.

This conception emerges from the colonial capitalist approach, which is rooted in the premise of transforming non-human creatures into objects of capital accumulation, initially a knowledge developed in Europe that undermines indigenous human-animal relations and interdependence for well-being (Montford & Taylor, 2020). On the other hand, the *Borana Gadaa* system views the environment holistically by considering humans and animals as co-inhabitants and interdependent physically and spiritually. In

contrast, in this case, the Western approach opposes spiritual considerations concerning animal rights and advocates for the separation of human and animal relations (Cederholm et al., 2014). In line with this, Huggan et al. (2017) argued that animal rights are most frequently violated when non-human life is in proximity to human settlements and competing for resources. To address this, the Western model proposes the formation of 'new zones' such as establishing parks aimed at animal protection, which separates animals from humans. In fact, what unites both frameworks, the *Gadaa* system of the *Borana Oromo* and Western perspectives, is their recognition that animal rights cannot exist without environmental protection. For better understanding, see the following Fig 1 conceptual framework concerning the *Gadaa* system and modern perspectives.

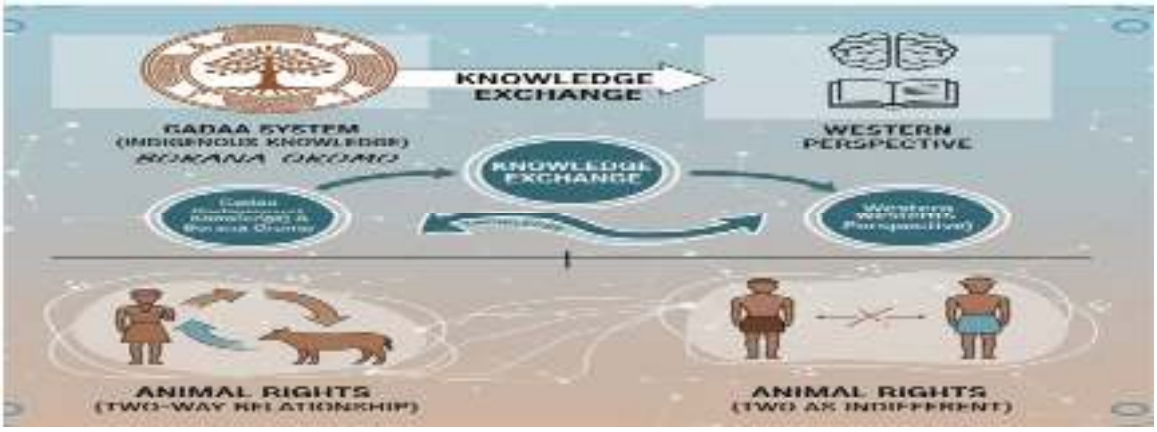


Fig 1 conceptual framework concerning the *Gadaa* system and modern perspectives.

Our analyses show that the *Gadaa* system offers a bottom-up model that contrasts sharply with the top-down Western approach concerning animal rights and environmental governance. While Western perspectives set animal rights aginst human utility for economic benefits, the *Borana Oromo* indigenous perspective positions animals with a unified moral framework. Huggan et al. (2017) emphasized that when animal rights are undermined, it directly challenges the ethical principles. In fact, in *Borana* culture, such a violation is not just a loss of wildlife but also a degradation of the human spiritual well-being.

Table 1: Comparative analysis between the *Borana Gadaa* system and Western approach related to animal rights and ethical principles.

Dimension	***Gadaa***	**Western perspective**	**Theoretical differences**
Moral foundation	Grounded in customary law moral morality	Utilitarianism	Collective and individualistic
Rights origination	Life as a sacred property of God	Cognitive ability	Divine versus scientific
Human role	Humans as custodians	Humans as superiors	Co-habitation versus stewardship
Legal agency	Enforced by elders	State judge	Community-led versus state
Ethical motivation	Driven by social shame	Rational empathy	Taboo versus moral reasoning
Spatial proximity	Shared environment	Separation	Shared versus separation
Ecological scope	Holistic	Protection	Holistic versus reductionist
Violation response	Cosmic imbalance	Legal infraction	Moral imbalance versus penalty

Source: self

Western utilitarianism often assesses animal value based on their utility for economic benefits to human beings. Under *Gadaa* law, on the other hand, animals are granted privileged rights. The Western legal systems categorize animals as property rather than legal subjects, necessitating complex legal interventions to provide basic protection. In this article, we examined that the *Gadaa* system relies on a bottom-up social contract, where every citizen serves as a protector of animals and their rights. This notion emerges from the fact that the *Borana* people have legal, moral, and spiritual obligations to contribute to the well-being of animals. On the other hand, Western systems rely on top-down, state-driven regulations. interviews, focus group discussions, and field observations within the *Borana* context, reveals that traditional/customary laws and ethical practices significantly contribute to animal protection. For instance, in sacred sites, wildlife is regarded as an essential element of the site and is protected. For this, sacred spaces serve animals as a safe area in which cutting down trees, killing, or hunting is unimaginable in *Borana Oromo* culture. In addition, under the *Borana Gadaa* system, animals are safeguarded across various landscapes, including natural forests. In *Gadaa* laws,

5. Conclusion

The discussion in this study highlights the ethical considerations and animal rights stemming from the *Borana* indigenous *Gadaa* System, alongside a comparative analysis with Western philosophical approaches. The *Gadaa* system of the *Borana Oromo* encompasses customary laws and ethical principles that grant inherent rights to animals, ensuring their survival, well-being, and protection from extinction, practiced since time immemorial. Our empirical investigation, including

animals are granted safe passage through villages and residential areas during migration and reproduction.

Morally and spiritually, the *Borana Gadaa* system prohibits the killing of animals during key periods such as giving birth, drinking water, and migration. Moreover, it is considered unethical or taboo to kill young animals for food; instead, it allowes the slaughter of older animals such as antelope in *Borana* culture. This stewardship of nature among the *Borana* contributes to animal conservation. In our examination of the *Borana* context, we identified that wild animals migrate seasonally across different places within *Borana* in Ethiopia and into Kenya, and vice versa. These migrations are often safe, both day and night, through villages and residential areas. In this case, the *Borana Gadaa* laws and morals prohibit hindering or killing these animals during their journeys. And violations of this principle can result in penalties ranging from advice and warnings to confiscation of cows or corporal punishment.

Conversely, the Western animal rights approach is rooted in Eurocentric cultural paradigms that position humanity as superior to nature, viewing animals merely as resources to be exploited for capital accumulation, reflecting a colonial legacy (Hall, 2023). This view sharply contrasts with the indigenous philosophical perspective of the *Borana Oromo*, where animals are not just subjects with rights but are integral components of *woyyuu/safuu*—spiritual and moral values that maintain harmony between the Creator (Waaqa), nature, and people.

In *Borana* culture, the mistreatment of animals, whether livestock or wildlife, is seen as a violation of *ayyaanaa* (spiritual essence), which would displease God and is also against *Gadaa* laws.

In this case, the ethical frameworks and customary laws of the *Borana Oromo* people possess both legal and spiritual dimensions rooted in their *Gadaa* system. In contrast, the Western legal approach to animal rights is inherently secular. Furthermore, the *Gadaa* system operates as a bottom-up approach, where every citizen acts as a protector of animals, whereas the modern or Western approach is top-down, often governed by the state.

This paper argues that this shows the presence of epistemological differences between *Borana* customary laws and ethical principles encoded in the *Gadaa* system and Western philosophical perspectives. The study states the expansion of National Parks and Wildlife Sanctuaries in *Borana*, aligning with the broader Western conservationist model that promotes separation between animals and humans, opposing the *Gadaa*

system in which animals are regarded as inseparable from people and their culture.

6. Recommendation for Further Research

In reality, against the preexisting communal governance of pastoral landscapes and the environment, which is a home for animals, there is increasing land privatization among the *Borana Oromo* people currently. Additionally, there is a growing conversion of the *Borana* people to multiple teachings of Protestant groups. In this context of cultural and political dynamics, further research is needed to determine whether these changes negatively or positively affect the existing belief systems, moral and spiritual values, and rights connected to animals coded in the *Borana Oromo Gadaa*

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Research Article

Effect of Climate Change on Livestock Production: Adaptive Strategies in Taltalle District of Borana Zone, Southern Ethiopia

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Abstract

Climate change affects livestock production directly through animal performance and indirectly via environmental degradation. Taltalle District of Borana Zoneis highly vulnerable to these impacts, particularly due to rainfall variability and recurrent droughts. This study examined the effects of climate change on livestock production and evaluated the adaptation strategies practiced by local pastoralists. Utilizing a cross-sectional survey design, primary data were collected from 392 sample households, six focus group discussions, and 13 key informants, supplemented by secondary meteorological and institutional data. Data were analyzed using linear trend analysis, the Standardized Precipitation Index, regression and correlation analysis, ranking indices, and a multinomial logit model. Results revealed that 90.9% of respondents perceived a decreasing rainfall trend, while 87.9% noted rising temperatures. Instrument data confirmed a 45-year trend of declining annual rainfall at a rate of 1.5538 mm/year, with a high coefficient of variation (24.14%). Annual rainfall fell below average for 21 years, subjecting the district to prolonged droughts. Acute water and feed shortages were identified as the primary factors limiting livestock production. This consequently, lead to climate change effects on livestock including reduced milk yields, shortened lactation periods, and declined reproduction rates. The study shows that to cope with these effects, pastoralists deployed adaptation strategies such as livestock mobility, species diversification, area enclosures, and haymaking. However, these efforts were heavily constrained by fundamental barriers, including capital constraints, inadequate information, and dwindling household herd sizes. The study concludes that severe rainfall variability and recurrent droughts have degraded livestock production and forage quality while undermining local adaptive capacities. Therefore, future policy interventions should better focus on developing sustainable water sources, improving livestock and rangeland management, and scaling up viable indigenous adaptation strategies.

Keywords: *Pastoralism, Climate Resilience, Arid and Semi-Arid Lands, Herd Diversification, Vulnerability Assessment, Borana*

1. Introduction

Climate change has emerged as a defining global environmental challenge, with far reaching implications for ecological system, socio-economic development and human well-being the 21th century. In Sub-Saharan Africa (SSA), it poses a persistent threat to the livestock production systems that sustain smallholder pastoralists. These pastoral populations depend heavily on climate-

sensitive agriculture, which globally supports the livelihoods of approximately two billion individuals (Sithole and Olorunfemi, 2024; Suh *et al*., 2025).

Concurrently, escalating temperatures, erratic rainfall patterns and an increased frequency of extreme weather events are severely compromising livestock productivity (Bashiru and Oseni, 2025; Ngongolo and Gayo, 2025). This degradation of production capacity directly threatens pastoral livelihoods, thereby exacerbating systemic poverty and socio-economic vulnerability. These climate-induced disruptions are particularly critical given that livestock assets generate approximately 35% to 55% of household income in mixed and rural agricultural systems, respectively (Mango *et al.,* 2025).

Reflecting these regional vulnerabilities, a robust body of literature has investigated the localized impacts of thermal stress, precipitation volatility, and recurrent droughts within Ethiopia. Existing scholarship consistently emphasizes how these climatic pressures induce severe forage deficits, acute water scarcity, compromised animal health, and adverse shifts in herd dynamics (Alemayehu and Fantahun, 2012; Lomiso, 2020; Chernet, 2022; Habte *et al*., 2022; Abrham and Mekuyie, 2022; Digesa, 2024).

Ethiopia is among the countries extremely vulnerable to climate variability and change since a large proportion of its population subsists on climate-sensitive livelihoods such as agriculture and pastoralism. The southern lowlands of Ethiopia, particularly Borana Zone, are among the most vulnerable areas to climate-related vulnerabilities. In recent decades, climate change, particularly frequent drought occurrence, has increasingly threatened the livelihoods of pastoralists. It has been observed that livestock die more quickly, more regularly, and in larger numbers during drought years than was experienced by previous generations (Solomon, 2003).

In Borana Zone, recurrent droughts during the 1980s and 1990s resulted in the deaths of approximately 37–42% of cattle populations. Over a period of 17 years, cattle mortality losses in Borana were estimated at nearly US$300 million (Desta and Coppock, 2004). Taltalle District, where this study was conducted, is one of the areas highly affected by climate change, particularly rainfall variability and frequent drought occurrence. Despite the growing impacts of climate change in the area, most previous studies conducted in the Borana lowlands mainly focused on the general effects of climate variability while giving limited attention to the analysis of long-term climatic trends and the increasing frequency of meteorological droughts. In addition,

there is little quantitative evidence regarding the effectiveness of adaptation strategies practiced by pastoralists in Taltalle District.

Moreover, limited studies have comprehensively examined the combined effects of rainfall variability, drought occurrence, temperature increase and rangeland degradation on livestock production in the study area. Comprehending these impacts and pinpointing locally practiced adaptation strategies are vital for improving the resilience of pastoral and agro-pastoral communities. Hence, this study investigated the effects of climate change in terms of rainfall variability, drought occurrence and frequency and temperature-related heat stress on livestock production, and to explore the adaptation strategies practiced by pastoralists in Taltalle District of Borana Zone, Southern Ethiopia.

2. Materials and Methods

Description of Study Area

2.1. Geographical location of Taltalle district

The study was conducted in the Taltalle district of Borana Zone, Southern Ethiopia, from January 2025 to March 2026. The district is one of the 10 districts of Borana zone in Oromia National Regional State. The district is located 668 km south of Addis Ababa and 100 km southwest of Yaballo, zonal city, between 4° 01’33” N - 5° 14’12” N latitude and 36° 40’04” E to 37° 37‟13” E longitude in the west of Borana Zone (TDAO, 2025).

The agro-ecology of the district is characterized by an arid climate with low and erratic rainfall. The altitude of the district ranges from 400 up to 1840 meters above sea level (TDAO, 2025). The district experiences bimodal rainfall; *Ganna* (March, April and May) is the main rainy season and *Hagayya* (September, October and November) is the short rainy season, and two dry seasons; *Bona Hagayya* (December, January and February) is the dry and hottest season, and *Bona Adoolessa* (June, July and August) is dry and coldest season. The total human population of the district is 161,673, of whom 78,135 are male and, 83,538 are female (TDAO, 2025).

The major production systems of the district are pastoral and agro- pastoral systems. Cattle, goats, sheep, donkey, mule, camel and poultry are major livestock raised, while maize, sorghum, teff, wheat and haricot-bean/common-bean are major crops produced in study area. Soil types in district are *vertisols* (black soil), *fluvisol*s (brown soil) and *Ferralsol* (red soil) (TDADO, 2025).

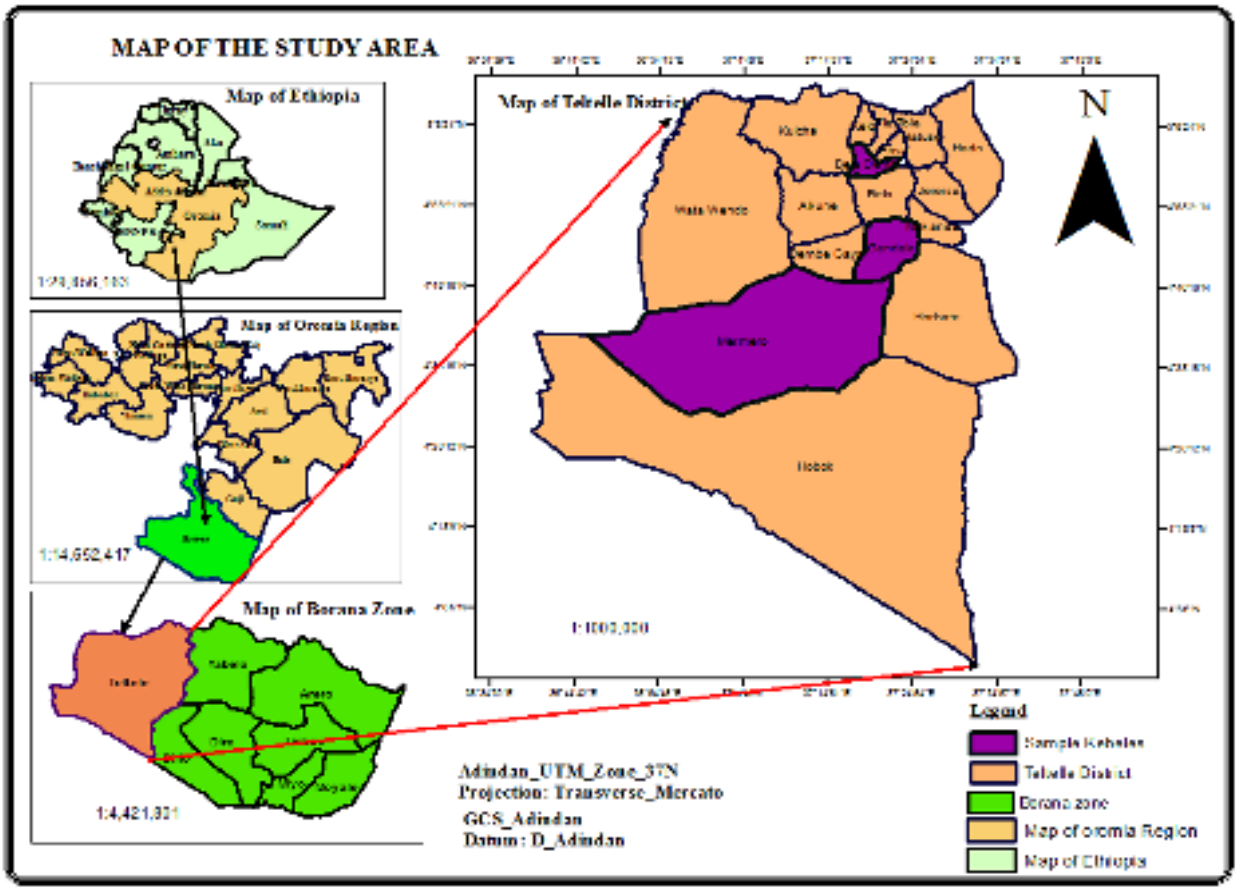


Figure 1: Map of study area

Source: Processed from ArcGIS 12.0, (2025).

2.2. Research Design

The cross-sectional survey was conducted to collect data about effects of climate change on livestock production and adaptation strategies practiced by pastoralists. Both qualitative and quantitative data were collected at one point in time from a sample selected to represent a larger population.

2.3. Sampling Techniques and Procedures

The target population of the study was households of the district who own livestock and the study was followed multi-stage sampling procedures. Taltalle district was purposively selected with the main criteria of the severity of effects of drought and representing the major production systems of the district. The district has 25 *kebeles* (14 agro-pastoral, 8 pastoral and 3 urban *kebeles)*. Secondly, the district was divided into two strata using stratified sampling procedure based on production systems of the district (pastoral and agro-pastoral). Using probability proportional to size method, one *kebele* from pure pastoral and two *kebeles* from agro-pastoral were selected, for a total of three *kebeles* were selected by a simple random sampling procedure. Then, sampling households were

selected using systematic random sampling technique. The simplified formula provided by Yamane (1967) was used to determine the required sample size at 95% confidence level and 5% level of precision as shown below.

$$\frac{N}{(1+N(e)^2)} = \frac{20192}{(1+20192(0.05)^2)} = 392$$

Where n is sample size, N is total population of selected *kebeles* and e is precision level.

Bowley's (1926) proportion allocation method was used to assign sample sizes for each selected *kebele*. $\mathbf{ni} = \frac{nNi}{N}$ Where ni is assigned sample size for each *kebele*, n is the total sample size, Ni is population size of a single *kebele,* and N is total population.

Table 1: Sample households of the study area

Sample *kebeles*	oduction system	Population size			Sample size		
		ale	Female	Total	ale	Female	Total
Bule Dambi	Agro-pastoral	1882	2038	3920		40	76
Gandhile	Agro-pastoral	3468	3756	7224	67	73	140
Marmaro	Pastoral	4344	4704	9048	84	92	176
Total		9694	10498	20192	187	205	392

2.4. Data Type and Data Source

Both primary and secondary data were used for the study. Primary data were collected directly from sample households, focus group discussion members, and key informants through questionnaires. Secondary data were obtained from Ethiopian National Meteorological Agency (ENMA) (45 years of completed rainfall and temperature data), and District Livestock Resource Development Office.

2.5. Methods of Data Collection

Household survey

Semi-structured questionnaires were prepared both for qualitative and quantitative data. The pastoralists were interviewed on related issues about their perception of climate change, effects of climate change on livestock production, and adaptation strategies practiced by herders. The interview schedule was pre-tested among 20 randomly selected pastoralists from two non-sampled *kebeles* having similar characteristics to the sampled household, and one *kebele* from each production system (pastoral and agro-pastoral). Data collection from households was carried out by applying face –to- face interview of the pastoralists.

2.6. Key informant interviews (KII)

A total of thirteen key informant were selected, including three developmental agents, six elder informants, one traditional early warning predictor (known locally as

"uchuu*"*) distributed each for three sample *kebeles*, and one expert from district livestock resource development office were selected to generate information about effects of climate change on livestock production and adaptation strategies.

2.7. Focus Group Discussions (FGDs)

Six FGDs of Pastoral and agro-pastoral communities representing different age groups, with different education level, both male and female, and different wealth groups were selected from each sampled *kebele*. The relative wealth status ranking method was used to identify wealth groups; which declares that a household is poor or rich in the context of its village. Two FGDs from each three *kebele* and one FGD consisted of 12 individuals, totally 72 FGD members were used during discussions. The discussion aimed to assess the effects of climate change and adaptation strategies for livestock keepers. It helped to cross-check the data obtained from household survey.

2.8. Methods of Data Analysis

To achieve the objectives of the study, both descriptive (percentages, frequency, rank index and mean value), and inferential (multinomial logit model) statistics were used to analyze collected primary and secondary data, while MS Excel, Statistical Packages for Social Sciences (SPSS) version 26, and STATA version 16 were the major tools for analyzing data and present the findings of the study.

Trends of long-term rainfall and temperature data were analyzed by undertaking linear trend analysis. Long-term rainfall data were also analyzed seasonally and annually by using the Standardized Precipitation Index (SPI) and Coefficient of Variation (CV). SPI was used to quantify the precipitation deficit for multiple timescales.

Table 2: SPI Values o Define Drought Magnitude

SPI Values	Moisture levels
≥ 2+	extreme wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	moderate drought
-1.5 to -1.99	severe drought
≤ -2.00	extreme drought

Source: McKee *et al*. (1993).

Standardized Precipitation Index (SPI) was calculated as the difference between the annual total of a particular year and the long-term average rainfall records divided by the standard deviation of the long term data. SPI= $(X-\bar{X})/SD$ Where SPI is Standardized Precipitation Index, X is discrete precipitation data, $\bar{X}$ is mean and SD is Standard Deviation.

Intra seasonal rainfall Variability was analyzed using the coefficient of variation (CV). According to Hare (1983), CV (%) values were classified as follows: < 20% as less variable, 20-30% as moderately

variable, and > 30% as highly variable. CV= SD/$\bar{X}$ *100 Where CV is Coefficient of Variation; SD is Standard Deviation and $\bar{X}$ is mean.

Mann-Kendall test was also used to analyze the long term trend of rainfall and temperature data of the district. Man-Kendall test, a technique based on the Kendall tau statistics has been introduced to test for randomness against trend in climatological time series (Zhang. *et al,* 2001).

The test statistics(S) for the Mann-Kendell test is given as:

$$S = \frac{\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} \operatorname{sgn}(Y_j - Y_i)}{\sigma_s} \qquad \sigma_s = \sqrt{\frac{N(N-1)(2N+5) - \sum_{i=1}^{n} t_i(i-1)(2i+5)}{18}}$$

Where: N is the number of data, Yj and Yi are the data values in two consecutive periods; ti is the number of ties, i.e. equal values, of extent i and N is the number of tied groups. The function sign(Yj-Yi)=1 if Yj- Yi >0; sign(Yj- Yi)=0 if Y=0 and sgn(Yj- Yi)=-1 if Yj- Yi<0.

The long term relationship between climate data and livestock population were analyzed by multiple regressions and correlation analysis. The equation for multiple linear regression relationship is expressed as: $Yi = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots\ldots\ldots + \beta_k X_k + \varepsilon_i$, Where Yi is the dependent variable, X_1 …. X_k are independent (explanatory) variables considered to have influence on the Y variable. β_1 ….β_k are regression slopes corresponding to the respective Xi. So, β_i is defined as the rate of change in Y for a unit change in Xi, while the effects of the other independent variables remain constant. ε_i is the residual variance in Y after taking into consideration the effects of the Xi variables included in the model. Correlation analysis between data of rainfall, temperature, and livestock population is given as below: $r = \frac{\sum xy}{\sqrt{(\sum x^2)(\sum y^2)}}$ Where r is correlation coefficient, X is independent and Y is dependent variables

Major factors affecting livestock production and rangelands in the district were analyzed by using ranking index method. Ranking index method was computed with the principle of weighted average which employed by Musa *et al*., (2006): Index = Rn*C1+Rn-1*C2+…. +R1*Cn/∑ Rn*C1+ Rn-1*C2…. R1*Cn Where; Rn = Value given for the least ranked level (example if the least rank is 3rd rank, then Rn =3, Rn-1=2 and … R1= 1). Cn = Count of the least ranked level (in the above example, the count of the 3rd rank = Cn, and the counts of the 1st rank = C1).

Following the descriptive statistics, the study employed multinomial logit model to assess adaptation strategies and factors affecting adaptation choices of the herders'.

The MNL model was used by many researchers to analyzed climate change adaptation strategies of farmers/pastorals (Nhemachena and Hassan, 2008; and Temesgen *et al.,* 2009). Therefore, the multinomial logit model is appropriate model to analyzed climate change adaptation strategies of pastoral and agro-pastoral of the study area.

The choice of a given adaptation option is discrete because it is chosen among other alternative option. Let P_{ij} represent the probability of choice of any given adaptation option by pastoralists, then equation representing as;

$$P_{ij} = \beta_{\circ} + \beta_1 X_1 + \cdots + \beta_k X_k + e \ldots . (1)$$

Where *i* takes values (1, 2, 3, 4, 5, 6), each representing the choice of adaptation option (1= Livestock diversification, 2= Hay making 3= Temporary migration for searching water and feed, 4= Area enclosure, 5= Bush thinning, 6= Income diversification).

$X_1 \ldots X_k$ are factors affecting choice of an adaptation option, β are parameters to be estimated and e is randomized error. With j alternative choices, the probability of choosing adaptation option j is given by,

$$P(Y_i = j) = \frac{e_{zj}}{\sum_{k=0}^{j} e_{zk}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where Z_j is a choice and Z_k is alternative choice that could be chosen (Greene, 2000).

The model estimates are used to determine the probability of choice of an adaptation option given j factors that affect the choice X_i .

$$\ln(\frac{P_{ij}}{P_{ik}}) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_K + e \ldots . . (3)$$

P_{ij} and P_{ik} are probabilities that pastoral will choose a given adaptation option and alternative adaptation option respectively. $\ln(\frac{P_{ij}}{P_{ik}})$ is a natural log of probability of choice j relative to probability choice k, α is a constant, β is a matrix of parameters that reflect the impact of changes in X on probability of choosing a given adaptation option , e is the error term that is independent and normally distributed with a mean zero. The marginal effects, measure the expected change in probability of a particular choice being made with respect to a unit change in explanatory variable (Greene,2003).

$$\frac{\partial Pj}{\partial Xi} = P_{j(\beta j - \Sigma_{k=P_k \beta_j}^{J}) = Pj(\beta j - \beta)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots . . (4)$$

Before running the model, it is useful to look into account the problem of multicolinearity among the independent variables. The explanatory variables for this study include household characteristics such as gender, age of the household head, education level, family size, farm size , and livestock ownership; institutional factors such as extension services on livestock

production, information on climate, access to credit and market.

Variance inflation factor test was used to test the multicolinearity for continuous independent variables. Multicolinearity associated with variance inflation factor is defined as:

$$VIF\ (Xi) = (1 - \mathrm{Ri}^2)^{-1} \ldots\ldots\ldots\ldots\ldots (5)$$

Where Ri^2 is the multiple correlation coefficients between explanatory variables. The larger the value of Ri^2, the higher the value of VIF (Xi), causing multicolinearity in the variable (Xi).

Table 3: Variables of the study

Independent variables	Definition
Sex of the household head	Dummy 1 if male, 0 otherwise
Age of the household	Continuous
Education level	Categorical
Family size	Continuous
Source of income	Continuous
Livestock holding	Continuous(in TLU)
Land holding	Continuous(ha)
Access to climate information	Dummy 1 if there, 0 otherwise
Access to extension services	Dummy 1 if there, 0 otherwise
Distance to market	Continuous (km)
Access to credit services	Dummy 1 if there, 0 otherwise

3. Results and Discussion

3.1. Trend Analysis of Climate Data of Taltalle District

3.1.1. Trend of annual rainfall

The trend of annual rainfall of Taltalle district is presented in Figure 2.

Meteorological data of the district showed that the trend of annual rainfall over 45 years was decreasing. The annual rainfall trend for the district was decreasing by 1.5538 mm, ranging from 210 mm in 2021 to 748.976 mm in 1995, whereas the mean annual rainfall over 45 years was 496.1393±35.98mm. Out of 45 years, annual rainfall was below average in 21 years, and the CV of annual rainfall was 24.14%.

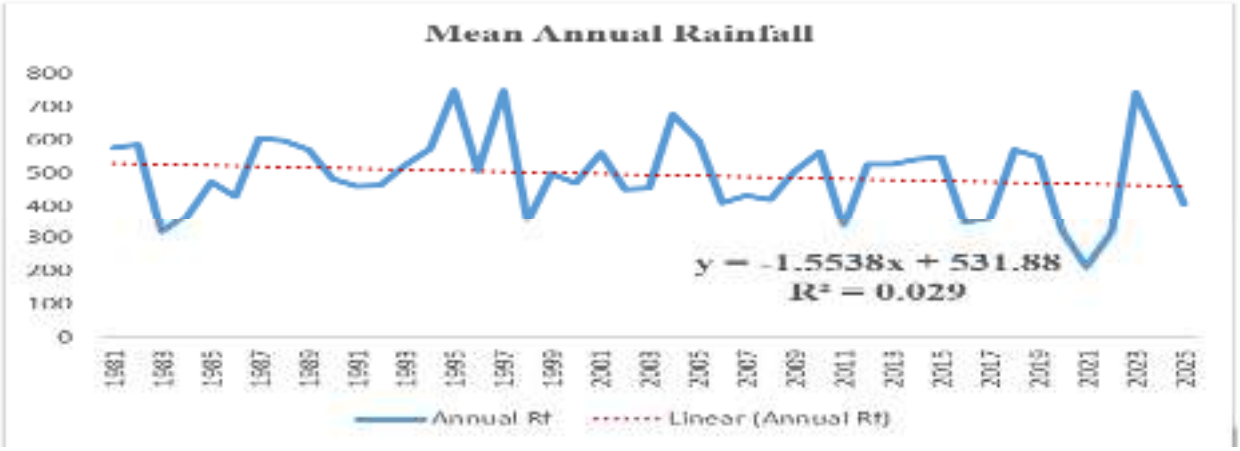


Figure 2: Trend analysis of annual rainfall of Taltalle district

This reduction of annual rainfall of the district is supported by others researches. The average annual rainfall reduction in Borana is far greater than the national average and the experience of highland Ethiopia (Woldeamlak and Conway, 2007).

3.1.2. Analysis of annual standard precipitation index

The annual drought analysis of the district is shown in Figure 3. According to the district's meteorological data, out of 45 years of annual rainfall, 21 years' annual rainfall was below average, and the district has been affected by a shortage of rainfall for all these years. The drought years of 1983, 1984, 1986, 1998, 2006, 2007, 2008, 2011, 2016, 2017, 2020, 2021, and 2022 were categorized as extreme annual drought (SPI values: -11.888, -5.907, -2.243, -6.181, -3.557, -2.868, -3.026, -7.954, and -6.824, -4.4309, -7.5749, -22.1141 and -7.4005), and 1991, 1992, 2000, 2002, 2003, and 2025 were moderate annual drought (SPI values: -1.367, -1.485, -1.109, -1.489, -1.344, and -1.6914) in the district.

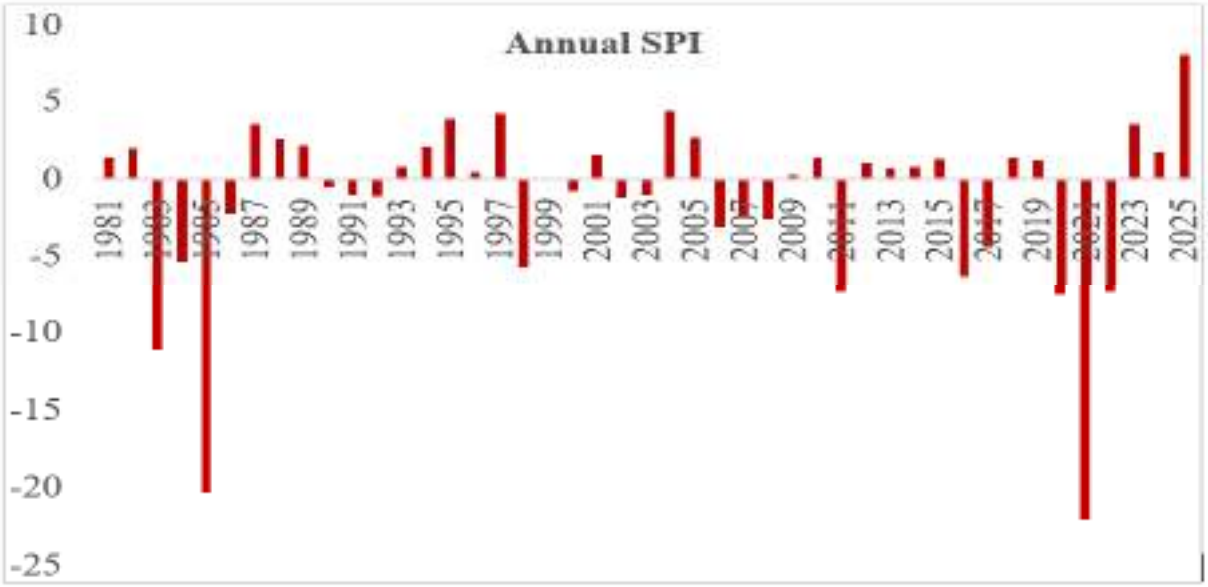


Figure 3: SPI of Annual rainfall of Taltalle district

Among the major annual drought years, the droughts of 1983, 1986, 1991, 2000, 2007, 2011, 2016, 2017, 2020, 2021, and 2022 were due to the failures of both the main and short seasonal rainfall, while the droughts of 1984, 1992, 1998, 2002 and 2006 were due to failure of main seasonal rainfall, and 2003 and 2008 drought year due to the failure of the short seasonal rainfall. Out of three decades of last 45 years, the last of three decades (2001-2025) had high drought frequency which shows climate variation from decade to decades or year to year which leads to high livestock mortality in the district.

A research conducted by Oxfam International (2010) also confirmed that in 1972-1974, 1984-1985, 1999-2000, 2002-2003, 2007 drought attacked lowlands of the region, particularly resulted in the loss of thousands of livestock in Borana zone.

Trend of mean annual temperature of the district

The trend of mean maximum and minimum annual temperature is presented in Figure 4. The results of 45 years of Taltalle district meteorological data of temperature indicated that, both annual mean maximum temperature and annual mean minimum temperature were slightly increasing by 0.0112^0C and 0.174^0C per annual and their means and SD were 31.325± 0.603^0C and 20.015± 0.338^0C respectively.

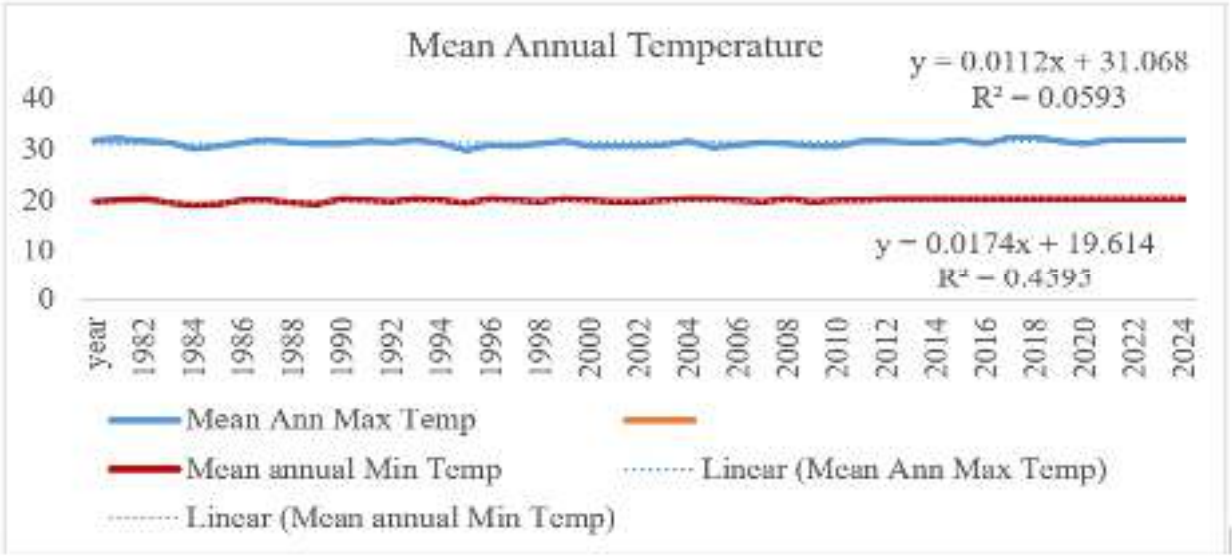


Figure 4: Trend of annual maximum and minimum temperature of Taltalle district

Similar to the result of meteorological temperature data of the district, other studies supported the increase of temperature in general. The observed monthly, seasonal and annual temperature in Borana Zone shows increasing from time to time, which directly and indirectly affects livestock production. Many studies (e.g. Thornton *et al.,* 2009; Nardone *et al*., 2010) confirmed that an increase in temperature directly poses thermal stresses on animals.

3.1.3. Trend analysis of climate data by Mann-Kendell test

The result of Mann-Kendell test of district climate variables is shown in Table 4. The trend of mean minimum temperature of 36 meteorological data was highly significant (p = 0.0008) while trends of annual rainfall and maximum temperature were not.

Table 3: Trend analysis of climate data of study area by Mann-kendell test

Variables	Mann-Kendell tau	Significant value
Annual rainfall	-0.076	0.522
Maximum temperature	-0.085	0.470
Minimum temperature	0.393*	0.000

** shows significant at 1% level*

Mann-Kendell test is very important to show the strong trend magnitude of the climate variables. The coefficients of annual rainfall and maximum temperature of the district shows decreasing in last 36 years but not as such significant. That means the trend magnitude of those variables were weak compare to mean minimum temperature. Increasing of mean annual minimum temperature was confirmed by other study. In Ethiopia, the average annual minimum temperature over the country has been increasing by 0.25^0C every ten years while average annual maximum temperature has

been increasing by 0.1^0C every decade (NMA, 2007). It is interesting to note that the average annual minimum temperature is increasing faster than the average annual maximum temperature (ENMSA, 2001).

3.2. Effect of Climate Change on Livestock Production in Taltalle District

3.2.1. Trends of livestock population in 2007 – 2025 years

The 19-year trends of livestock population of the district are indicated in Figure 5. The livestock population of the district is increasing, but not consistently. Following the rainy years, the number of livestock increased (especially cattle and sheep), while in dry years it declined at a high rate (except for some drought-resistant species like goats and camels).

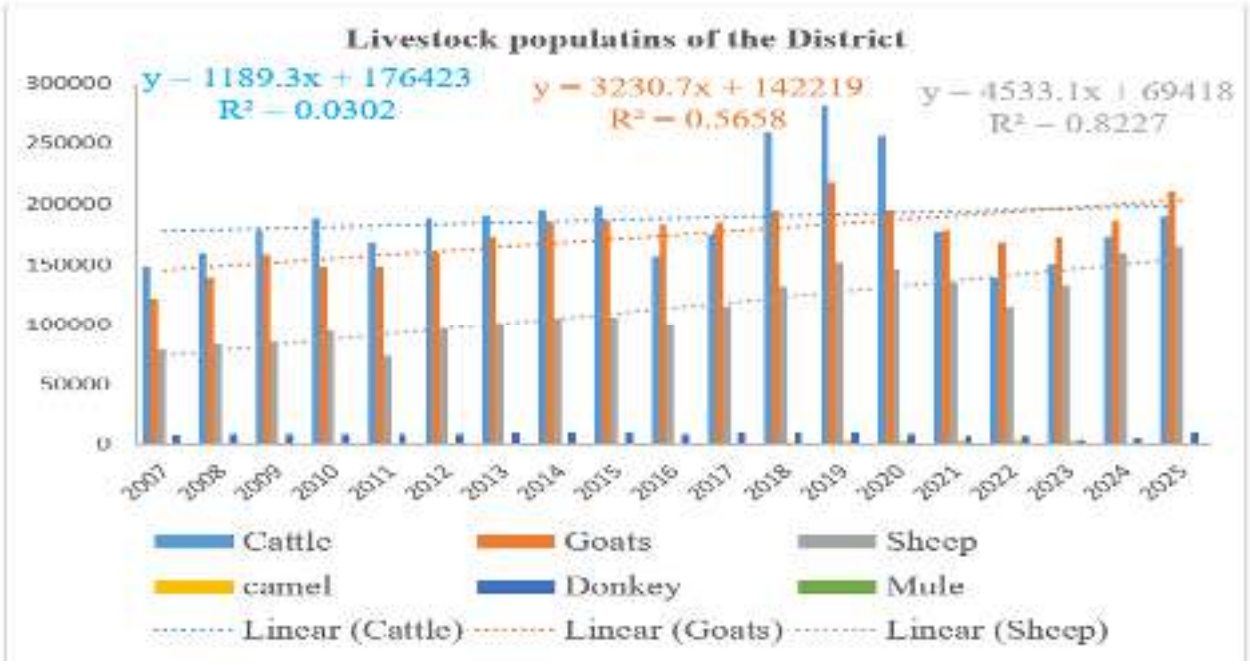


Figure 5: Trend of livestock population in study area in 19 years

On the other hand, the ratio of livestock to households has been decreasing from time to time. According to the results of livestock per household data from 2019 and 2025 showed, the mean of livestock per household decreased from 26.59±12.484 in (2019) to 14.27±6.092 in 2025 (see Table 5).

Table 5: Descriptive statistics of TLU per Household of 2019 and 2025 in the study area

Variables	N	Minimum	Maximum	Mean	Std. Deviation
TLU(2019)	392	6	73	26.59	12.484
TLU(2025)	392	2	27	14.27	6.092

The main reason for decrease in livestock number per household could be due to increasing human population, declining availability of grazing land, and shortage of feed, which is influenced by high frequency of drought occurrence and climate variability in the district. A study conducted in the neighboring Yaballo district, confirmed that households experienced a severe reduction in their assets, with an average reduction of 80% in livestock holdings from their peak holdings over the past ten years mainly due to climate change- induced shocks (Stark *et al.*, 2011).

3.2.2. Major effects of climate change on livestock production and productivity

The ranking order of the effects of climate change on livestock production as per the respondents of pastoral households is discussed below.

Table 6: Effect of climate change on livestock production and productivity in study area

Variables	Pastoral		Agro-pastoral	
	Index	Rank	Index	Rank
Reduction of milk production	0.205	1st	0.173	1st
Reduction of lactation length	0.179	2nd	0.144	2nd
Reduction of reproduction rate	0.166	3rd	0.144	2nd
Increasing of calving interval	0.154	4th	0.139	4th
Reduction of production life	0.099	5th	0.129	5th
Increasing of age at first calving	0.091	6th	0.117	6th
Increasing of age at sexual maturity	0.070	7th	0.107	7th
Livestock mortality due to drought	0.038	8th	0.026	8th

The effects of climate change on feeds and water availability and quality leads to the reduction of livestock production and productivity in study area.

3.3. Correlation between climate change and livestock population

The results of correlation analyses between livestock and climate variables of the district during the 2007-2025 years are presented in Table 7. Both cattle and sheep populations showed a strong positive correlation with main rainfall (p = 0.003 and p = 0.022), respectively. However, they were negatively correlated with maximum temperatures (p = 0.037 and p = 0.019), respectively. This dual response occurs because higher seasonal rainfall directly boosts pasture availability and forage quality, whereas elevated temperatures induce severe heat stress and accelerate forage depletion, both of which compromise livestock health and productivity. Conversely, the goat population demonstrated a strong positive correlation with minimum temperature (p = 0.002).

Table 7: Correlation of climate data and livestock population of study area

Variables	Cattle	Goat	Sheep	Camel	Donkey	Mule
Annual RF	.735*	.350	.526	.463	.276	.230
MAM RF	.855**	.521	.707*	.440	.342	.279
SON RF	.458	.095	.225	.494	.178	.168
Max temp	-.661*	.665*	-.720*	.383	242	.127

Min temp	-.003	.845**	.358	.661*	.718*	.772**

*Note: **, * Significant at 0.01 and 0.05 level (2-tailed).*Camel, donkey and mule population had positive correlation with minimum temperature (p = 0.037, p = 0.019 and p = 0.009), respectively.

Statistically, values close to -1 indicate a strong negative (inverse) relationship, values close to 1 indicate a strong positive relationship and value close to zero indicates poor relationship which is not significant. For instance, cattle and sheep population were a strong positive relationship with main rainfall and negative relationship with maximum temperature. On other hand, goat population was strong positive relationship with minimum temperature.

3.4. Regression of climate variables on livestock population

According to the regression result of major livestock species with climate variables during last 19 years of study area showed in Table 8.

Table 8: Regression results of livestock population and climate data of study area

Model	Unstandardized Coefficients	Standardized coefficients	R^2	Adjusted R^2	T	Sig.
	Std. Error	Beta				
Cattle(Constant)	125214.071	12720.119			11.176	.000
Main RF	260.586	60.405	836	. 983	.662	4.314	.003
Goat(Constant)	1395220.190	260525.445				5.355	.001
Tmin	7849.114	2738.590	.420	.868	.831	2.866	.024
Sheep (Constant)	1067588.817	138664.715				7.699	.000
Main RF	129.823	35.403	.325	. 847	.975	3.667	.010
Camel(Constant)	36023.924	9609.210				3.749	.007
Tmin	1875.161	478.875	.725	.763	.697	3.916	.006
Donkey(Constant)	34629.346	8278.545				4.183	.004
Main RF	4.662	1.362	.571	.818	.768	3.420	.010
Mule(Constant)	81.931	24.171				3.390	.010
Tmin	7.075	1.190	.910	.669	.804	5.940	.000

Statistically, the coefficient of determination (R^2) value is used to express the degree of dependence of dependent variable on independent variable, which showed the strength relationship. As Table 6 indicated that among six dependent variables, cattle, sheep and donkey populations highly depends on main rainfall, while goat, camel and mule populations were mainly depending on minimum temperature that indicated strong relationship between two variables.

3.5. Effects of Climate Change on Rangeland in District

According to the perceptions of household respondents, the major source of feed resources in the district include natural pastures, hay, crop residues and weeds, and

the quantity and quality vary with climate condition especially rainfall. Household survey results are shown in table 9.

Table 9: Factors affecting the rangeland of the district

VARIABLES	Pastoral		Agro-pastoral	
	Index	Rank	Index	Rank
Rainfall variability	0.295	1st	0.294	1st
Bush encroachment	0.292	2nd	0.287	2nd
Drought	0.255	3rd	0.249	3rd
Flood	0.160	4th	0.168	4th

FGDs and KII were supported the decreasing of feeds resource availability and quality due to rainfall variation and increasing of unpopular plants species into rangeland from time to time during their interviewed and discussions. Increasing temperatures and decreasing rainfall reduce yields of rangelands and contribute to their degradation. Other studies have confirmed these results. The causes of bush encroachment have been a contentious issue in rangeland ecology, where possible causes include shortage of rainfall, notably wet cycles (Kraaij, 2003; Ward, 2005); heavy grazing, absence of hot brush killed fires, loss of large trees and soil nutrient changes.

Table 10: Major Bush encroachments in the district

Variables		Pastoral		Agro-pastoral	
Scientific name	Local name	Index	Rank	Index	Rank
Acacia mellifera	*Saphansa*		1st	0.227	1st
Acacia reficiens	*Sigirsoo*		2nd	0.139	2nd
Acacia horide	*Caaccannee*		3rd	0.132	4th
Acacia senegal	*Hidaadhoo*		3rd	0.107	7th
Acacia nubica	*Waangaa*		5th	0.125	6th
Dichrostachys cinerea	*Jirimee*		5th	0.139	2nd
Acacia drepanolobium	Fulleessa		7th	0.129	5th

3.6. Adaptation Methods Practiced By Herders of Study Area

To reduce the effect of climate change, pastoralists and agro-pastoralists of the district practiced adaptation strategies. As the household interview results show, most pastoralists and agro-pastoralists (92.41%) applied adaptation strategies, while a few respondents (7.59%) did not. Moreover, herders who did not adapt gave many reasons for their failures to adapt which include lack of information, lack of money, shortage of labour, shortage of land and poor in livestock ownership.

3.7. Estimation of the results of multinomial logit model

As the results of MNL model showed, there were high influences of independent variables on herders' adaptation choices to apply climate change adaptation strategies in the district and also some significant levels of the parameters estimates. According to the result of MNL model, likelihood ratio of the ch2 statistics was (LR chi-square (66) =154.29 was highly significant Prob> chi2= 0.0000), suggesting the model had a strong independent power. The estimated coefficients of all dependent variables were taking no adaptation as base category. The coefficient estimations from the multinomial logit model show the direction of the effect while multinomial logit model regression shows the magnitude effect of determinant variables for each category versus the base category. That means the base category was the household who did not choose any adaptation strategy. The maximum likelihood method was employed to estimate the relative importance of predictor variables on the pastoralists' decision to choose adaptation strategies. The parameter estimates of the MNL model estimates neither actual size of change nor the probabilities, but it gives only the direction of the effect of explanatory variables on the dependent variable. Therefore, we can compute the magnitude of effect by using STATA command mfx2 after MNL regression and it gives marginal effect.

Table 11: Marginal effect (β) of adaptation strategies of study area

Independent Variable	Livestock diversify	Hay making	Area enclosure	Livestock mobility	Income diversif	Bush thinning	No adaptat.
Sex	. 385	1.279	-.592	. 579	. 969	-.466	-.055
Age	. 038	. 038	.056	. 026	. 024	. 080	-.059*
Education	.007	.051	.066	-.069	.053	.057	.015
Family size	.112*	.074	.890**	.036	.011	.057	.006
Income	.068 **	.064*	-.013	.086	.001	.006	.003
Land size	.183**	.031	.041	.056	.016	.150***	-.011
TLU	.029***	.005	.014**	.038	.010	.015*	-.021
Market	.144	-.070	.166	.0132	.091	.170**	.017
Information	.246 *	.038	.104	.121	.085	.068	-.190***
Credit	.096	.057	.220	-.066	.120**	.079	-.069**
Extension	.097	.095	.189**	-.057	.080	.079	-.060**

*Notes: ***, **,* = significant at 1%, 5% and 10% probability level, respectively.,*
Source: Analysis based on survey data, 2025.

3.8. Interpretation of marginal effect of adaptation strategies of study area

Age of household head: Age of household head has negative and significant effect on the no adaptation to climate change. As age of household increase by one unit, the no adaptation decreases by 5.9% (p =0.054), keeping other variables constant. This result was in line with the findings of Deressa *et al*. (2008).

Family size of household: family size has positive and significant effect on adaptation strategies to climate change. As the number of family size increase by one unit, the herders' adaptation methods of livestock diversification and area enclosure increase by 11.18% (p =0.071) and 89% (p =0.044) respectively, keeping other variables constant.

Income of household: income of the household has also a positive and significant effect on adaptation strategies to climate change. The increasing one unit of household income increases livestock diversification and hay making by 6.84% (p =0.011) and 6.4% (p =0.095), respectively, holding other variables constant. The impact of income on adoption found a positive correlation (Deressa *et al*., 2008). When the main source of income in pastoralists increases, pastoralists tend to invest on productivity smoothing options.

Land holding: land holding by household has a positive and significant effect on adaptation strategies to climate change. Increasing in one unit of land size increases livestock diversification and bush thinning by 18.3 %(p = 0.054 and 15% (p = 0.007), respectively, holding other variables constant.

Livestock holding: livestock holding by household has positive and significant effect on adaptation strategies to climate change. As livestock holding by household increase by one-unit livestock diversification, area

enclosure and bush thinning increases by 2.9 % (p = 0.000), 1.4% (p = 0.044), and 1.46% (p = 0.083) respectively, keeping other variables constant.

Market accessibility: access to market has positive and significant effect on adaptation strategies to climate change. Market accessibility increases bush thinning by 17 % (p =0.049), holding other variables constant.

Climate information: climate information has positive and significant effect on adaptation strategies while negative and significant on no adaptation strategies to climate change. As household information on climate change increase livestock diversification increase by 24.58 % (p = 0.090) and the no adaptation to climate change decrease by 19% (p = 0.012), keeping other variables constant. The availability of better climate information helps farmers make comparative decisions among alternative adaptation practices and hence choose the ones that enable them to cope better with changes in climate (Baethgen *et al*., 2003; Jones, 2003).

Credit accessibility: credit service has positive and significant effect on adaptation strategies while negative and significant on no adaptation strategies to climate change. As credit accessibility increase income diversification increase by 12 % (p = 0.042) and the no adaptation to climate change decrease by 69% (p = 0.014), holding other variables constant. Access to affordable credit increases financial resources of farmers and their ability to meet transaction costs associated with various adaptation options they might want to take (Nhemachena and Hassan, 2008).

Extension services: also extension service has positive and significant effect on adaptation strategies while negative and significant on no adaptation strategies to climate change. As extension services increase area enclosure increase by 18.9 % (p = 0.027) and the no adaptation to climate change decrease by 6% (p = 0.030), holding other variables constant. Nhemachena and Hassan (2007) confirmed that extension on crop and livestock production and information on climate represent access to the information required to make the decision to adapt to climate change.

Table 12: Standard Errors of adaptation strategies of study area

Ind.Variable	Livestock diversifi.	Hay making	Area enclosure	Livestock mobility	Income diversif	Bush thinning	No adapt.
Sex	.043	.047	.013	.013	.035	.038	.044
Age	. 032	.030	.043	. 036	. 036	. 060	.011
Education	.029	.025	.033	.024	.020	.029	.016
Family size	.042	.036	.047	.047	.033	.046	.028
Income	.027	.037	029	.030	.019	.027	.014
Land size	.045	.028	.034	.039	.041	.056	.030
TLU	.005	.006	.008	.007	.007	.006	.002
Market	.036	.037	.037	.026	.040	.047	.024
Information	.025	.011	.046	.049	.044	.003	.040
Credit	.043	.011	.028	.036	.039	.029	.028
Extension	.016	.018	.043	.040	.042	.010	.028

Statistical Interpretation of the Values

In statistical theory, a Standard Error (SE) quantifies the precision and stability of an estimated coefficient (beta). It measures how much the coefficient estimate is expected to vary from sample to sample. The estimation matrix exhibits robust structural stability and high-fidelity parameter estimation, characterized by standard errors that are universally tightly bound between (0.002) and (0.060). The zenith of statistical precision is concentrated within the Tropical Livestock Units (TLU) vector ($0.002 \leq SE \leq 0.008$), Information access under the *Bush thinning* pathway (SE = 0.003), and Extension services under *Bush thinning* (SE = 0.010). This exceptional precision establishes that asset endowments and institutional frameworks serve as the most mathematically stable behavioral determinants of adaptation choices across the sampled population.

Furthermore, with the localized variances for Age (SE = 0.060) and Sex (SE = 0.038) under *Bush thinning* operating within nominal distributions, alongside Income under *Area enclosure* maintaining an optimal precision threshold (SE = 0.029), the entire estimation architecture demonstrates uniform empirical reliability. This systemic minimization of sampling variance effectively mitigates concerns regarding heteroscedasticity, thereby ensuring a highly resilient foundation for subsequent hypothesis testing and policy inference.

3.9. Policy Implications of The Study

- The study explicates that reduced rainfall, increasing temperatures and perennial droughts are strictly affecting livestock production and pastoral livelihoods in Taltalle District. These findings demostrate the necessity for holistic, long-term climate adaptation policies should focus on strengthening pastoral resilience instead of relying primarly on emergency interventions.
- Government policies should prioritize investment in climate-resilient sustainable water infrastructure such as

wells, water harvesting systems and enhanced climate information early warning system to address lingering water scarcities. Durable rangeland management policies are also indispensable, comprising bush thinning, rehabilitation of degraded pasturlands, paddock grazing and communal natural resources management strategies to recover forage availability and control land degradation.

- The findings further highlight the significance of upholding climate-smart livestock management through advancing herd diversification toward drought-tolerant species such as goats and camels, and supporting feed conservation practices. Scaling-up veterinary and extension services is essential to address climate-related livestock diseases and diminishing productivity.
- Access to livestock insurance, climate information, markets, roads, and telecommunications should be improved as these factors considerably influence pastoralist' ability to adopt adaptation strategies. Policies should also reinforce indigenous drought early warning systems and incorporate it into climate adaptation planning at regional and national levels.
- Lastly, national and regional climate policies should mainstream pastoral adaptation by supporting community-based adaptation strategies, livelihood diversification and programs aimed at strengthening sustainable resilience that condense vulnerability to recurrent climate-induced shocks in arid and semi-arid areas of Borana zone in particular and Ethiopia in general.

4. Conclusion

In conclusion, both pastoral respondents and 45 years of district meteorological data indicate a decrease in rainfall, an increase in temperature, and a high frequency of drought. This high frequency of drought has severely affected livestock production, as well as feed availability and quality. To mitigate the negative effects of climate change on livestock production, herders have implemented several adaptation strategies. Ultimately, age, family size, income, farm size, access to markets, access to credit, extension services, livestock ownership, and access to climate information were the main factors influencing the herders' choice of climate change adaptation methods in the study area.

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Authors' Contributions

All authors contributed to the research project, from the initial proposal writing to the submission of the final results. Galma Halake prepared and revised the manuscript.

Conflicts Of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Nutritional composition, Micro-nutrient Profiles, *Invitro* digestibility and Gas production characteristics of *Azolla Pinnata* and Major crop residues for Ruminant livestock feeding in Ethiopia

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Abstract

The study was conducted to evaluate chemical composition, micronutrient profiles, invitro digestibility and gas production characteristics of Azolla pinnata cultivated in artificial ponds at school of Animal and Range sciences, Hawassa University, Ethiopia. The chemical analysis revealed that Azolla meal has a high crude protein (CP) content (28.64%), comparable to Noug seed cake (31.50%), and is rich in essential minerals like calcium, phosphorus, potassium, and magnesium. DM and fiber analysis (NDF, ADF, and ADL) showed that Azolla had lower dry matter (DM), organic matter (OM), and neutral detergent fiber (NDF) but higher ash and acid detergent lignin (ADL) content than local residues. Eventhough Azolla's DM content is lower than local feeds, it is still a superior source of protein and minerals. Azolla contains high levels of potassium (22.64 g/kg DM), calcium (7.45 g/kg DM), phosphorus (6.69 g/kg DM), and magnesium (2.99 g/kg DM), all of which are essential for livestock growth and reproduction. The calcium and phosphorus levels meet recommended standards for livestock, supporting bone development and metabolic processes. Azolla's potassium content, which is higher than many terrestrial types of forage, contributes to alternative feed resources in livestock. Trace minerals like manganese and iron are present in significant amounts, further enhancing Azolla's nutritional value. However, the study detected its bioaccumulation of heavy metals such as nickel, lead, and cadmium, which could pose risks of mineral toxicity to livestock if not managed properly. The study also demonstrated that Azolla pinnata has superior in vitro digestibility, gas production, and metabolizable energy (ME) values compared to locally available crop residues like wheat straw, maize Stover, and haricot bean haulms. Azolla exhibited higher gas production, organic matter digestibility (OMD), and metabolizable energy, making it a highly digestible and enesergy-efficient feed source. Moreover, its lower methane production and higher short-chain fatty acid (SCFA) production indicates improved rumen fermentation and reduced environmental impact. These results confirm Azolla's potential as a more effective feed supplement for ruminants, enhancing feed efficiency and livestock performance.

Key words: *Azolla pinata, chemical composition, invitro gas production, micro-nutrient profiles*

1. Introduction

In Ethiopia, the human population is growing quickly which is decreasing the crop land coverage with time. As a result, livestock are dependent on crop residues that are low in crude protein and low in nutritional quality. Additionally, the concentrate, which is the most important component of animal feed, is quite expensive and is can be a blame for

decreasing income. The development of inexpensive protein sources is urgently required to support and improve production performance of sheep and raise the income of producers. *Azolla pinnata* can serve as an alternative source of protein replacement in this situation. *Azolla* meal has been tested as a partial replacement for concentrate mixture in livestock diets by various researchers. The performance outcomes of sheepfed Azolla meals varied between studies. Moreover, there is not enough information about the use of Azolla meal for sheep in Ethiopia.Therefore, the current study was carried out to evaluate the substitution effect of Noug seed (*Guzoitia abyssinica*) cake with Azolla (*Azolla pinnata*) meal on nutrient digestibility, gas production profile, growth performance, and carcass characteristics of Arsi-bale sheep with the following specific objectives; to determine chemical composition, *invitro* digestibility, and gas production profiles of Azolla meal.

2. Materials and Methods

2.1. Description of the study area

The study was conducted at the Small Ruminant Experimental Shed of the School of Animal and Range Sciences, Hawassa University, located in Hawassa, Sidama Regional State, southern Ethiopia. Hawassa is situated approximately 275 km south of Addis Ababa, the capital city of Ethiopia, and lies within the Great Rift Valley.

The experimental site is part of Hawassa University's agricultural research and teaching facilities, which are used for practical training and research activities related to animal production, nutrition, health, and management. The Small Ruminant Experimental Shed provides a controlled environment suitable for conducting feeding trials and evaluating the performance and nutritional responses of sheep and goats. The area is characterized by a sub-humid climate, with moderate temperatures and bimodal rainfall patterns. The average annual temperature ranges from approximately 20°C to 25°C, while the annual rainfall generally ranges from 800 to 1,200 mm.

2.2. Cultivation of Azolla

Azolla pinnata was obtained from Sebeta Research Center Oromia Regional State and was transported to Hawassa University College of Agriculture School of Animal and range Science farm. Azolla was cultivated in 12 pits; each with a dimension of 3m x 2m (6 m^2) was made with 30 cm depth and 40-50 kg sieved forest soil was uniformly spread over the silpauline sheet in each pit. Water 250-350 liters water was poured onto the sheet to make the water level reach about 10 cm. Later, water was filled to a three-fourth level in each pit and

regular care was taken to maintain the water up to the same level. About 10 kg of fresh cow dung thoroughly mixed and dissolved in 20 liters of water and spread evenly throughout the area. A few hours later, about 1kg to 2 kg of fresh and pure *Azolla pinnata* cultures was inoculated in to each pit. Once every 15 days, an application of 10 kg cow dung per pit was done to keep continuous growth of Azolla and avoid nutrient deficiency. In case of contamination of the pits by pests and diseases, a fresh inoculation was done with a pure culture of Azolla after clearing the previous biomass of Azolla and water from the affected pit.

2.3. Collection, yield, and storage of Azolla

The fresh-grown Azolla was collected every five days from all the pits. Harvested Azolla was washed thoroughly in clean water to get rid of the cow dung smell and to remove the extraneous materials. To form Azolla meal, it was sun-dried for 3-5 days under shade. Every day, it was manually stirred more than three times a day to facilitate better drying, and every evening it was put indoor to minimize the reabsorption of moisture. After drying the amount required for the entire experiment, it was collected, put in sacks and transported to a sheep farm, and stored until required for the formulation of the experimental rations.

2.4. Feed Chemical Analysis

Representative samples (offered and refusal) used in the feeding experment and fecal samples were taken to Hawassa University, College of Agriculture, Department of Animal and Range Science Animal Nutrition Laboratory for chemical composition analysis. The samples of the experimental diet were analyzed for dry matter, crude protein, and, metabolizable energy content before the start of the feeding trial to determine the amount of the proportion of each ingredient in the ration formulation. During the feeding trial , samples of hay refusals were collected weekly from each lamb and pooled for each treatment. The collected samples were partially dried at 60ºC in a forced draft oven for 72 hours and ground to pass through a 1 mm sieve. Determination of DM, Ash, and N contents was conducted according to the AOAC (2005) procedure. The N content was determined, and then the Crude protein (CP) content was determined by Multiplying as N x 6.25. Organic matter (OM) was calculated as the difference between DM of feed and ash content. Neutral detergent fibers (NDF), acid detergent fibers (ADF), and acid detergent lignin (ADL) were analyzed using the procedures of Van Soest and Robertson (1985). The energy value of feed was estimated according to McDonald *et al.,* (2014) metabolizable energy (MJ/kg

DM) = 0.016DMOI; where DOMI is digestible OM intake per kg DM.

***In vitro* gas production: -** The gas production technique of Menke and Steingass (1988) as described by (Abdulrazak *et al.,* 1999) was used in the *in vitro* gas production assessment. Rumen fluid was obtained from four sheep before the morning feed. Incubation was carried out according to (Menke and Steingass, 1988) in 120 ml calibrated syringes in one batch at 39^0c. The gas production was measured at 3, 6, 12, 24, 48, and 72 h. The average volume of gas produced from the blanks was deducted from the volume of gas produced per sample. The volume of gas production characteristics was estimated using the equation $y = a + b (1 – e^{ct})$, where y = volume of gas produced at a time 't', a = intercept (gas produced from the soluble fraction), b = gas production from the insoluble fraction, (a+b) = total gas production, c = gas production rate constant for the insoluble but digestible fraction (b) and t = incubation time the post-incubation parameters such as metabolizable energy (ME, MJ/kg DM), organic matter digestibility (OMD %) and short-chain fatty acids (SCFA) was estimated at 24 h post gas collection (Menke and Steingas, 1988). At the end of 24 h incubation, 4 ml of 1n Na $(OH)_2$ was added to the substrate in each syringe to determine the methane production (Fievez *et al.,* 2005). *In vitro* organic matter digestibility (IVOMD) was calculated from the equation: OMD (%) = 18.53 + 0. 9239 gas production (at 48 hrs) + 0.0540 CP (Menke and Steingass, 1988). Where: OMD = organic matter digestibility at 48 hours and CP=crude protein (%DM). Metabolizable energy (ME) is calculated from the equation: ME (kj/g DM) = 2.20+0.136gp+0.0057cp (Menke and Steingass, 1988) where: GP=gas production over 24rs of incubation; CP=crude protein content of feed samples, short chain fatty acids (SCFA) was calculated from the equation: SCFA = 19 0.0239*GP– 0.0601.

3. Results and Discussion

3.1. Chemical Composition of Locally Available Basal Feed and Azolla Meal

The chemical analysis of sun-dried and ground Azolla meal and locally available major crop residues are presented in Table 1. The crude protein (CP) content of Azolla meal recorded from the current study was 29.42 percent which indicated that Azolla could be used as a potential natural protein source in livestock feeds.

Table 4: Proximate composition of *Azolla pinnata* and Major local available crop residues

Feed type	Chemical composition (% of DM and % DM for others)						
	DM	Ash	CP	NDF	ADF	ADL	EE
Azolla meal	15.17	19.95	29.42	50.4	34.97	15.07	3.12
Haricot bean haulms	93.2	8.43	9.98	62.5	26.09	9.02	0.96
Barley straw	93.68	6.89	4.95	75.7	40.18	11.83	0.53
Teff straw	93.6	9.24	6.31	73.3	46.32	9.69	1.08
Maize Stover	90.6	7.52	5.21	63.4	43.1	9.06	0.03
Wheat straw	94.6	10.68	4.35	75.5	35.06	8.41	0.1

DM = dry matter, CP = crude protein, NDF = nutrient detergent fiber, ADF = acid detergent fiber, ADL = acid detergent lignin, EE = ether extract

The CP value (29.42) recorded of Azolla meal was significantly higher than that of the results obtained by Ahmed *et al.* (2016), Basak *et al.* (2002) Rawat *et al.* (2015) and Cherryl *et al.* (2014) reported values of 26.62, 25.78, 24.1 and 23.49 percent CP respectively. However, the result was lower than that reported by Al-Suwaiegh (2023) recorded value (32.83%). This variation may be due to differences in management practice, soil type, and climatic conditions of the different areas.

According to the result of this study, the ash content in Azolla meal was 19.95%, significantly higher than the major local available crop residues, indicating a higher mineral content. The study revealed that the value obtained was higher than the findings of Acharya *et al.* (2015), Anitha *et al.* (2016), Ahmed *et al.* (2016), and Al-Suwaiegh (2023) reported 18.75, 17.34, 16.8, and 15.59 respectively. However, the value is lower than that reported by El-Fadel *et al.* (2020), Kumar *et al.* (2020), and Cherryl *et al.* (2014) who reported ash content of 27.14, 26.1, and 24.26) respectively.

The NDF, ADF, and ADL content of Azolla in the present study were recorded at 50.4%, 34.97%, and 15.07%, respectively. Azolla had higher CP, ASH, ADF, ADL, and EE but lower DM, OM, and NDF content than major locally available crop residues; however, the DM (15.17%) in *Azolla pinnata* was lower than that of the locally available basal feed used in this study. In this study, the crude protein of major locally available crop residues is recorded as 9.98, 6.31, 5.21, 4.95, and 4.35 for Haricot bean haulm, Teff straw, Maize Stover, Barley straw, and Wheat straw,respectively and the CP values has lower than Azolla meal. This indicates Azolla to be a reasonably good source of energy and a high source of protein source to Arsi-Bale sheep (Kumar *et al*., 2015; Basak *et al*., 2002; Rawat *et al*., 2015; Anitha, 2016) who studied the chemical composition of sun-dried Azolla and mentioned the DM content of Azolla was comparatively less but suggested to be

used as a supplement to meet the DM requirements in livestock feeds.

3.2. Micro-Nutrient Profiles of Azolla Meal

The mineral profile of *Azolla pinnata*, both major and trace minerals measured in grams per kilogram of dry matter (g/kg DM) is presented in Table 2. The major mineral profile of *Azolla pinnata* obtained in the present study indicated that calcium (7.45 g/kg DM), phosphorus (6.69 g/kg DM), potassium (22.64 g/kg DM), and magnesium (2.99 g/kg DM). These values suggest that Azolla could serve as a valuable dietary supplement in livestock diets, particularly for ruminants that require substantial amounts of these minerals for optimal growth and reproduction.

Table 5: Micro-nutrient profiles of *Azolla pinnata* leaves and stems

Minerals	**g/kg DM**	**Amino acids**	**µg/KgDM**	**Amino acids**	**µg/KgDM**
Calcium	7.45	Lysine	3750.5	Aspartate	1366.5
Phosphorus	6.69	Methionine	3194.5	Glutamate	2899
Potassium	22.64	Cystine	4398	Histidine	4406
Magnesium	3.0	Threonine	2626	Alanine	1709
Sodium	11.34	Arginine	3959		
Trace Minerals	**ppm**	**Amino acids**	**µg/KgDM**		
Manganese	329.1	Leucine	2776		
Zinc	150.7	Phenylalanine	3405.5		
Copper	5.2	Tyrosine	3671.5		
Iron	129	Glycine	1726.5		
Copper	0.005	Valine	3750.5		
Mercury	0.012	Proline	2972.5		
		Isoleucine	2623.5		

The calcium content of Azolla in the present study was revealed higher than the value of Anitha *et al.* (2016); and Bhatt *et al.,* (2020) reported (1.64 and 1.51) respectively. The phosphorus content also meets the requirements for livestock, as outlined by the National Research Council (NRC, 2000), which emphasizes the need for balanced calcium-to-phosphorus ratios to prevent deficiencies.

The potassium level (22.64 g/kg DM) is particularly noteworthy, as potassium is

crucial for maintaining osmotic balance and muscle function. This concentration is higher than some terrestrial forage, making Azolla a beneficial addition to diets where potassium levels are low Bhatt *et al.,* (2020).

The mineral profile of Azolla obtained in the present study is almost similar to the values reported by Anand & Geetha (2007), and Kavya (2014). The calcium content of Azolla is similar to the reports of Tamang *et al.* (1993). The Magnesium content of Azolla obtained in the present study is similar to the value reported by Alalade & Iyayi (2006). Higlevels

Table 6: *In vitro* digestibility, Gas production profiles, and Metabolizable energy values of *Azolla pinnata* and Major locally available crop residues

Post-fermentation Parameters	HPM	HCH	BS	TS	MSt	WS	P-value	SEM
IVDMD(%)	71.9^{a}	53.7^{dc}	49.1^{d}	60.8^{b}	56.2^{c}	51.6^{d}	0.001	2.27
GP24(ml/200mg)	56a	49.3bc	51.3bc	53ab	47.3c	48.3c	0.007	2.36
GP48(ml/200mg)	63.5^{a}	55.0^{b}	55^{b}	56^{b}	53.5^{b}	54.5^{b}	0.006	2.67
OMD (%)	78.9^{a}	71.4^{b}	69.6^{b}	70.6^{b}	68.2^{b}	69^{b}	0.003	2.51
SCFA(mM/l)	1.28^{a}	1.12^{bc}	1.17^{bc}	1.21^{ab}	1.07^{c}	1.09^{c}	0.007	0.056
ME(MJ/kgDM)	9.98^{a}	9.56^{ab}	9.21^{bc}	9.44^{ab}	8.67^{c}	8.79^{c}	0.004	0.34
Methane production (ml/200mg)	64.7^{b}	81.6^{a}	69.9^{b}	71.5^{ab}	82.2^{a}	75^{ab}	0.002	5.44
MRP (%)	21.4^{a}	4.5^{c}	16.7^{a}	14.6ab	3.9^{c}	11.1^{ab}	0.002	5.44
Fitted parameters								
a	34.5^{b}	37.5^{a}	34.4^{b}	32.3bc	31.6^{bc}	30.5^{c}	0.004	1.87
b	41.3^{b}	35.6^{c}	33.3^{d}	32^{d}	35.6^{c}	47.3^{a}	0.002	1.69
c	0.026^{b}	0.016^{d}	0.026^{b}	0.037^{a}	0.023^{c}	0.016^{d}	0.001	0.04
RSD	2.052^{a}	0.987^{d}	2.201^{a}	2.119^{a}	1.381^{b}	1.493^{b}	0.001	0.58

IVDMD = invitro dry matter digestibility; GP = gas production; ml = millilitre; mg = milligram; OMD = organic matter digestibility; ME = metabolic energy; MRP = Methane reduction potential; HPH = Azolla meal; HCH = Haricot bean haulm; BS = Barley straw; TS = Teff straw; MSt = Maize Stover; WS = Wheat straw

In vitro gas production of Azolla were found to be 56 ml /200 gm / 24 hours; 63.5 ml /200 gm. / 48 hours; and ME content was 9.98 MJ / kg DM. The amount of gas produced from Azolla meal (56, 63.5) at 24h and 48h incubation was markedly higher (p >0.05) than gas produced from Haricot bean haulm (49.3, 55.0), Barley straw (51.3, 55), Teff straw (53, 56), Wheat straw (48.3, 54.5) and maize Stover (47.3, 53.5), respectively. The *in vitro* net gas production and metabolizable energy density of Azolla obtained in the current study were higher than those reported by Buckingham *et al*. (1978) and Kavya *et al.* (2014), However, lower than the value reported by Alalade and Iyayi (2006), Khatun *et al.* (1999) and Ramesh (2008). The *in vitro* dry matter digestibility of Azolla obtained in the present study was almost similar to that reported by Becerra *et al.* (1995).

Wheat straw and haricot bean haulm had lower GP values at 48 hours (48.3 ml/200mg

and 49.3 ml/200mg, respectively). High gas production is often associated with increased fermentation of readily digestible carbohydrates, suggesting that Azolla offers better fermentable energy compared to crop residues like barley and wheat straws.These findings corroborate those by Getachew *et al.* (2004), who observed lower gas production in cereal straws compared to leguminous feed sources like Azolla. The higher GP of Azolla highlights its potential as an energy-efficient feed, particularly for enhancing rumen microbial activity in livestock.

The organic matter digestibility (OMD) of Azolla (78.9%) was again superior to all other tested crop residues ($P < 0.01$). Maize Stover (68.2%) and barley straw (69.6%) had the lowest OMD, indicating poor organic matter utilization. This confirms the potential of Azolla as a more digestible source of organic matter, suitable for improving livestock feed efficiency. Acharya *et al.* (2023) also found that Azolla has higher OMD than traditional straws, supporting its use as a valuable alternative feed resource for ruminants.

Azolla pinnata showed the highest ME value (9.98 MJ/kg DM), significantly surpassing most of the crop residues, particularly wheat straw (8.79 MJ/kg DM) and maize Stover (8.67 MJ/kg DM) ($P = 0.004$). The relatively high ME content of Azolla suggests that it can provide better energy for growth and production compared to other local residues. The ME values obtained in the current study for Azolla are in agreement with previous findings by Anitha *et al.* (2016), who reported ME values of 9.5-10 MJ/kg DM for Azolla species used in ruminant diets.

Methane production (ML/200mg) was significantly lower in *Azolla pinnata* (64.7 ml/200mg) compared to haricot bean haulm (81.6 ml/200mg) and maize Stover (82.2 ml/200mg) ($P = 0.002$). Lower methane production is desirable in livestock production as it indicates better feed efficiency and reduced environmental impact.

The present study revealed that the Production of short-chain fatty acids (SCFA) in Azolla (1.28 mM/l) was higher than in other major locally available crop residues. However, the Present value is lowest in Maize Stover (0.07). Potential methane production (ml/200 mg) ranged from 81.6 in Haricot bean haulms to 64.7 in *Azolla pinnata*, with Methane reduction potential (MRP) 3.9-21.4%. Higher SCFA production indicates better rumen fermentation and microbial efficiency, contributing to improved animal performance. As fermentation time increase, gas production increase (Fig 1).

The gas production from immediately soluble portion “a” value ranged from

37.5% (Haricot bean haulms) to 30.5 % (Wheat straw). The gas production from water-insoluble but degradable portion "b" fraction was higher in Wheat straw (47.3%) to 32% in Teff straw. The rate of gas production from insoluble but degradable portion "c" ranged from 0.037%/hr in Teff straw to 0.016 %/hrs in both Wheat straw and Haricot bean haulms.

The fitted parameters and gas production characteristics provide additional insights into the kinetics of fermentation. Azolla pinnata had a higher asymptotic gas production (75.8 ml) compared to crop residues such as teff straw (64.3 ml) and maize Stover (67.4 ml), suggesting a higher potential for gas production and fermentable carbohydrate availability (P = 0.001). The fractional rate of gas production (c) was also higher in Azolla (0.026), indicating faster fermentation rates compared to wheat straw and haricot bean haulm.

Figure 1 shows that in vitro gas production differed among Azolla pinnata meal and the tested crop residues. Azolla meal (HPH) produced relatively high gas volumes, indicating greater ruminal fermentability than most crop residues. Haricot bean haulm (HCH) also showed comparatively high gas production, whereas barley straw (BS), teff straw (TS), maize stover (MSt), and wheat straw (WS) generally produced lower gas volumes. The results suggest that Azolla meal and haricot bean haulm possess better fermentation characteristics and may be more suitable feed resources for improving rumen fermentation compared with the cereal crop residues evaluated.

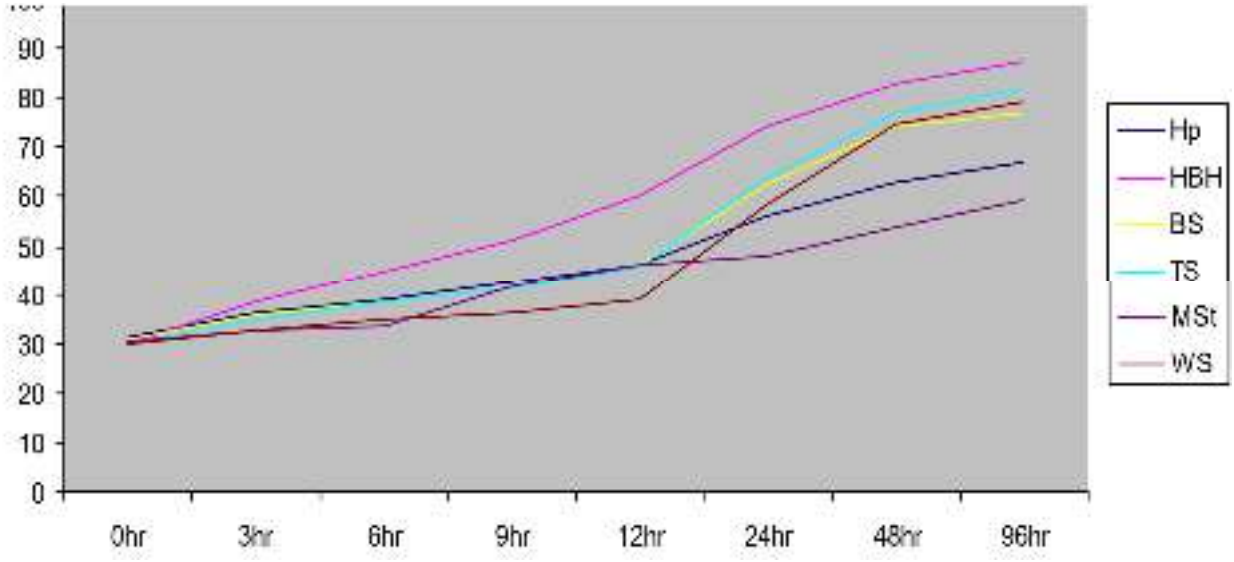


Fig 1: *In vitro* gas production of *Azolla pinata* and some crop residues

HPH = Azolla meal; HCH = Haricot bean; BS = Barley straw; TS = Teff straw; MSt = Maize Stover; WS = Wheat straw

4. Conclusion and Recommendation

The study revealed that the Azolla meal has a higher crude protein (CP) content (29.42%) compared to local major crop residues, making it a promising natural protein source for livestock feeds. Its CP content is significantly higher than values reported by several other studies which can be attributed to variations in environmental conditions and management practices. Azolla also demonstrated higher ash content (19.95%), indicating its rich mineral composition compared to local crop residues.

Chemical analysis showed that Azolla had lower dry matter (DM), organic matter (OM), and neutral detergent fiber (NDF) but higher ash, CP, EE and acid detergent lignin (ADL) content than local residues. Although Azolla's DM content is lower than local feeds, it is still a superior source of protein and minerals. The comparison showed that local crop residues had significantly lower CP content, emphasizing Azolla's potential as a valuable supplement.

*Azolla pinnata i*s a mineral-rich feed resource containing high levels of essential macro- and trace minerals, particularly potassium, calcium, phosphorus, magnesium, manganese, sodium, and iron. These minerals support important livestock functions such as growth, bone development, reproduction, and metabolic activity. Its calcium and phosphorus contents meet or exceed recommended livestock requirements, highlighting its potential as a valuable dietary supplement. However, the presence of heavy metals such as nickel, lead, and cadmium indicates the need for careful monitoring of cultivation conditions and feed safety to ensure its safe use in animal nutrition.Azolla's potassium content, which is higher than many terrestrial types of forage, contributes to maintaining osmotic balance and muscle function in livestock. Trace minerals like manganese, sodium, and iron are amounts, further enhancing Azolla'snutritional value. However, the study also detected the bioaccumulation of heavy metals such as nickel, lead, and cadmium, which could pose risks to animal health if not managed properly.

The study demonstrated that *Azolla pinnata* has superior *in vitro* digestibility, gas production, and metabolizable energy (ME) values compared to locally available crop residues like wheat straw, maize Stover, and haricot bean haulms. Azolla exhibited higher gas production, organic matter digestibility (OMD), and metabolizable energy, making it a highly digestible and energy-efficient feed source. Moreover, its lower methane production and higher short-chain fatty acid (SCFA) production indicate improved rumen fermentation and reduced environmental impact from methane

emission from ruminants. These results confirm Azolla's potential as a more effective feed supplement for ruminants, enhancing feed efficiency and livestock performance while reducing methane emission.

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Competing Interest

The authors declare no competing interests.

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Research Article

Feed Availability, Chemical Composition and In Vitro Digestibility of Major Livestock Feeds in Dalifage District of Afar Region, Ethiopia

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Abstract

A study was conducted in the Dalifage District, Afar Regional State, Ethiopia, to assess seasonal feed availability and the chemical composition and in vitro digestibility of major livestock feed resources under pastoral and agro-pastoral production systems. Samples of major browse species, grasses, and maize stover were collected and analyzed for dry matter (DM), ash, crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), in vitro digestible organic matter in dry matter (DOMD), and metabolizable energy (ME). The results revealed that fodder trees and shrubs (51.0%) and natural grazing lands (42.3%) were the main feed resources, while free grazing (92.7% of the respondents) on communal rangelands was the predominant feeding system. Destocking (50.3%) and livestock migration (31.1%) were the principal coping mechanisms experienced during feed shortage periods. The DM content of browse species varied from 87.95% to 92.55%. The CP values ranged from 15.58% to 22.74%, with the highest value attributed to Ziziphus mauritiana. Conversely, the dominant grasses, Cymbopogon pospischilii and Chrysopogon aucheri, and maize stover exhibited lower CP values, ranging from 3.82% to 8.73%. The NDF values ranged from 27.48% to 53.88%, while ADF ranged from 14.72% to 36.09%. ADL values ranged from 5.12% to 12.99%, with Grewia ferruginea recording the highest lignin content. The DOMD value of browse species ranged from 32.49% to 52.82%, while ME values ranged from 5.20 to 8.45 MJ/kg DM. Generally, browse species demonstrated higher crude protein content, lower fibre fractions, and better digestibility and energy values when compared to grasses and maize stover. Therefore, sustainable management and conservation systems should not be ignored to improve livestock productivity and the resilience of pastoral production systems. An implication of this finding is that further studies on anti-nutritional factors, seasonal nutrient dynamics, and animal feeding trials to better evaluate the feeding value of the major browse species.

Keywords: Browse species, nutritive value, *in vitro* digestibility, seasonal feed availability, pastoral and agro-pastoral system, Afar Region

1. Introduction

Ethiopia is well known for possessing huge livestock resources among African countries. The country is home to about 65 million cattle, 40 million sheep, 50 million goats, and 49 million poultry (CSA, 2020). Livestock are the main livelihood of many Ethiopian smallholder farmers who primarily live in rural areas (TRAIDE Ethiopia, 2021). Large numbers of animals are kept under the dominant mixed crop-livestock farming system, and livestock production has many economic and social functions for the rural people as a source of varieties of food, income, savings, draft power, and compensation (Japaro, 2021). Ethiopia is known for its large livestock population but does not fully benefit from its resources due to different complicated technical and non-technical constraints. Feed shortage in quantity and quality is the main problem of livestock production, particularly in smallholder pastoralist and agro-pastoralist communities.

The problem of animal feed supply and quality is challenged in arid and semi-arid tropical regions with erratic and unreliable rainfall that limits the biomass yield and growing season of herbaceous species (Bayissa *et al*., 2022). The main sources of animal feed in Ethiopia are natural pastures, crop residues, and agro-industrial by-products. The total area of grazing and browsing is estimated to be between 61 and 65 million hectares. From this, 12% is utilized for mixed farming, and the rest ispastoral areas (Malede & Takele, 2014). According to Olafadehan and Okunade (2018), browse fodders serve as valuable and cost-effective feed sources for livestock in developing countries, particularly during the dry season when herbaceous pastures, grasses, and legumes are in short supply. Since in Afar the main feed resource is rangelands, animals freely graze or browse on the forage available. However, in some areas, supplementary feeding occurs in limited proportions, and priority is given to pregnant and lactating cows and weak animals (Harinder *et al*. 2018).

The Dalifage district is characterized by arid and semi-arid climatic conditions and erratic rainfall. Due to this, browse feed species have a great role in livestock feed. This is because of their drought resistance, and browse species stay green for a long period of time. The climate of an area affects the nutrient composition of the forage species growing in the area. The concentrations of nutrients in forage species depend not only on the prevailing seasonal and

environmental conditions but also on the individual plant species (Waliszewska *et al*., 2024; Onyeonagu *et al*., 2013). A detailed study on feed quality and quantity is needed to document available nutrition and nutritive value.

In this regard, there is a gap in knowledge of the chemical composition of locally available feed resources and a widely recognized variation in the available nutritional information for these feeds. Nutritional profiles are important for efficient utilization of locally available feed resources in a given area. Hence, this study was carried out with the objective of evaluating the chemical composition and in *vitro* digestibility of selected livestock feed resources in the Dalifage district of Afar Region.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in the Dalifage district of administrative zone 5 of the Afar regional state, Ethiopia. It is a triangle-shaped district located near the base of the eastern escarpment of the Ethiopian highlands and bordered on the south by Hadele-Ele, on the west by the Amhara region, and on the north by the Borkana River, which separates it from Dewe. It is located 10°28’ 26” N to 10° 41’ 38” N latitude and 40° 08’ 07” E to 40° 23’ 38” E longitude. It covers 164,600 hectares. The district has 11 kebeles; of these, 7 kebeles are home to agro-pastoralists, and 4 kebeles are home to pastoralists.

The agro-ecology of the district is almost an arid zone, and about 33°C and 350 mm are the average annual temperatures and rainfall, respectively. The main rainy season, karma, accounts for 60% of annual rainfall and occurs from mid-June to mid-September. This is followed by rainy showers in mid-December called *dada* and a minor rainy season during March-April called *sugum*. Disruptions to the performance of any rainy season have impacts on the availability of pasture and water as well as the overall insecurity, like ethnic conflicts and the situation of the pastoral and agro-pastoral communities (ANRS, 2010).

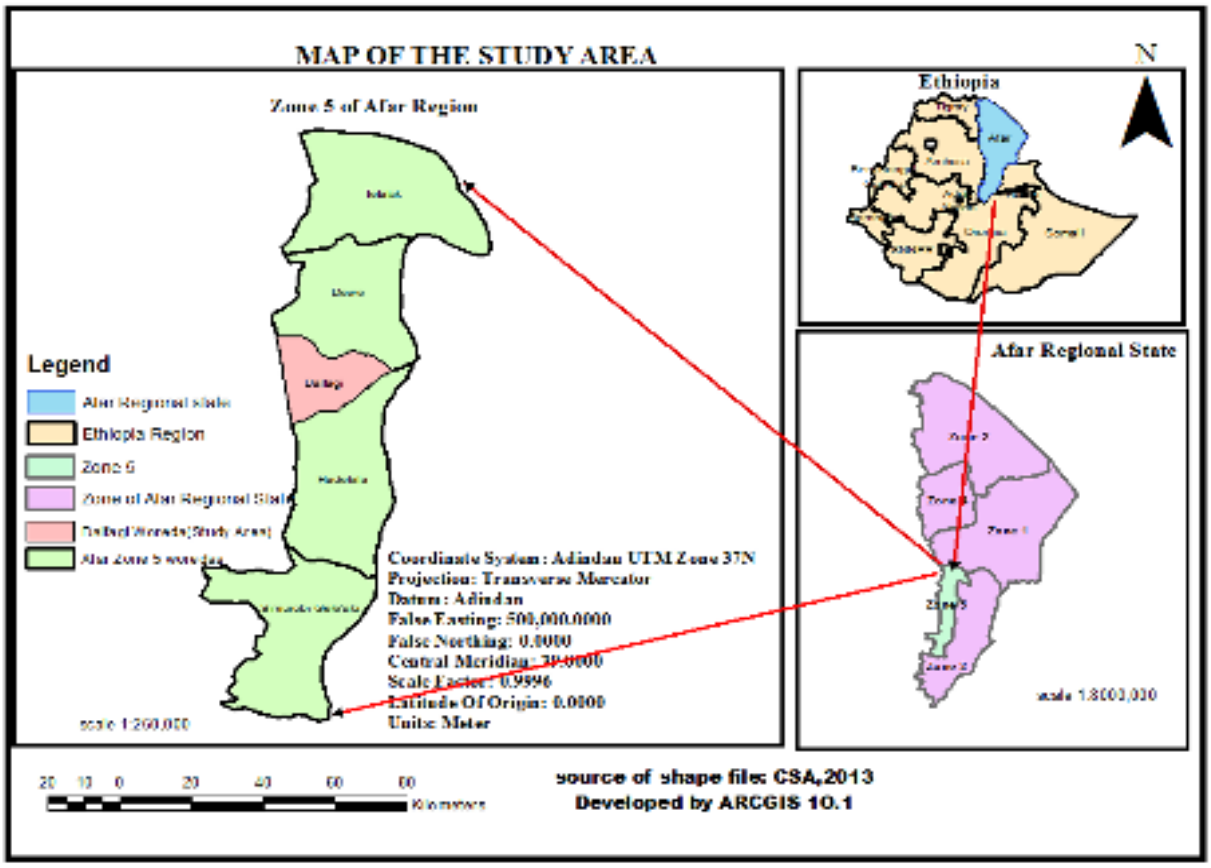


Figure 6.Map of zone 5 of Afar Dalifage district

2.2. Sampling And Preparation Of Feed Resources

Single visits of the formal survey method were used to collect information on livestock feed resources, feeding system, and related data. During the formal survey, 151 respondents participated in both pastoral and agro-pastoral production systems. During informal interviews and focus group discussions, the major available feed resources in the district were listed and identified. The feed resources were ranked from one to fifteen according to their availability and importance. After discussion and interviews, eight major livestock feed species were selected that are common in pastoral and agro-pastoral areas. In the district, two sites were selected purposively based on the availability of the selected feed resource species and practices of utilization for animal feeding from pastoral and agro-pastoral farming systems.

Two parallel transect lines; each 1.2 km long were randomly established for sample collections in both pastoral and agro-pastoral selected sites. Within the selected transect lines, quadrats of 20 m x 20 m size were laid along the lines at an interval of 50 m to collect samples of the selected browse species.

Browse species found within these quadrats were sampled, properly identified, and labelled by species name for subsequent analysis.

The samples were collected at three portions; top, middle, and bottom of the trees to get representative samples. Samples of browse species were hand-plucked with a mix of all edible parts (leaves, fine stems, and pods), and a composite sample of one kilogram on a fresh basis from ten plants was taken from each species where more important and available along rural pastoral and agro-pastoral areas.

The samples of grass were collected from two sites of rangeland in pastoral and agro-pastoral farming systems. The sites were selected purposively, and 1 m x 1 m quadrats were used to harvest forages at about 5 cm above the ground, and then the species were separated. Forages of the same species were pooled over the production system separately, and a sub-sample of 1 kg each was taken for chemical analysis.

Fresh samples with high moisture content were initially weighed using a suspended beam balance. To ensure safe transport and prevent spoilage, the samples were partially shade-dried in the field. They were then transported to the Animal Nutrition Laboratory at the Debre Berhan Research Center, where they were oven-dried at 60°C for 72 hours to a constant weight. Afterward, the dried samples were ground to pass through a 1 mm sieve and stored in airtight plastic containers at room temperature until chemical analysis.

The sample of crop residue (maize stover) in the agro-pastoral farming system was taken from 10 purposively selected households. Samples were taken from the top, bottom, and two sides of stacked maize stover after identifying households that conserved maize stover. Then, after bulking, the sample that was collected from different households (1 kg) was sub-sampled.

2.3. Chemical Analysis of Feed Samples

Dry matter (DM), ash, and total nitrogen (N) contents of feed samples were determined following standard methods of AOAC (2002), and CP was calculated as N x 6.25. Samples for chemical analysis were dried in an oven at 65°C for 48 hr. Parts of the samples were also dried in an oven at 105°C overnight to determine absolute DM. Ash content was determined by burning the dried sample in a muffle furnace at 550°C for 3 hr. The neutral detergent fibre (NDF) was determined by the method of Van Soest *et al*. (1991), while acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined by the procedures of Van Soest and Robertson (1989).

2.4. Digestibility Of Organic Matter and Metabolizable Energy

Digestibility of organic matter in the dry matter of selected feed resources was determined according to the two-stage procedures of Tilley and Terry (1963) at the HARC animal nutrition research laboratory. The metabolizable energy contents of the major feeds were estimated from the digestibility of organic matter in dry matter as described by McDonald et al. (2002).

ME (MJ/kg) = 0.16 * DOMD, Where: DOMD = digestibility of organic matter in the dry matter

2.5. Statistical analysis

Microsoft Excel 2010 was used for nutrient composition data management and entry. The data were analyzed by the SAS package version 9.0, and the comparisons of significant differences of mean were done by using Tukey at a 5% level of significance.

The model used for the statistical procedure

Yij = μ + Si + eij; where, Yij = individual observation, μ = overall mean, Si = the effect of i^{th} variables, and eij = random error.

The major available feed resources in the study area were summarized based on the index method computing with the principle of weighted average according to the following formula employed by Musa et al. (2006):

Index = Rn* C_1 +Rn- 1 * C_2 ….. R_1 * Cn/∑ Rn* C_1+Rn-1* C_2…..R_1:

Where: Rn = Value Given for the least ranked level (example if the least rank is 5^{th} rank, then; Rn-5, Rn-1=4 and … R1=1); Cn = Counts of the least ranked level (in the above example, the count of the 5^{th} rank = Cn, and the counts of the 1^{st} rank = C1);

3. Results and Discussions

3.1 Livestock Feed Resources and Feeding Systems in the Study Area

According to the respondents, the dominant feed resources were fodder trees and shrubs, followed by natural grazing lands (Table 1). In both the pastoral and agro-pastoral production systems of the study area, fodder trees and natural pastures were identified as the major feed resources, whereas hay and concentrate feeds each contributed less than 10% of the total feed resources. Natural pasture and browse vegetation constituted the principal feed resources in the study area. This finding is consistent with the report of Abate et al. (2010), who found that natural pasture and woody plants were the major livestock feed resources in the pastoral areas of southeastern Ethiopia. However, the present finding differs from that of Minyahel et al. (2016), who reported that grasses, shrubs, and crop residues

accounted for 39% and 23% of the feed resources in the Amibara and Gewane districts, respectively. Similarly, Harinder et al. (2018) reported that livestock feeding strategies in the arid and semi-arid areas of Ethiopia depend largely on naturally available forage during the dry season, including grazing pasture and browse species.

The major feed resources in both production systems of the study district are obtained from communal grazing lands composed of indigenous grasses, legumes, and browse species. This heavy reliance on native rangeland vegetation and browse is consistent with the findings of Philimon et al. (2016) in the Afar Region and Tolera (2007) in the lowlands of southern Ethiopia, where extensive natural pastures and woody browse constitute the primary livestock feed resources. Mohammed and Abule (2015) also reported that the availability of these feed resources varies with season. During the dry season, indigenous fodder trees become particularly important feed resources in the study area.

The predominant livestock feeding system in the study area was free grazing (Table 1). Grazing lands were communal and were grazed continuously throughout the year. According to the respondents, livestock depended almost entirely on free grazing, while only a small proportion of animals received feed through cut-and-carry or group-feeding systems. These findings are consistent with those reported by Abate et al. (2010) and Teshome et al. (2016). In addition, some pastoralists provided supplementary feed to weak and sick animals because such animals were unable to travel long distances for grazing and were therefore less able to survive under the prevailing grazing conditions.

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Table 7. Livestock feed resources and feeding systems in the study area (N, %)

	Pastoral		Agro-pastoral		Total	
Parameter	N	%	N	%	N	%
Feed resources						
Natural grazing land	36	44.4	28	40.0	64	42.3
Hay	1	1.2	1	1.4	2	1.3
Crop residues	-	-	4	5.7	4	2.6
Concentrate	3	3.7	1	1.4	4	2.6
Fodder trees & shrubs	41	50.6	36	51.4	77	51.0
Feeding systems						
Cut and carry feeding	1	1.2	1	1.4	2	1.3
Group feeding in the yard	3	3.7	6	8.6	9	6.0
Free grazing	77	95.0	63	90.0	140	92.7

N=number

During the dry season, herders migrate in and out of the region with cattle and camels and come back when the feed resources are available. The small ruminants do not migrate with cattle because they are used as cash income to the pastoralists in the study area, and they feed on the pods and fruits of the browse species. The boys and girls feed the goats and sheep by shaking the browse trees to drop their pods, leaves, and fruits to the ground during the dry season. These activities are also practiced by pastoralists of the central rift valley of Ethiopia, whereby they feed their small ruminants (especially goats) by shaking the Acacia trees to drop pods from the trees Belete *et al*. (2012).

Major mechanisms used by pastoralists and agro-pastoralists to minimize feed shortage are shown in Table 2. The majority of the respondents in both pastoral and agro-pastoral farming systems of the study district indicated that destocking (sale of livestock) was the major coping mechanism for feed shortage during the dry season in the community, followed by migration (Table 1) in and out of the region. Migration and destocking (sale of dry animals) were the major drought coping strategies in pastoral and agro-pastoral farming systems, which agree with those reported by Mohammed and Abule (2015), Yayneshet and Kelemework (2004), and Abule *et al*. (2005). The findings do not align with earlier reports from other districts in Ethiopia, where 56.7%, 20%, and 12% of farmers engage in conserving hay and crop residues, destocking, and purchasing forage from local farmers (Endale, 2015). The reason might be the suitability of these areas and the availability of the feed resources to be conserved as hay. During the dry season, cattle and camels migrate with young boys to neighboring rangelands with in and beyond the region (Chefa valley of the Amhara region). However, the small ruminants do not migrate with cattle because they feed on browse species, pods, and leaves of trees.

Table 8. Major coping strategies of feed shortage (N, %)

Parameter	Pastoralist		Agro-pastoralist		Total	
	N	%	N	%	N	%
Feed conservation	-	-	6	8.6	6	4.0
Purchase of concentrate	14	17.3	6	8.6	20	13.2
Destocking	46	56.8	30	42.2	76	50.3
Migration	21	25.9	26	37.1	47	31.1
Improved pasture production	-	-	2	2.9	2	1.3

N=number

3.2 Seasonal Availability of Feed Resources

Natural pastures and browse are more available from July to September and slightly available till November (Table 3). During the dry season, livestock (cattle, camels, sheep, and goats) feed on browse species because they remain green for a long period of time. In the agro-pastoral farming system, farmers cultivate maize using both irrigation and rainwater, while also conserving the stover to address feed shortages. The seasonal feed availability highlights a reliance on Browse as a year-round constant, supplemented by Natural Pastures during the peak summer months (July–September). Maize stover is effectively used to bridge feed gaps during the late and early year months, particularly in December, ensuring livestock nutritional needs are met when pastures are less available.

Table 9. Seasonal availability of feed resource

Feed resources	Months of the year											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Agu
Natural pastures	**	*	*	-	-	-	-	*	-	-	**	**
Browse	**	**	**	**	*	*	*	**	*	*	**	**
Maize stover	-	-	*	**	*	-	-	*	*	-	-	-

Double asterisks (**) =more available, single asterisk (*) = low available

3.3 Ranking of the major feed species with scientific and vernacular names in the study district

In the group discussion, elders and agricultural extension experts participated to gather information about the major livestock feed resources in the study area. The members of the group discussion identified fifteen (15) major livestock feed resources according to availability and abundance, and ranking was done from first to fifteenth by using the index formula (Table 4). After ranking the feed resources, only eight major feeds were selected for chemical analysis. Six browses, two grasses, and maize stover

were included in the selected feed for chemical as well as digestibility analysis.

Table 10. Index and rank of the major feed species with scientific and vernacular names selected by local Communities in Dalifage District of Afar rangeland

Scientific name	Vernacular name	Index	Rank
Acacia mellifera	Merkato	0.099	1
Grewia ferruginea	Hidayto	0.088	2
Salvadora persica	Adaito	0.086	3
Chrysopogon aucheri	Durfu	0.084	4
Cadaba rotundifolia	Adanglaita	0.080	5
Dobera glabra	Gersa	0.079	6
Ziziphus mauritiana	Kusrayto	0.078	7
Cymbopogon pospischilii	Issusuy	0.077	8
Balanites aegyptiaca	Udda	0.058	9
Acacia tortilis	Eibeto	0.056	10
Tribulus terrestris	Bunket	0.053	11
Cordia sinensis	Mederto	0.046	12
Calotropis procera	Kelayto	0.045	13
Acacia Senegal	Gerento	0.044	14
Acacia nilotica	Keselto	0.033	15

The chemical composition of the studied browse species in the study area is presented in Table 5. There were differences in nutrient contents of the browse species, possibly due to species differences and location. The laboratory DM reports in the current study are similar to the figure (89.7-92%) reported by Merga *et al*. (2016a) for browse in Afar rangelands. Solomon (2001) reported that the nutrient content of browse varies highly even within the same plant species. This variability is driven by factors such as the plant part, harvesting regime, season, and location. Ultimately, these factors influence chemical composition, palatability, and how animals utilize the nutrients through rumen degradability, digestibility, and voluntary intake. When the browse species are compared to grasses, they have high CP and low NDF and ADF contents, which is an indication of higher nutritive quality than grasses. The chemical composition of different browse species in the study area had significant differences ($p<0.05$) in nutrient contents (ash, NDF, ADF, and ADL) among the studied browse species (Table 5. The ash and CP values in pastoral and agro-pastoral areas were 11% to 24% and 16% to 23%, respectively. The NDF and ADF values range from 27% to 54% and 5% to 13% in pastoral and agro-pastoral farming systems, respectively.

The DOMD of the browse species in the pastoral farming system was in the range between 36.36% and 50.08%. The highest value was recorded for *Cadaba rotundifolia,* and the lowest value was recorded for

Grewia ferrugnia. However, DOMD in the agro-pastoral farming system was in the range of 32.02% - 52.82%.

Table 11. Chemical composition of selected animal feed resources in the study district

Farming System	FC	**Feed resources**	DM %	%DM						
				Ash	CP	NDF	ADF	ADL	DOMD	ME (MJ/kg)
Pastoral	Browse	*Acacia mellifera*	92.55	14.65^{b}	17.97^{bc}	53.88^{a}	36.09^{a}	6.37^{b}	37.51^{c}	6.00
		Grewia ferruginea	92.50	$13.02b^{c}$	18.42^{b}	40.32^{bc}	33.15^{ab}	8.55^{a}	36.38^{d}	5.82
		Salvadora persica	90.50	$13.58b^{c}$	17.90^{bcd}	39.85^{bc}	23.96^{bc}	5.77^{b}	43.04^{b}	6.88
		Cadaba rotundifolia	87.95	12.46^{c}	15.59^{d}	27.48^{c}	14.72^{c}	6.84^{b}	50.08^{a}	8.01
		Dobera glabra	90.50	21.53^{a}	15.82^{cd}	47.21^{ab}	31.06^{ab}	7.06^{ab}	43.51^{b}	6.97
		Ziziphus mauritana	92.44	11.74^{c}	22.74^{a}	39.82^{bc}	23.91^{bc}	6.39^{b}	38.00^{c}	6.08
	Grasses	*Cymbopogon pospischilii*	92.01	9.38^{b}	8.73^{a}	74.72	64.01^{a}	6.53^{b}	27.03^{a}	4.32
		Chrysopogon aucheri	92.5	15.59^{a}	4.34^{b}	75.05	58.17^{b}	8.66^{a}	18.36^{b}	2.99
A-pastoral	Browse	*Acacia mellifera*	89.53	11.51^{d}	18.14^{b}	45.08^{a}	32.36^{a}	6.11^{de}	35.29^{d}	5.67
		Grewia ferruginea	92.10	15.46^{c}	18.53^{b}	45.71^{a}	29.52^{ab}	12.99^{a}	47.99^{b}	7.67
		Salvadora persica	91.94	23.00^{a}	19.32^{b}	40.69^{a}	26.66^{b}	7.52^{C}	32.49_{e}	5.20
		Cadaba rotundifolia	91.00	19.015^{b}	17.99^{b}	31.71^{b}	17.47^{c}	8.86^{b}	52.82^{a}	8.45
		Dobera glabra	91.50	23.72^{a}	15.58^{c}	45.91^{a}	29.87^{ab}	6.34^{d}	42.52c	6.08
		Ziziphus mauritana	90.00	10.56^{d}	22.16^{a}	39.85^{a}	31.96^{a}	5.21^{e}	37.46^{d}	5.99
	Grasses	*Cymbopogon pospischilii*	92.50	7.52^{b}	6.33	75.50	60.56	8.75	20.25	3.24
		Chrysopogon aucheri	93.50	18.05^{a}	5.38	77.68	55.58	6.75	18.69	2.99
	Crop residue	Maize Stover (*Zea maize*)	92.5	5.30	3.82	59.50	38.96	8.24	47.99	7.68

FC= feed category; DM = dry matter; NDF=neutral detergent fiber; CP= crude protein; ADF=acid detergent fiber. Means with the same superscript letter for each feed type between farming systems in a column (for each feed type) are not significantly different (P>0.05)

The ash contents of the browses in both farming systems are consistent with the findings of Merga *et al*. (2016a), who reported levels ranging from 20.4% to 11.9% in the Awash, Fentale, and Amibara districts of the Afar rangelands. However, it slightly differs from the figure reported by Belete *et al*. (2012) for the mid-rift valley of Ethiopia. It is also greater than the values that were reported by Merga *et al*. (2016b) and Mulken *et al*. (2015), the figures (6.8%-25.70% and 11.2%-5.98%) in the Borana rangeland of southern Ethiopia and northern dryland Ethiopia, respectively. The reasons might be the stage of maturity, the type of soil, and the environment. The higher levels of ash and crude protein (CP) in browse feed resources may largely be associated with the nutritive potential of the fodder, particularly in relation to its mineral profile and overall quality.

The CP values of browse species were almost the same in both farming systems, which agrees with the figure reported by Merga *et al*. (2016a) but is slightly higher than that of Belete *et al*. (2012) and Megersa *et al*. (2017). The CP content of the browse species in the study is higher than the minimum level of 7-8% DM required for optimum rumen function and fed intake in ruminant livestock (Van Soest, 1994). This implies that browse feed resources (species) are used as livestock supplementation to low-quality feed resources like crop residue and rangeland grasses.

NDF, ADF, and ADL contents of the studied browse species in the current study area were 27%-54%, 15%-36%, and 5%-1%, respectively. The cell wall contents (NDF, ADF, and ADL), which represent the most important fraction of the feed in the browse species. The contents in the current study agree with earlier reports of Solomon *et al.* (2010), values range (58.6-28.9%, 41-20.4%, and 20.6-5.8%, respectively, for browse species in the northern parts of Ethiopia. With *A. millifera* and *D. glabra,* the browse species considered in this study contained less than 45% NDF on a DM basis in both farming systems, and this qualifies them as good quality roughages, since fibrous feeds with similar NDF content are classified as high-quality roughage feeds (Singh and Osting, 1992). The NDF and ADF values of *D. glabra* and *Z. mauritana* in this study are similar to the reports of Merga *et al*. (2016a) and Belete et al. (2012), respectively. The fibre content of *A. mellifera* in the study area was greater, but *Z. mauritania* and *G. ferruginea f were* comparable with the report of Welay *et al*. (2018) that was reported in the rangelands of Mieso, Ethiopia. Fibre contents of browse species were lower than those grasses and crop residues. The low contents of fibre (ADF, NDF, and ADL) indicated the quality

of feed resources. According to the current finding, most browse species had relatively low fibre contents.

The DOMD of browse species was in the range between 36.51 and 50.8% and 32.49 and 52.82% in pastoral and agro-pastoral systems, respectively. The lowest value was recorded for *Acacia milifera* in both farming systems, but the highest value was recorded for *Cadaba rotundifolia* in both pastoral and agro-pastoral farming systems. This current study was comparable with the report of Merga *et al*. (2016a) in the Afar rangeland and less than the findings of Zewdie (2010) which reported the value (47.72-68.28%) in the highland and central Rift Valley of Ethiopia.

The ME content of the browse in the study area was higher than that of the grass species. This could be due to high CP and low fibre contents in browse species. The ME of commonly used browse feed resources was high in *Cadaba rotundifolia* (8.45 MJ/kg DM) from both farming systems, followed by *Salvadora persica* in pastoral and *Debra glabra* in agro-pastoral farming systems. The ME content varied from 8.45 to 5.2 MJ/kg DM, and this value was less than Zewdie's (2010) finding, which reported the figure 7.16 to 10.23 MJ/kg DM in the high and central riftt valleys of Ethiopia. The higher ME content could be associated with a relatively lower proportion of fibre components.

3.4 Chemical Composition of grasses and maize stover in the study districts

The nutritive value of grasses is presented in Table 5. In addition to browses, two grass species and maize stover were selected as major animal feed by the respondents during the focal group discussion. There were slight differences in the percentage of ash, CP, NDF, ADF, and ADL values of *Cymbopogon pospischilii* between pastoral and agro-pastoral farming systems. Ash contents of the grasses in the study area were higher for *Cymbopogon pospischilii* than *Chrysopogon aucari* in both farming systems, which are in line with the reports of Keba *et al*. (2013) in Borena rangelands of Ethiopia.

The CP content of grasses is low, which agrees with the figure (6.9%) reported for grasses in the Borana rangeland (Keba *et al*., 2013) and is less than the value of grazing grasses (8.96%) that was reported by Mekuanint and Girma (2017) in the Bale zone of Ethiopia. The CP content of grasses is generally within the recommended range (6 to 8%), considered adequate for the maintenance requirements of most wild and domestic herbivores (Ganskop and Bohnert, 2001; Hussain and Durrani, 2009), but lower than the critical limit of 10.6% proposed by Minson (1990). Using either scale, it is clear

that the common grass species could provide inadequate levels of nitrogen for a considerable part of the year. The CP value of the grasses in the study area was lower than that of the browse species. This indicated that browses of higher quality than grasses. NDF value contents of common grasses in the study area do not have significant differences in pastoral and agro-pastoral farming systems. *Cymbopogon pospischilii* and *Chrysopogon aucheri* have higher than 74% NDF contents, which agrees with the results reported in previous studies by Keba *et al*. (2013) in the Borana rangeland of Ethiopia. The higher ADF contents of grasses were recorded for *Cymbopogon pospischiliin* in both farming systems.

The DOMD and ME of grass species in the study area were lower than those browse species. This could be associated with high fibre contents and low CP values. The DOMD of grass might be affected by the maturity and stage of harvesting. Zinash *et al*. (1995), Kitaba and Tamir (2007), and Tessema *et al*. (2010) reported that decreased DOMD occurred when the grass species were harvested at a relatively advanced stage of growth. This might be due to the deposition of lignin in the cell wall with increasing maturity and the increasing proportion of stem, which becomes less digestible when compared with the leaf portion at advanced maturity (McDonald et al., 1995). Moreover, the chemical composition of maize stover in the study area is presented in Table 8. The values (ash, ADF, and NDF) are lower, and CP and ADL are higher than the value reported by Mengistu et al. (2016) in Kedida Gamela District, Southern Ethiopia.

4. Conclusions and Recommendations

The current study provides information on nutritional attributes of major livestock feed resources available in the Dalifage district of the Afar region, Ethiopia. The chemical composition analysis revealed that the browse species have higher contents of CP (15.59%-22.7%) than grasses and maize stover. However, the dominant grasses (*Cymbopogon pospischilii* and *Chrysopogon aucheri*) and maize stover contained low crude protein (3.82–8.73%) and high fibre fractions, indicating poor nutritive quality. Furthermore, browse species demonstrated lower fibre fractions, enhanced digestibility, and superior energy values when compared to grasses and maize stover. For instance, *Cadaba rotundifolia* exhibited the lowest fibre concentration and the highest digestibility values. Therefore, the browse feed resources are used as a supplement to lower-quality roughage feeds. Moreover, the study provides

information that would be essential for the development and implementation of relevant policies that will have benefits for the sustainable growth of livestock production. However, further studies should be made on important browse species, including the effects of anti-nutrients and animal feeding trials for detailed information about feed qualities and feed resources.

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Competing Interest

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