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ASSESSING THE IMPACTS OF CLIMATE-SMART DUAL-PURPOSE SORGHUM AND TEFF CROPS INTERVENTION ON FOOD SECURITY AND LIVELIHOOD SUSTAINABILITY

OF AGRO-PASTORAL COMMUNITIES IN KENYAN DRY LANDS

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ABBREVIATIONS AND ACRONYMS

ASAL	Arid and Semi Arid Lands
CVI	Composite Viability Index
WEAI	Women's Empowerment in Agriculture Index
GTA	Gender Transformative Approach
DFID	Department for International Development
EBA	Ecosystem-Based Adaptation
CSA	Climate Smart Agriculture
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
KII	Key Informant Interviews
NGO	Non Governmental Organization

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ABSTRACT

This study assessed the contributions of climate-smart dual-purpose sorghum and teff to food and feed security, livelihoods, and environmental sustainability for agro-pastoral communities in the Kiina, Burat, and Ngaremara wards of Isiolo County, Kenya, with a specific focus on the roles of women and youth in these communities. A mixed-methods approach, including household surveys, focus group discussions, and key informant interviews, was used to assess the impact of introducing climate-smart sorghum and teff varieties on food and feed security, livelihoods, production systems, and environmental sustainability in the study areas.

Results show that the introduction and adoption of climate-smart dual-purpose sorghum and teff have significantly improved the availability of food and livestock feed for farming and herding communities, especially during the dry seasons. Sorghum has generated more income for farming communities than teff. While livestock herding practices have improved feed availability, the increase in livestock numbers threatens the sustainability of this feed source. Adoption of climate-smart agricultural practices for sorghum and teff cultivation is moderate. Farmers have adopted several practices, such as drip irrigation, improved seeds, and crop rotation, but still face challenges accessing water resources, agricultural extension services, and agricultural inputs. Women and youth are actively involved in cultivating these crops but face significant challenges in gaining access to agricultural land.

The environmental sustainability of the agricultural systems used to grow these crops is generally positive but fragile due to climatic variations. The availability of water resources within the farming communities is the most limiting factor for the agricultural sustainability of these regions. For these crops and farming communities to sustain their beneficial environmental, agricultural, and economic contributions to the counties in which they are grown, there is a need to invest in improving the water systems within these regions, developing markets for their agricultural products, improving the inclusion of women and youth farmers in agricultural decision-making, and improving the agricultural extension services in these regions.

Keywords: Climate-smart agriculture, agro-pastoral systems, livelihood resilience, food and feed security.

1.0 INTRODUCTION

1.1 Background to the Study

Agro-pastoral communities in the country's arid and semi-arid lands (ASALs) are heavily dependent on livestock. The interdependence between livestock and the well-being of agro-pastoral communities leads to food insecurity when livestock sustainability is disrupted (Mohamed, 2025).

The impact of the changing climate on the region has been a rise in temperatures, erratic rainfall patterns, and an increase in the frequency and severity of droughts. These factors have had a major impact on livestock productivity in the region, as available pastures and water resources for livestock have decreased (Ahmad et al., 2022). Hence, there is a need for sustainable, climate-resilient agricultural practices to improve livestock productivity in the region.

One practice promoted in the region's dryland areas is the use of dual-purpose crops, such as sorghum and teff, to provide food for both humans and livestock. These crops are well-suited to dryland environments because they are drought-tolerant and can improve agro-pastoral systems in these regions (Njiru et al., 2026).

Despite the promotion of these crops, there are limited studies investigating their performance in relation to food security, feed provision, livelihoods, and environmental sustainability in agro-pastoral areas. Most studies on these crops report constraints to their adoption by smallholder farmers, especially women and young farmers (Liwenga, 2018; Makokha et al., 2018).

Given these knowledge gaps, this study investigates the role of dual-purpose crops such as sorghum and teff in strengthening the resilience of agro-pastoral communities in Isiolo County. The findings of this study will contribute to the existing literature on climate-smart agriculture, particularly regarding climate-resilient livestock productivity and the livelihood outcomes of agro-pastoral communities in Kenya's dryland regions.

1.2 Purpose of the Study

The purpose of this research study was to investigate the role of climate-smart dual-purpose sorghum and teff crops in enhancing food security, livestock feed availability, livelihood resilience, and environmental sustainability within the Isiolo County agro-pastoral communities. The inclusion of such crops as part of climate-smart agricultural practices has recently become more prevalent within the county as a means of countering the challenges of food and feed insecurity, low incomes among rural farm households, and environmental degradation.

Beyond investigating the role of dual-purpose crops in enhancing food and livestock feed availability, the study also examined issues related to the inclusion of these crops in agricultural production systems within the counties, as well as the implications of such inclusion for the environment. The insights gained from such a study will allow for the improvement of existing agricultural policies and programs within Isiolo County.

Specifically, this study was conducted to assess the knowledge and attitudes of rural farming communities toward climate-smart agriculture; to investigate the contributions of sorghum and teff to food and livestock feed availability; to analyze the role of these crops in enhancing the income of farming households; to evaluate the participation of women and youth in farming activities; and to assess the implications of these farming activities for the use of natural resources and the environment.

Furthermore, this study investigates the role of farming characteristics within counties in relation to the adoption and sustainability of the crops examined. The study's findings will provide policymakers, development agencies, and other stakeholders involved in the formulation and implementation of agricultural policies and programs in Isiolo County with valuable insights.

2. 0. METHODOLOGY

2.1 Study Design

To determine the impacts of interventions aimed at developing climate-smart dual-purpose sorghum and teff, both quantitative and qualitative methods were used. These methods allowed not only the determination of impacts on aspects such as food and feed availability and farmers' income, but also the collection of opinions and experiences from farmers and experts regarding the crop and the implementation of these agricultural initiatives.

2.2 Study Area and Target Population

The study was conducted in Isiolo County, located within Kenya’s arid and semi-arid regions, where the economy is predominantly based on pastoralism and agro-pastoralism. Isiolo County is characterized by low, variable rainfall and periodic droughts. These factors make the region vulnerable to the impacts of climate change. Data were collected from agro-pastoral households and stakeholders in Isiolo South Sub-County, specifically in the Ngaremara, Kiina, and Burat wards, which were selected for the presence of climate-smart agriculture interventions.

2.3 Data Sources and Collection Methods

The study used three main methods for data collection:

Questionnaires were administered to agro-pastoral households to collect data on food and feed availability, income and livelihood sustainability, access to resources and services, and women's and youth's participation.

Focus group discussions were held with community members to gather information on their experiences with the crop interventions, the benefits they experienced, the challenges they encountered, and the participation of women and youth. Key informant interviews were conducted with government officials, agricultural extension officers, and development partners to gather information on the policy and the challenges to implementing these crop interventions.

2.4 Sampling Approach

A multi-stage sampling approach was used to select the study participants: First, the study wards were purposively selected because they had the intervention. Within these wards, villages were randomly selected. Then, households within these villages were sampled for the study. The participants in the FGDs and KIIs were purposively selected because they had knowledge and experience relevant to the discussions.

2.5 Data Analysis

The quantitative data were analyzed using descriptive and inferential statistics, including chi-square tests, Fisher’s exact tests, Cramér’s V, and the Composite Viability Index (CVI) to assess relationships among variables. The qualitative data from the FGDs and KIIs were analyzed through thematic analysis to identify issues and insights from each focus group. The findings from each group were compared and combined to provide an overall understanding of the study results.

2.6 Limitations

- The study relied on self-reported data, which may be subject to recall bias.
- Some areas were harder to access than others.
- Data was collected from various wards, which may not be generalizable beyond the study areas

3.0 RESULTS AND DISCUSSION

3.1 Analytical Framework and Policy Lens

Data interpretation is conducted across the various dimensions of sorghum and teff farming communities. These dimensions include sustainability, livelihoods, production systems, food and feed security, climate resilience, markets, and institutions.

Each of these dimensions is assessed to determine the extent of opportunities and threats within each ward, as well as their impact on the sustainability of those communities.

The framework used to interpret the study results is the Climate-Smart Agriculture framework, developed by the Food and Agriculture Organization (FAO) in 2013. The framework is intended to evaluate farming systems based on their potential impacts on productivity, resilience, and equity.

In addition to the CSA framework, interpretation was conducted from various thematic perspectives, including gender, ecosystem-based adaptation, agroecological systems, and sustainable land management. Furthermore, each of these analyses was informed by insights from the fields, experts, and relevant policies. Each of these approaches ensures that the report reflects both the data and the experiences of the individuals in the study.

3.2 Demographic Profile of Respondents

The study data were collected from 123 households that cultivate sorghum and teff. The demographics of these farmers provide context for the study outcomes.

A slight majority of farmers are women (Annex 1, fig1). However, the gender makeup varies greatly from ward to ward. Ngaremara has a majority of female farmers, indicating the role of women in adopting climate-smart crops. In contrast, the farmers in Kiina are mostly male, whereas those in Burat have a more balanced mix of men and women (Figure 1). The gender makeup of the farmers indicates the diverse roles within farming communities, as some roles are more favourable to certain genders than others.

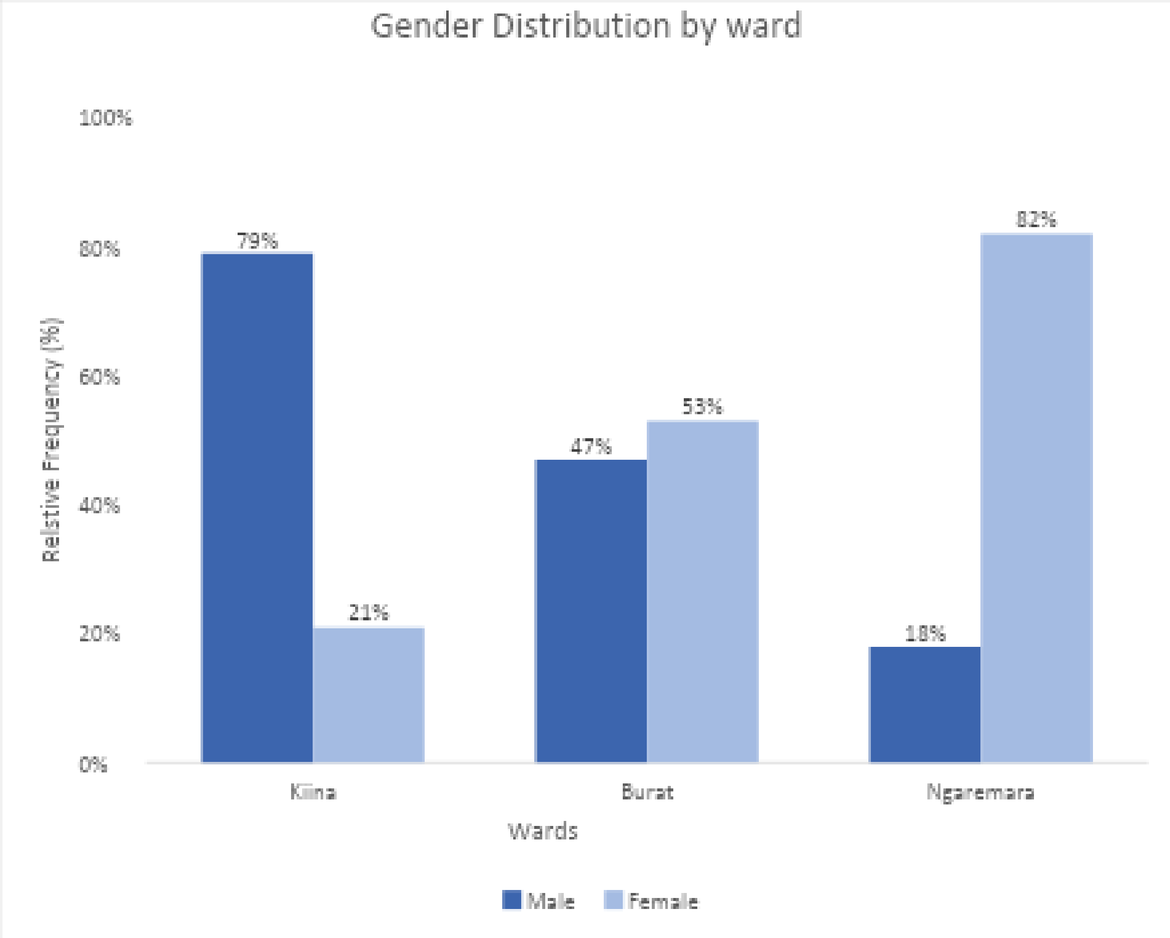


Figure 1: Gender Distribution of Respondents by Ward

The age distribution of the farmers is predominantly within the economically active age range, with the majority in the 25-49 years age group and the largest share in the 35-49 years age group (Annex 1, fig 2). The villages of Kiina and Burat have a higher proportion of younger farmers, while Ngaremara has a higher proportion of older farmers. Ngaremara has no farmers under 25 years old (Figure 2). Only a small number of farmers are outside the economically active age spectrum; only a small proportion of farmers in each farm is within the 18-24 years or 65+ years age groups.

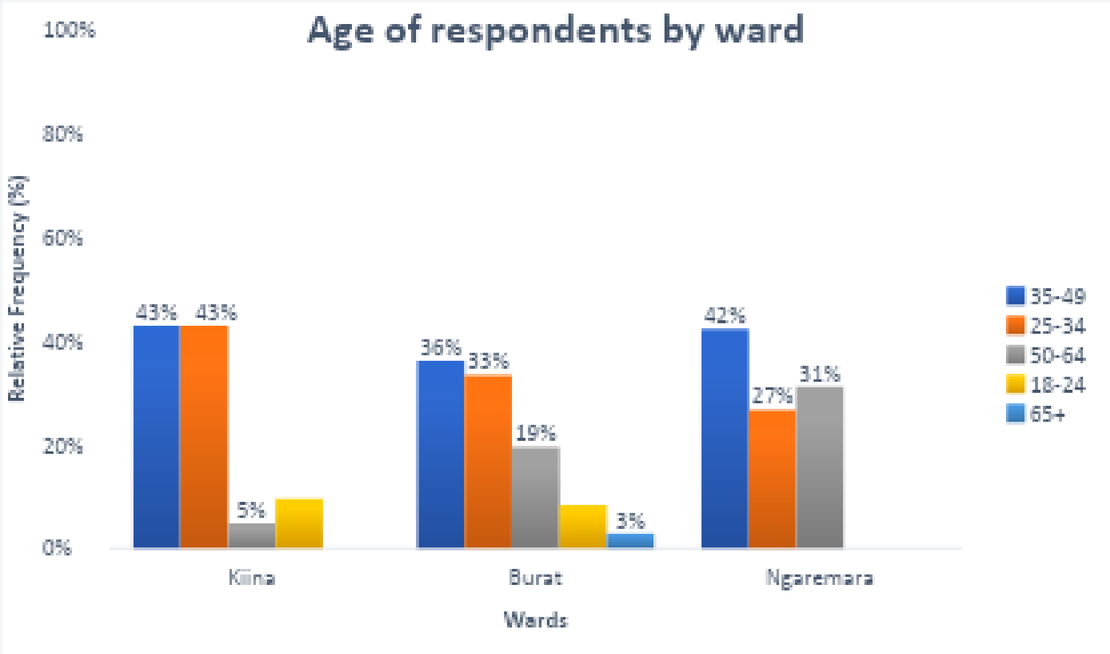


Figure 2: Age distribution of respondents by ward

Most individuals in the surveyed households were household heads. The next most represented individuals within the households were the spouses of those household heads. Fewer individuals in households were sons or daughters of the household heads. Thus, farming decisions in these areas are made by household heads and their spouses, not by any other household members. In Kiina, however, most individuals who make household farming decisions are household heads. In Ngaremara, though, most of the individuals within the households who make decisions regarding farming are the spouses of those household heads, and those spouses are women (Annex 1, fig 6 & 7).

Most households in the study areas have between 4 and 10 members. Ngaremara has some households with more members than other areas in the study. Burat has some households with fewer members than other areas in the study. In most households, though, only 1-3 members are involved in farming activities. Burat has a higher proportion of households with few members involved in farming than any other area. Ngaremara has a higher proportion of household members who participate in farming activities (Annex 1, figs. 8 and 9).

The majority of individuals within households have received only primary education. Some individuals within households have received secondary education. A substantial proportion of individuals within households have no formal education. Few individuals within households have received tertiary education. Virtually no individuals within households have received vocational training (Annex 1, fig 3). A higher proportion of individuals in Ngaremara have no formal education than in any other area within the study. Kiina has the highest proportion of individuals within households who have received secondary and tertiary education. Burat falls somewhere in between in terms of the educational levels of individuals within their households (Figure 3).

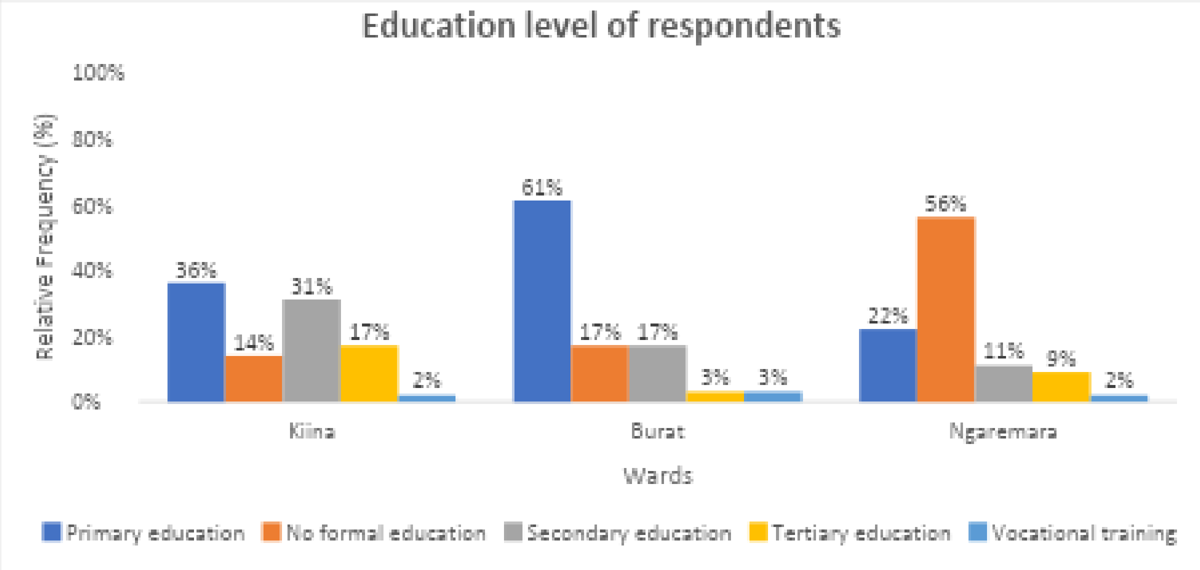


Figure 3: Educational level of respondents by ward

3.3 Women and Youth Inclusion In Sorghum and Teff Cultivation

3.3.1 Scope of Analysis

The roles of women and youth in smart climate crop systems are critical. The Women's Empowerment in Agriculture Index (WEAI) (Alkire et al., 2013) informs this discussion and measures women's empowerment in agricultural systems across four main variables: control over resources, decision-making, income, and leadership. An alternative framework for understanding the role of women within these agricultural systems is the Gender Transformative Approach (FAO, 2018). This framework examines the structural and socio-cultural barriers that prevent gender equality in agricultural systems. Furthermore, an assessment of participation, agency, and access to assets and benefits will be conducted in each ward. Understanding these variables will enable the development of strategies to increase productivity and drive transformation in agro-pastoral agricultural systems.

3.3.2 Participation Across the Agricultural Value Chain

Results

Women and youth are involved in agricultural labor. However, the nature of their involvement varies across different agricultural activities. Although women participate in all activities, their involvement is highest in production activities and then declines in post-harvesting and marketing activities, especially in decision-making regarding the use of crops (Figure 4). Despite their involvement in agriculture, women are predominantly laborers rather than decision-makers or owners of agricultural enterprises, as evidenced in the focus groups and interviews with key informants.

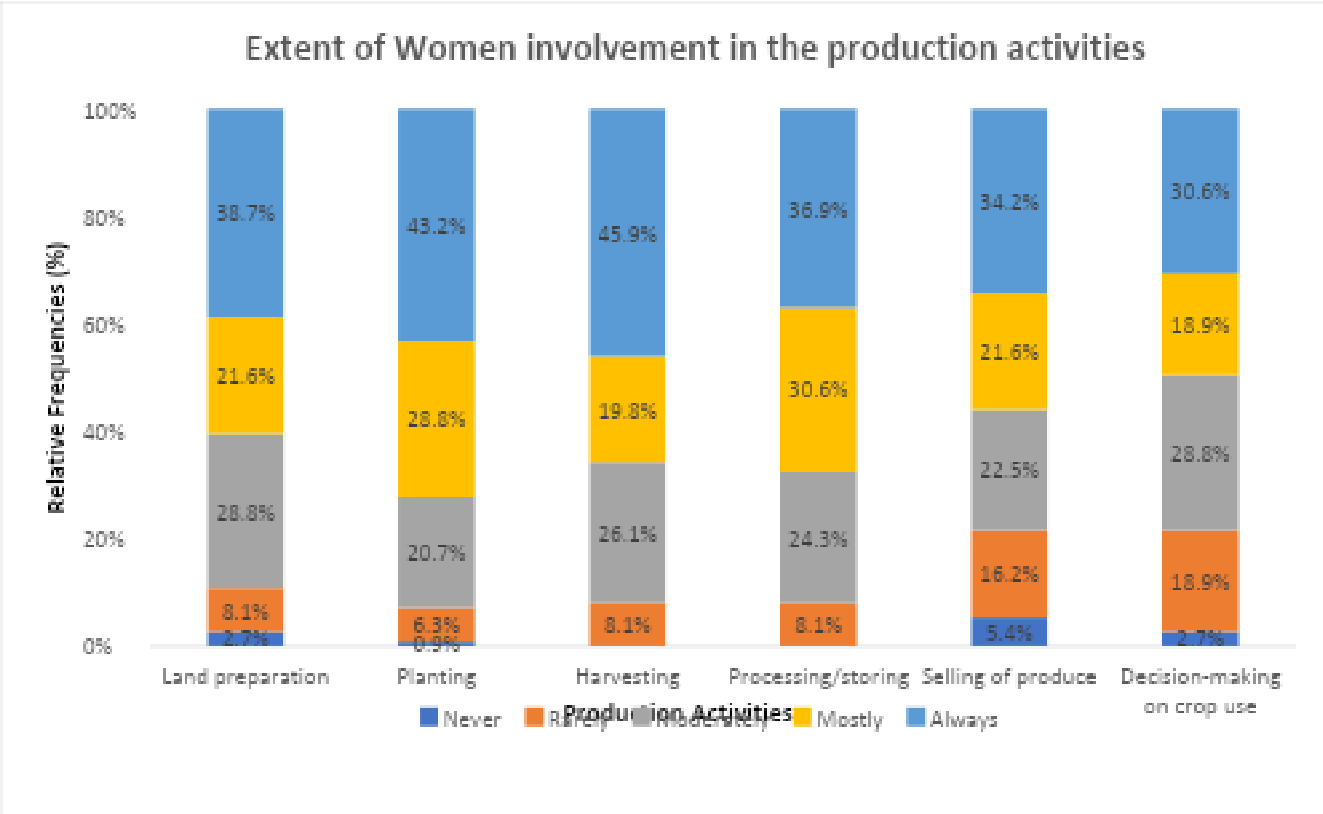


Figure 4: Extent of women's involvement in production activities

These findings are also reflected in perceptions of women's participation in the community, which are statistically significant across wards ($p = .049$). Furthermore, Fisher's Exact Test was used to assess this finding and was also statistically significant ($p = .040$). However, the effect size of this test was small (Cramer's V = .218), indicating that although there were differences in women's participation across wards, the differences were not large in magnitude (Table 1). Thus, these findings suggest that, overall, there are significant differences in perceptions of women's participation across the city's wards.

Table 1: Community Perceptions of Women's Participation in Sorghum/Teff Activities

Statistic	Value	df	p-value
Pearson Chi-Square (3-ward)	6.022	2	.049
Fisher's Exact (collapsed 2x2)	—	—	.040
Continuity Correction (collapsed)	3.846	1	.050
Likelihood Ratio (collapsed)	4.793	1	.029
Cramer's V (collapsed)	.218	—	.022
N of Valid Cases	111	—	—

The pattern of youth participation is similar but less intense. Only 20-26% of youth are consistently involved in cultivation activities such as land preparation, planting, and harvesting. However, the percentage of youth involved drops sharply in post-harvest activities, including processing crops, storing surplus crops, selling crops, and making decisions about farming activities. For instance, 56% of youth in Burat are not involved in any sales activities, while 53% in Burat are not involved in farming decisions. In contrast, youth in Kiina are more involved in sales and decision-making activities (Figure 5). The reasons for such involvement among youth are that farming is physically demanding and offers few economic returns to young farmers.

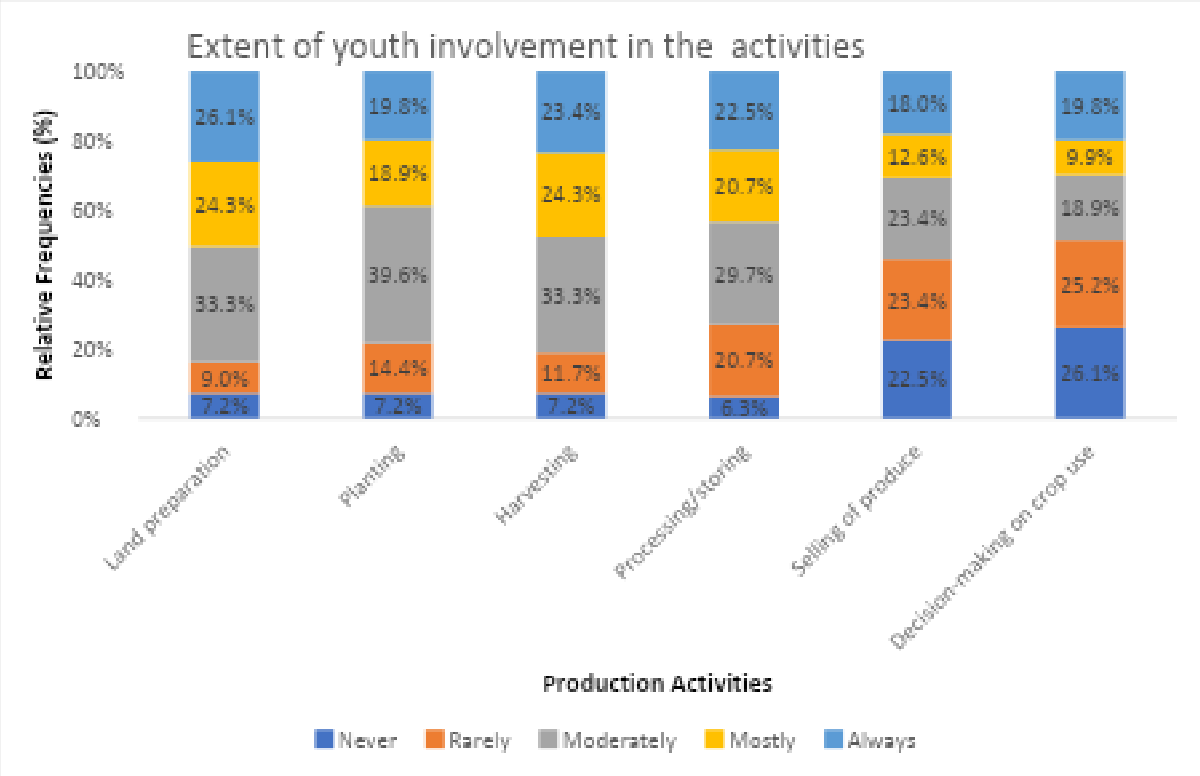


Figure 5: Extent of Youth involvement in production activities

An analysis of the association between ward and perception of youth involvement in sorghum and teff activities shows a statistically significant association ($p = .021$). The effect size is moderate (Cramer's $V = .265$), indicating that, although statistically significant, youth involvement in these activities is not strongly associated with the ward in which a youth lives. The robustness of this result is further supported by the likelihood ratio test ($p = .016$). Finally, all expected frequencies in the contingency table exceed the minimum threshold (Table 2), indicating that the Chi-square test assumptions have been met.

Table 2: Community Perceptions of Youth's Participation in Sorghum/Teff Activities

Statistic	Value	df	p-value
Pearson Chi-Square	7.772	2	.021
Likelihood Ratio	8.252	2	.016
Cramer's V	.265	—	.021
N of Valid Cases	111	—	—
Cell count status	CLEAN — 0 cells < 5, minimum = 12.19	—	—

Discussion

These patterns indicate the intersection of the principles of CSA, the WEAI, and the GTA, all of which recognize that participation in agricultural labor alone is insufficient unless individuals also have agency, access to resources, and decision-making power (Matla, 2025). The results of the surveys, focus groups, and interviews conducted within the study indicate that while women participate in agriculture at high levels, this participation is mostly limited to the production of agricultural goods rather than to decision-making regarding those practices. Additionally, some interviews indicated differences in the level of youth involvement in decision-making regarding agricultural practices, with higher levels in Kiina than in the other wards in the study region. Thus, these findings suggest that simply participating in agricultural labor does not necessarily imply empowerment of those individuals to have an impact upon agricultural practices within their regions, and that true CSA should also include efforts to enable women, youth, and other disadvantaged groups to have agency within agriculture and to redistribute power and opportunities within their countries' agricultural sectors.

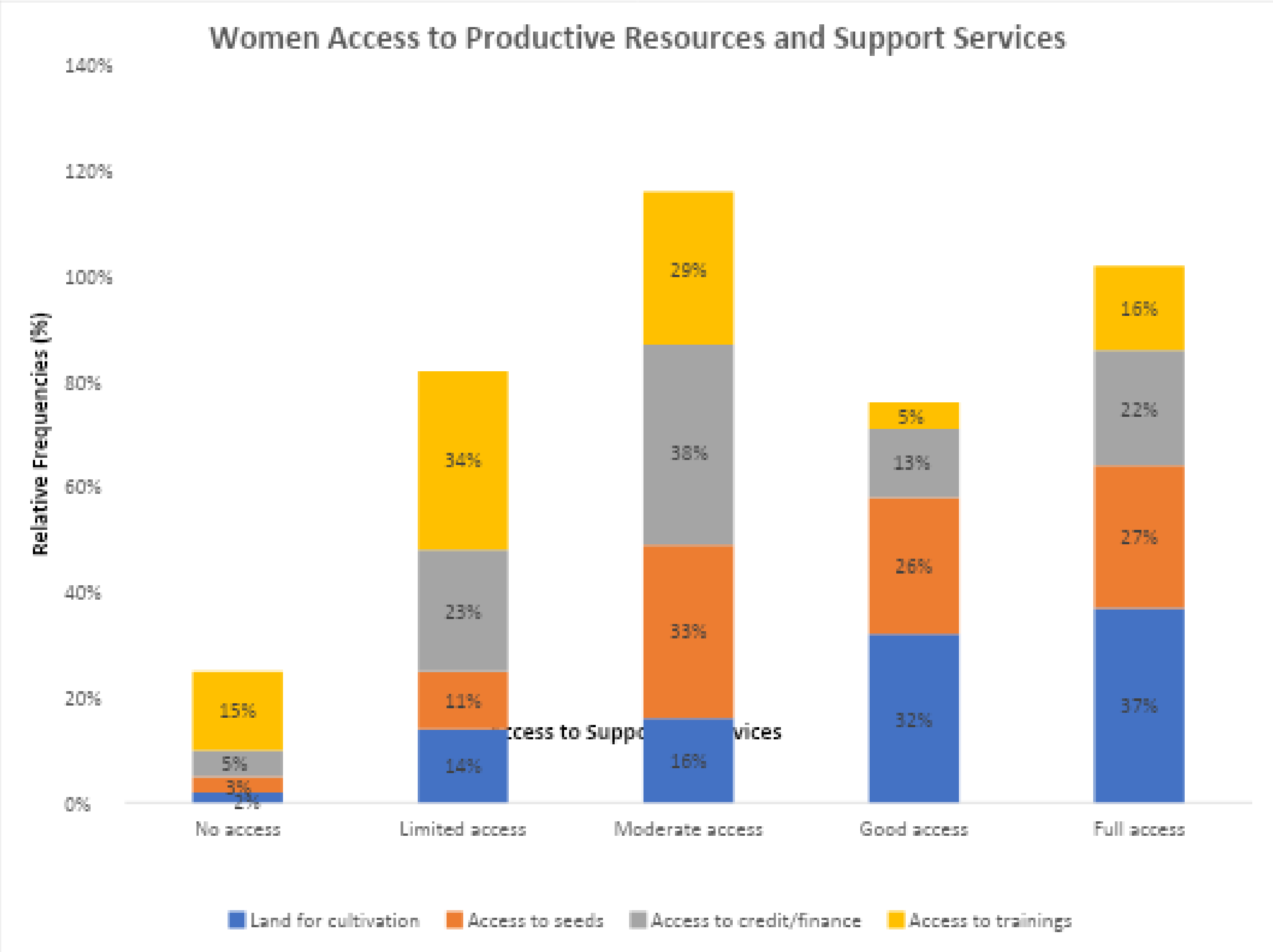
3.3.3 Access to Productive Resources and Support Services

Results

Despite improved access to land and seed, women still have limited access to credit and training opportunities (Figure 6). Access to these resources varies significantly across the region. For instance, Ngaremara offers women better access to land and seed, while Kiina offers women relatively better access to credit and training (Annex 2, figs. 1-6).

Figure 6: Women access to productive resources and support services

Youth have limited to moderate access to agricultural resources. Access to land and seeds is relatively more attainable by youth as compared to credit and training opportunities. Additionally, very few youth gain access to the good or full access to agricultural resources which indicates that there are limited opportunities for these youth to advance in their agricultural production activities (Figure 7). The constraints to agricultural resources are more prevelent in Ngaremara and Burat as compared to Kiina which has relatively better access to



agricultural resources by youth (*Annex 2, fig 7-12*).

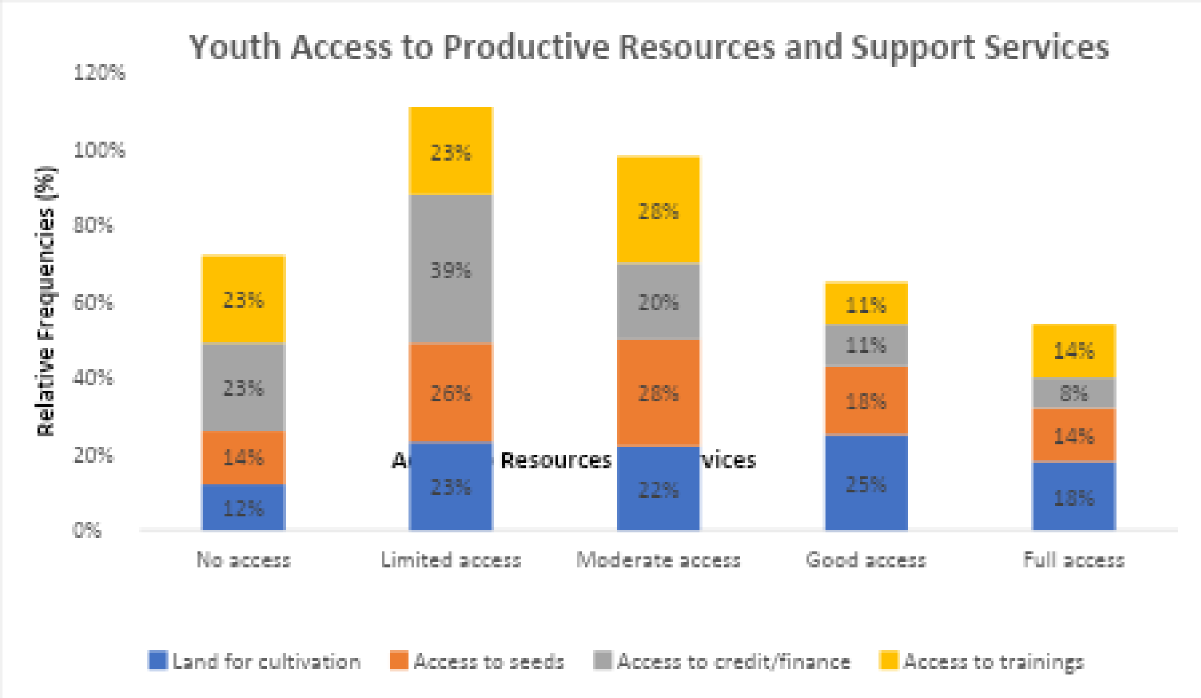


Figure 7: Youth access to productive resources and support services

The participation patterns for each ward are presented in Table 3. The tables reveal that women's participation levels are similar across the three sites, but youth participation levels differ across locations. In Kiina, youth are the most engaged with the programs at all locations. Burat has the lowest levels of youth engagement, and Ngaremara is somewhere in between. Detailed information on the number of youth in each ward who participated in each activity is presented in Annex 2.

Table 3: Composite Means: Women and Youth Participation Indices

Ward	Women Mean (SD)	Youth Mean (SD)	N
Kiina	3.80 (0.958)	3.63 (0.930)	33
Burat	3.74 (0.521)	2.79 (0.876)	34
Ngaremara	3.98 (0.669)	3.16 (1.040)	44
Total	3.85 (0.731)	3.19 (1.006)	111

Discussion

The participation patterns of women and youth exhibit differences. The participation of women is almost the same across wards and comparable to that reported in other studies by Therond et al. (2017). However, youth participation varies significantly from ward to ward.

Women's participation in agricultural activities is more consistent than that of youth. Furthermore, youth involvement is limited to agricultural production activities (Annex 2, table 4). Their participation in other activities of the agricultural value chain is low. This finding aligns with Devaux et al. (2018), who stated that youth may participate in agricultural labor but not in other segments of the value chain.

The limited participation of youth and women in other segments of the agricultural value chain can be explained by their limited access to the productive resources required for such participation. These findings indicate a lack of access to land, credit, and agricultural extension services necessary for the effective implementation of CSA. Onyango et al. (2026) also found that the limitations of these resources, especially among women and youth, limit their ability to implement these strategies effectively. Furthermore, youth lack access to the credit and training necessary to start their own farms. Additionally, those who run farms report that the lack of access to these resources limits youth's ability to participate in farming activities.

These disparities in access to resources limit the agency of these two groups relative to other farm laborers in the area. As a result, their participation in agricultural activities does not lead to their empowerment. To empower these two groups, their structural inequalities must be addressed.

3.3.4 Structural and Socio-Cultural Barriers to Inclusion

Results

Beyond the impact of available resources on the participation of young people and women in agricultural activities, a range of constraints also affects their participation. For women, the major constraints include limited access to education and training, domestic duties, and cultural expectations. For youth, the major constraints relate to farming experience, agricultural education and training, and access to the resources required for agricultural activities (Figure 8). For instance, among women, structural and cultural constraints are most pronounced in Kiina, whereas in Burat they relate to women's education and domestic duties. Ngaremara faces structural constraints on access to resources for agricultural activities, while fewer youth and women in Ngaremara experience the impact of cultural constraints. Among young people, Ngaremara faces structural constraints related to experience and access to agricultural resources; Burat faces constraints related to education and cultural factors; and Kiina faces these factors as well as constraints related to migration out of the area (Annex 2, figs 21-22).

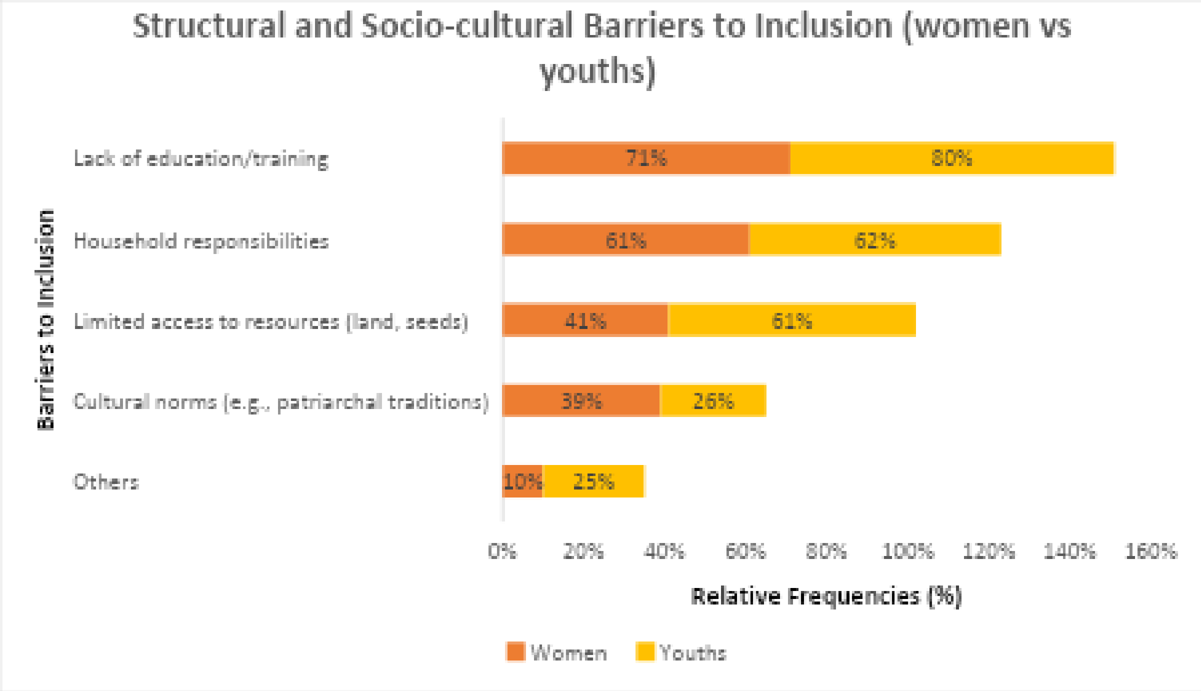


Figure 8: Structural and socio-cultural barriers to inclusion

Discussion

These findings demonstrate the impact of structural and socio-cultural factors on the depth and quality of women's and youth's participation in CSA systems (Wekesa, 2015). Both groups face structural and socio-cultural challenges that limit their participation in CSA training and activities. Women’s time constraints and socio-cultural obligations constrain their participation in training and market activities. Similarly, youth’s socio-cultural perceptions of farming limit their interest in CSA training and activities. However, participation levels among women and youth vary across the wards in which they reside. The CSA principles emphasize the importance of inclusiveness in the social and institutional systems that govern agricultural activities, aligning with the Gender Transformative Approach to these activities. Additionally, focus groups (Thematic box 1) with participants from specific wards have demonstrated how these challenges are distributed across wards. These findings demonstrate that interventions must be tailored to each ward's specific challenges to increase women's and youth's participation in CSA activities (Khan, 2026).

3.3.5 Thematic Box 1: Women and Youth Inclusion in Sorghum–Teff Production Systems

Key Evidence from Field Consultations (FGDs & KIIs)

- Women play a leading role in income generation from the sorghum value chain.
- The level of youth involvement in the value chain is limited to tasks that require much labor.

There are variations in the level of involvement by gender and age within the wards:

- Kiina has high levels of female involvement in the value chain but limited participation by youth.
- Burat has active women-led groups that engage in flour processing.
- Ngaremara's sorghum production depends on women, but training for young women has begun to be implemented.

Field Perspectives

- "Women dominate production and value addition for sorghum; youth are involved only in some labor-intensive tasks." - Key Informant Interview, Farmer Leader
- "Sorghum was introduced to the region as an alternative crop that can grow with very little rain." - Focus Group Discussion Participant, Burat

Interpretive Insight

- The insights gained from the field are in alignment with the findings in the preceding discussion. The contributions of the various genders to the sorghum-teff value chain differ significantly, with women playing a significant role and youth contributing minimally. Thus, despite the inclusion of youth in the labor requirements of the crop, they do not benefit from this involvement in the production system.

Policy Implications

Governments and other stakeholders should formulate policies that enhance women's participation in sorghum-teff production and enable youth to share in the benefits of this crop. Suggestions for such policies include:

- Increasing the use of mechanization in the production of sorghum and teff to reduce the labor required from smallholder farmers.
- Creating training and educational opportunities for both women and youth to enhance their skills in the production of sorghum.
- Providing access to financial instruments such as loans and grants for women and youth to create and expand their sorghum-based enterprises.
- Supporting the existing women-led groups involved in the processing of sorghum flour.
- Formulating policies that enable youth to assume leadership and ownership of sorghum-based businesses.

3.4 Agricultural Production & Land Use

3.4.1 Scope of Analysis

The patterns of agricultural production affect issues ranging from household food security and the availability of feed for livestock to the sustainability of agriculture as an economic sector. Factors to consider in agriculture include adopting crops such as sorghum and teff, crop diversification, land use, and seed systems for these crops. The different patterns of agriculture across the wards of Isiolo County can reveal the strategies households in those wards have adopted to adapt to their region's climate. Each of these discussions can occur within the context of Climate-Smart Agriculture, as advanced by the Food and Agriculture Organization (FAO, 2013), or sustainable land management practices (Lal, 2015; Pretty, 2008).

3.4.2 Crop Diversification and Current Production Patterns

Results

The production history of households is largely characterized by diversification in the crops they traditionally produce, rather than by the dominance of sorghum in each area (Figure 9). The cultivation of teff is minimal throughout the region (Figure 10), and experience with intercropping is also limited in each of these areas. In relation to the crops currently grown by these households, however, there is some diversification in the types of crops cultivated (Figure 11).

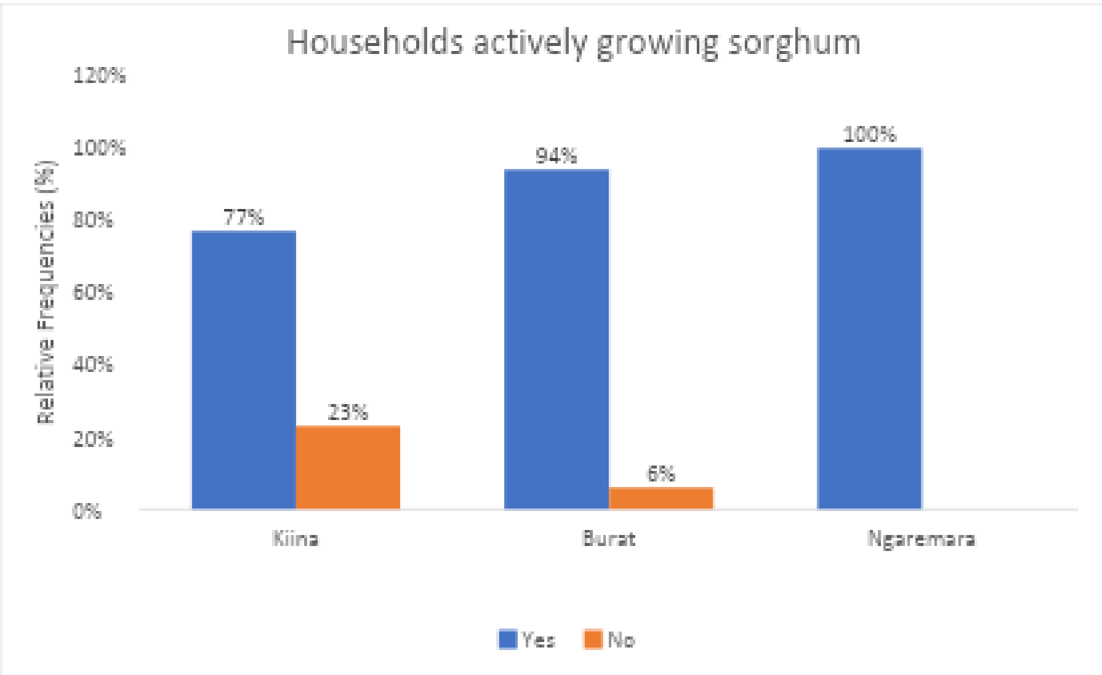


Figure 9: Households growing sorghum

Discussion

The dominance of sorghum and the relatively few varieties of other crops grown within these agro-pastoral systems indicate a strategy to maximize the resilience of these crops in these environments. The fact that additional crops are being grown in these areas indicates that diversification is being pursued to some extent, but the relatively low number of these alternative crops suggests that the farming communities are still mainly focused on using their well-adapted, established crops. This strategy generally aligns with the principles of sustainable land management and climate-smart agriculture, which call for the use of resilient crop varieties and crop diversification (Balakrishnan and Marimuthu, 2026). Thus, while the farmers of these regions are beginning to diversify their agricultural production, their strategy remains largely focused on the crops that have traditionally been grown within these areas.

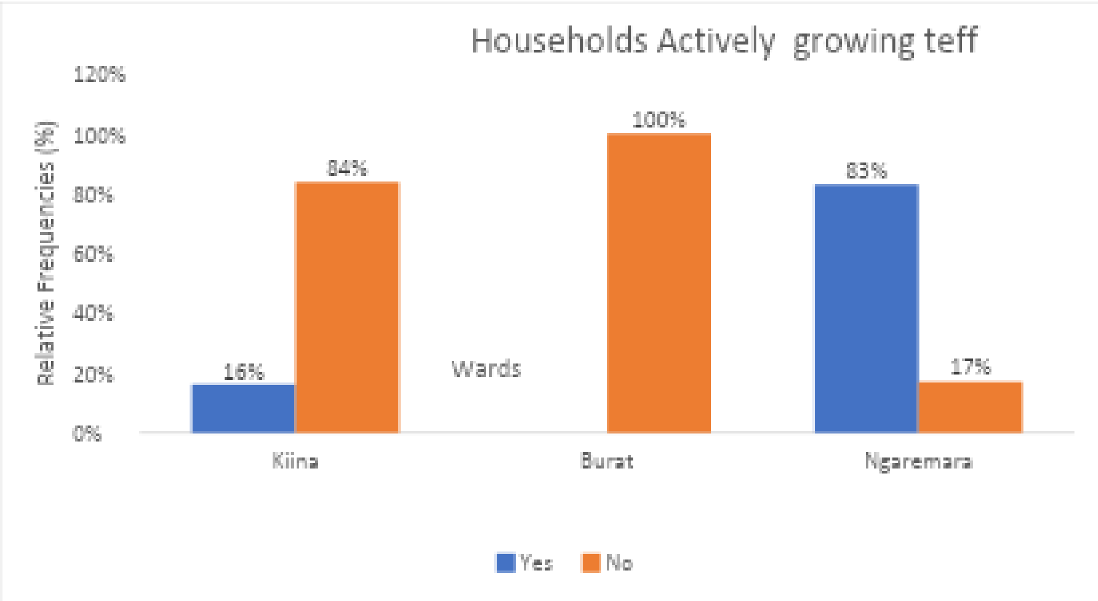


Figure 10: Households growing teff

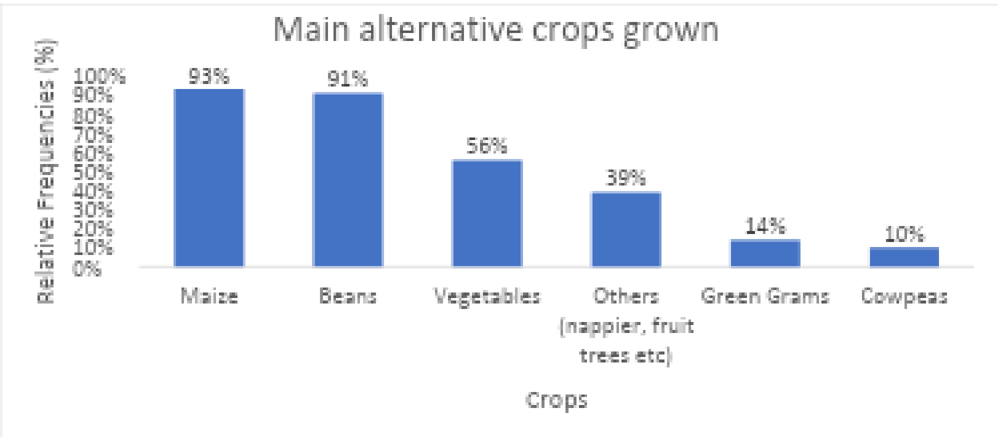


Figure 11: Alternative crops grown by households

3.4.3 Adoption Dynamics and Continuity of Smart Climate Crops

Results

Figure 12 shows that sorghum cultivation is not a new practice in any of the locations studied. Indeed, most households have been cultivating sorghum for several years. Furthermore, Burat and Ngaremara tend to have longer cultivation periods than Kiina. However, Kiina has some farmers who have cultivated the crop for shorter periods, indicating some degree of dynamism within the farming communities in this location. These findings indicate that farmers in these dryland regions of Kenya cultivate sorghum over extended periods. The discontinuation of sorghum cultivation in Kiina and Burat Wards is limited. Factors associated with discontinuation in these two wards include market constraints, pest infestations, and the availability of sorghum seeds for planting (Figure 13). In focus group discussions, farmers in Ngaremara Ward demonstrated high levels of continuity in cultivating teff. These findings indicate that despite the low prevalence of teff farming in the counties surveyed, this crop is well integrated into the farming systems of the communities studied.

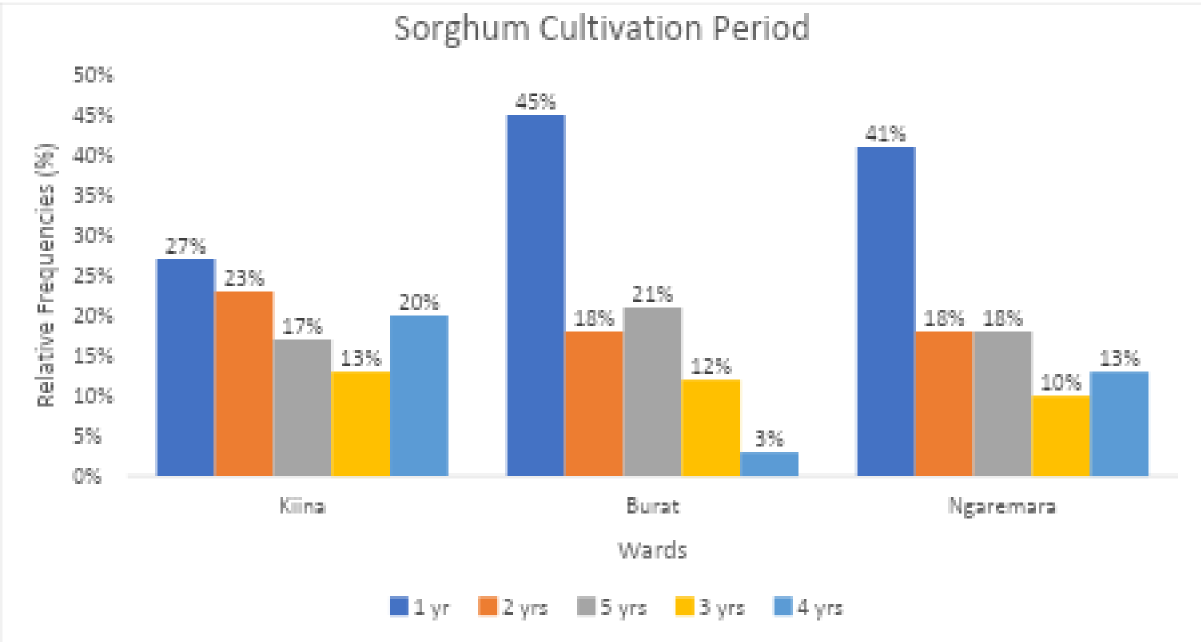


Figure 12: Years Since Introduction of Sorghum Cultivation

Discussion

The findings on the adoption of these crops suggest that while there is willingness to adopt them, their continued use depends on the presence of certain enabling conditions, a sentiment also reported in a study by Autio et al. (2012). For instance, while there is willingness to adopt crops like sorghum, the continued use of that crop is limited by inadequate pest and disease management and a lack of market and seed systems to support its continued use by adopters.

Overall, these findings relate to the concepts of both climate-smart agriculture and sustainable intensification. Climate-smart agriculture aims to develop methods to increase the adoption of technologies and practices that enable farmers to build greater resilience to the impacts of climate change. Sustainable intensification aims to develop methods to increase the sustainability of agricultural practices, such as improving the environmental suitability of those practices and enabling their sustainability through enhanced functionality of the management and regulatory systems that control agriculture (Ouedraogo et al., 2025). The results from focus groups help to explain why many of the respondents in the study indicated a tendency to discontinue the adoption of these types of crops after their initial adoption. Furthermore, the spatial analysis of the continued adoption of these crops in some wards yet not others indicates that the adoption of various agricultural practices can be better managed according to the conditions present within each of these areas rather than applying a uniform method of adoption to each area within the country.

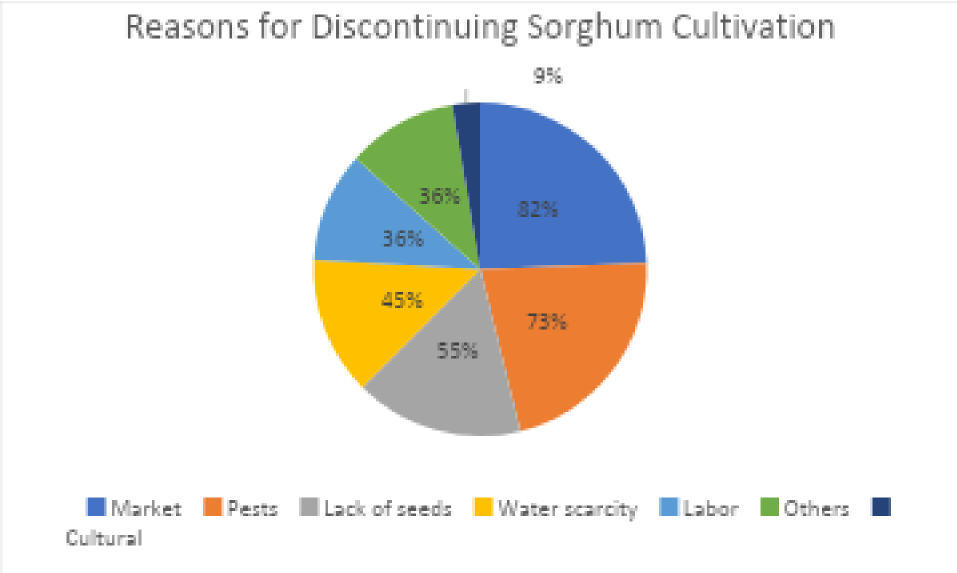


Figure 13: Reasons for discontinuation of sorghum cultivation

3.4.4 Land Allocation, Plot Size, and Tenure Security

Results

There is a clear distinction in the spatial allocation of the two main crops at the household level. Sorghum is grown on very small plots, while teff is cultivated on larger plots, with medium- and larger-sized allocations to teff production more evident in Kiina and Ngaremara (Figure 14).

High land ownership in Burat and Ngaremara enables these farmers to make long-term investments in teff production. In contrast, in Kiina, land is more commonly owned in common with other farmers in the ward (Figure 15). The allocation of land for teff production varies significantly depending on the tenure system of the land owned by these farmers. A chi-square test was performed to assess the significance of differences in tenure systems across wards. The results show that tenure systems differ significantly by ward, $p < .001$, Cramér's $V = 0.517$ (Table 4).

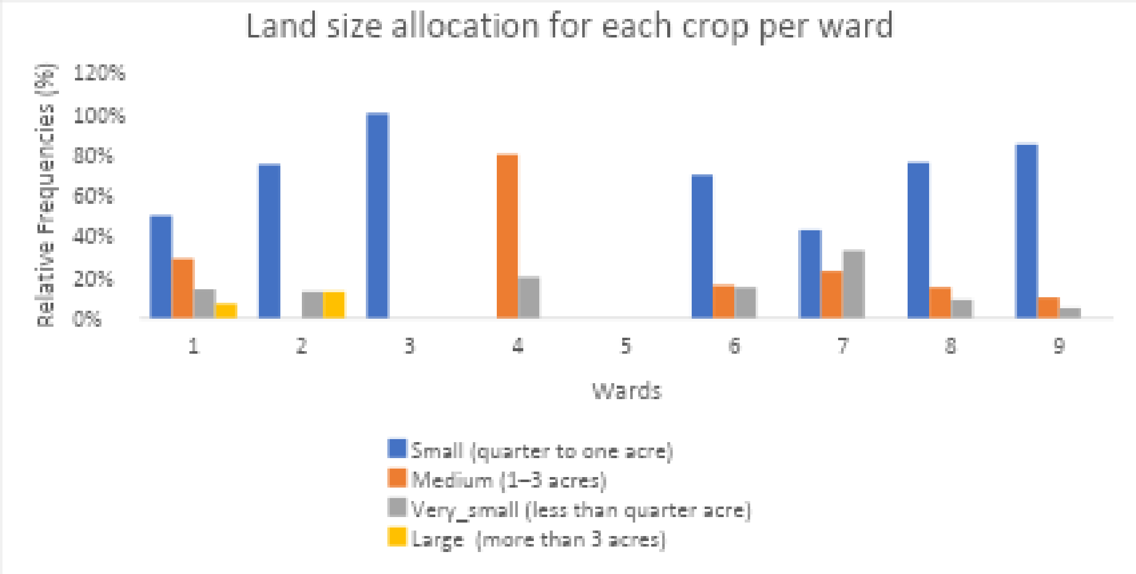


Figure 14: Land allocation for each crop

Discussion

Differences in the types of landholdings associated with each crop indicate how farmers in each area allocate land resources to each crop (Reynolds et al., 2020). The differences between these two crops can be understood through the FAO Land Tenure Governance Framework. Fragmented and flexible land tenure systems encourage the cultivation of crops that pose little risk to landowners, thereby spreading crops like sorghum. Conversely, more stable land tenure systems that permit consolidated holdings allow farmers to invest in their land in ways that support the growth of crops like teff.

These results indicate that tenure systems vary across the wards in Isiolo. These differences create distinct environments in which farmers make land management and agricultural decisions (Murken et al., 2024). Thus, these findings underscore the role of tenure systems and structures in Isiolo in shaping smallholder farmers' decisions about which crops to cultivate. These findings are supported by the study's qualitative findings, which revealed that knowledge of land availability, the tenure systems governing that land, and the reasons for its current uses are the factors that most influence smallholder farmers' land allocation decisions in Isiolo.

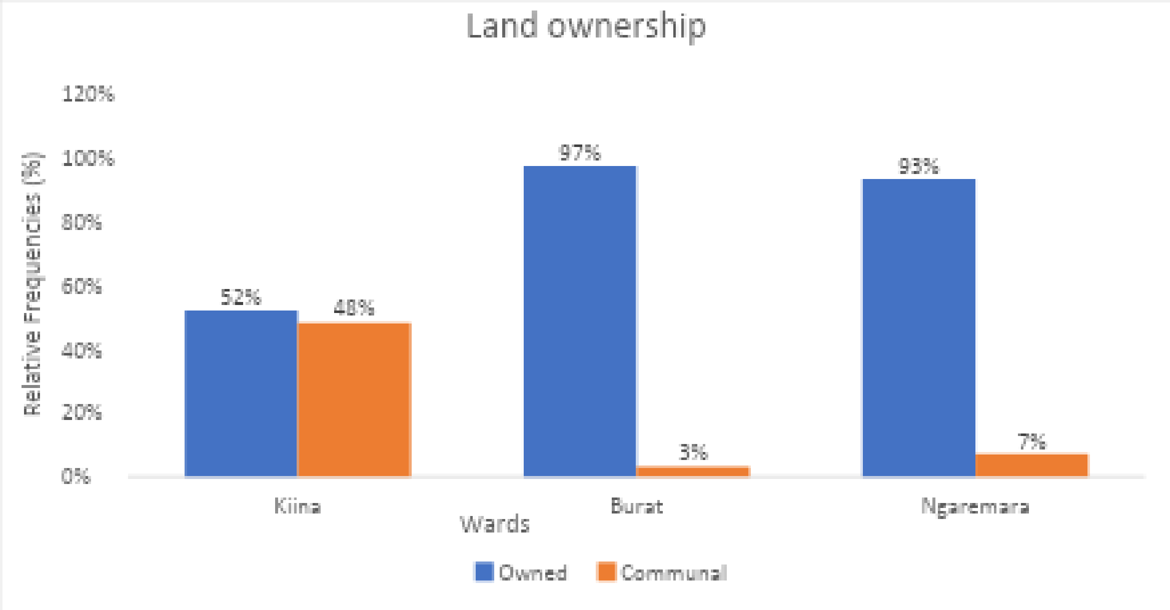


Figure 15: Land ownership

Table 4: Ward Differences in Land Tenure

Statistic	Value	df	p-value
Pearson Chi-Square	29.705	2	< .001
Cramér's V	0.517	—	< .001

3.4.5 Seed Systems and Institutional Support

Results

Access to seeds across all three wards stems from a variety of sources. These include institutional, private, and farmer channels. However, these sources are not equally represented across the wards. Ward I's access to seed sources is provided by a variety of different sources. Sources include Karlo, farmers, county offices, and support systems, but NGOs are a less prominent source of these seeds. Burat's sources of seeds include NGOs as the most prominent source, followed by the county, Karlo, and then farmer-saved seed. Ngaremara's sources of seeds include NGOs as a major source, followed by Karlo. Other sources include the county offices, other programs, and then the least represented source: the farmers that grow the crops within the ward (Figure 16).

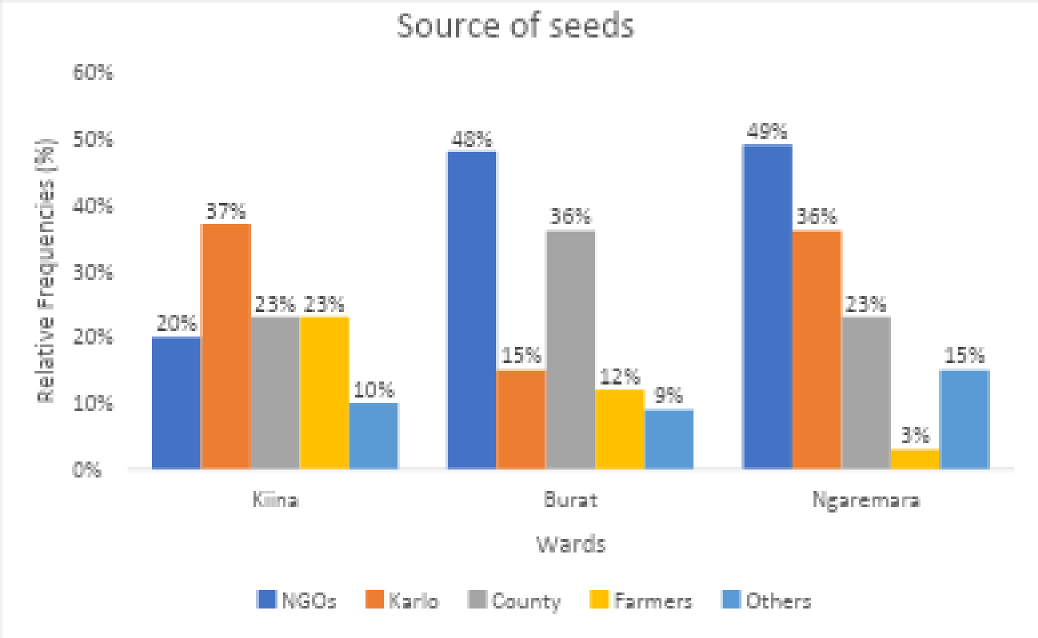


Figure 16: Ward-Level Sources of sorghum and teff seeds

Discussion

Seed access within the study area is provided by various sources, including institutions, NGOs, and farmers. The different locations had different balances of these seed sources.
From the perspective of Sayer et al. (2013), the sustainable land-use framework indicates that the seed system within the study areas has both strengths and vulnerabilities to threats and adverse outcomes.
Using the principles of smallholder intensification outlined by Giller et al. (2011), the findings in these areas indicate a partial shift toward the development of a sustainable intensification system within these farms and agricultural areas. However, the role of farmers within these systems is weaker than that of external institutions that supply the seeds.
The qualitative findings (Thematic box 2) support these results and reveal concerns about these farmers' dependence on external seed providers. Overall, these findings indicate that while the areas have established systems and institutions that contribute to seed availability for these smallholder farmers, there is a need to develop stronger systems that enable farmers to produce and manage their own seeds to increase the sustainability of the region's agricultural systems.

3.4.6 Thematic Box 2: Agricultural Production and Land Use in Sorghum and Teff Systems

Key Evidence from Field Consultations (FGDs & KIIs)

- Adoption of sorghum and teff is driven by their drought resilience and the lower requirements for farmers to plant and cultivate these crops for high yields.
- The major crops cultivated by these communities include sorghum and teff, which are mostly grown alongside livestock management systems.
- Challenges to the adoption of these crops include limited access to certified seeds, labor-intensive field preparation for planting, bird infestations that damage crops after harvest, unpredictable rainfall, and the high costs of purchasing the tools and equipment needed to cultivate these crops.

Some of the specific challenges within each ward include:

- Kiina ward faces challenges with labor-intensive practices for preparing the fields for planting, as well as the difficulties of transporting the crops to market.
- Burat farm challenges include the use of recycled seeds, women-led groups that process the crops, and price fluctuations in the markets.
- Ngaremara's main challenges with the adoption of these crops include integrating livestock management with crop cultivation, issues with seed quality, and a lack of linkages between farmers and markets.

Illustrative Field Perspectives

"*We were told these crops can withstand drought better than maize."* - Focus Group Discussion Participant, Kina

"*You can lose almost half to birds if you don't guard all day."* - Focus Group Discussion Participant, Kina

"Sorghum was introduced as an alternative because it can grow with very little rainfall." - Focus Group Discussion Participant, Burat

Policy Implications

- Introduce improved crop-rotation methods to increase the availability of certified seeds.
- Invest in mechanizing agricultural practices within these wards.
- Organize training for farmers on labor- and pest-management practices.
- Introduce agricultural extension programs tailored to the specific challenges of each ward.
- Introduce programs that will enable the integration of these crops into livestock systems.

3.5 Livelihood & Economic Sustainability

3.5.1 Scope of Analysis

The integration of climate-smart crops into the agriculture of these wards has multiple implications for the income households can generate, the livelihoods of individuals, and the effectiveness of the institutions within those wards. The principles of Climate-Smart Agriculture, as defined by the Food and Agriculture Organization of the United Nations (FAO, 2013), provide the framework for understanding the impact that climate-smart crops can have on income, livelihoods, and institutions within the wards. Additionally, the study draws on the perspectives of the World Bank Gender and Agriculture Sourcebook (2009) and the UNDP Inclusive Development Framework (2016) to discuss equity, diversification, and the effectiveness of institutions. Finally, observations of households, individuals, and groups within these wards, gathered through questionnaires, focus groups, and interviews, provide additional insights into the impact of integrating climate-smart crops into the agriculture of these wards.

3.5.2 Market Participation & Income Effects

Results

Figure 17 presents the results of household sales of sorghum and teff. The majority of households reported selling their produce. However, the number of households selling their products varied significantly across wards. In Kiina, more farmers sold larger volumes of sorghum and teff, whereas in Burat, fewer farmers sold smaller volumes of the crops. In Ngaremara, fewer farmers sold sorghum, and there were no teff sales, possibly because teff prices in the ward were high (Figure 18).

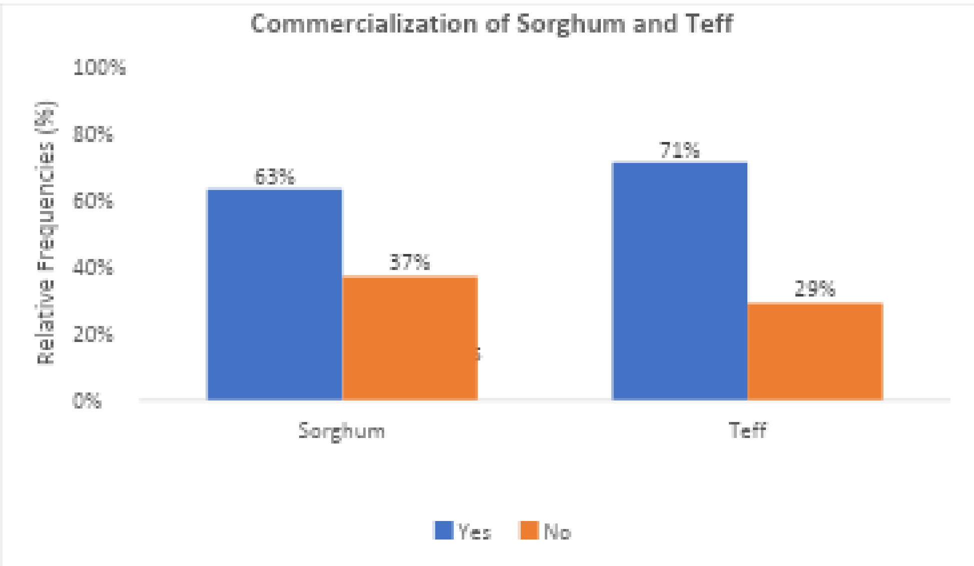


Figure 17: Comparative commercialization of sorghum and teff

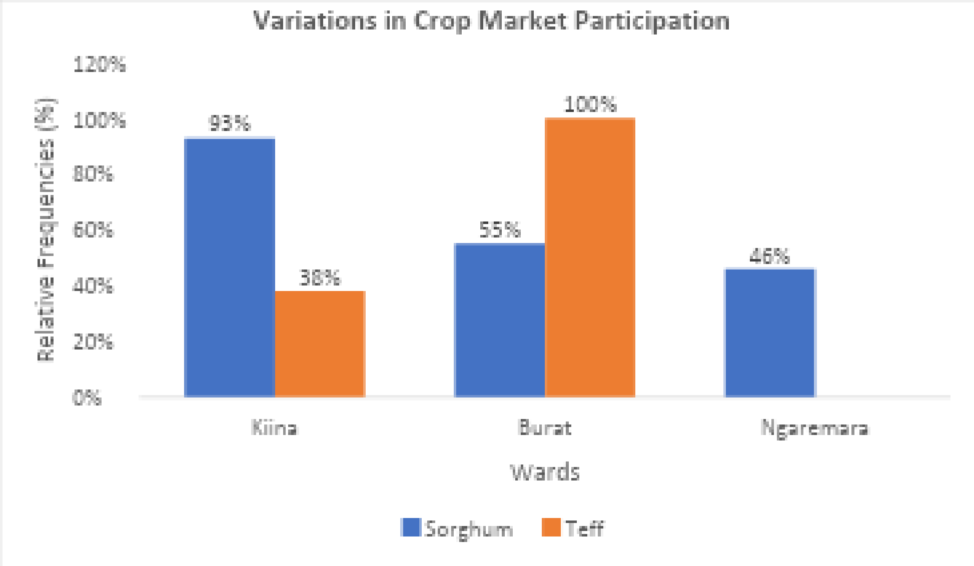


Figure 18: Ward-level variation in crop commercialization

Ward level differences in market participation were statistically significant (Table 5).

Table 5: Ward-Level Differences in Market Participation and Spatial Participation Trends

Statistic	Value	df	p-value
Pearson Chi-Square	17.519	2	< .001
Likelihood Ratio	19.309	2	< .001
Linear-by-Linear Association	16.663	1	< .001
Cramer's V	.397	—	< .001
Fisher's Exact (collapsed 2x2)	—	—	< .001
N of Valid Cases	111	—	—
Cell count status	CLEAN — 0 cells < 5, minimum = 13.38	—	—

Discussion

The test of significance for the association between ward and market participation indicates a statistically significant association (Cramér's V = 0.397), of moderate strength. These findings corroborate the descriptive analysis, which indicated that markets in Kiina tend to exhibit higher transaction volumes than those in Burat and Ngaremara, and that markets within Burat and Ngaremara tend to have lower sales volumes (particularly for teff). Overall, the data indicate that farmers' location within the region significantly affects the extent to which they participate in market activities (Kangile et al., 2020).

The qualitative interview and focus group data help explain differences in market participation rates (Thematic box 3). Farmers in the region indicated that crops like sorghum are used to generate household income, while crops like teff may yield higher returns but require more investment to produce. Additionally, many farmers noted that transport limitations to the market could affect their ability to participate in and benefit from market activities. These findings relate to the concept of SMSA, as participation in market activities is essential to ensure that farmers in the region benefit from their agricultural production. Furthermore, these findings align with development theories, which suggest that an individual's ability to benefit from their agricultural production is influenced by various structural and institutional factors within the economy (Shiferaw et al., 2016). These findings also indicate differences in opportunity across the wards.

The integration of both survey and interview data helps provide a complete understanding of the topic. Survey data helps reveal the extent to which farmers in the region commercialize different crops, while interview data helps explain the differences in their commercialization. Overall, the findings indicate that various factors affect farmers' participation in market activities. Those factors include the types of crops cultivated, the benefits those crops may provide to farming households, and factors that may limit farmers' ability to participate in market activities and gain those benefits.

2.5.3 Income Reliance & Seasonality of sorghum and teff cultivation

Results

The income from climate-smart crops is seasonal. Most farmers earn income from sorghum for only a few months each year and from teff for a period longer than sorghum but still limited to a few months. Some farmers earn income from these crops for longer than a few months, but none rely on them as their sole source of income throughout the year (Figure 19).

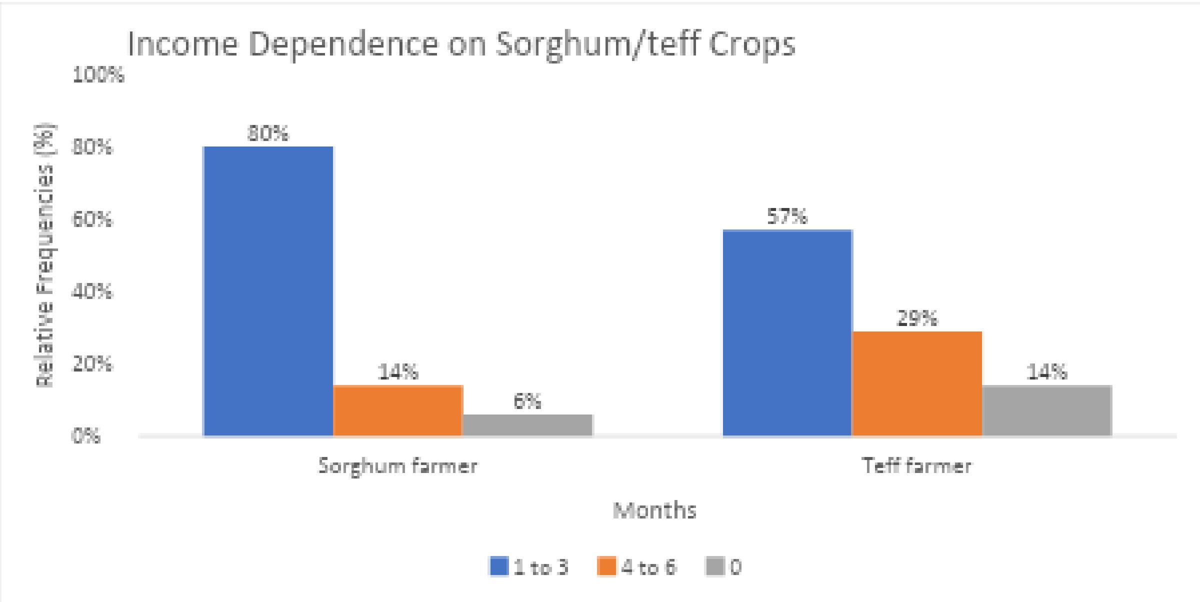


Figure 19: Annual income dependence on sorghum/teff crops

Ward-level differences are again notable. The Ngaremara ward shows short-term reliance on sorghum income, whereas a subset of farmers in the Kiina ward experiences longer periods of sorghum income. Furthermore, the difference in the duration of reliance on sorghum income across wards is statistically significant (Table 6). Teff yields slightly more income than sorghum (Annex 4, fig. 4).

Table 6: Ward-Level Differences in Duration of Reliance on Sorghum Income

Statistic	Value	df	p-value
Pearson Chi-Square (3-ward)	8.901	2	.012
Likelihood Ratio (3-ward)	10.753	2	.005
Fisher's Exact (collapsed 2x2)	—	—	.008
Continuity Correction (collapsed)	6.668	1	.010
Cramer's V (collapsed)	.368	—	.003
N of Valid Cases	64	—	—
Cell count warning (3-ward)	3 cells (50%) < 5, minimum = 2.53	—	—

Discussion

The results indicate that income from climate-smart crops has a seasonal component, but it is also uneven in the length of time these crops can provide income to households within each ward. Significant differences in the length of income across wards, along with a moderate association between the two variables, suggest that the duration of income to these households is driven by local conditions within the wards. Kiina experiences longer periods of income from these crops than the other wards, indicating that it has conditions more favorable for growing and harvesting them. In contrast, wards like Burat and Ngaremara experience shorter periods of income from these crops. Thus, even though there is income from these crops, it is not sustained for those farmers, a sentiment shared by Tanti et al., 2024.

Based on farmers' feedback, the seasonal income from these crops is limited by the few options available to extend the period during which income can be generated. Options such as establishing value-added crops, increasing storage capacity, or changing planting methods can extend the period during which income can be generated, but farmers lack the skills and knowledge to employ these strategies. Thus, each of these farmers is unable to provide year-round income for their families. These findings indicate that income from climate-smart crops depends on farmers' ability to earn it over time (Hossain et al., 2025). The short period during which these crops are harvested indicates that farmers cannot rely on them as a sole source of income.

3.5.4 Access to and Effectiveness of Farming Support

Results

The results of a survey of farmers on smart climate crop production reveal a lack of support for this form of agriculture. Most farmers do not receive any support for smart climate crop production (Figure 20), and those who do receive assistance from their institutions find it ineffective in supporting their crops with these technologies (Annex 4, fig 5).

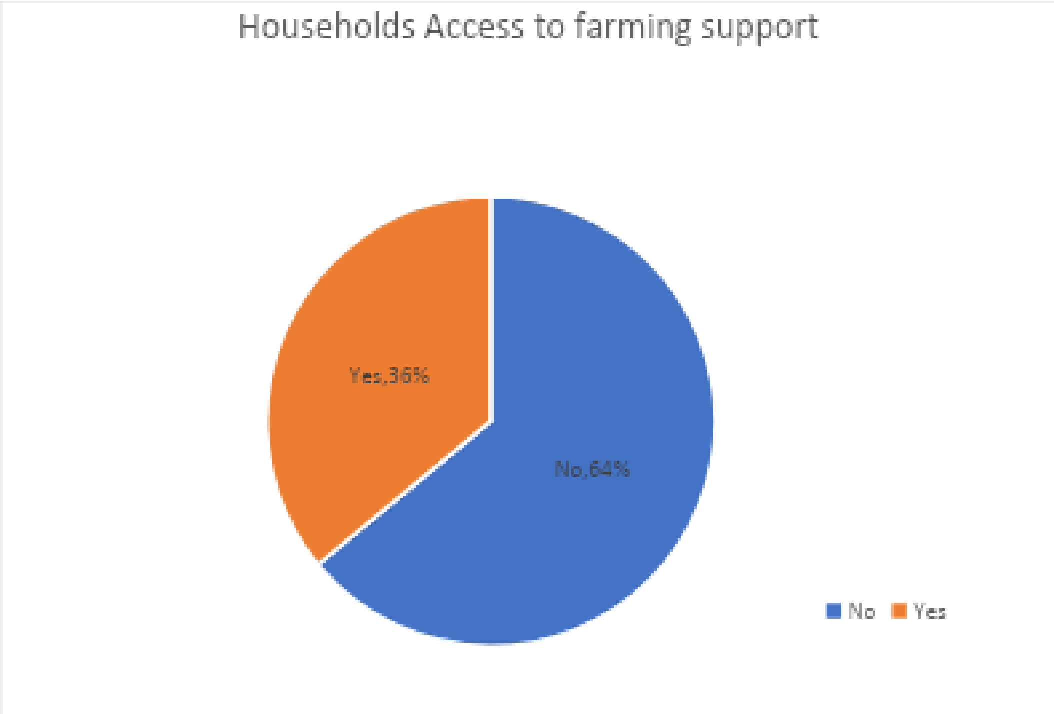


Figure 20: Households' access to farming support

The effectiveness of these supports varied across wards: Kiina has the lowest level of access, while Burat and Ngaremara have moderate levels (Figure 21). Teff farmers reported that there is no support at all for these smallholder farmers (annex 4, fig 6). These differences are statistically significant in their effect on smallholder farmers (Table 7).

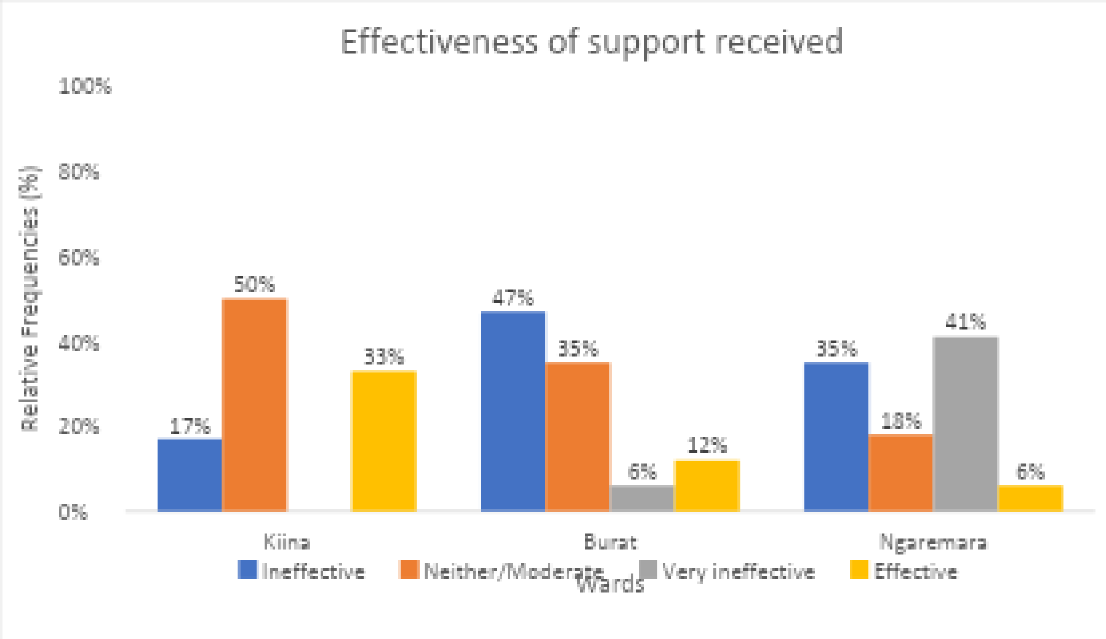


Figure 21: Effectiveness of farming support received

Discussion

The study's findings demonstrate a lack of institutional support for climate-smart crop production in most wards. The majority of farmers receive no assistance from institutions related to climate-smart agriculture. Among those who do receive assistance, many report that it is ineffective. The level of support that farmers receive from institutions is also unevenly distributed across the wards. Farmers in Kiina receive less institutional support than those in Burat and Ngaremara. Furthermore, teff farmers receive less institutional support than other farmers in the study area. These differences are statistically significant.

The quality of institutional support provided to farmers is also lacking. According to the survey results, the support provided to farmers is not aligned with the needs and conditions of the crops they cultivate. This finding aligns with the findings of the studies by Wright et al. (2017) and Hansen et al. (2019). Such ineffective support does not increase farmers' productivity in the study area.

The lack of impact of institutional support on climate-smart agriculture outcomes in the study area is due to the uneven distribution of this support to farmers and the ineffectiveness of the support delivered to them. The support provided to farmers is neither sufficiently distributed to meet their needs nor sufficiently tailored to the conditions and requirements of the crops they cultivate.

Table 7: Ward-Level Differences in Access to Agricultural Support Services

Statistic	Value	df	p-value
Pearson Chi-Square	7.569	2	.023
Likelihood Ratio	7.973	2	.019
Linear-by-Linear	2.804	1	.094 (NS)
Cramer's V	.261	—	.023
N of Valid Cases	111	—	—
Cell count status	CLEAN — 0 cells < 5, minimum = 11.89	—	—

Institutional support for agriculture is weak and uneven across the country. The support provided to farmers is generally lacking in both targeting and effectiveness. To strengthen this component of the agricultural system, support for farmers would need to be expanded and improved to better meet their needs and operational requirements.

3.5.5 Thematic Box 3: Contribution of sorghum and teff cultivation to Livelihoods & Economic Sustainability

Key Insights (FGD & KII)

- Sorghum and teff generate income through the sale of both the raw grains and the resulting flour.

At the ward level, different strategies are being utilized:

- Burat utilizes the sale of flour to increase their income and save for educational fees.
- Ngaremara increases their bargaining power by selling their products collectively.
- Kiina sells their products locally but faces constraints in their transport and profitability from these sales.

Representative Voices

"These crops will allow me to cover any emergencies within my household without depending on anyone else for that income." FGD, Ngaremara

"Selling flour allows us to have more income than if we sold the grain alone." FGD, Burat

Policy Implications

- Support the processing of grains into flour to increase their income.
- Increase the cooperative structure to strengthen their bargaining power.
- Improve the transport system to increase their profitability.
- Introduce price stabilization to enhance the farmers' income.

3.6 Food Security Outcomes of Sorghum and teff cultivation

3.6.1 Scope of Analysis

The implications of implementing climate-smart agriculture practices for the cultivation of sorghum and teff within the wards are significant for household food security. An examination of the extent to which the implementation of these practices contributes to households' food security within the wards will be conducted. In the discussions, the Food and Agriculture Organization of the United Nations (FAO) framework for food security will be used, which categorizes food security as availability, access, utilization, and stability (FAO, 2008). Additionally, the Department for International Development (DFID) framework for sustainable livelihoods will be utilized, which considers food security as one of the outcomes of an individual's livelihood, comprising their natural, financial, human, and social capital (DFID, 1999). Thus, each of these frameworks will allow the discussion to focus on the commercialization of the crops, their consumption by farming households, and the extent to which those households rely on them for food security. Overall, the introduction of climate-smart agriculture practices for sorghum and teff has contributed to the food systems of households in the wards. However, these benefits are not provided equally to all wards within the city, and the benefits provided to each crop are also not provided equally to all wards within the city.

3.6.2 Production Performance and Food Availability

Results

Sorghum yields from households vary considerably, ranging from low to high. However, most farms have low to medium yields. Yields also differ across the wards. Kiina has higher yields and a wider yield range across farms within the ward. Burat farms exhibit medium yields, with a few farms having high yields. Ngaremara has low yields from most farms within the ward (Figure 22).

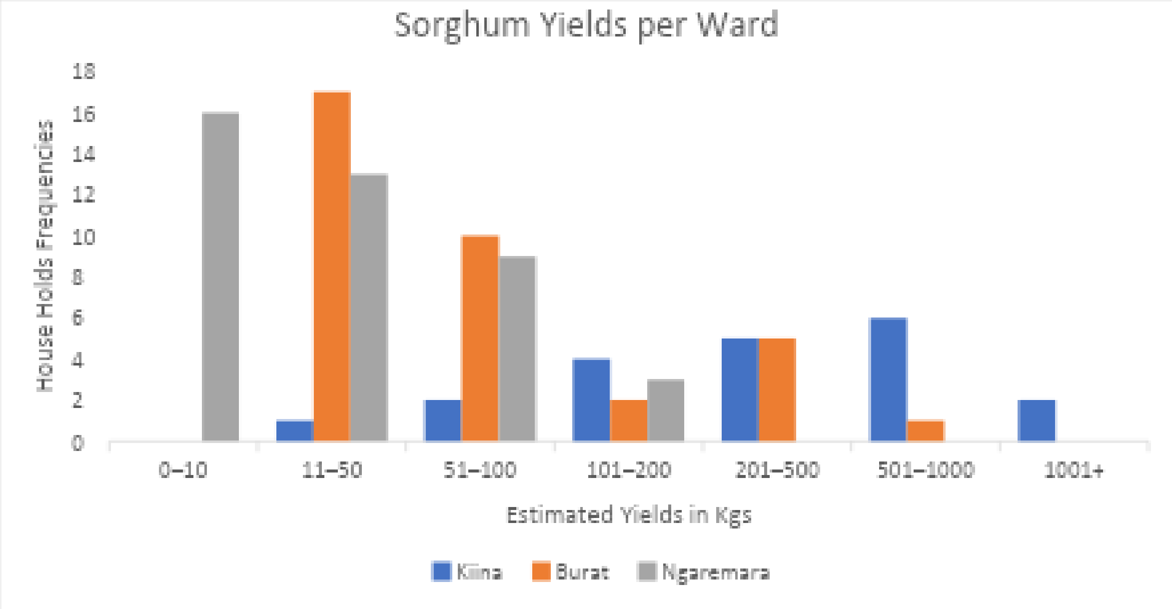


Figure 22: Ward-Level Household Sorghum Yields

Figure 23 displays the distribution of sorghum yields produced by households in the previous season. The majority of farmers in the survey produced low sorghum yields (Figure 23). Few farmers produced high yields of sorghum. The distribution of sorghum yields is right-skewed, with most yields clustering at the lower end and a long tail extending to higher yields; this indicates that a few farmers produce much higher yields than the majority of farming households in the area. The mean yield of sorghum was 154.91 kg, yet the standard deviation was relatively large at 235.863 kg.

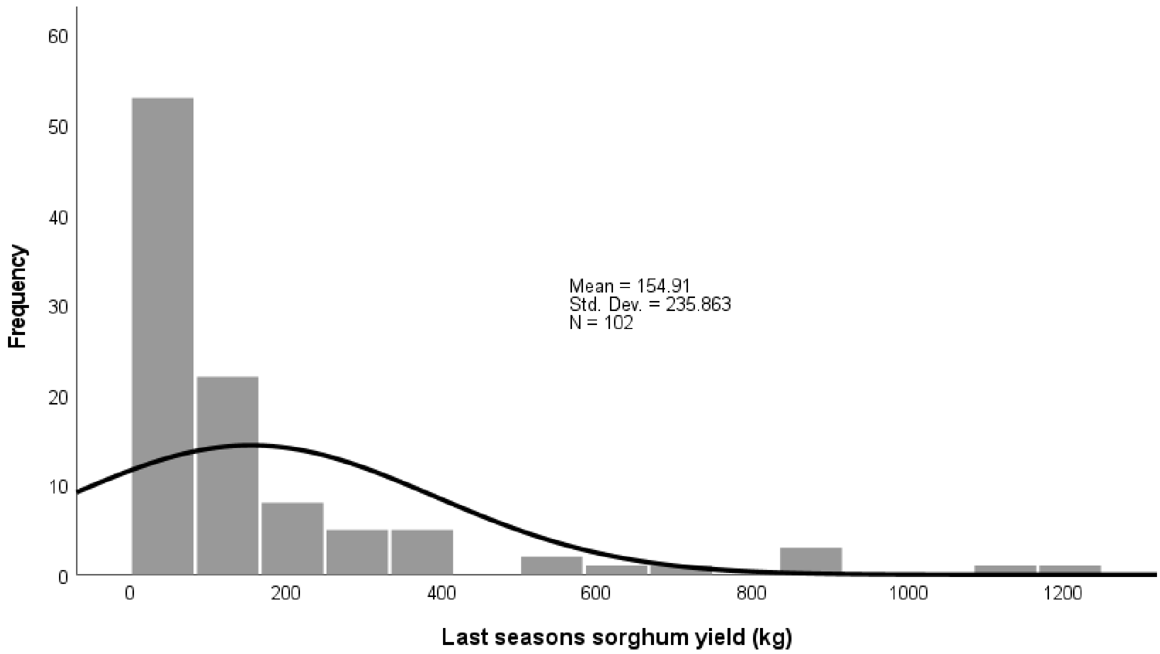


Figure 23: Distribution of Last Season's Sorghum Yield Across Households

A characteristic of teff production is low yields. Most households produce little teff. The map displays the characteristics of teff production within each ward. Kiina consistently produces moderate amounts of teff. Ngaremara produces low amounts of teff. Burat also produces limited amounts of teff across the ward, although one farm displays high levels of teff production (Figure 24).

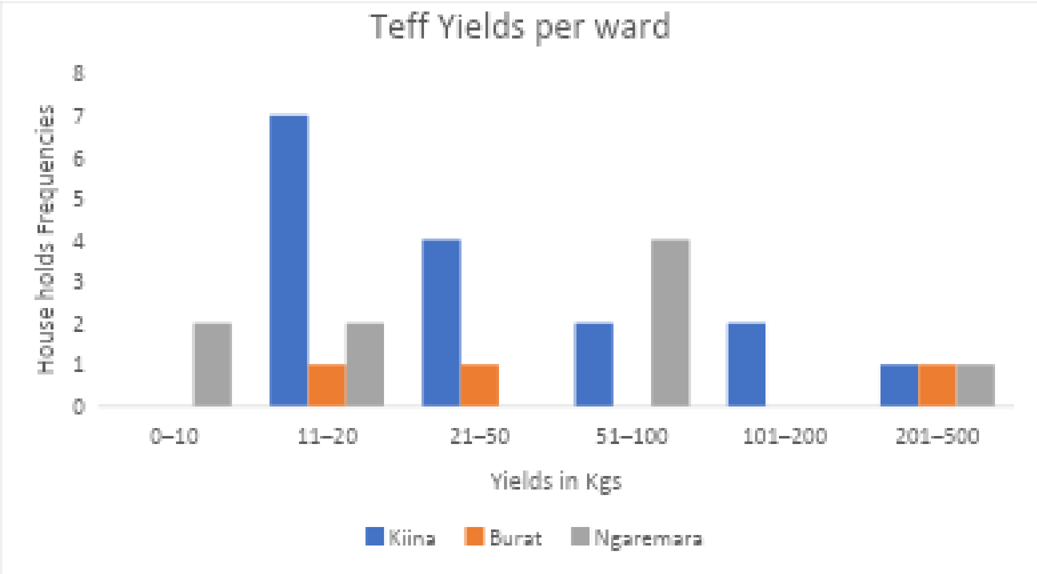


Figure 24: Ward-Level Household Teff Yields

While yields from most households' crops are low to moderate, food availability has improved for most households. The majority of households in these regions have reported an improvement in their food availability. Most reported slight improvements in food availability, though some reported more substantial improvements within their households (annex 5, fig 1). The results of the Spearman's correlation test confirm a positive relationship between these two variables. Both total crop yield and sorghum crop yield (Table 8) have significant positive relationships with changes in food availability within these households. Thus, the greater the household crop yields, the more food is available within those households. However, total crop yield has a weak negative relationship with the impact on food security within the households that is statistically significant. The relationship between sorghum crop yields and household food security is also negative, but not statistically significant. Thus, there is no clear relationship between these two variables within the data (Table 8).

Table 8: Correlation Between Yield and Food Security Outcomes (Spearman's rho)

Correlation Pair	rs	N	p-value
Total yield × Food availability change	.330	101	.001 *
Sorghum yield × Food availability change	.302	102	.002 *
Total yield × Food security impact	--.194	110	.042 *
Sorghum yield × Food security impact	--.168	102	.091 (NS)

** p < .05. NS = not significant.*

The yields of teff are highly concentrated in the last season's production. The majority of households produced low yields of teff, with only a few achieving higher yields; thus, the yield distribution has a pronounced right tail. This indicates that the majority of the data are from low-yielding teff in these households, with a few individuals producing significantly more teff than the rest of the population. The mean yield of teff is 104.29 kg per household, with the standard deviation of the mean being 140.847 kg, indicating the dispersion of the yields of teff from each household within the sample (Figure 25).

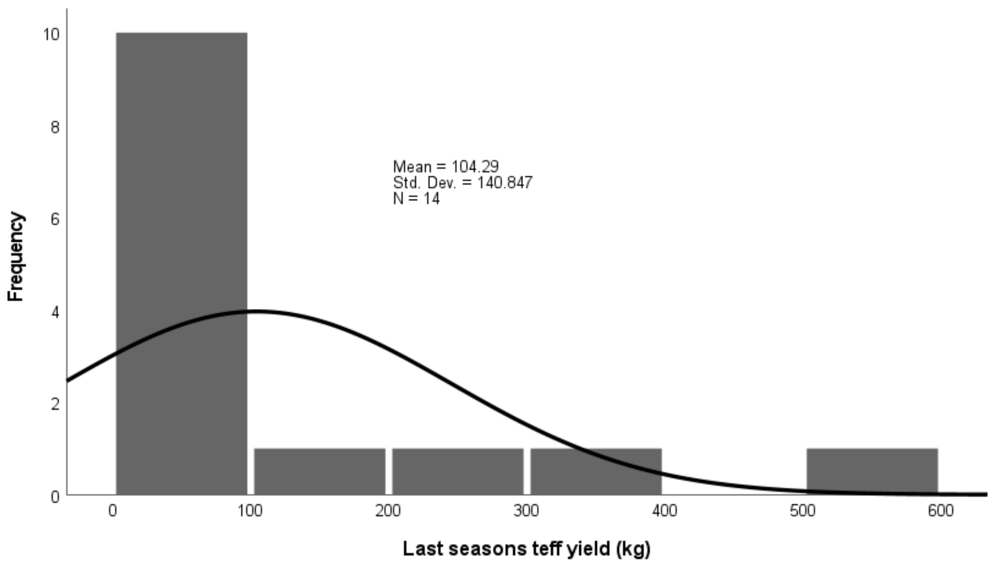


Figure 25: Distribution of Last Season's Teff Yield Across Households

Burat and Ngaremara show the most consistent positive outcomes, with over 90% of participants reporting improvement with each intervention. Kiina shows more variability in intervention outcomes, with a larger proportion of participants experiencing substantial increases in wellbeing, but also a proportion experiencing no change or reductions in their reported wellbeing measures (Figure 26).

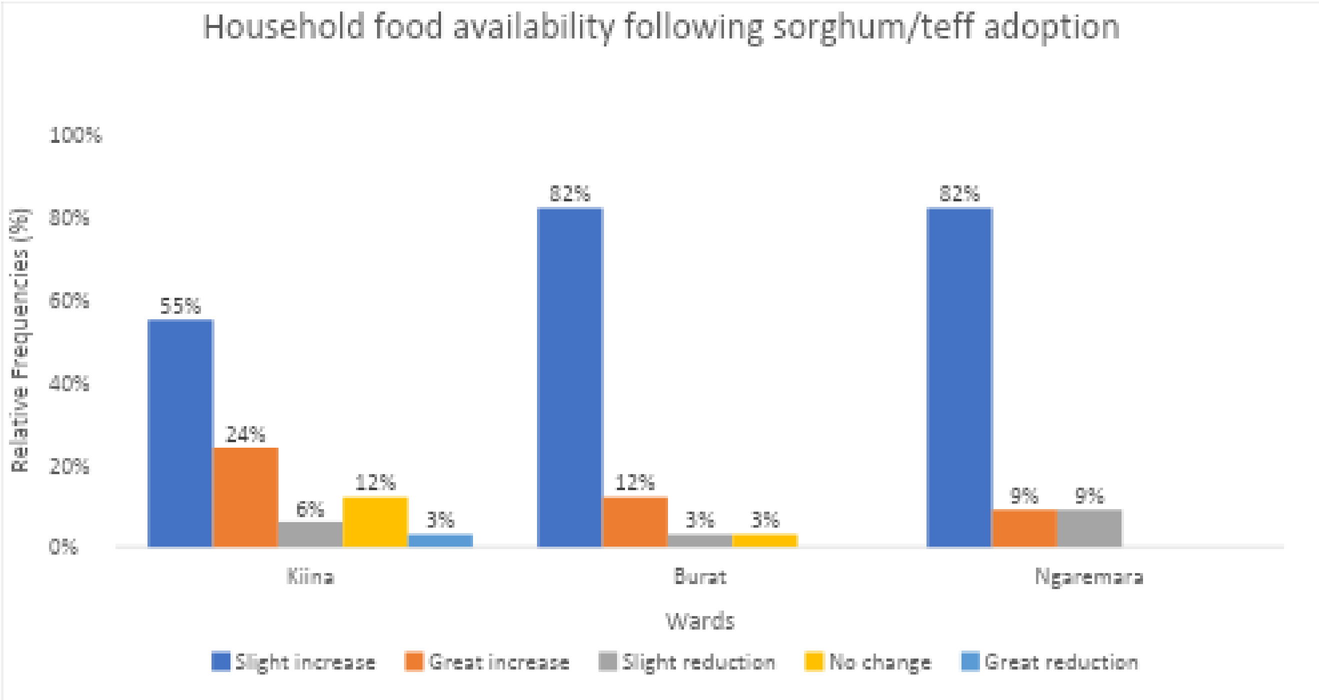


Figure 26: Household Food Availability Across Wards Following the Adoption of Sorghum and Teff Technologies

Discussion

As indicated in the results above, there are clear signs of improvement in food availability, even among households with low-to-moderate production levels. Thus, even small improvements in yields possible within these dryland agricultural regions are associated with increased food availability (Haddad et al., 2021). Additionally, the correlation results help to confirm these findings regarding food availability. The total crop yield per household is positively correlated with changes in food availability. Additionally, sorghum yields appear to have a similar positive relationship with food availability. However, the relationship between crop yields and food security concepts other than availability is weaker, indicating that while yields are associated with households' food availability, they do not correspond to food security within those households.

The yields of sorghum and teff within each ward of the study area also show variation in their distributions. For instance, sorghum yields mostly fall within the lower portion of the distribution, yet a few households have high yields. In contrast, teff yields mostly fall at the low end of the distribution, with few high-yield households in the study area. These distributions are reflected in the yields across the wards within the area. For instance, the Kiina ward has higher yields of both sorghum and teff than the other wards within the study area. In contrast, the Ngaremara ward produces mostly low yields of both crops. Finally, the Burat ward has somewhat similar yields to the Ngaremara ward, yet there are some differences in the yields of individual households within that ward.

Overall, these differences in yields are associated with the availability of crops in individual households (Ritzema et al., 2017), since availability is a measure of the amount of food that can be obtained.

3.6.3 Household Consumption, Utilization, and Dietary Integration

Results

Household consumption of sorghum varies considerably: some households consume none in a year, while others consume very high amounts; the distribution is right-skewed (Figure 27). The mean amount of sorghum consumed by households is 76.53 kg, with a standard deviation of 132.45 kg (Table 16).

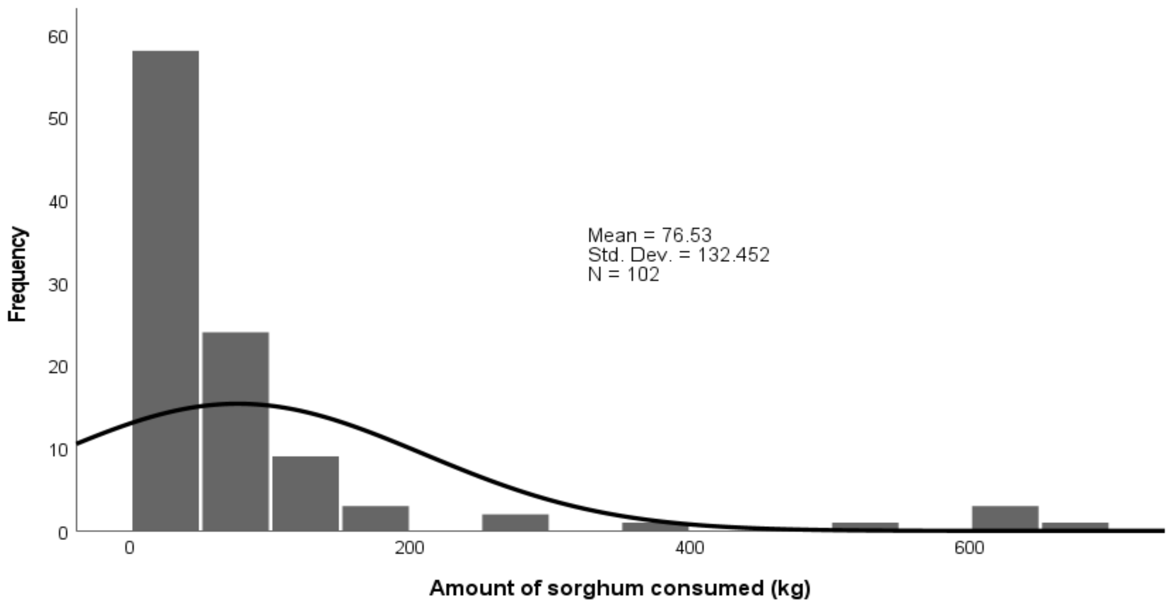


Figure 27: Distribution of Annual Household Sorghum Consumption

Clear differences within the ward are also apparent. Wards like Kiina show high and diverse consumption of these products, while wards like Burat show more moderate consumption, and Ngaremara shows low consumption (Figure 28).

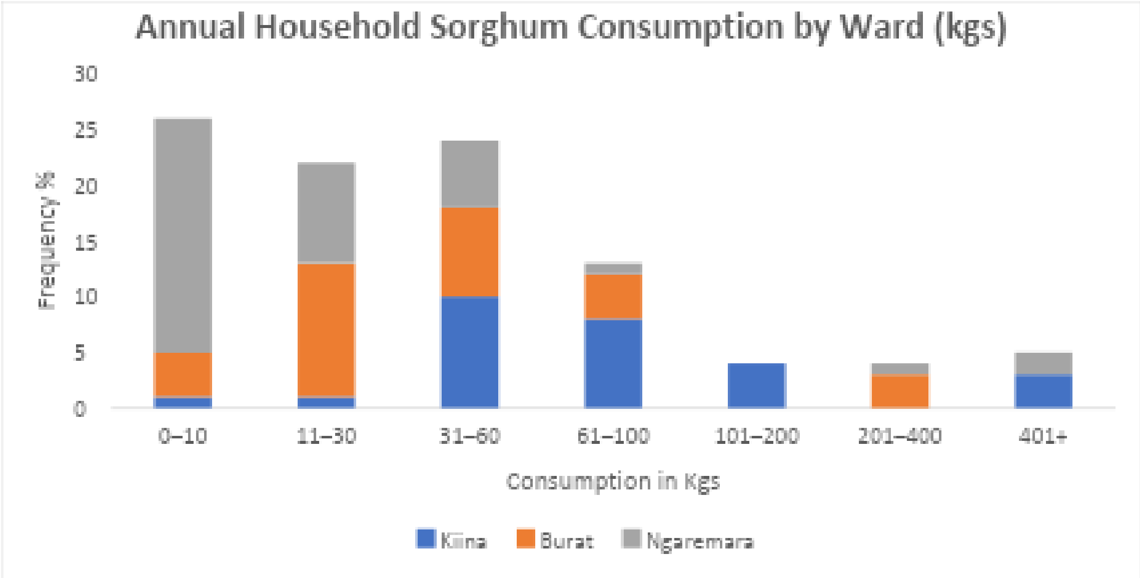


Figure 28: Annual household sorghum consumption by ward

Teff consumption is generally lower than sorghum consumption. Most households consume low to moderate amounts of teff, but a small number of households that consume high amounts create the right skew in the distribution (Figure 29).

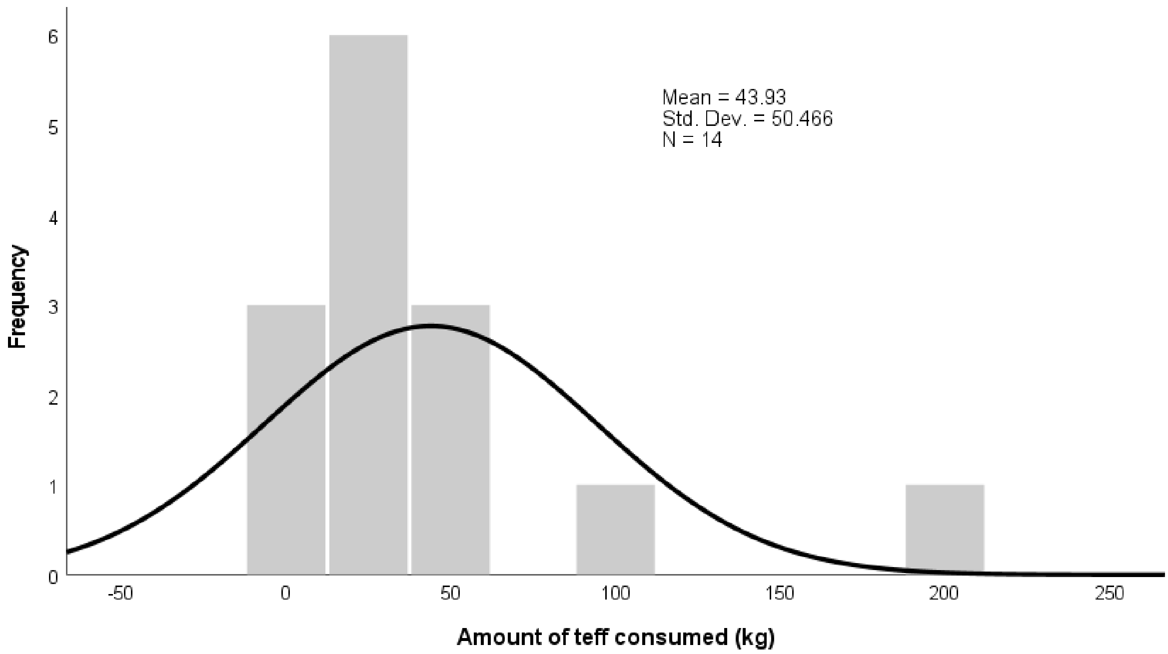


Figure 29: Distribution of Annual Household Teff Consumption

Spatial differences are also evident across the wards. Kiina shows moderate teff consumption, whereas Ngaremara has low levels. Burat has one instance of high teff consumption, but overall consumption remains limited within the ward (Figure 30).

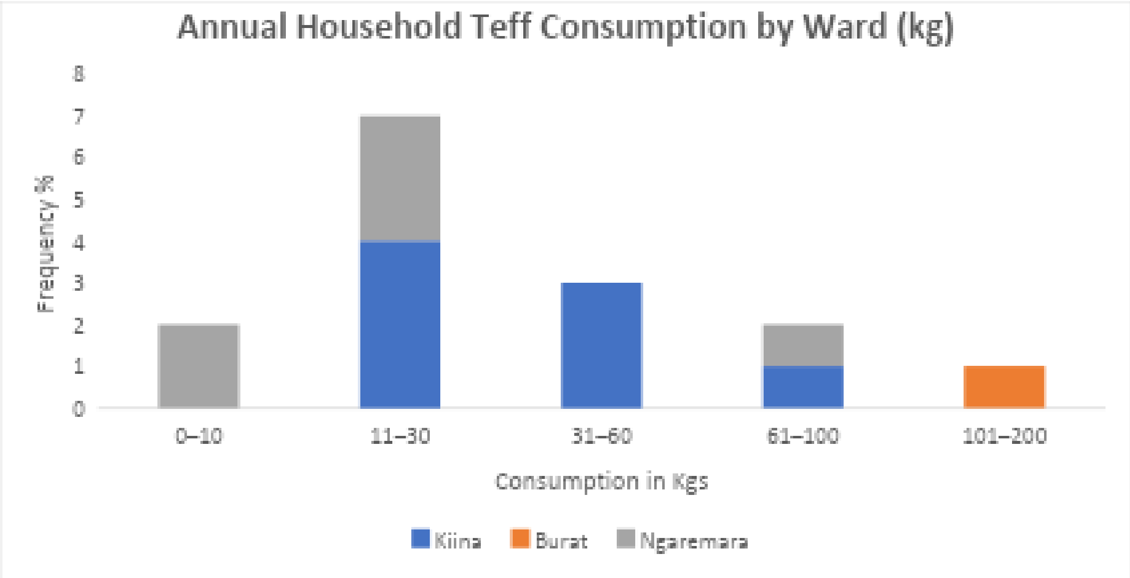


Figure 30: Annual household teff consumption by ward

These descriptive patterns are statistically supported by a Kruskal-Wallis test, which indicates significant differences in crop yields across wards. The mean ranks indicate that Kiina produces the highest yields, followed by Burat, with Ngaremara producing the lowest. Post hoc tests within the Kruskal-Wallis framework indicate that each of these differences is significant (Table 9).

Table 9: Ward Differences in Combined Crop Yield (Kruskal–Wallis and Post-hoc Tests)

Component	Ward / Comparison	Statistic	Value
Sample distribution	Kiina	n	32
	Burat	n	34
	Ngaremara	n	44
	Kiina	Mean rank	82.58
	Burat	Mean rank	64.63
	Ngaremara	Mean rank	28.75
Overall Test	Kruskal–Wallis H	H(2)	57.109
		p-value	< .001
Pairwise Comparison	Kiina vs Burat	U = 296.5, Z = -3.188	.001*
	Kiina vs Ngaremara	U = 85.0, Z = -6.523	< .001*
	Burat vs Ngaremara	U = 190.0, Z = -5.660	< .001*

Discussion

Overall, the link between crop production across wards and individuals' consumption within those wards is evident. The higher the yield of a crop within a ward, the higher the consumption rates of that specific crop. Thus, individuals within wards that are able to produce significant amounts of a crop are able to consume more of that same crop than individuals within wards that produce less of that same crop (Frelat et al., 2016). Additionally, those that produce less of a crop are unable to provide as much of that specific crop to be consumed by their individuals, and also to be sold to other areas and provide income for those wards (Ngaremara, for instance, produces significantly less sorghum and teff than any of the other wards in the study).

Beyond the growth of crops within each ward, however, the dietary consumption of those crops also depends on the decisions that individuals within the ward make regarding the use of that production. If individuals within a ward decide to consume the crops grown by the farmers within that ward, they will have higher rates of consumption of those crops than if they use those crops as income to provide for others within the ward. Thus, the more individuals within a ward who use their agricultural production as income, the less likely they are to have high consumption rates of those crops (Meyer et al., 2022).

From the perspective of food security, the utilization of crops is determined by both the production of those crops and the allocation of agricultural products within each ward. Thus, food security within each ward is created not just through the production of crops, but also by how those crops are utilized by the individuals of that ward (Rios-Avila et al., 2021). Both the ability of individuals to use those crops for food or income and the extent to which they do so impact the level of food security that exists within those different wards.

From the Sustainable Livelihoods perspective on agriculture, these two variables are considered transformed into livelihood outcomes for that ward. If individual farmers in a ward decide to use the crops grown in their area, they will achieve greater self-sufficiency and reduced reliance on other income sources. However, if they decide to sell the crops produced on their farms, those farmers will instead be transforming their agricultural production into income that can be used to purchase other products or resources within the area (Baer-Nawrocka and Sadowski, 2019).

Thus, the consumption rates of sorghum and teff across the different wards correlate with the amount of those crops produced within each ward. Wards that produce more of a crop, such as Kiina, exhibit higher consumption rates of that same crop than those that produce less, such as Ngaremara. The relationship between crop yields and consumption across these wards indicates a strong, consistent association between the two variables, reinforcing the link between agricultural crop production and crop outcomes in relation to food security within the study area (Ickowitz et al., 2019).

3.6.4 Market Engagement, Food Access, and Income Pathways

Results

The commercialization of these crops reveals differences between the two. A majority of sorghum farmers participate in crop sales. In contrast, fewer teff farmers participate in commercial sales (Figure 17). There are also differences in commercialization across the wards. Kiina shows the highest level of commercialization among sorghum farmers compared with the other wards. Burat has moderate commercialization of sorghum, while Ngaremara has the least commercial activity among sorghum farmers (Figure 18). Sales vary in the quantity of sorghum sold. Some sell very small quantities of sorghum, while others sell much larger volumes. The majority of farmers who sell the highest volumes of sorghum live in Kiina.

The Chi-square test results show a significant association between ward and sorghum commercialization, and the value of Cramer's V indicates that the association between farmers' ward location and the commercialization of their sorghum is moderate to strong. The significant Linear-by-Linear Association indicates a clear gradient in sorghum commercialization among farmers across these wards (Table 10).

Table 10: Ward Differences in Commercialization Rate

Statistic	Value	df	p-value
Pearson Chi-Square	17.519	2	< .001
Cramér's V	0.397	—	< .001
Linear-by-Linear Association	16.663	1	< .001

Despite the relatively low levels of commercialization of both sorghum and teff, most households in the area appear to have some degree of food security. More specifically, a high proportion of households that cultivate sorghum and teff report strong food security. Among the areas surveyed, the majority of households in Ngaremara and Burat report improvements in their food security. However, Kiina reports some improvements in food security, though with somewhat more variability between households (Figure 31).

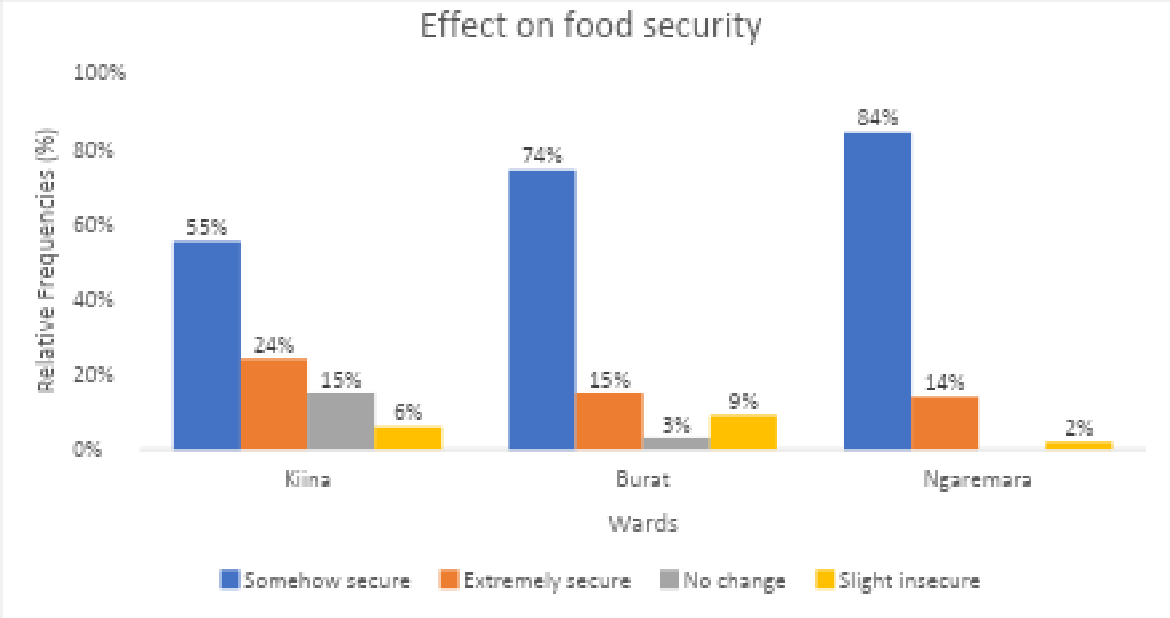


Figure 31: Effect of sorghum/teff cultivation on household food security

Discussion

The findings show that improvements in food security within the study area stem from both the direct consumption of food produced by local farmers and the conversion of that food into income through the sale of surplus production. In areas like Kiina, which is more market-oriented, much of the sorghum grown there is sold to the market. As a result, the income from those sales is used to purchase the food required by those farmers and their communities. Consequently, food security in these areas is more reliant on the market and the stability of food prices within it.

In areas like Ngaremara, which is less commercialized, the crops grown are consumed by farmers in that area, and their reliance on income from crop sales is much lower. Thus, each of these areas experiences different levels of food security due to the varying lengths of food self-sufficiency periods within each location. These different outcomes across areas reflect the access dimension of food security, since the availability of food within the area is only one of the factors related to food security when farmers are unable to either consume their own crops or gain income from those sales. Thus, access to markets allows farmers to convert their agricultural production into financial capital, which can then be used to purchase the food that is necessary to satisfy food needs (Ma et al., 2024).

Furthermore, from the perspective of the Sustainable Livelihoods framework, the ability of these farmers to sell their crops and convert their agricultural production into financial capital is one means of ensuring the sustainability of their livelihoods within the area. While selling crops allows for the conversion of their natural capital to financial capital, and for that financial capital to help them meet their food needs, such a practice also increases their exposure to risks related to the commercialization of their agricultural products (Davis et al., 2021). Finally, these two forms of livelihood sustainability within the study area indicate that farmers' livelihoods are sustained through the use of their crops for both consumption and income, both of which contribute to the food security of farming communities.

3.6.5 Duration of Reliance and Seasonal Stability of sorghum and teff

Results

Reliance on sorghum and teff to meet households' food needs in the study area is generally short-lived. Most households in the study area rely on these crops for a limited period each year. A smaller proportion relies on them for a moderate period. Only a very small fraction depends on them for extended periods (annex 5, fig 3). Furthermore, the duration of households' reliance on sorghum and teff for their food needs within the study area also reveals some differences. The ward of Ngaremara exhibits the shortest reliance periods on these crops for household food needs. Most households in Ngaremara rely on these crops for brief periods only. By contrast, Kiina village displays longer periods of reliance on these crops for food needs within households. A substantial number of households in Kiina rely on these crops for extended periods. Burat village lies somewhere in the middle in terms of the duration of households' reliance on these crops to meet their food needs (Figure 32).

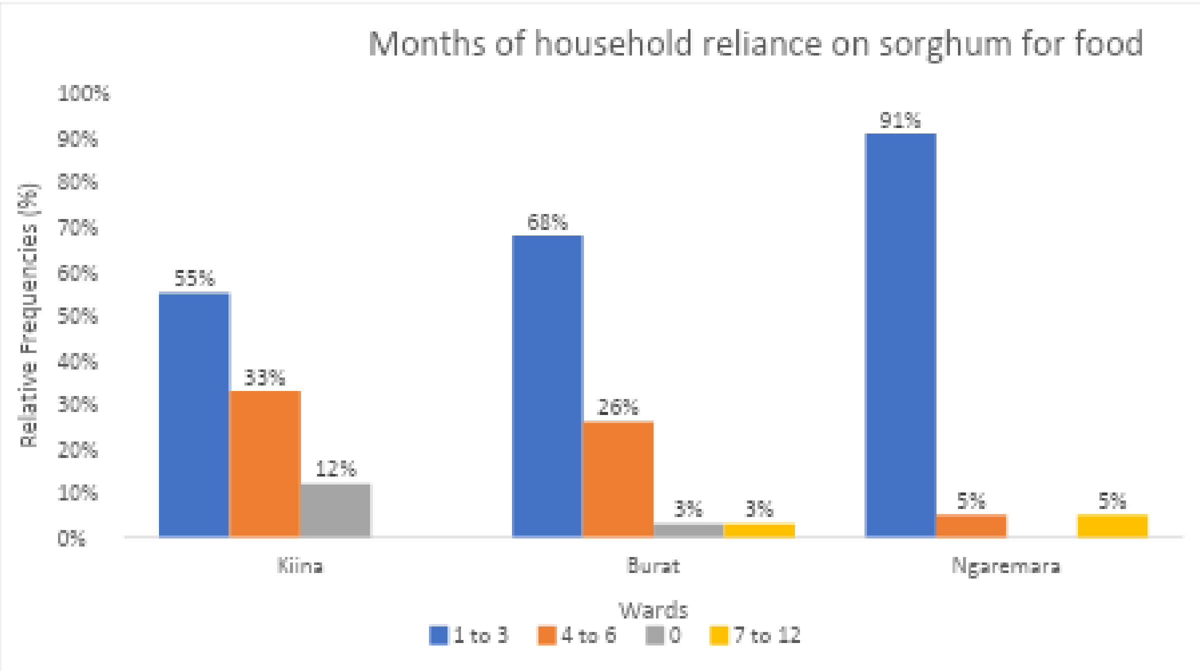


Figure 32: Duration of Household Reliance on Sorghum and Teff for Food Supply

Interestingly, although sorghum is grown and consumed by a larger share of the population, teff can play a stronger role in meeting households' food needs over longer periods (Figure 33).

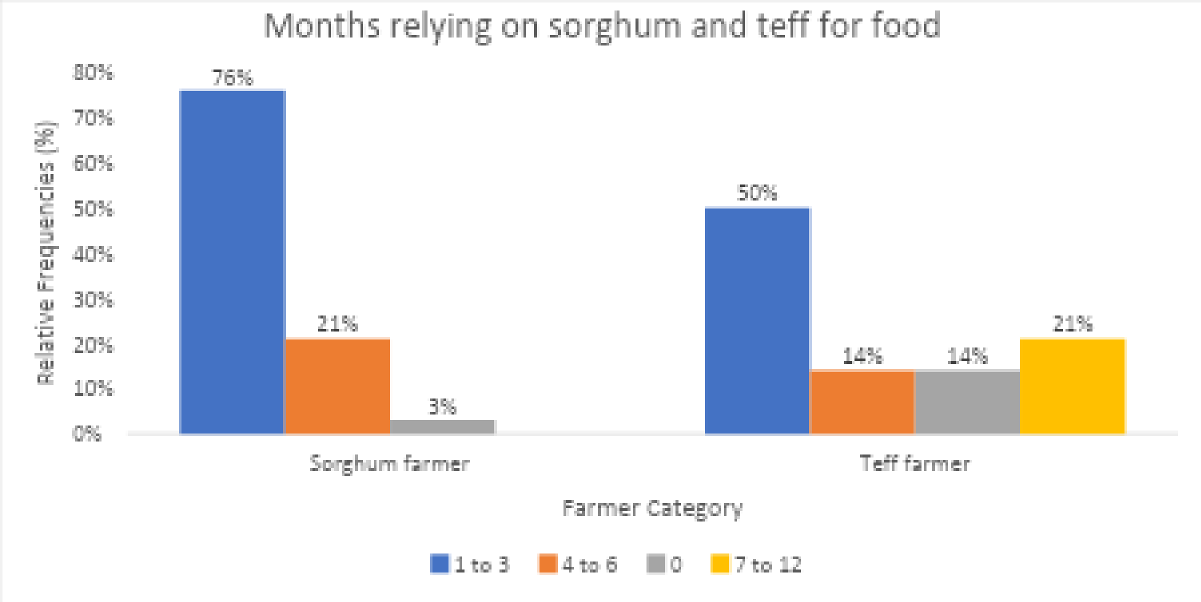


Figure 33: Months Households Depend on Sorghum versus Teff for Food

Discussion

The study indicates that households in the study area rely on sorghum and teff for short-term use. The majority of households in the study area rely on these crops for only a brief period each year. Fewer households have longer periods of reliance on these crops, and these longer periods are not even distributed equally among the different wards within the city.

Wards like Ngaremara have very short periods of reliance on sorghum and teff because of lower production and consumption of these crops within the ward. In contrast, wards like Kiina experience longer periods of reliance on these crops, likely due to higher production within the ward. Burat falls somewhere in between Ngaremara and Kiina in terms of the length of reliance of its households on these crops. Furthermore, the results indicate that teff shows longer reliance periods in certain wards than sorghum, likely because the crop is incorporated into the diets of households in those areas, which exhibit longer reliance on teff.

These patterns are similar to those reported by Majhi et al. (2023), who noted that although sorghum and teff have increased food availability in the region, these crops have yet to contribute to the region's food security. As a result, while individuals in the region may have greater food availability throughout the year, a lack of storage capacity, crop production, and crop diversity limits households' ability to maintain consistent food availability from season to season.

Within the framework of food security, these results indicate the stability of the region's food supply. Food security is a condition in which an individual, family, or community can consistently obtain food to survive year after year (García-Díez et al., 2021). Thus, the short periods of reliance on sorghum and teff indicate that the region's food supply is not as stable over time.

From the perspective of the Sustainable Livelihoods framework, the short periods of reliance on sorghum and teff in the region also indicate a lack of individuals' capacity to build adequate assets to provide for themselves and their communities. In other words, their vulnerability to food insecurity in the region increases over time due to their inability to provide for themselves (Hadley et al., 2023). Thus, overall, these results help explain why, despite the benefits the introduction of sorghum and teff to the diets of individuals in the region has provided to those communities, those benefits are not yet sufficient to ensure food security in the region.

3.6.6 Thematic Box 4: Food Security Outcomes of Sorghum and Teff Cultivation

Key Insights (FGD & KII)

Climate-smart sorghum and teff enhance household food availability, access, and consumption, contributing to both short-term and seasonal food security.

Ward-level variations in food security include:

- Ngaremara experiences low sorghum and teff production yet gains in food security; they mainly use these crops as a short-term solution to food insecurity.
- Burat experiences moderate yields and consumption of sorghum and teff. Most households process sorghum into flour, which enhances the nutritional content of their diet and allows them to save money compared with buying flour from commercial mills.
- Kiina experiences high yields and consumption of sorghum and teff. These households also show high rates of commercialization and income from these crops; however, the duration of their reliance on them varies.
- Sorghum is grown as a staple food security crop, whereas teff is primarily grown as a supplementary and commercial crop.

Representative Voices

"*We no longer skip meals during droughts because we have sorghum."* - FGD, Kiina
"*We always have something to eat, even when other crops fail."* - FGD, Ngaremara
"*Selling flour gives us more than selling grain."* - FGD, Burat

Policy Implications

- Promote dual-purpose crops and small-scale processing of crops into flour to enhance nutritional content and increase household income.
- Encourage the storage of surplus crops, the diversification of crops that are cultivated, and the planting of sorghum and teff at different times of the year to ensure the availability of crops.
- Improve market infrastructure to increase the income of these farming households from the sale of their crops.
- Adopt strategies specific to each ward to increase the impact of interventions, such as utilizing peer-learning strategies in Kiina to scale best practices; promoting strategies to improve sorghum and teff yields and storage capacity in Ngaremara; and promoting strategies that enhance the nutritional content of sorghum and the savings that result from milling sorghum into flour in Burat.

3.7 Feed Security and Crop–Livestock Integration

3.7.1 Scope of Analysis

The implications of climate-smart sorghum and teff cultivation for feed security and livestock productivity within ASAL households are significant. Particular attention is given to the role of crop residues and by-products in livestock feeding systems and in livestock productivity within mixed crop-livestock production systems.

The analysis of these systems is informed by the ASAL Livelihood Resilience Frameworks (Ifejika Speranza et al., 2014; SEI, 2025; AHN, 2026) and the Crop-Livestock Integration Framework for Drylands (ICARDA, 2024). These frameworks clarify the relationships among feed security, agricultural resilience, and integration within ASAL systems. Considering these frameworks helps explain how integration enhances the resilience of livestock and crop systems and contributes to household livelihoods. Furthermore, these frameworks can inform interventions to enhance feed availability, livestock productivity, crop yields, and agricultural sustainability in ASAL regions.

3.7.2 Residue Utilization and Feed Availability

Results

The use of stover is widespread across the region, as the vast majority of farmers use sorghum and teff residues as feed for their livestock (*Annex 6, fig 1*). The use of stover as a fuel source for biogas is prevalent in Ngaremara and Kiina, though it is somewhat more limited in Burat (Figure 34).

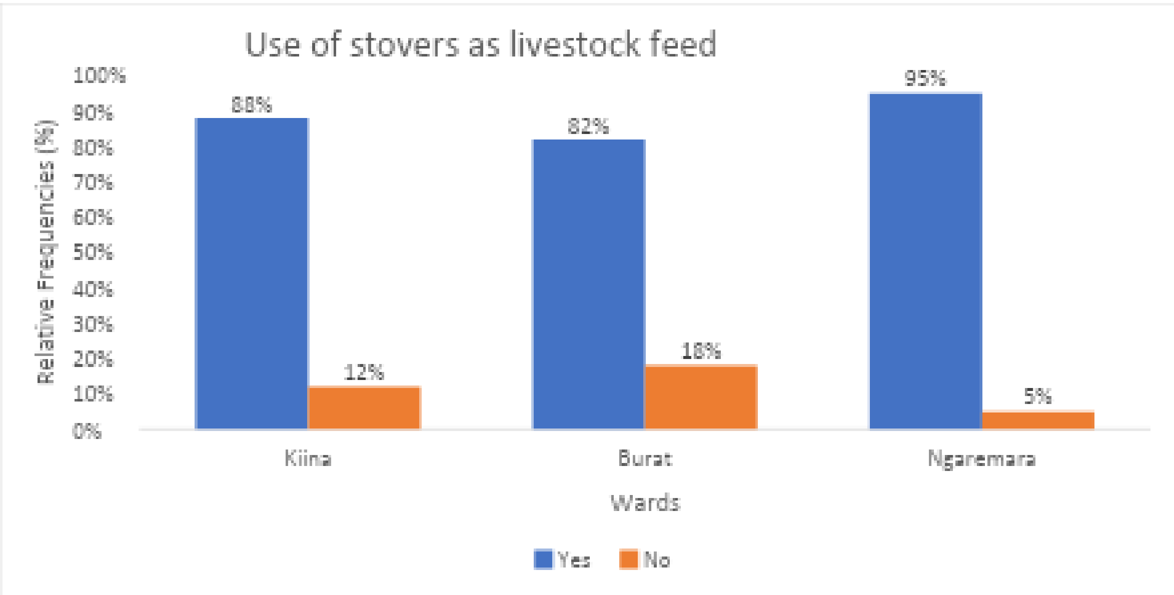


Figure 34: Utilization of Stovers for Livestock Feeding across Wards

Across the different crop types, crop residue use is observed among both sorghum and teff farmers (Figure 35).

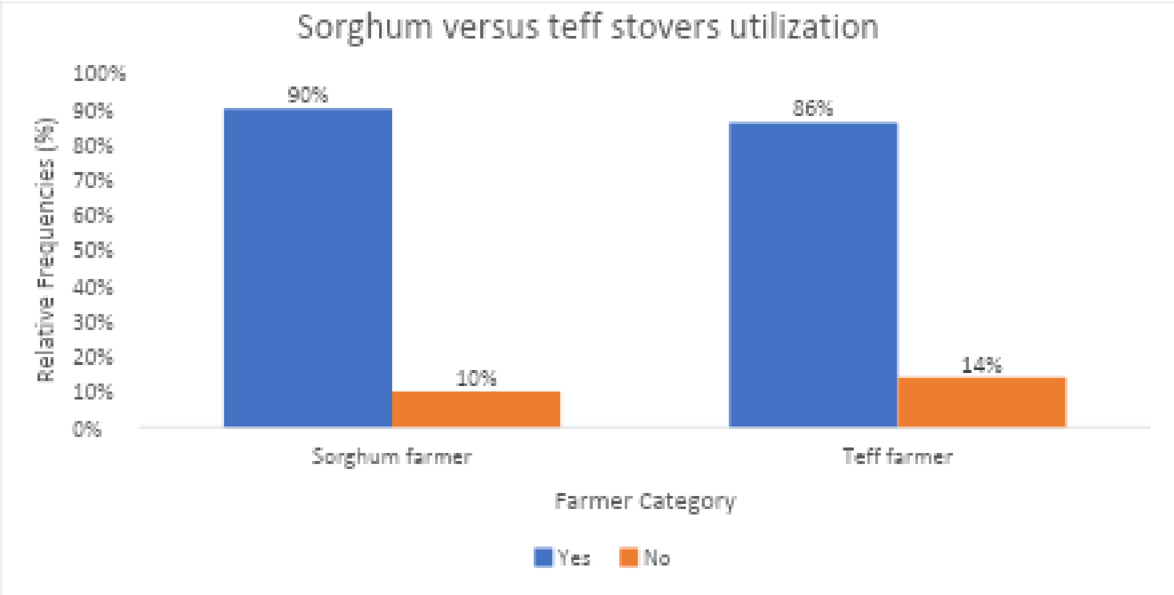


Figure 35: Use of Sorghum versus Teff Stovers for Livestock Feed

Most report some improvement in the availability of livestock feed. The majority report a modest improvement, while a smaller group report a substantial improvement in the availability of feed for their livestock (Figure 36). Fewer report no change in livestock feed availability, while the smallest group report a decline.

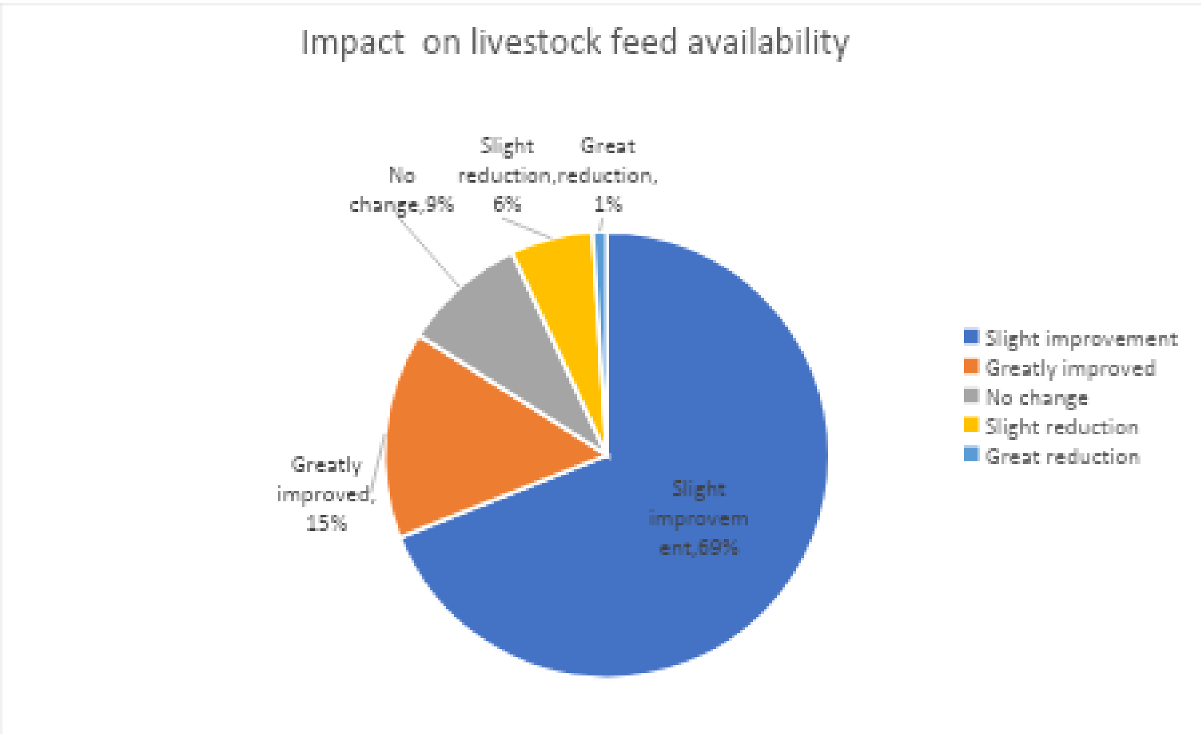


Figure 36: Impact of sorghum and teff cultivation on feed availability

The ward-level analyses indicate that Ngaremara experiences the strongest improvements in feed availability, followed by Burat; Kiina, however, shows more mixed outcomes within the region, as some farmers report declines in available feed (Annex 6, fig 4). These regional differences are reflected in the types of crops traditionally grown in each area. For instance, areas like Ngaremara see improved availability of crops such as sorghum, while other crops, such as teff, show more varied outcomes across regions (Figure 37).

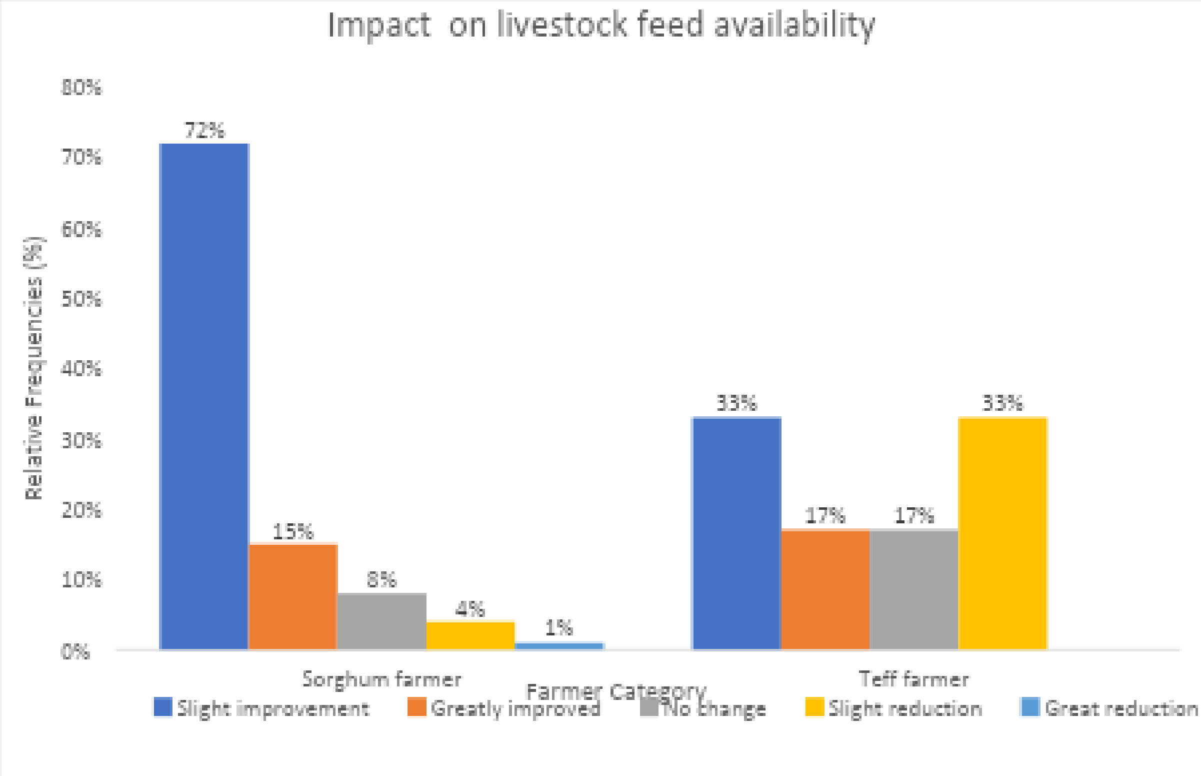


Figure 37: Crop-Specific Impact on Livestock Feed Availability

Figure 38 shows that most households depend on crop residues for up to a few months. A smaller proportion of households use crop residues for medium periods, and only a very small number of households use them for longer periods within the year.

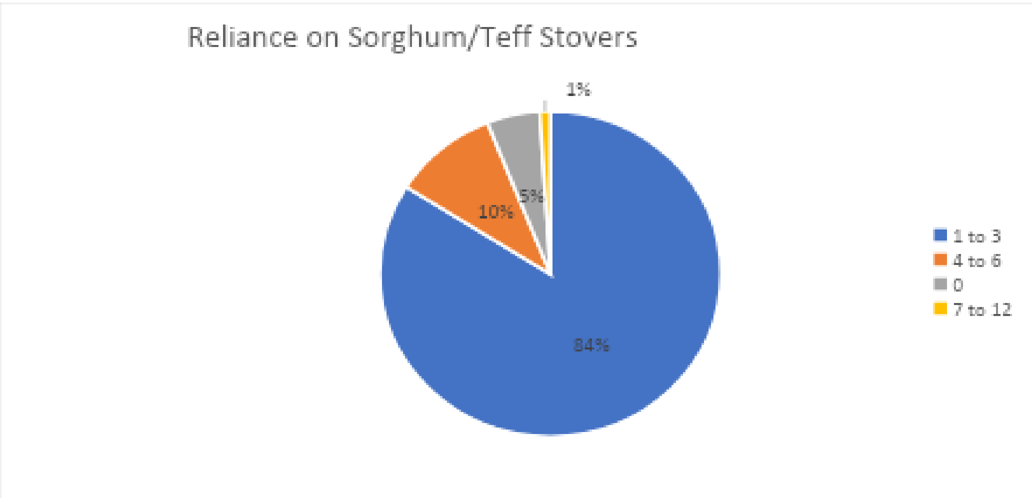


Figure 38: Months of Reliance on Sorghum and Teff Residues for Feed

Ngaremara shows the greatest dependence on crop residues for feed supplementation compared with the other two herds, although Kiina and Burat show periods of longer reliance on crop residues (Annex 6, fig. 2). The finding that crop residues were used only during the dry season in these herds suggests they were used primarily to supplement the herds' feed rather than to replace it entirely.

Discussion

The use of sorghum and teff residues as livestock feed is widely practiced by households within the area. The integration of these dual-purpose crops into farmers' agricultural systems increases the availability of livestock feed during periods of feed scarcity (Akplo et al., 2023). Thus, the biomass produced by these crops helps livestock avoid feed shortages during these periods. Within each ward, the benefits from these crops as livestock feed are not consistent across areas. Areas that show improvements from using these feed sources experience greater availability of livestock feed, whereas those that show mixed results experience similar variations within their herds.

For each of these crops, outcomes are inconsistent. Herds that utilize sorghum residues see improved availability of livestock feed, whereas those that utilize teff residues see either improved or reduced availability. Thus, each of these crops contributes differently to the availability of livestock feed, as explained by differences in biomass yield, the amount of biomass that can be stored, and the efficiency with which it can be utilized (Sarkar et al., 2020).

The time livestock use these crop residues is relatively short. Most herds that utilize these residues experience the benefits of this type of feed only during short periods within the dry season, after which reliance on these feed sources declines. Overall, the majority of herds experience improvements in the availability of livestock feed as a result of using these crop residues; a smaller number experience more substantial improvements, but none experience declines in livestock feed availability. Thus, the use of residues from both sorghum and teff increases the availability of livestock feed, but only during periods when those livestock utilize them.

3.7.3 Feed Stability and Perceived Feed Security

Results

After adopting sorghum and teff, most households experience feed shortages for their livestock only once a year. Some households experience feed shortages more frequently, but still within the moderate range. Fewer households experience feed shortages at high rates, and the majority reported no feed shortages (Figure 39).

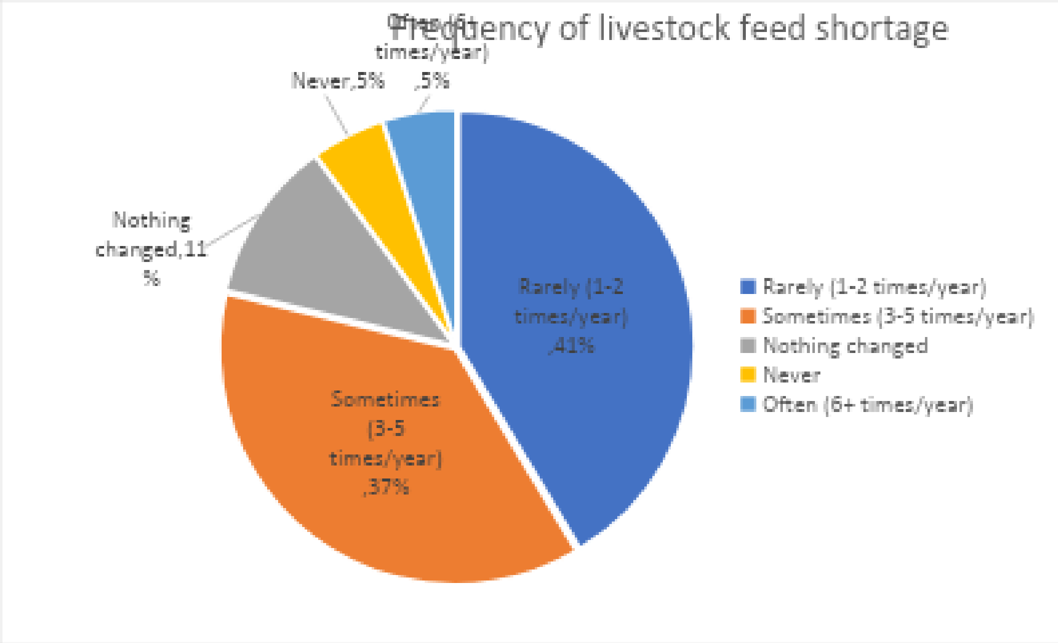


Figure 39: Frequency of Feed Shortages after the Introduction of Sorghum and Teff Farming

There are differences across the three wards regarding livestock feed shortages. In Kiina, for instance, most households report that feed shortages occur only occasionally in their areas and that they have not occurred more frequently. In Burat, however, a greater number of households experience feed shortages in their areas each year, though fewer of those households experience them more frequently. In Ngaremara, most households within the ward experience feed shortages in their areas each year, though a smaller proportion of households report that the shortages in their areas are rare (Figure 40).

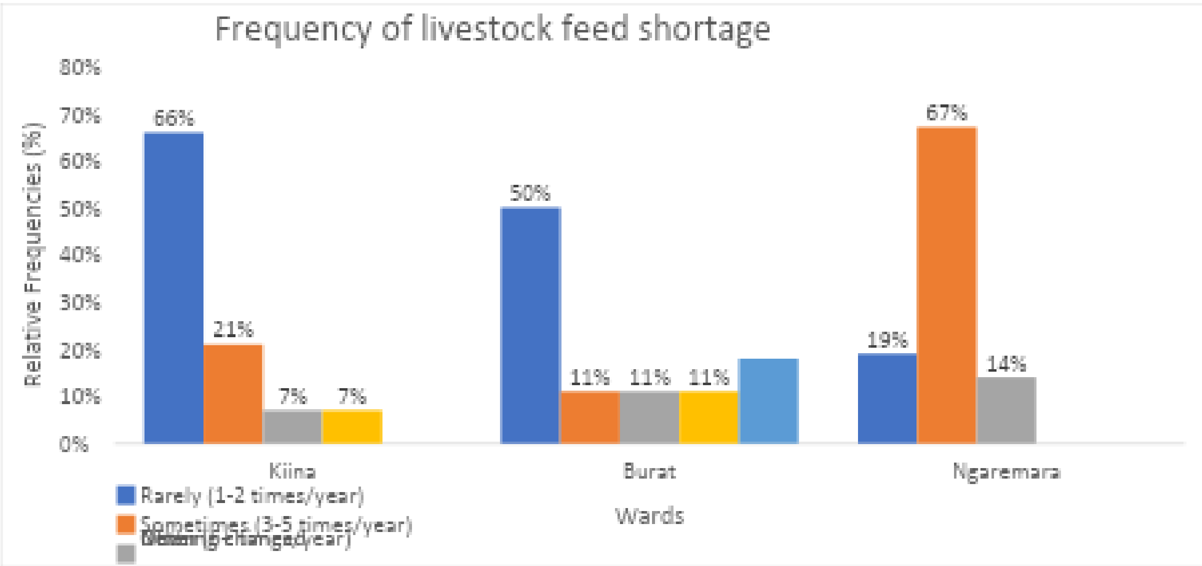


Figure 40: Frequency of Livestock Feed Shortages by Ward Following Sorghum and Teff Cultivation

In addition to survey data on the program's effect on feed costs, farmers' perceptions of feed security also indicate a positive effect of the program. In general, most households surveyed reported moderate feed security for their livestock, with fewer reporting high confidence in feed availability. Furthermore, most responding households indicated that their feed security has improved over time (Figure 41).

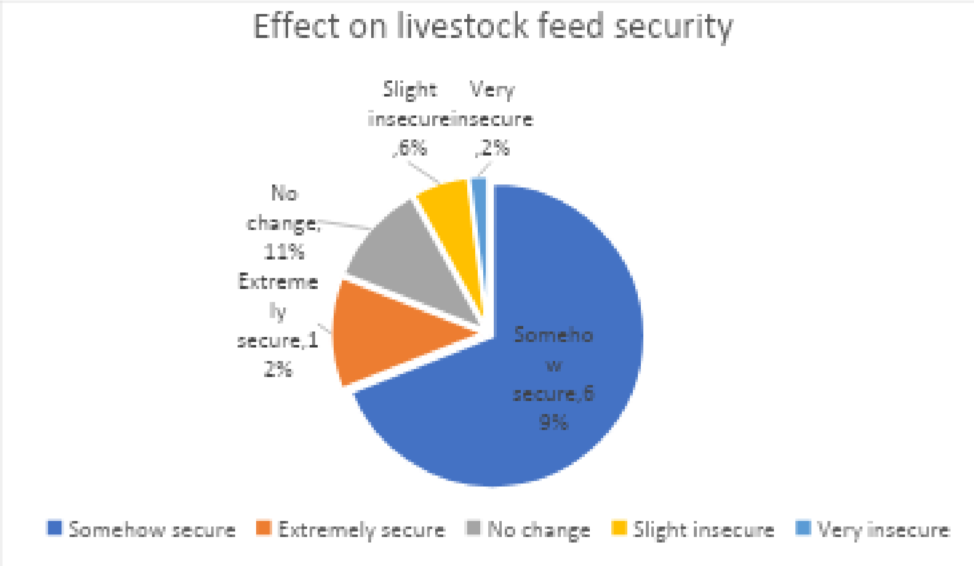


Figure 41: Effect of sorghum/teff cultivation on feed security

Ngaremara has the strongest perception of feed security, while Kiina has a comparatively larger proportion of households that are confident in the availability of feed within the region (Annex 6, fig 6). Furthermore, differences in the types of crops grown within each of these areas indicate that those who farm primarily teff have a greater perception of feed security than those who grow other crops, such as sorghum (Figure 42).

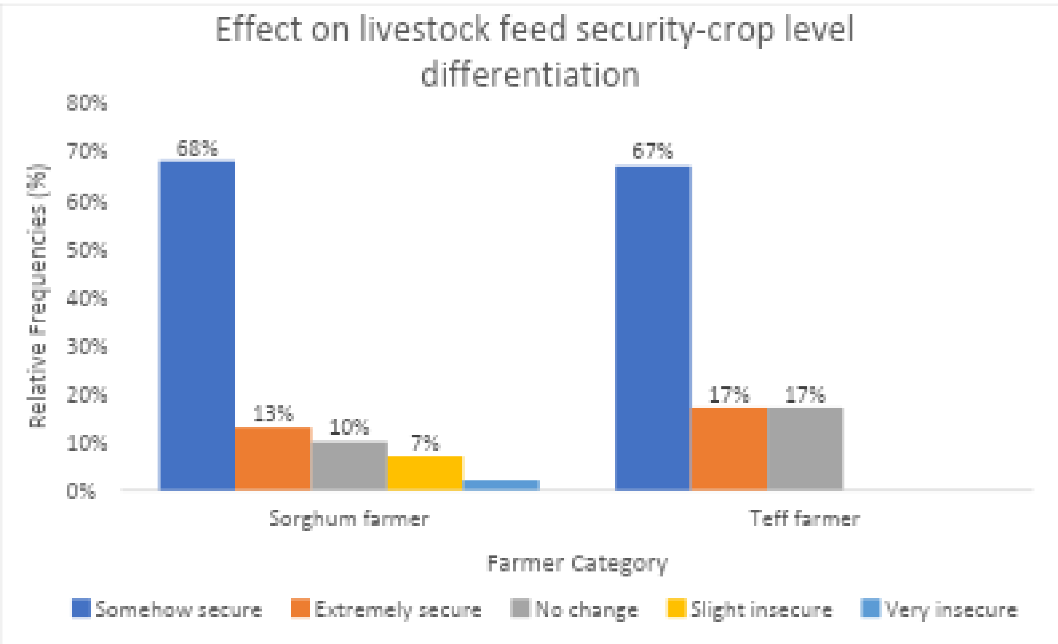


Figure 42: Crop-Specific Effects on Feed Security

Discussion

The findings indicate a shift toward greater stability in livestock feed availability following the introduction of sorghum and teff. Most households experience feed shortages only occasionally throughout the year, while fewer experience them more frequently, and very few experience none at all. These findings are similar to those of Duguma and Janssens (2021), indicating a general reduction in feed shortages within households' production systems. Within the wards, some areas exhibited greater stability in feed availability than others. Areas like Kiina and Burat experienced more stable conditions with fewer feed shortages. Ngaremara, however, experienced feed shortages more intermittently.

Overall, most households reported moderate availability of livestock feed, while some indicated high availability. Only a limited number of respondents reported experiencing feed insecurity for their livestock. Ngaremara exhibited the most stable response to general feed availability, while Kiina had the highest proportion of respondents who were confident in the availability of feed for their livestock. In relation to the crops grown, those who farmed teff reported more stable conditions in feed availability for their livestock, while those who farmed sorghum reported feed availability issues, though fewer individuals indicated the presence of such problems than those who farmed teff.

The reduction in livestock feed shortages and increased confidence in feed availability indicate that integrating these crops with livestock has contributed to greater stability in feed availability. However, the intermittent occurrence of livestock feed shortages indicates that seasonal constraints on feed availability persist and remain a challenge for livestock farmers in Ngaremara.

3.7.4 Livestock Dynamics and Grazing Dependence

Results

The livestock owned is mainly small ruminants, especially goats, followed by sheep. Additionally, poultry is extensively raised, but cattle are kept much less widely (Figure 43).

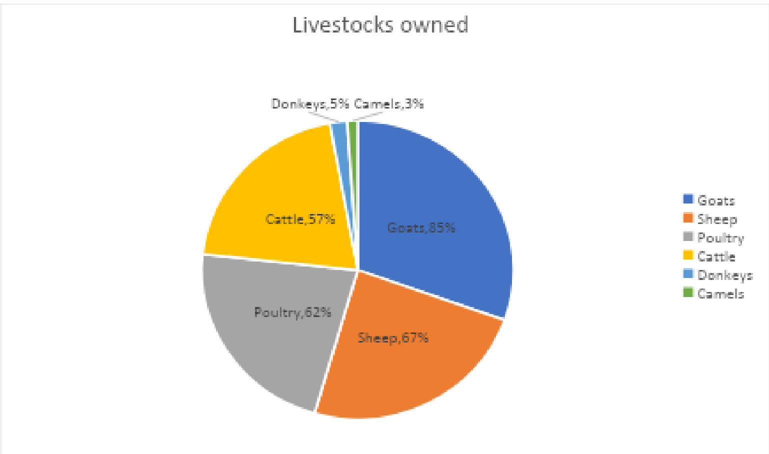


Figure 43: Livestock owned by households farming sorghum/teff

Figure 44 indicates that Burat and Ngaremara raise small ruminants, while Kiina maintains a more diversified portfolio that includes cattle and working animals.

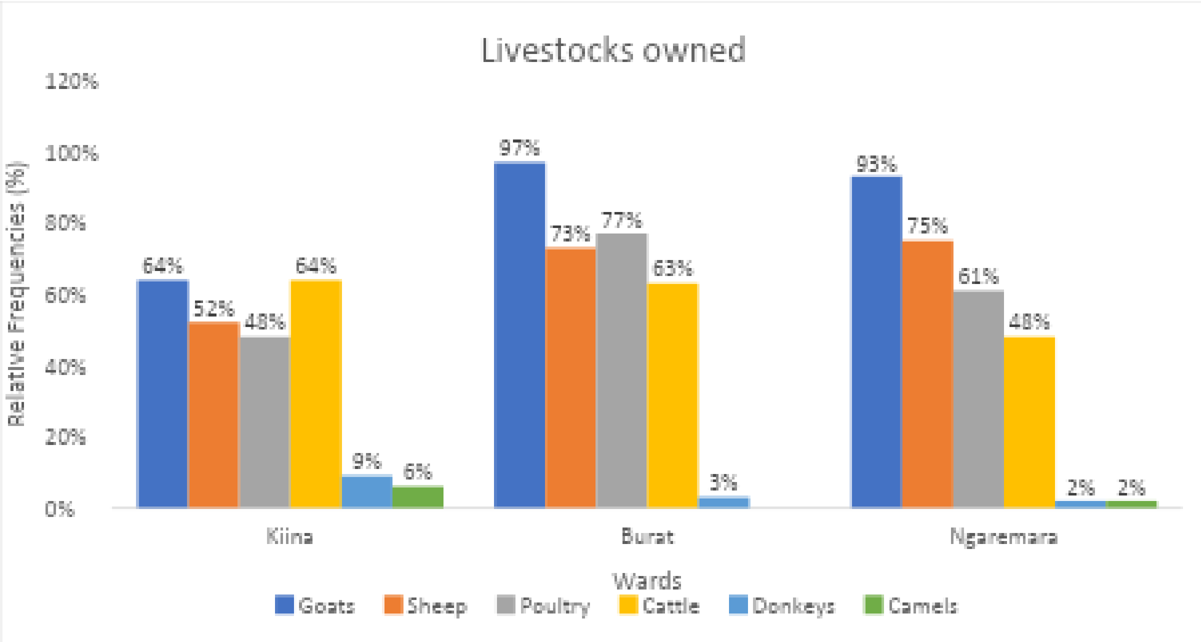


Figure 44: Variation in Household Livestock Ownership Among Sorghum and Teff Farmers Across Wards

The increased availability of fodder has generally been associated with higher household livestock numbers. Most households have seen herd sizes increase due to improved fodder availability for their livestock. The majority of villages experienced an increase in household livestock numbers, with Ngaremara recording the largest increase, followed by Burat. In Kiina, however, some households reported a decrease in the number of livestock they owned (Figure 45).

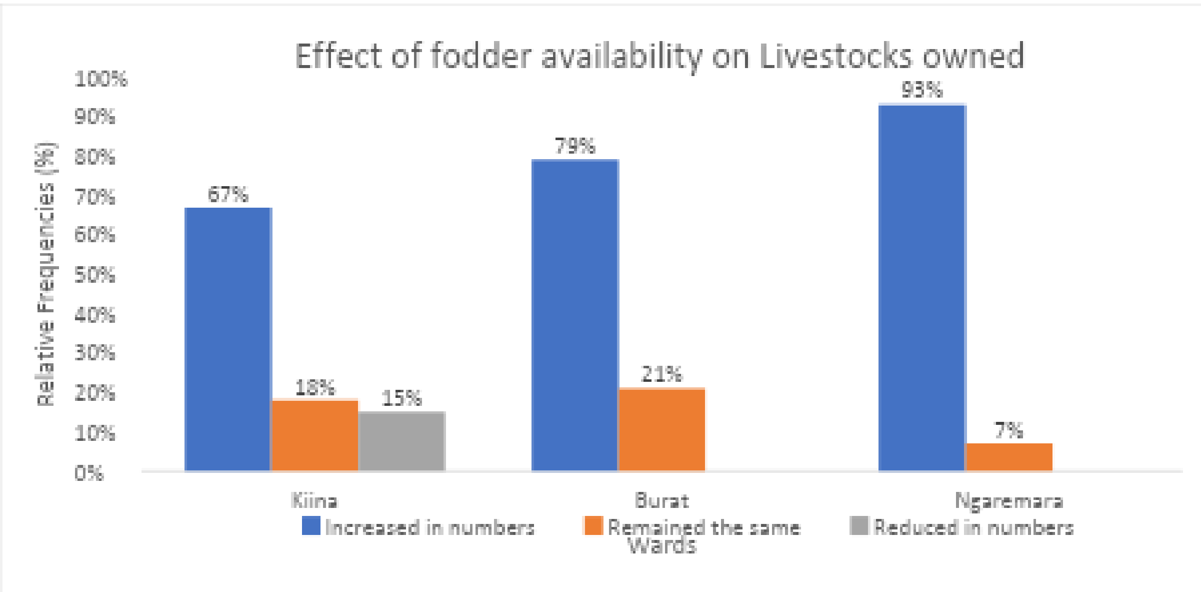


Figure 45: Effect of fodder availability on livestock owned by specific wards

The level of dependence on livestock production varies across the study area. Some households have experienced a decline in their dependence on livestock for their livelihoods. Others, however, indicated that their dependence on livestock production within their household livelihood strategies has increased (Figure 46). These contrasting findings indicate that while some households are gradually moving away from livestock-based livelihood strategies, many others still rely on livestock to meet household needs.

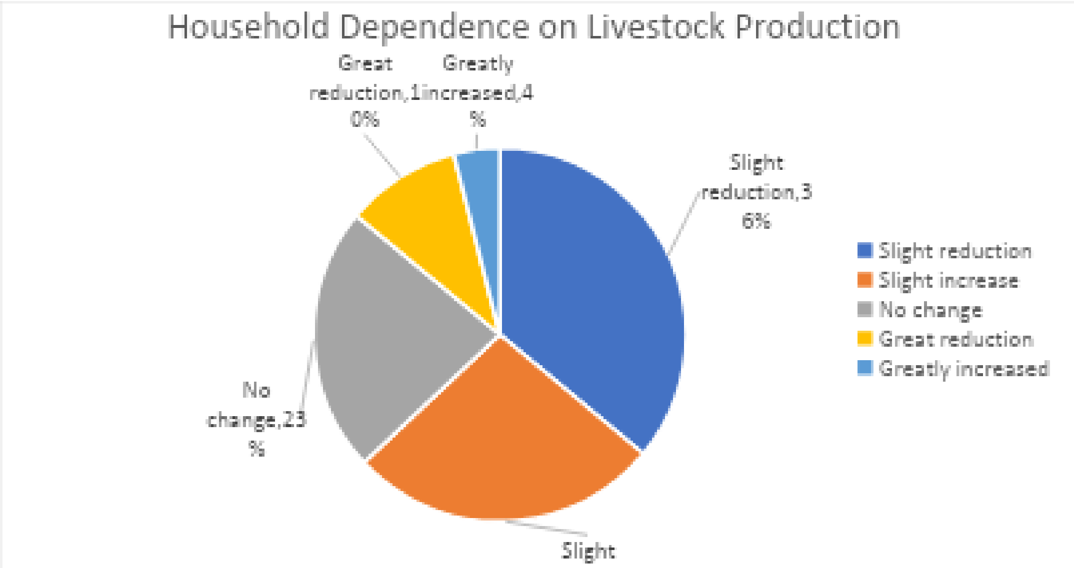


Figure 46: Changes in Household Dependence on Livestock Production as a Livelihood Source following adoption of sorghum/teff cultivation

The patterns within each ward also show some differences. In Ngaremara, most households reported a slight reduction in their reliance on livestock. In Burat, however, a considerable number of households reported increasing their reliance on livestock (Figure 47). Thus, livestock dependence is decreasing in one ward but increasing in another.

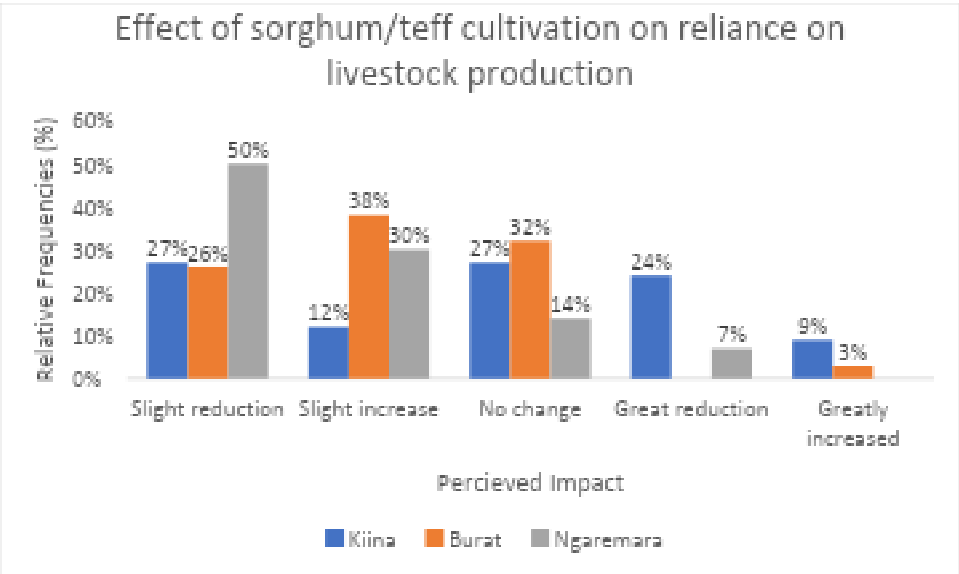


Figure 47: Effect of sorghum/teff cultivation on household reliance on livestock production

Reliance on grazing land varies notably across the wards. In Kiina ward, most individuals have reduced their reliance on grazing areas. Burat ward, however, has a considerable number of households that have increased their reliance on grazing land. In Ngaremara ward, households have either decreased or increased their reliance on grazing land (Figure 48). Thus, there are differences in the transitions of grazing land use across the wards.

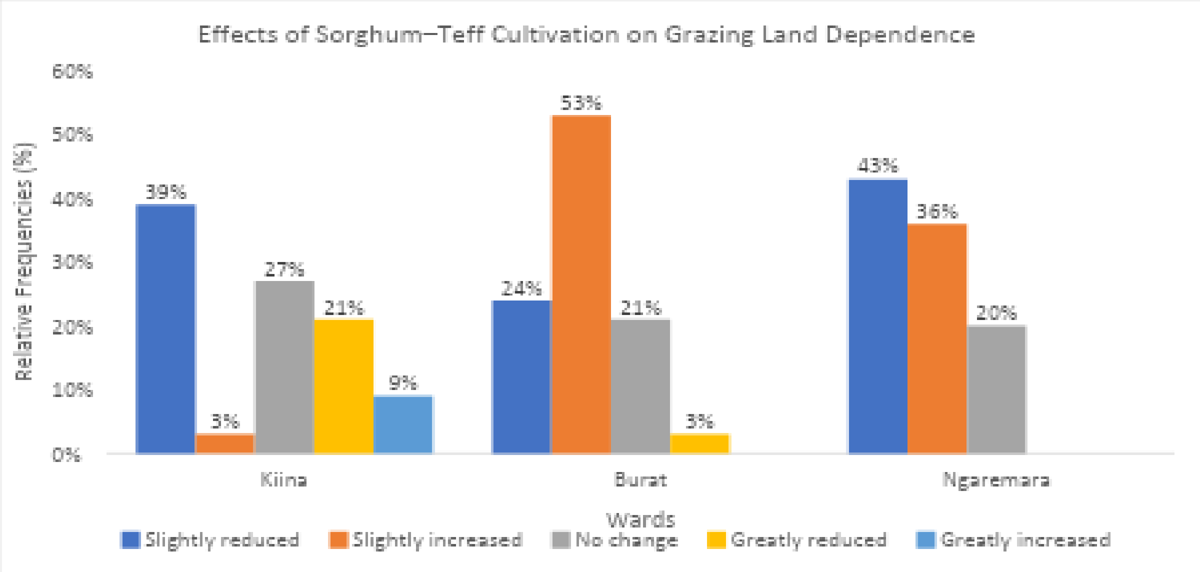


Figure 48: Effects of Sorghum–Teff Cultivation on Grazing Land Dependence

Discussion

The results suggest that livestock diversity in the study area is undergoing transformation, though not uniformly. The types of livestock kept by households in the area are shifting toward more climate-resilient species as the region's climate and resources become less favorable to traditional livestock. Thus, livestock systems in the area are evolving toward fewer, higher-maintenance species.

Changes in livestock types and fodder-related outcomes reported by Amole (2016) indicate that livestock systems have improved with greater fodder availability. Fodder availability has led to increased livestock performance in many households. However, there has been no increase in the number of livestock species within the herds, indicating that fodder improvements alone are insufficient to increase livestock numbers in the area.

Another indication of changes in livestock systems within the study area is that herds are being used differently by farmers. Some farmers are increasing their dependence on livestock as an essential component of their livelihoods, while others are decreasing their reliance on livestock within their herds (Mayanja et al., 2022). This behavior indicates that while the species kept by farmers are changing, the importance they place on livestock varies.

In addition, changes to grazing lands within the area are another indication of the incomplete transformation of the livestock feed systems in the area. Improvements to livestock feed systems reduce some farmers' reliance on grazing lands, but increase the grazing requirements of other farmers in the same area. Thus, changes to the livestock feed system are creating counteractive effects on the use of grazing lands by different groups of farmers within the area.

Overall, these results suggest that the livestock species in the area are undergoing a transition toward more climate-resilient breeds, but this transition is not yet complete. Although there have been improvements in livestock feed management, the herds have not undergone corresponding changes in land-use management practices. Thus, while livestock herds have become more efficient, a common model of livestock production has yet to emerge.

3.7.5 Thematic Box5: Feed Security Outcomes of Sorghum and Teff Cultivation

Key Insights (FGD & KII)

Climate-smart sorghum and teff contribute to livestock production by providing crop residues that can supplement feed during dry seasons in ASAL agroecosystems.

Residues are used as dry-season livestock feed, improving livestock productivity and health and reducing the dependency of livestock herds on grazing lands.

Ward-specific findings reveal that:

Ngaremara: Crop residues are valued by livestock herd members and are critical to their survival during dry seasons.

Burat: There is an integration of crops and livestock, whereby farmers budget for and allocate feed to livestock.

Kiina: Reduced dependence on grazing lands due to the use of crop residues to supplement livestock feed; however, farmers note the labor burden of processing and feeding these residues.

Sorghum crop residues are used as livestock feed, while teff crop residues provide supplementary feed for livestock.

Representative Voices

“Animals survived droughts that would have killed them before.” - FGD, Kiina

“*Residues improve livestock productivity and reduce reliance on pasture grazing*.” - KII, Farmer Leader

Policy Implications

- Introduce dual-purpose crops such as sorghum and teff that are climate-smart and provide livestock feed.
- Facilitate training on conservation of crop residues, treating residues as feed, and livestock feed budgeting.
- Construct fodder storage facilities and introduce small mechanization tools to support livestock feed processing.
- Encourage the integration of livestock and crops. Implement strategies tailored to each ward’s livestock challenges, including storage and rationing of crop residues in Ngaremara, feed budgeting for livestock using sorghum and teff residues in Burat, and the introduction of labor-saving tools for managing teff and sorghum crop residues in Kiina.

3.8 Environmental and Climate Effects of Sorghum and Teff Cultivation

3.8.1ScopeofAnalysis

Integrating climate-smart practices into the cultivation of sorghum and teff has significant implications for environmental sustainability within these wards. The impact of integrating these crops into the agricultural systems of these wards will be discussed, focusing on their effects on soil conditions, water-use efficiency, climate resilience, and farmers' perceptions of the environment.

The Agroecological Systems Framework by Altieri (1995) examines how ecological sustainability can be achieved within agricultural systems through crop diversity and soil conservation practices. Furthermore, the DPSIR Framework (Driver, Pressure, State, Impact, and Response; 1999) examines the relationships among management practices for ecosystems, biodiversity, environmental change, and climate resilience. Each of these frameworks will be used to understand how the adoption of climate-smart agricultural practices can lead to more sustainable resource management within these wards.

3.8.2 Water Access and Water-Use Efficiency

Results

The availability of water resources is another critical factor that affects the climate resilience of the agricultural systems established within these households. Some agricultural systems within these regions are entirely dependent upon rainfed agriculture to grow the crops that are sold for income by those farming households; others rely upon irrigation to fulfill the same purpose; and yet others utilize both irrigation and rainfed agriculture to grow their crops (Figure 49).

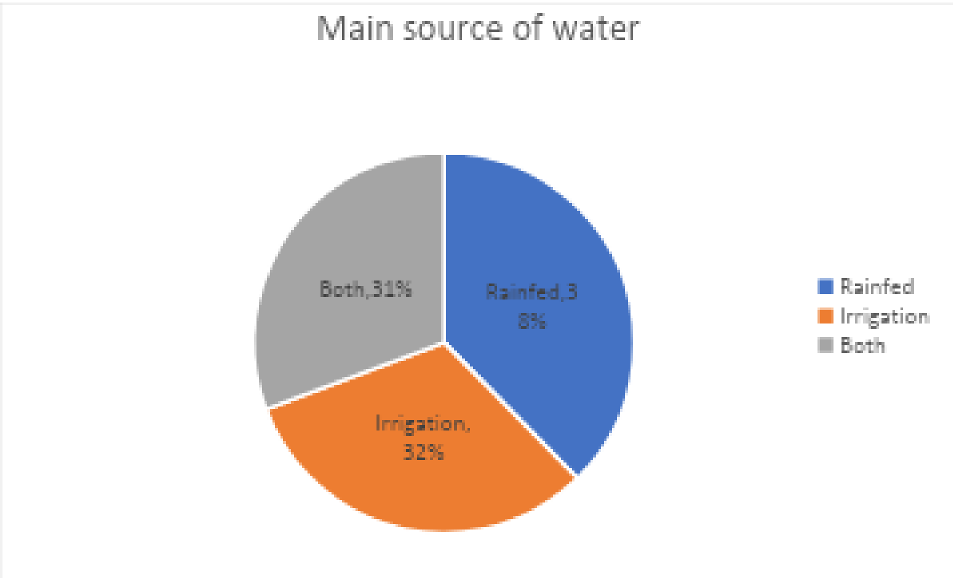


Figure 49: Main source of water for sorghum/teff cultivation

However, there are also notable differences in spatial patterns. For instance, while all areas within the study have some form of irrigation system or method of providing water to agricultural lands, there are differences in the extent to which those irrigation systems are utilized. For example, areas like Kiina have irrigation systems in place, whereas areas like Burat and Ngaremara are entirely dependent on rain-fed agriculture (Figure 50).

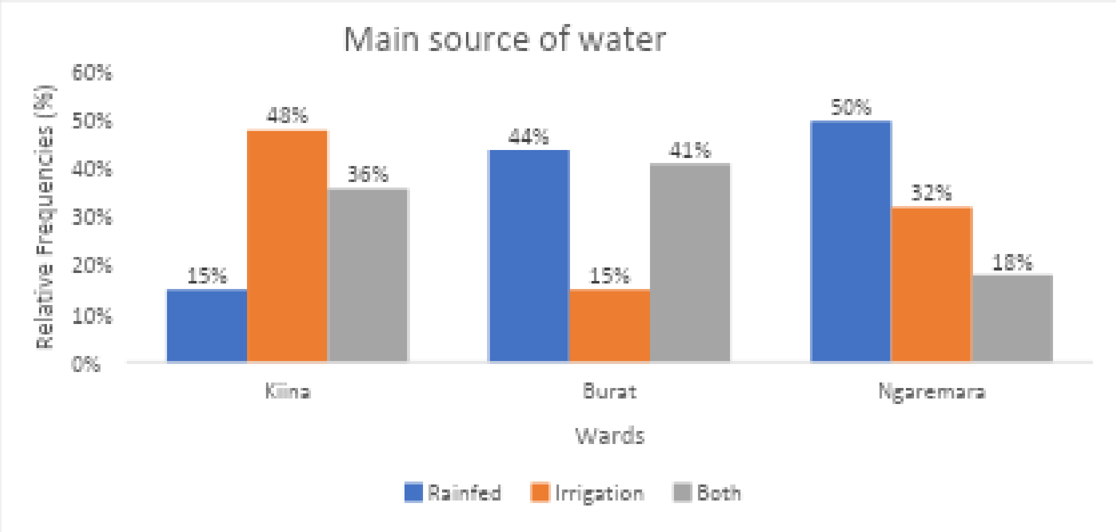


Figure 50: Ward-Level Differences in Main Water Sources for Sorghum and Teff Cultivation

Crop-level differences are also evident. For instance, sorghum farmers appear to rely primarily on rainfed agriculture, whereas teff farmers more often use irrigation in conjunction with rainfall (Figure 51).

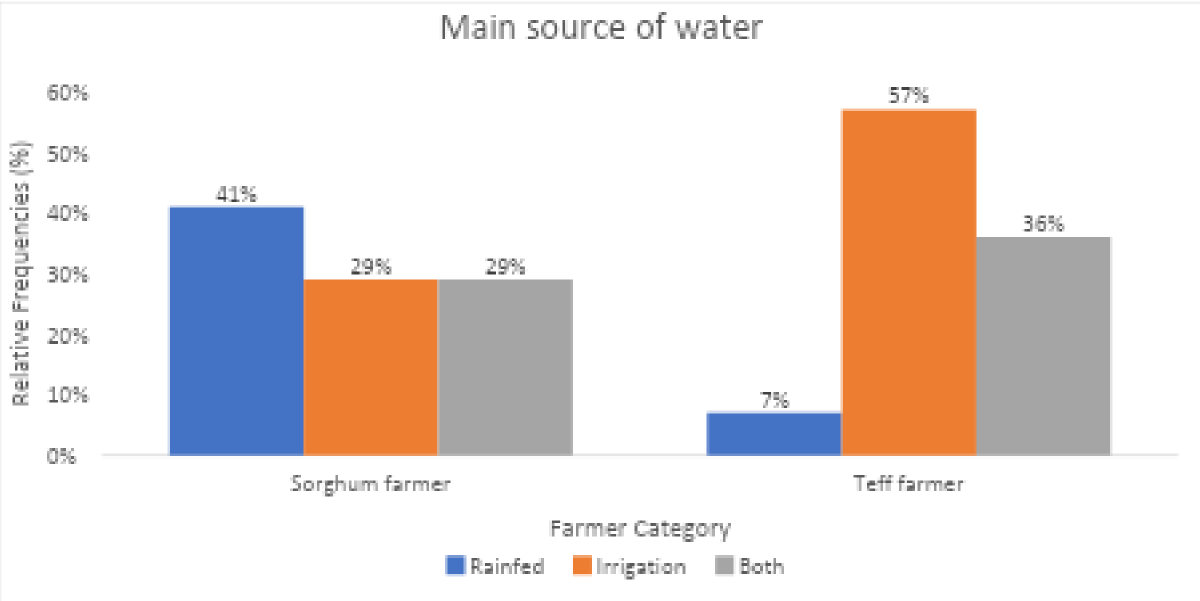


Figure 51: Primary Water Sources for Sorghum and Teff Production

Despite these differences, there is no significant efficiency gain from using these climate-smart crops. Most farmers reported no change in water use, though some reported slight improvements (Figure 52).

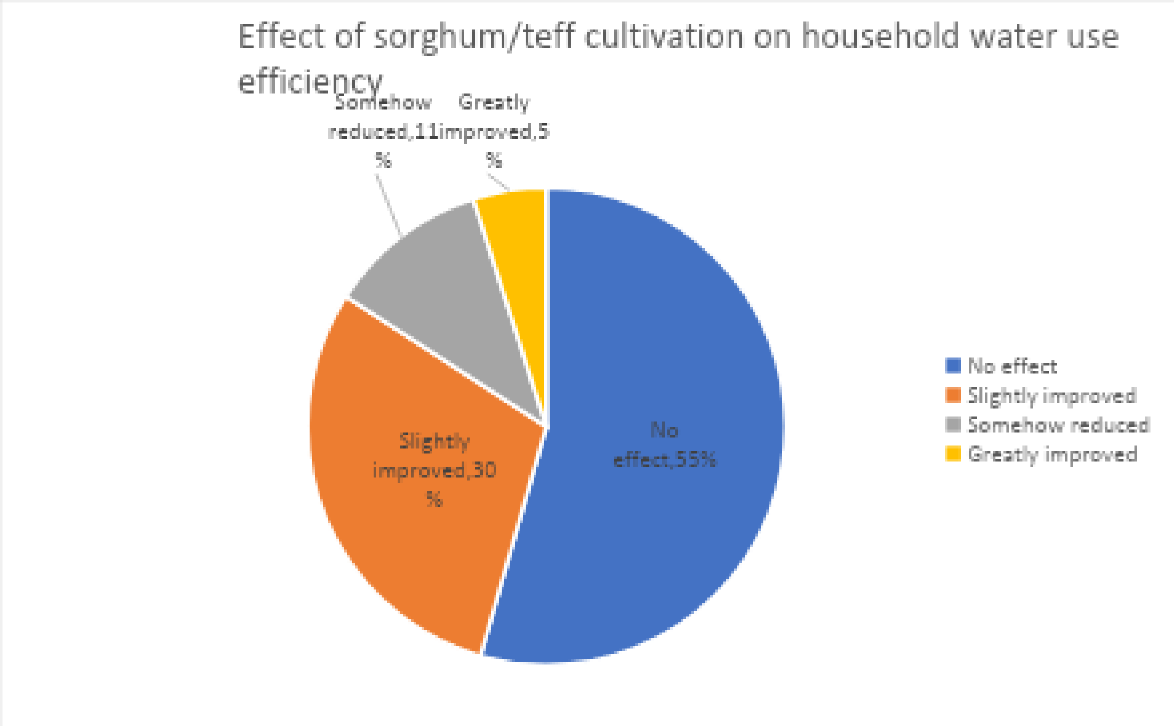


Figure 52: Effect of sorghum/teff cultivation on household water use efficiency

Discussion

The availability of water within the region is thought to be the main factor determining the climate resilience of the agricultural systems; households tend to employ rainfed agriculture, irrigation, or both. However, the type of agricultural system established within each region varies; some regions within the area have a higher rate of irrigation systems on their farms than others, which are mostly rainfed. Additionally, some crop types in the area use irrigation systems or combined rainfed and irrigated systems more than others.

However, an assessment of water-use efficiency in the area reveals that the introduction of climate-smart crops has been limited to improving the water efficiency of the region's agricultural systems. Most farmers in the area report little to no change in their region's water efficiency following the introduction of climate-smart crops (Alharbi et al., 2024). These findings align with the principles of Ecosystem-Based Adaptation (EbA) for agriculture, which suggest that the climate resilience of agricultural systems within an area is best supported by integrating those ecosystems into the systems (regardless of the type of agriculture practiced in the region).

These findings are further supported by qualitative data collected from farmers in the region (Thematic box 6). Focus group discussions indicated that constructing structures to harvest water within the region, mulching areas on the farms, and building irrigation infrastructure were more likely to increase the efficiency with which water was used on the farms than introducing climate-smart crops. Additionally, interviews with key informants, such as extension officers, revealed that the best agricultural outcomes in the region are achieved by combining climate-smart crops with on-farm water management strategies, in line with findings from Sikka et al. (2018). Thus, these findings support integrating both agricultural and ecosystem-based management practices to increase the climate resilience of the agricultural systems in the study area.

3.8.3 Climate Shock Exposure and Crop Loss

Results

Climate change remains a significant threat to food security. Across all wards, a majority of farmers experienced crop losses due to climate change (Figure 53).

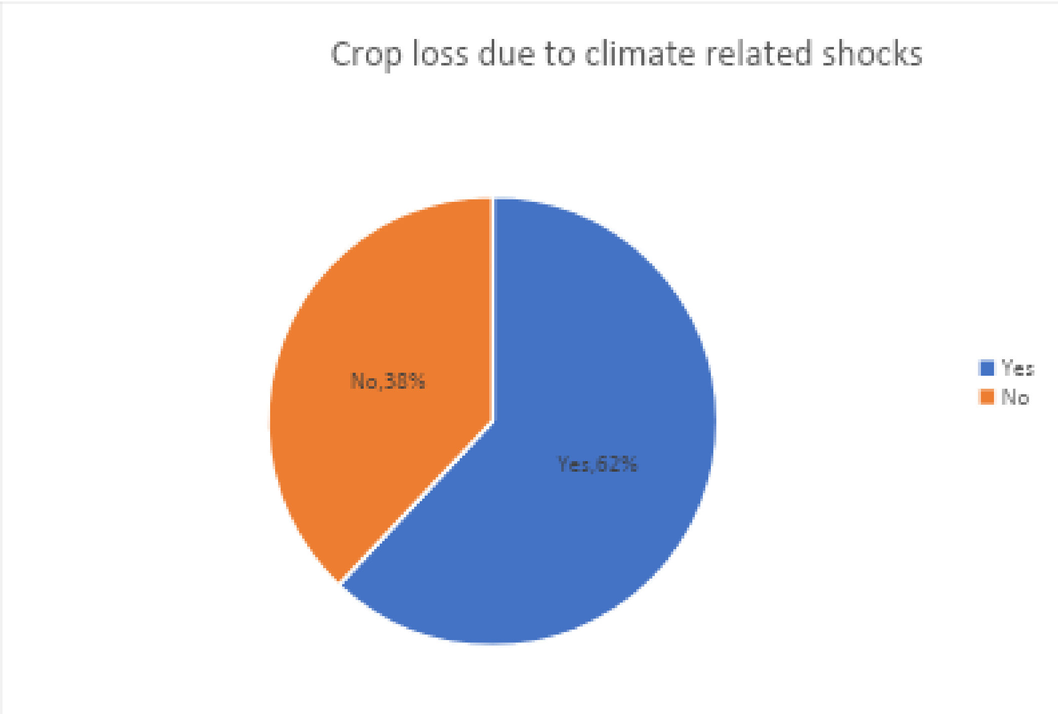


Figure 53: Crop loss due to climate-related shocks

The distribution of these impacts is shown in Figure 54. Burat was the ward most affected by the study's outcomes, with nearly all farmers there reporting losses due to the issue. Ngaremara and Kiina also experienced significant losses among their farmers, though not to the same extent as Burat (Figure 54).

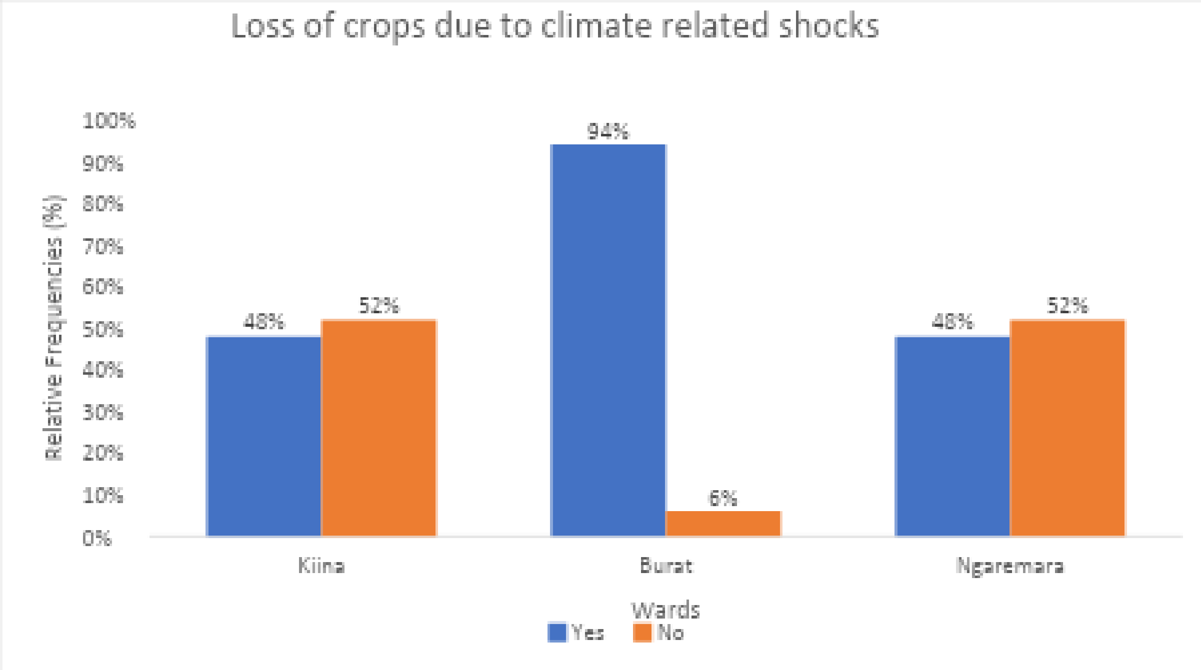


Figure 54: Ward-Level Differences in Crop Losses Due to Climate-Related Shocks

Furthermore, at the crop level, farmers who cultivated sorghum experienced greater crop losses than those who cultivated teff (Figure 55). Thus, these results indicate that teff farmers fared better in the environment in which they farmed.

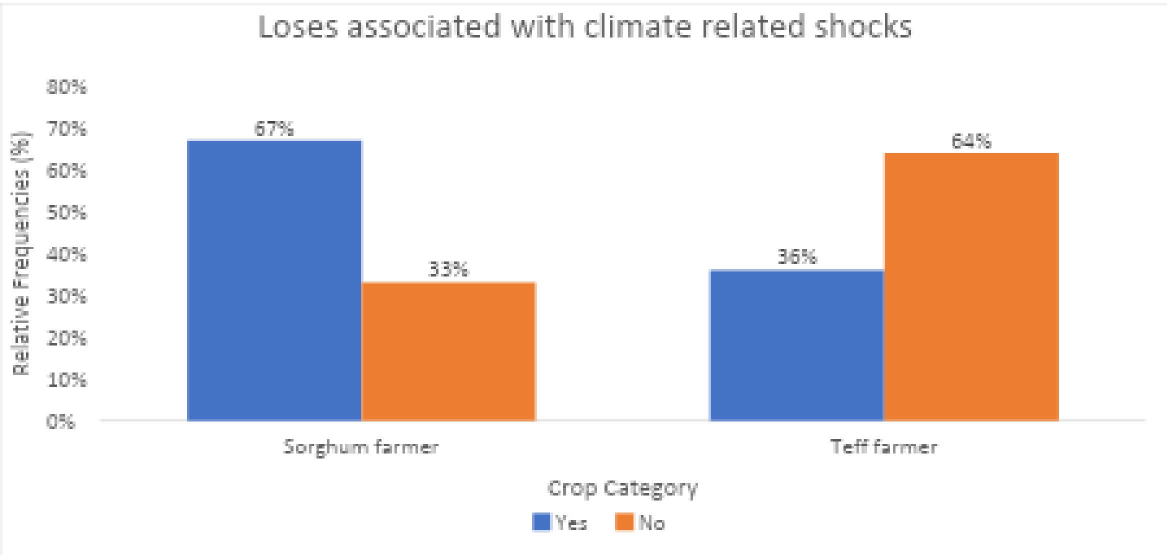


Figure 55: Crop-Level Losses in Sorghum and Teff Farming Associated with Climate Shocks

The distribution of crop area lost to climate shocks shows that most farmers experience little loss; a smaller proportion experiences higher losses, particularly among those who produce teff. Most of the distribution of crop area loss is concentrated in the lower categories, with fewer farmers experiencing severe losses. However, the mean and standard deviation for the area of crops lost reveal moderate variability in the amount of crop area lost by farmers in the area (mean = 0.50 acres, standard deviation = 0.501 acres; Figure 56). Thus, most farmers experience similar losses of crop area, but there are differences among farmers in the extent of their losses.

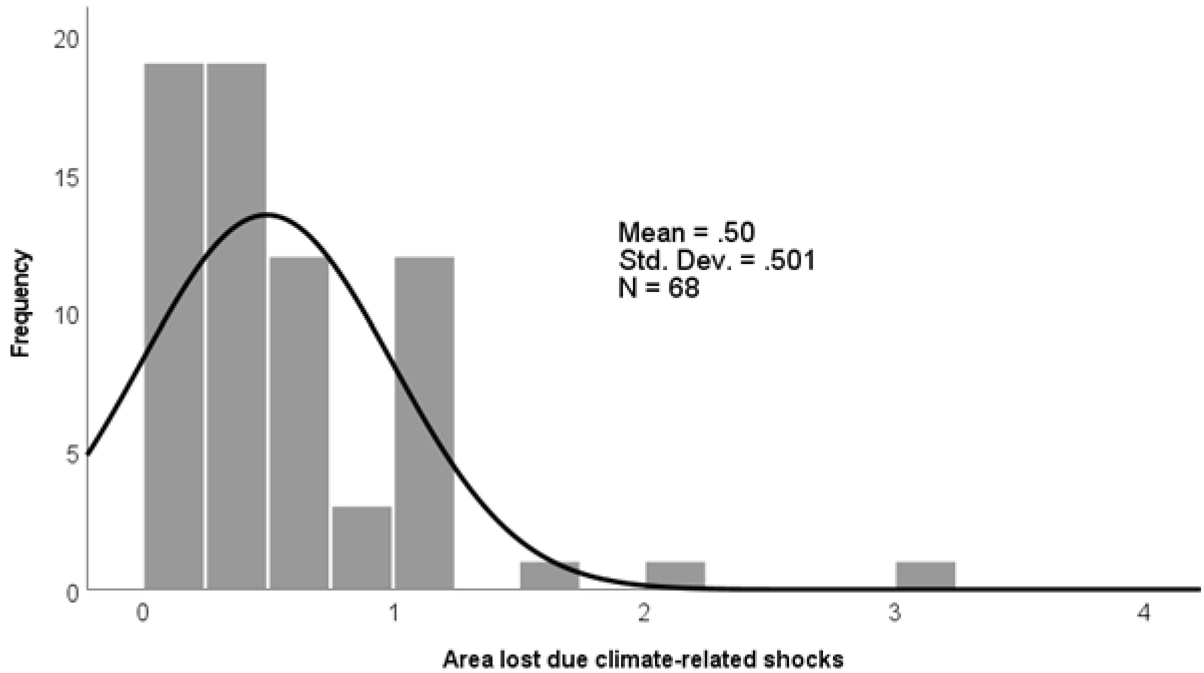


Figure 56: Distribution of area loss due to climate-related shocks

Farmers in the area are experiencing several climate-related shocks that affect their ability to produce agricultural goods. The types of climate shocks the farmers are encountering include drought, heat, flooding, and crop diseases. Furthermore, the climate shocks appear to have a spatial component to their impacts; Burat is experiencing drought and heat more frequently than the other regions, Ngaremara is experiencing flooding more frequently, and Kiina is experiencing crop diseases more frequently (Figure 57).

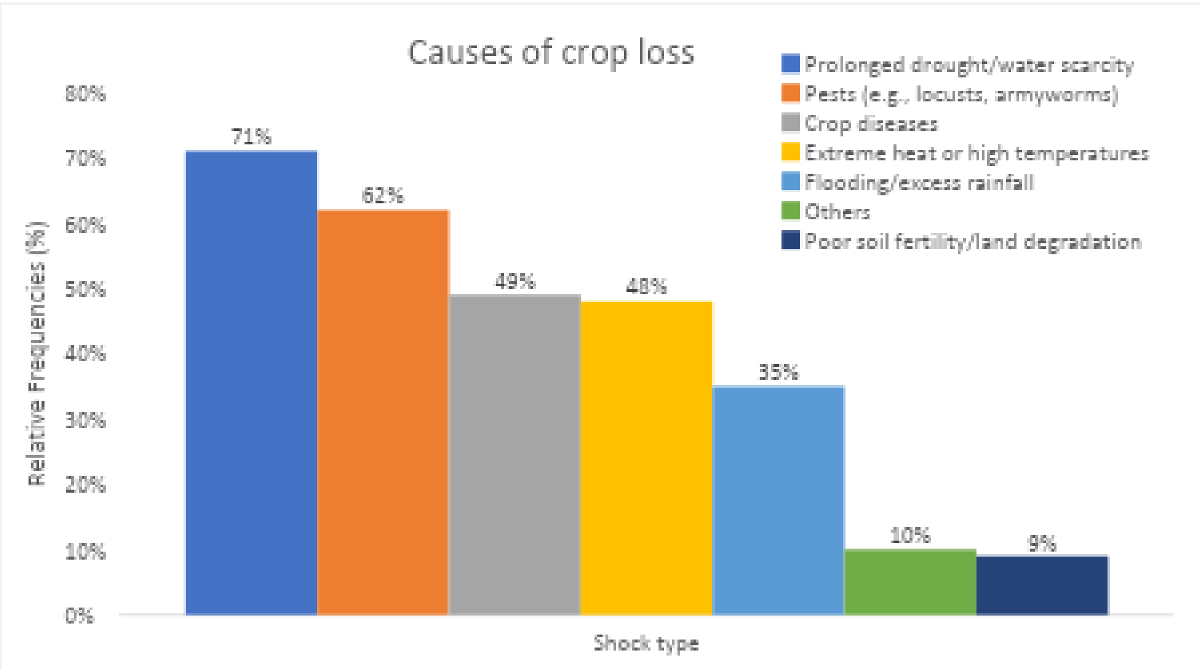


Figure 57: Major causes of sorghum/teff crop losses

Discussion

The study's findings indicate that smallholder farmers are exposed to a range of climate shocks that affect their agricultural production. These shocks include drought, crop pests and diseases, extreme temperatures, and flooding in some farming areas. Smallholder farmers in the study area are exposed to all of these climate shocks simultaneously, and many interact to destabilize agricultural production.

Further, smallholder farmers are exposed to these climate shocks across different spatial areas within the study area. Some smallholder farming areas within the study wards are more affected by drought, heat stress, and pests and diseases in their crops, while other areas are more affected by flooding and other climate-related production shocks. These spatial differences in the impact of climate shocks have the potential to affect the level of agricultural production in each area (Zhang et al., 2025).

Most smallholder farmers in the area identified that most climate shocks affecting their agricultural production are interconnected and interact with one another. For instance, smallholder farmers report that drought-affected areas experience higher pest and disease levels in their crops. This finding is also supported by observations from agricultural officers working on these farms, who report both increasing rainfall variability in the area and an increasing prevalence of pests in crops produced by smallholder farmers.

These findings support the idea that climate shocks interact on smallholder farms and that managing these risks requires an approach that integrates their various impacts (Naylor et al., 2020).

3.8.4 Environmental Pressures and Ecosystem Change

Results

The environmental pressures affecting each ward differ. Half of the farmers in the area experience soil erosion; Ngaremara has the highest number of affected farmers, while Kiina and Burat have the fewest (Figure 58).

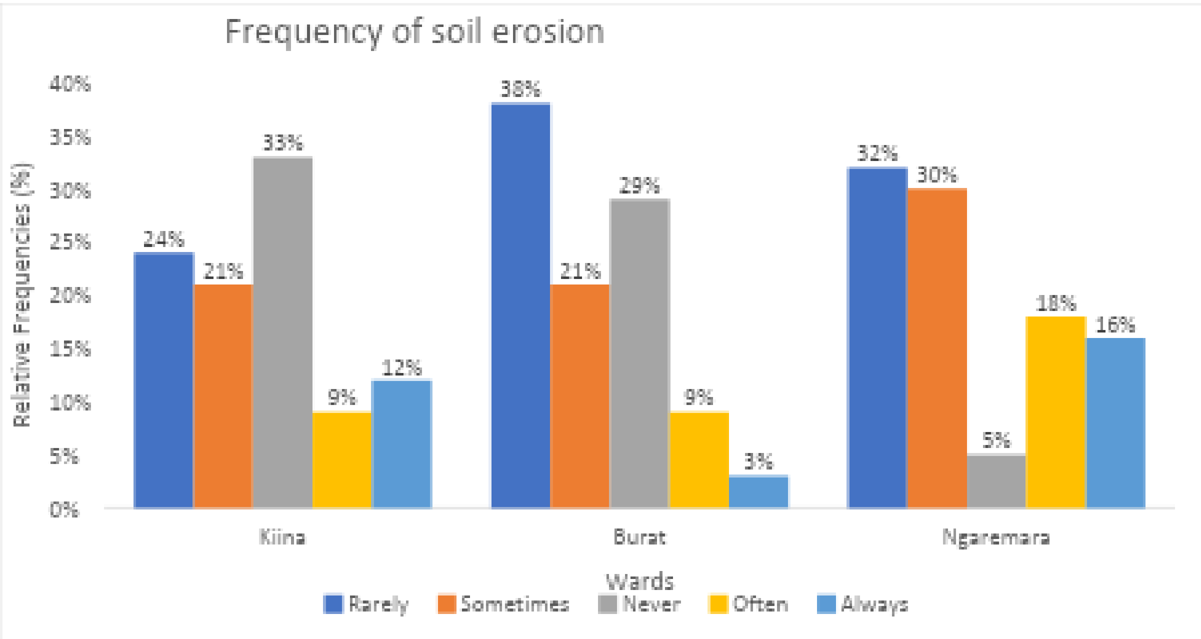


Figure 58: Frequency of soil erosion on sorghum/teff cultivated areas

Vegetation and water resource stress also vary spatially. Ngaremara shows pronounced vegetation depletion, with many farmers reporting a decline in vegetation cover, whereas Kiina shows more stable vegetation cover, with most farmers reporting minimal or limited decline (Figure 59).

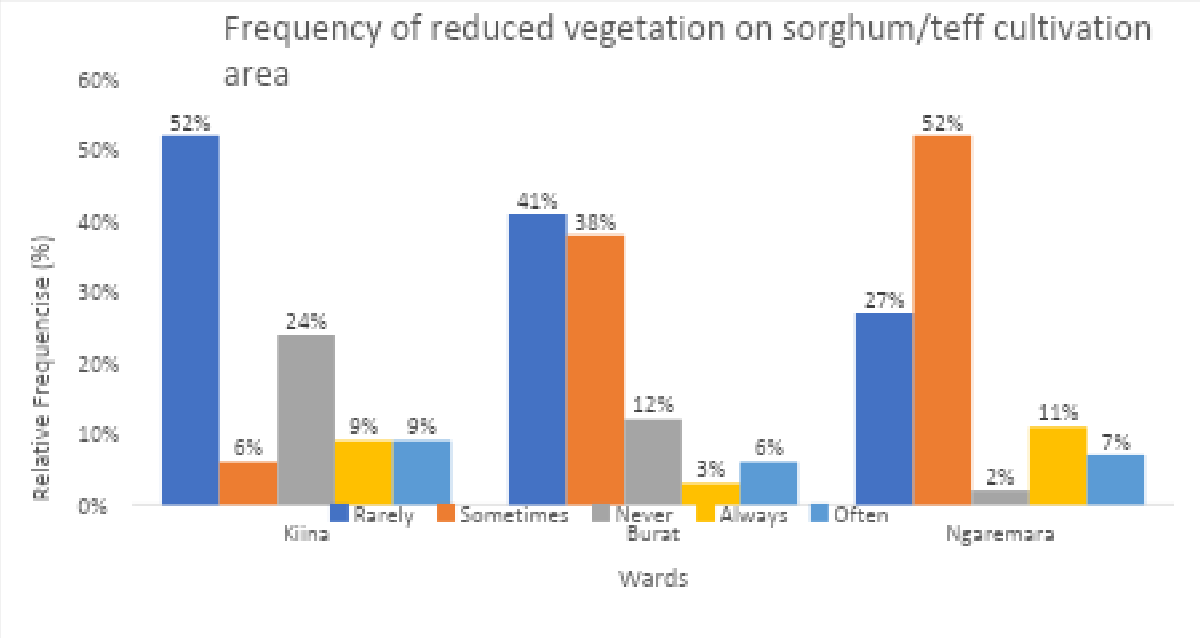


Figure 59: Frequency of Vegetation Decline in Sorghum and Teff Cultivation Areas

Burat ward experiences the greatest depletion of its water sources, whereas Kiina and Ngaremara experience much less depletion (Figure 60).

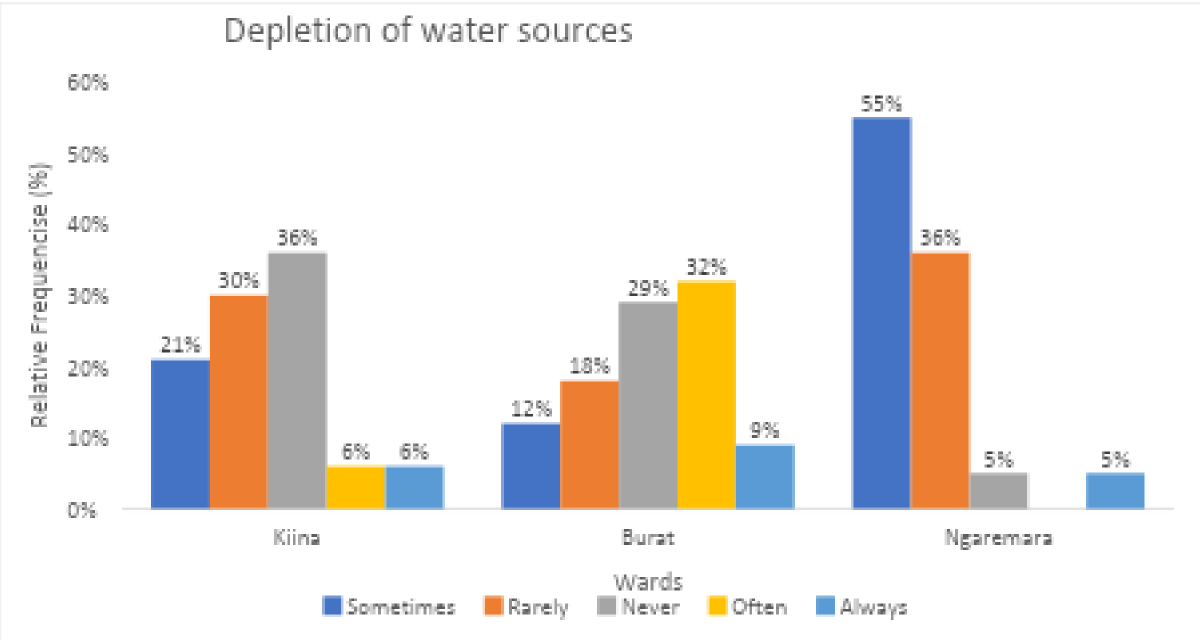


Figure 60: Frequency of Water Source Depletion in Sorghum and Teff Cultivation Areas

However, one of the major environmental concerns associated with the data is the change in land use for the implementation of climate-smart crops. The majority of surveyed farmers reported clearing land of its natural vegetation to plant these crops (Figure 61). The majority of these land-use changes occurred in Burat and Ngaremara (Figure 62).

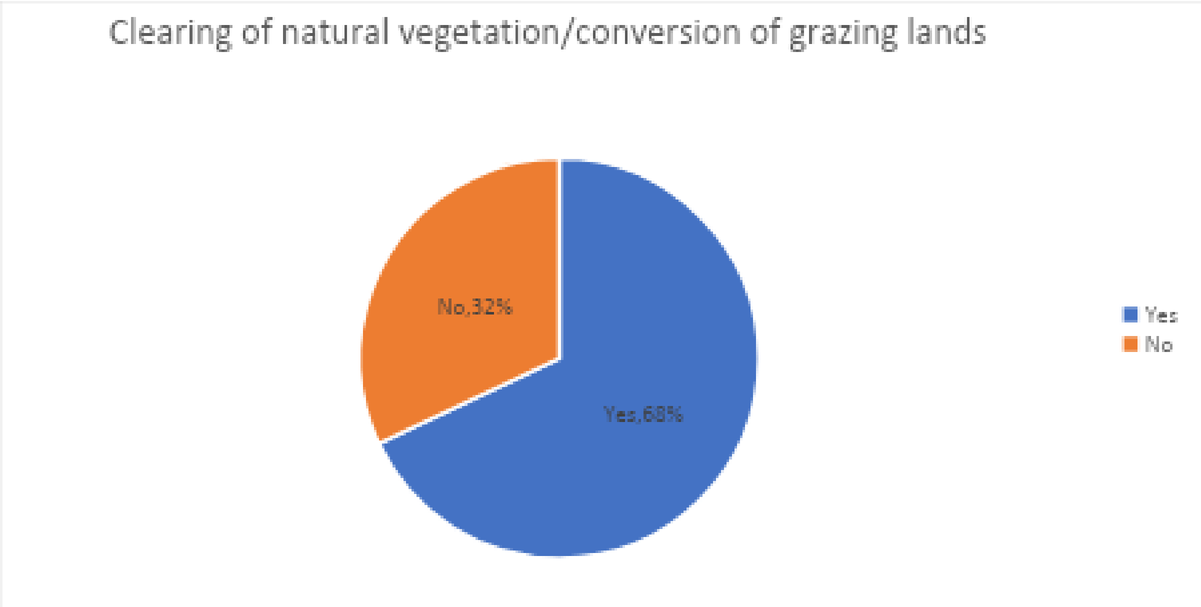


Figure 61: Conversion of natural/grazing lands to sorghum/teff cultivation areas

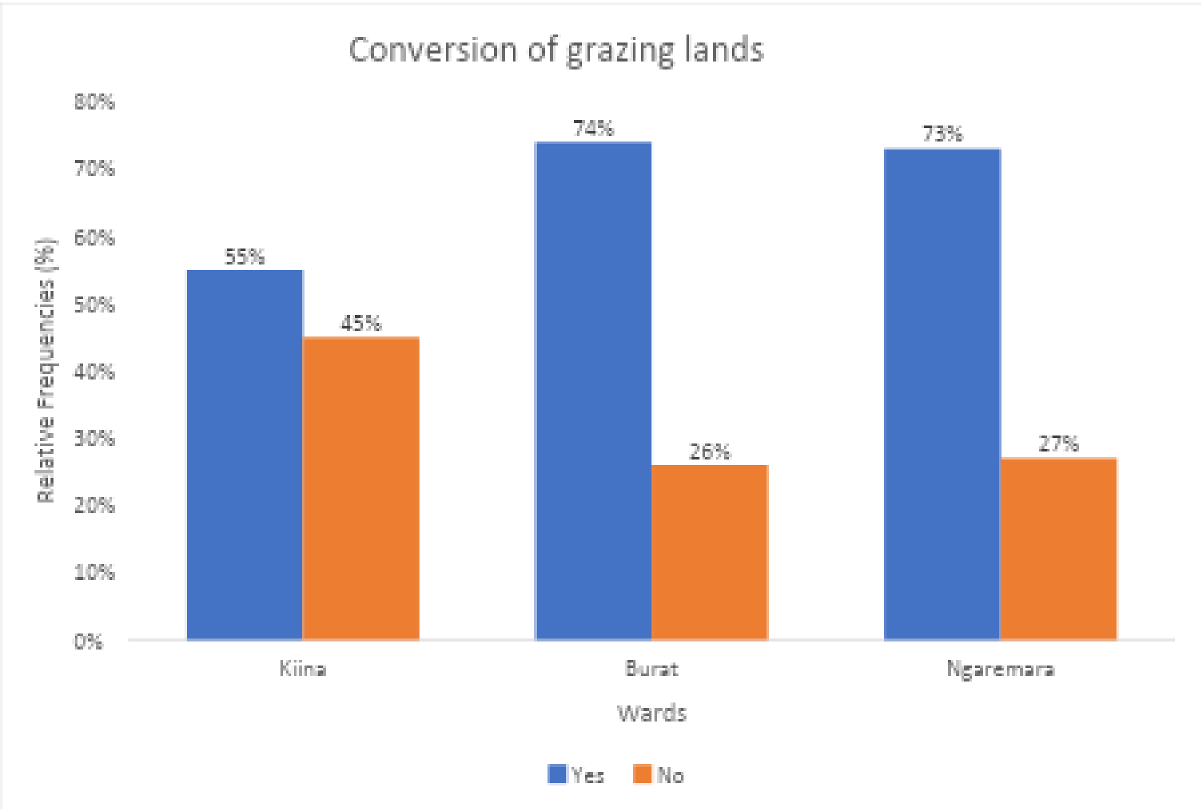


Figure 62: Ward-Level Conversion of Natural and Grazing Lands into Sorghum and Teff Cultivation Areas

Discussion

The impact of environmental pressures on agricultural systems within the ward varies considerably. Soil erosion affects a large number of farmers in the study, with Ngaremara experiencing the highest number, followed by Kiina and Burat, which have fewer affected farmers. Additionally, vegetation and water resource stress impact Ngaremara the most, with Ngaremara experiencing the highest levels of vegetation depletion, Kiina experiencing the most stable vegetation levels, and Burat experiencing the highest levels of water depletion. Finally, the rate of land conversion is high in Burat and Ngaremara, suggesting that these two wards are experiencing increasing environmental stress on their land systems.

The impact of climate change on agricultural systems is dynamic (Mir et al., 2025). Climate change and agricultural systems interact, indicating a relationship between them. Furthermore, these findings reflect the trade-offs occurring within these agricultural systems, as reported by Thomson et al., 2019, because the increased need for climate-resilient crops comes at the cost of environmental stress on the land systems of these farms.

The findings of these assessments of environmental pressures on agricultural systems within each ward align with the Agroecological Systems Framework, highlighting the relationship between agriculture and the ecosystems in which those farms operate. The requirement to cultivate climate-resilient crops puts pressure on the land systems of those farms.

Furthermore, qualitative information supports these findings. Farmers in these areas have noted converting grazing land to cropland to mitigate environmental stress on grazing animals. Additionally, agricultural officers note that while the inclusion of climate-resilient crops has increased the stability of agricultural production in these areas, the conversion of land to grow these crops without regulation is depleting vegetation systems. To ensure the sustainability of these agricultural systems, land management and ecosystem protection strategies should be implemented.

3.8.5 Adoption and Effectiveness of Climate-Smart Practices

Results

Climate-smart agricultural practices are widely adopted in the study wards. Agroforestry and soil conservation practices are commonly adopted by farmers in the study wards to conserve biodiversity and maintain soil stability (Figure 63). However, adoption of fodder storage is relatively low, indicating a lack of awareness of its environmental benefits.

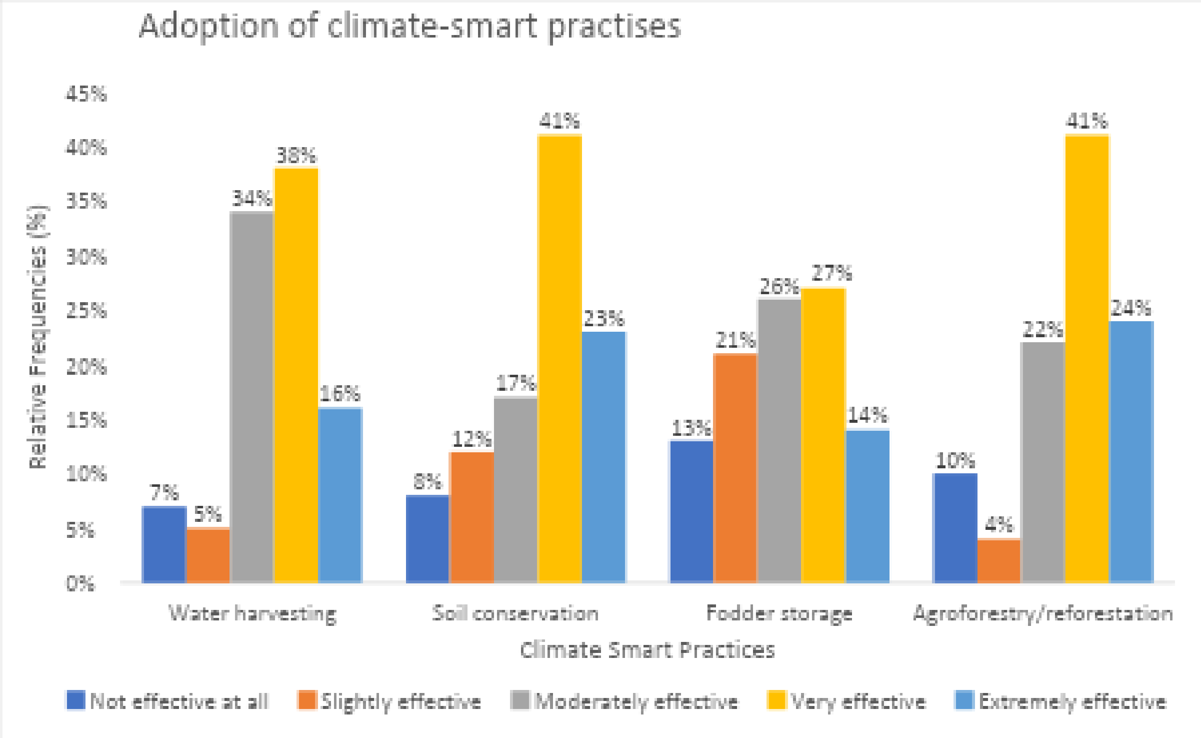


Figure 63: Adoption of climate-smart practices alongside sorghum/teff cultivation

Other practices exhibit ward-specific patterns. Water harvesting is considered beneficial for reducing land degradation, but its effectiveness varies by location. While Burat has the highest percentage of farmers who indicated that the practice is effective, Kiina has the highest percentage who indicated that it is highly effective (Figure 64).

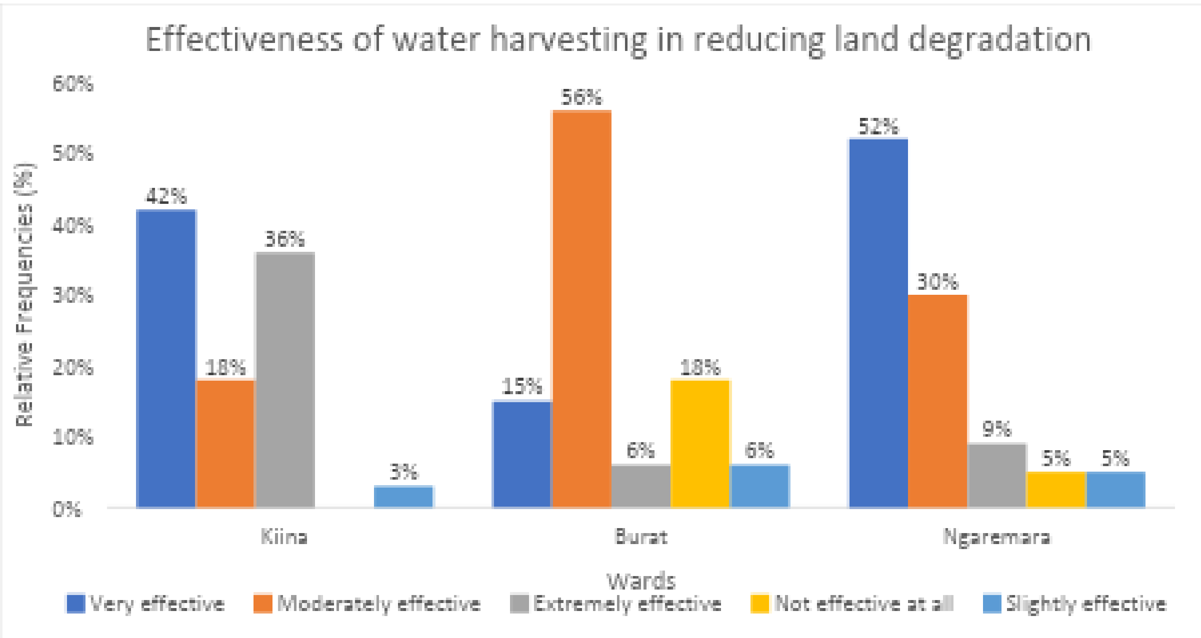


Figure 64: Ward-Level Effectiveness of Water Harvesting in Reducing Land Degradation

The role of fodder use in reducing land degradation is perceived as the most effective in Kiina, given the benefits reported by farmers, whereas Burat farmers report mixed responses. Farmers in Ngaremara rate it as moderately effective (Figure 65). Overall, however, these responses make it clear that Kiina farmers use fodder more effectively than farmers in the other wards in the area.

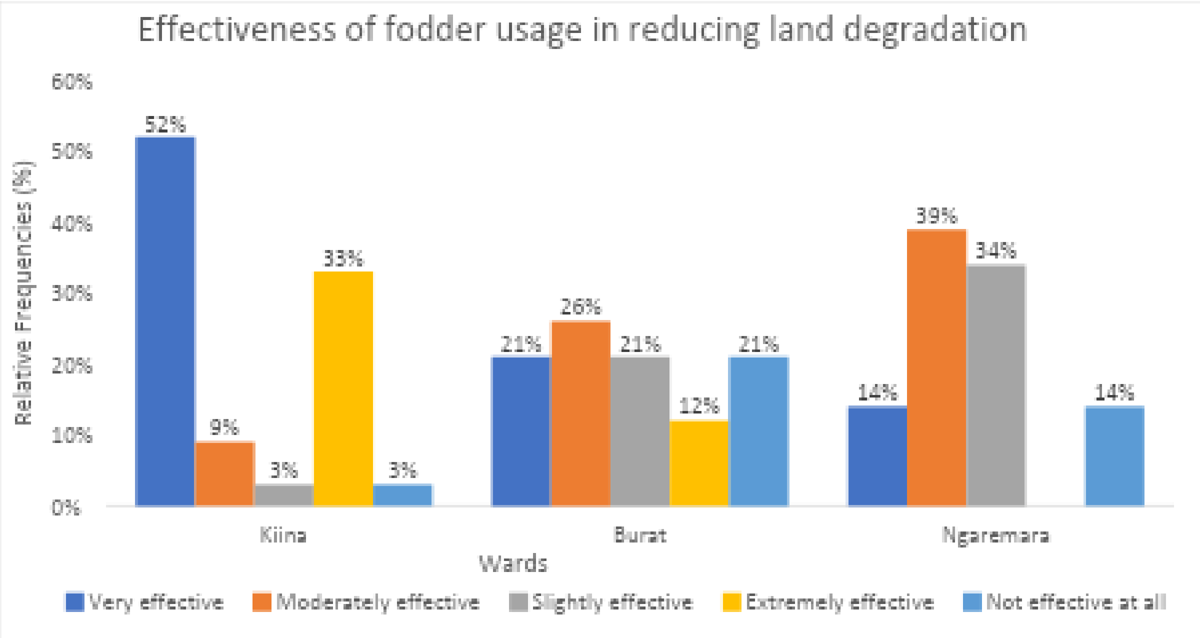


Figure 65: Ward-level variation in the effectiveness of fodder usage in reducing land degradation

Discussion

The findings indicate that some wards experience more benefits from fodder storage than others. The wards of Kiina derive greater benefits from fodder storage than the wards of Burat and Ngaremara. Farmers in Kiina derive greater benefits from fodder storage than those in Burat and Ngaremara, due to better integration of fodder storage into their cropping and livestock systems. The responses of farmers in Burat are mixed, while Ngaremara experience fodder storage as less effective in their agricultural systems.

The effectiveness of land degradation control methods is linked to the integration of crop and livestock systems within the farm (Chuanrum and Shrestha, 2024). The better the integration between these two components of farming systems, the more effective resource-recycling methods, such as fodder storage, will be at reducing pressure on natural vegetation and grazing lands. The effectiveness of fodder storage aligns with the Agroecological Transition Framework, which promotes the adoption of sustainable farming practices to enhance the sustainability of agricultural systems.

The interviewees revealed that planting trees, building soil bunds, and constructing water-harvesting structures are effective methods for reducing land degradation and increasing land productivity. These methods are only as effective as the support and training farmers receive to implement and adopt them.

3.8.6 Soil Fertility and Climate Resilience Outcomes

Results

The influence of climate-smart crop cultivation on soil conditions is generally positive. Most farmers report that soil fertility has improved after adopting climate-smart agriculture techniques (Figure 66). A smaller group reports no change in soil fertility, while an even smaller group notes a decline in soil quality.

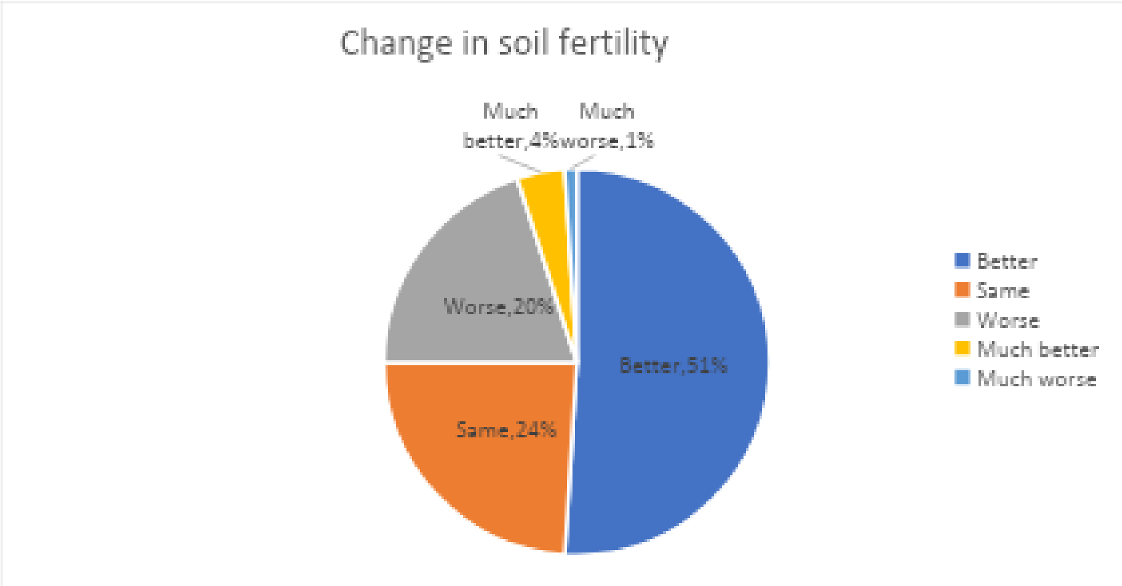


Figure 66: Changes in soil fertility following sorghum/teff adoption

Figure 67 displays differences in soil conditions across the regions of the country. The regions of Kiina and Burat are associated with more positive outcomes in soil fertility, while the region of Ngaremara is associated with more negative outcomes in soil conditions. These differences in outcomes across regions may indicate a relationship between the implementation of soil management practices and soil health outcomes in those regions.

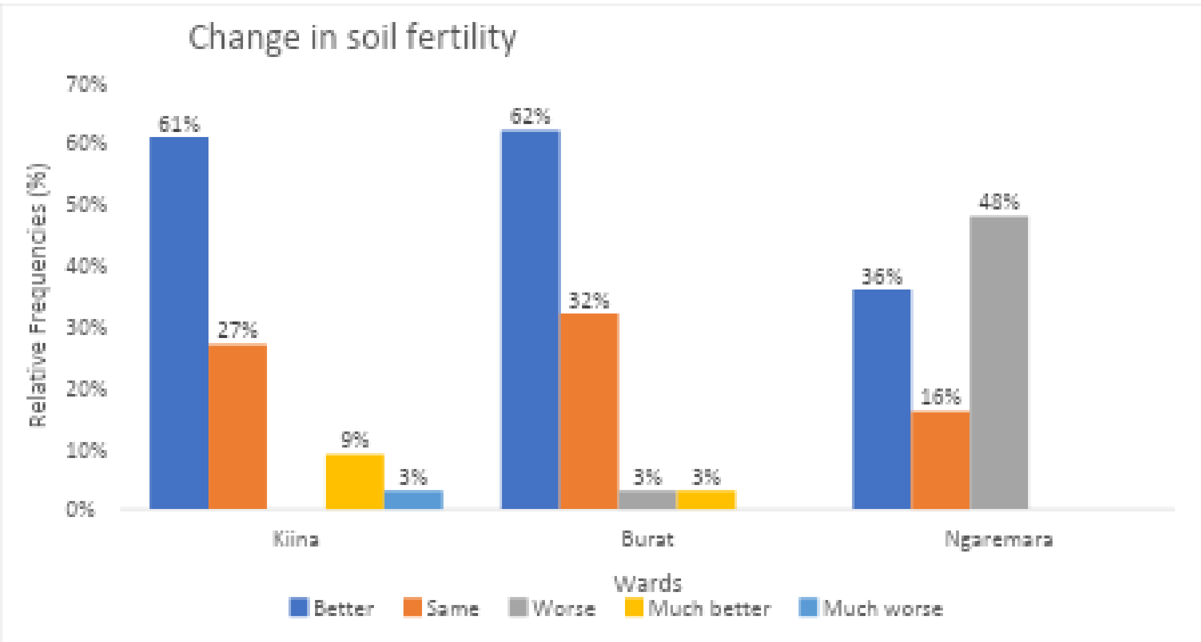


Figure 67: Change in soil fertility since the introduction of sorghum/teff cultivation

Despite these variations, most farmers reported increased farm resilience from using these climate-smart crops. Across wards, a large majority of farmers reported that their farms could better cope with drought and flood conditions (Figure 68). In Burat, the majority of farmers reported an improvement in their ability to withstand drought and flood conditions (Figure 69).

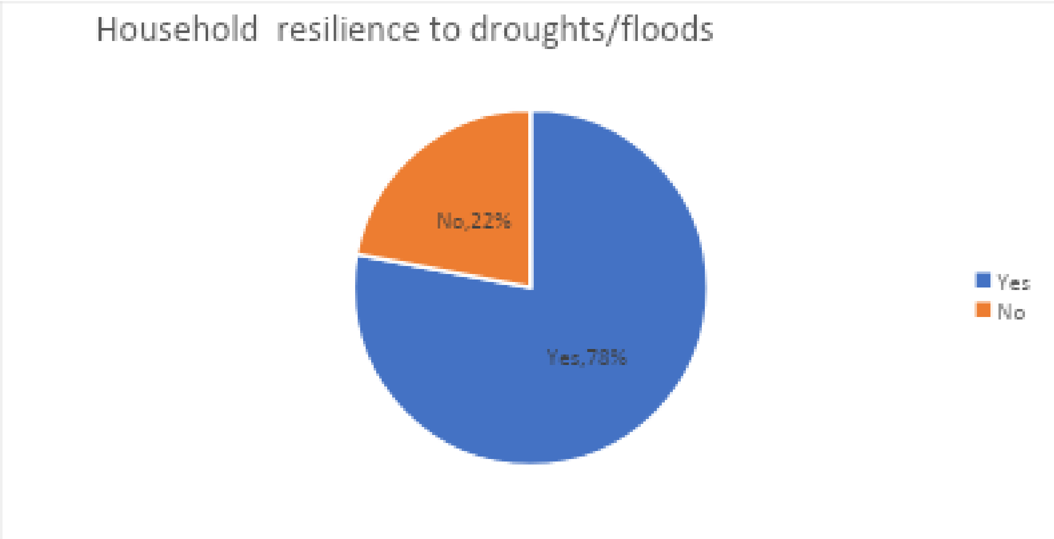


Figure 68: Households' resilience to droughts/floods associated with cultivation of sorghum/teff

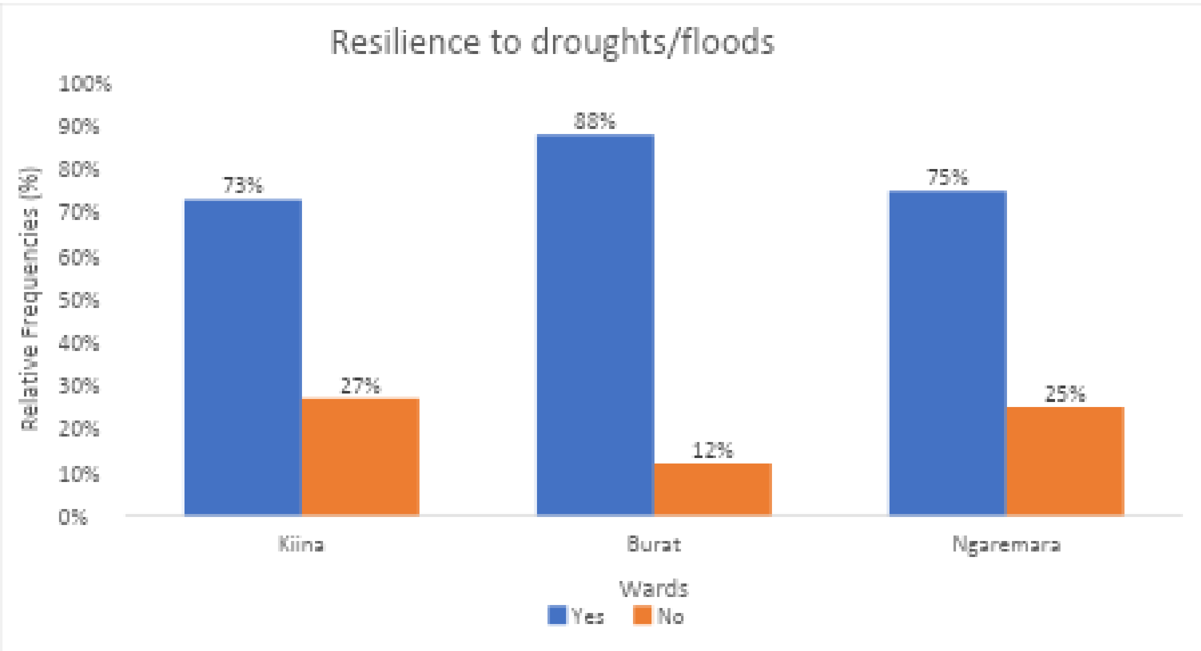


Figure 69: Ward-Level Household Resilience to Droughts and Floods through Sorghum and Teff Farming

Figure 70 indicates that farmers have a high level of confidence in the ability of climate-smart crops to contribute to climate resilience, with only a very small proportion lacking confidence in their effectiveness.

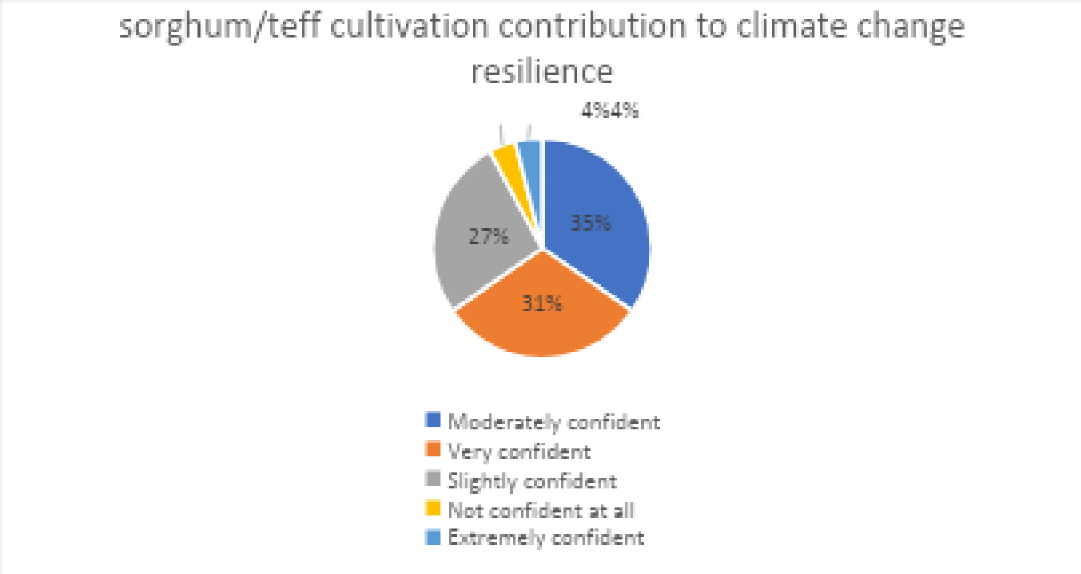


Figure 70: Level of confidence in sorghum/teff cultivation in improving the community's resilience to climate change

Discussion

The findings on soil and climate resilience outcomes of climate-smart agriculture are generally positive. Most farmers reported improved soil fertility after adopting climate-smart crops. However, some reported no improvement in soil quality. The wards of Kiina and Burat have reported improvements in soil quality compared with Ngaremara, which continues to experience adverse soil conditions.

The majority of farmers also reported improved climate resilience as a result of adopting climate-smart crops. Most notably, Burat has experienced significant improvements in climate resilience. Similar to the findings of Debela et al. (2025), the majority of these farmers are confident that these crops improve their climate resilience, with only a small proportion reporting any adverse effects.

Variation in soil quality outcomes suggests that the benefits of climate-smart crops may depend on the presence or absence of other land management practices in the observed areas. This finding aligns with the Sustainable Land Management Framework, which recommends a range of soil management practices for agricultural production systems.

The interviewees indicated that crops such as sorghum and teff can enhance the climate resilience of farming communities experiencing drought, but they also noted that soil fertility must be managed through practices such as soil conservation. Several key informants emphasized the need for soil fertility management practices, especially in areas like Ngaremara, where land degradation is a challenge. Thus, these findings indicate that the benefits of implementing climate-smart crops are best realized when paired with sustainable land management strategies (Balakrishnan and Marimuthu, 2026).

3.8.7 Thematic Box 6: Environmental and Climate Effects of Climate-Smart Sorghum and Teff

Key Insights (FGD & KII)

- Climate-smart sorghum and teff varieties contribute to improved soil fertility, reduced land degradation, enhanced ground cover, and greater resilience to drought and flooding.
- The expansion of these crops into areas that naturally support vegetation and are grazed by livestock presents environmental challenges for the wards.

Within each ward, there are variations in the degree of soil degradation, land coverage by vegetation, and the adoption of practices to improve water-use efficiency:

- Ngaremara Ward experiences high rates of soil degradation and vegetation loss; while improvements in water-use efficiency were observed, adopting agroforestry helps mitigate environmental stress on the land.
- Burat Ward observes an increase in land's resilience to drought and flood damage, the successful establishment of small water-harvesting areas, and a reduction in crop losses due to drought, with minimal impact on the environment.
- Kiina Ward has high rates of adoption of irrigation and fodder storage; soil fertility and water-use efficiency have improved moderately. Vegetation loss is minimal, and environmental pressures on land are manageable within the ward.

Individual differences between the two crops show that sorghum relies more on rainfall and is susceptible to drought and pests, whereas teff varieties require more irrigation and exhibit drought resilience, with occasional larger plot crop losses due to crop diseases.

Representative Voices

“Even when the rains fail, our sorghum survives better than before in the fields, yet some of the land washes away due to the hills’ slopes.”

“With the water harvesting ponds, our teff does not suffer as much, and the land stays fertile.”

“We have fewer patches of bare land now; the crops cover the soil well.”

Policy Implications

- The soil health and fertility benefits of climate-smart sorghum and teff can be maximized by promoting practices that strengthen ecosystem and soil resilience.
- Adoption of these crops can be further integrated into existing environmental policies and strategies targeting drought, land degradation, and flood damage.
- Environmental interventions should be tailored to each ward’s environmental challenges and its capacity to adopt specific strategies; areas with more stable environmental conditions can model and implement strategies for others to adopt.
- Extension services for farmers can be encouraged to adopt techniques and practices that enhance the environmental sustainability of these crops and their resilience to the impacts of climate variability and extreme weather events.

3.9 Adoption, Scaling And Viability

3.9.1 Contextual Overview

In addition to understanding the current and future potential of the technology for use in the Kenyan drylands, it is essential to examine the factors that influence its potential for widespread adoption and implementation beyond the initial areas where it is to be implemented. The evidence gathered within the previous discussion areas can help determine the technology's ability to be widely adopted and to remain in use in the future.

Methods of gaining an understanding of these factors include the use of models like the Diffusion of Innovations Theory by Rogers (2003), which helps to explain how innovations are adopted among farming communities, and the Sustainable Agricultural Intensification (SAI) Framework by authors including Pretty et al. (2011), which explains the factors that contribute to the successful scaling of agricultural technologies. Each of these models can provide insight into the factors that will contribute to the integration of smart agricultural technology in Kenya's dryland regions.

3.9.2 Factors Enabling Adoption of Climate-Smart Sorghum and Teff

Results

Within the study population, access to water and irrigation was identified as the most important enabling factor for expanding climate-smart crops, followed by training in climate-smart agricultural practices. Access to quality seeds and markets was also cited as an important enabling factor, whereas credit and access to finance were considered less important. Additionally, gender-inclusive programs were mentioned the least in the interviews (Figure 71).

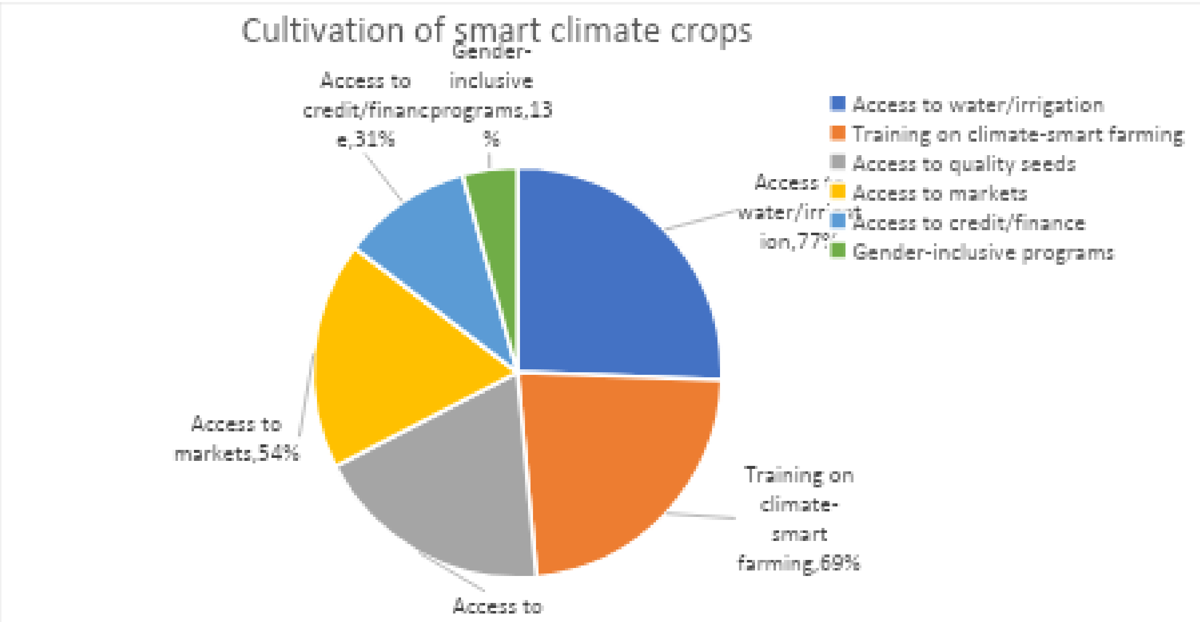


Figure 71: Factors Encouraging Increased Cultivation of Climate-Smart Crops

Ward-level priorities vary by ward, reflecting the agricultural systems within each ward. For instance, Kiina's priorities include market and credit access, which are more commercially oriented than those of other farms in the country. Burat's priorities include water availability and training, as the ward experiences more drought than other parts of the country. Ngaremara's priorities also include water availability and training, as these resources are required to scale up climate-smart smallholder agricultural practices implemented in the ward (Figure 72).

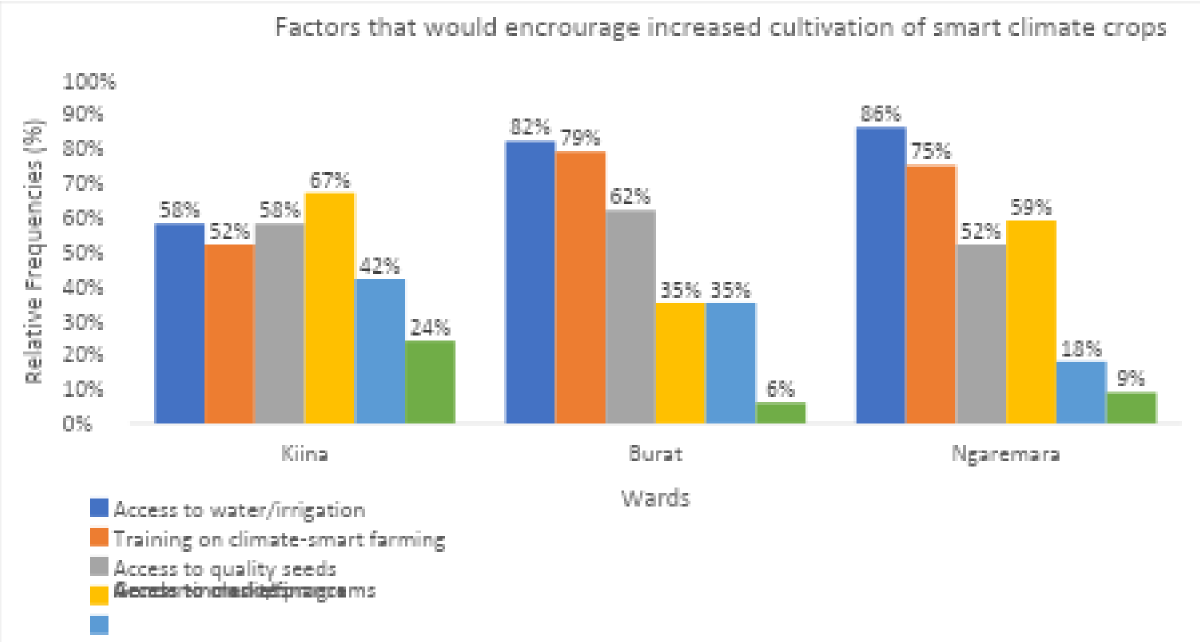


Figure 72: Ward-Level Factors Encouraging Increased Cultivation of Climate-Smart Crops

Discussion

These differences at the ward level indicate the relationship between the usefulness of innovations and the conditions under which farmers make their decisions. In areas with more commercial agricultural systems, the focus on gaining access to credit suggests that farmers prioritize innovations that will yield higher economic returns for their farms (Devaux et al., 2018).

In areas that are more climate-stressed and resource-limited, however, the focus on gaining access to water and on training indicates that the primary drivers of farmers' decisions to adopt these innovations are related to these environmental stresses and to their lack of knowledge about how to address them (Berger et al., 2017).

Overall, these findings indicate that the scaling of climate-smart agricultural practices is linked to the existing agricultural systems of each of these regions. More commercial agricultural systems exhibit adoption rates of these innovations that are related to their access to financial and market systems, while more vulnerable agricultural systems exhibit relationships between the introduction of these innovations and their availability of resources and knowledge to adopt the practices.

3.9.3 Barriers to Adoption

Results

Water scarcity and inadequate training are the most significant constraints to adopting climate-smart crops. Following these constraints are problems related to limited access to quality seeds and markets, as well as pests (Figure 73).

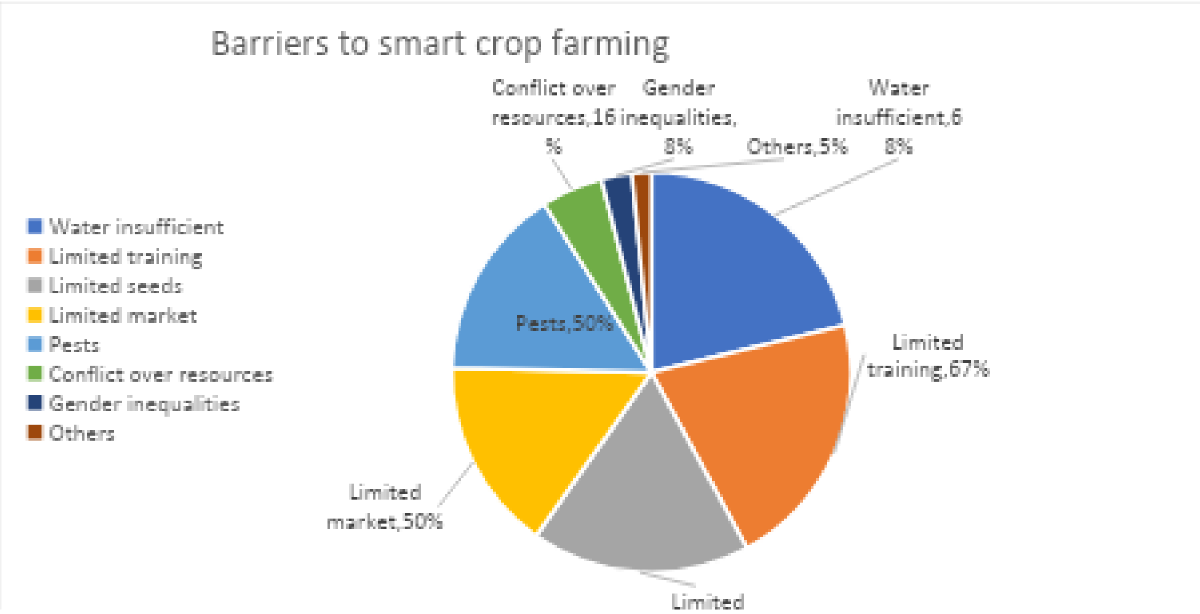


Figure 73: Barriers to smart crop farming in Isiolo County

Ward-level variations exist in relation to the constraints within each of these areas. Burat faces significant challenges related to water, training, and resource-use conflicts. Kiina's main challenges are market and gender-related, as well as pests. Ngaremara faces the most challenges related to pests, followed by water and seed quality (Figure 74).

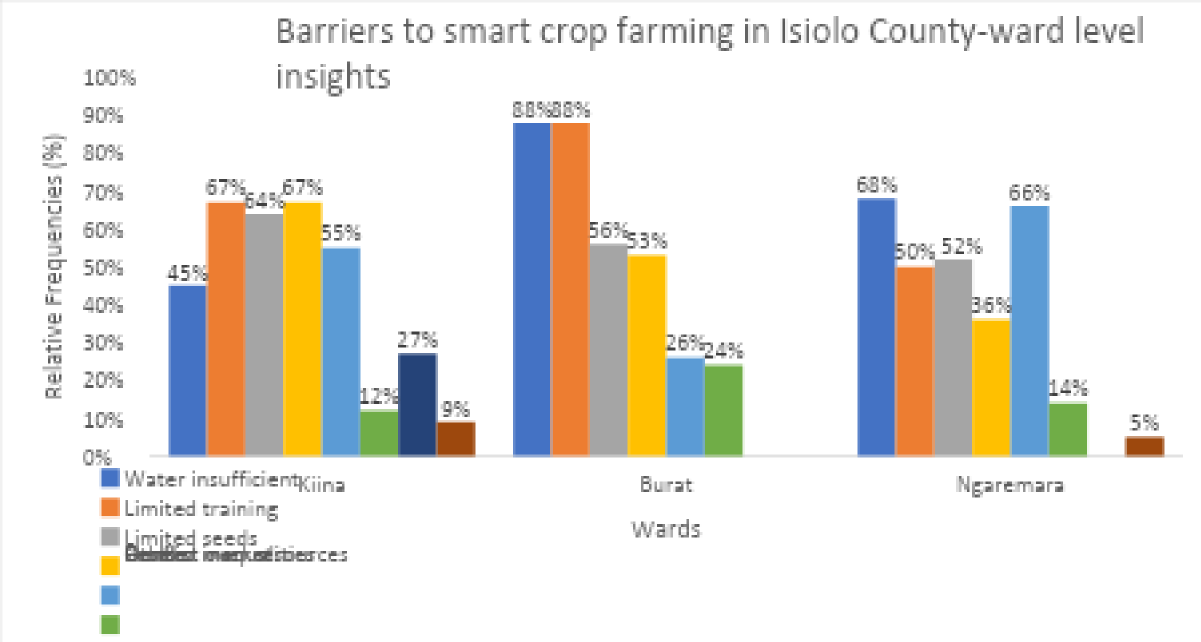


Figure 74: Ward-Specific Barriers to Climate-Smart Crop Farming in Isiolo County

Discussion

The findings indicate that the adoption of climate-smart crops is hindered by several constraints related to farmers' available resources, their knowledge of the practices required to adopt such crops, and related market issues. Water scarcity and limited access to training are the most critical constraints, indicating that these two factors significantly limit farmers' ability to adopt climate-smart agricultural practices. In addition to these factors, limited access to seeds and markets, and the presence of pests on many farms also act as barriers to the adoption of these crops (Sachan, 2024).

Within each ward, however, the most significant constraints to adopting climate-smart crops differ. In Burat, for instance, the major constraints to adoption include water scarcity, insufficient farmer training, and issues related to natural resources. In contrast, Kiina's major constraints relate to market, gender, and pest issues. Finally, Ngaremara's major constraints are the presence of pests in the area, as well as limited availability of water and quality seeds for farmers to use on their farms. Thus, each ward faces constraints to the adoption of climate-smart crops, but the major constraints differ. These constraints hinder the adoption of climate-smart agricultural practices within these different regions; the more constraints that exist within a region, the more complex the adoption of climate-smart practices becomes, and the fewer benefits that will accrue to those regions and their farmers (Kaine and Wright, 2022).

Further insight into the nature of these constraints was provided by interviews with farmers in each region. The farmers in each region indicated that water scarcity and a lack of technical knowledge for adopting these practices were their major constraints to adopting climate-smart agricultural practices on their farms. Thus, these interview findings suggest that addressing these constraints will increase the adoption of climate-smart agricultural practices.

3.9.4 Viability Assessment of Climate-Smart Crop Adoption

Results

Table 11 shows that the Composite Viability Index (CVI) for climate-smart agriculture is approximately 54%. The economic aspects of implementing climate-smart agriculture are the most viable, followed by environmental resilience and then the social aspects. The technical/production aspect is less viable than the other aspects. The sub-indicators related to the environmental component of implementing climate-smart agriculture show mixed results but are generally moderate in their viability.

Table 11: Variability of Multi-Dimensional Viability and Composite Viability Index

Variability Assessment Analysis					
Indicators and Composite Index Components	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Economic Viability Index (income/sales; 0–1)	**66**	**.412**	**.862**	**.60710**	**.115681**
Technical/Production Viability (food+feed; 0–1)	**99**	**.258**	**.663**	**.49983**	**.070477**
Social Viability: Social fit (0–1)	**111**	**.000**	**1.000**	**.50901**	**.233374**
Environmental/Resilience Viability (0–1; higher=better)	**111**	**.323**	**.906**	**.55903**	**.127773**
Composite Viability Index (CVI; mean of Economic, Technical, Social, Environmental/Resilience; 0–1)	**101**	**.281**	**.820**	**.53916**	**.092196**
Composite Viability Index (CVI; 0–100)	**101**	**28.1**	**82.0**	**53.916**	**9.2196**
# of non-missing pillars contributing to CVI (0–4)	**123**	**0**	**4**	**3.15**	**1.213**

The parameters of land degradation management and water and soil resilience show relatively stronger performance, while the livestock diversification indicator demonstrates more moderate performance, and the grazing land use indicator shows the lowest performance (Table 12). Thus, although smallholder farmers report experiencing benefits from these practices, their confidence in the extent to which these benefits can be scaled is moderate.

Table 12: Environmental and Resilience Viability (component-level + aggregated environmental index)

Descriptive Statistics					
Viability components	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Env: land degradation signals (0–1; higher=better)	111	.000	1.000	.60435	.237162
Env: water/soil/resilience (0–1; higher=better)	111	.167	.917	.64865	.180629
Env: grazing reliance & land clearing (0–1; higher=better)	111	.125	1.000	.42905	.259819
Env: shift away from livestock reliance (0–1; higher=better)	111	.000	1.000	.55405	.266299
Environmental/Resilience Viability (0–1; higher=better)	111	.323	.906	.55903	.127773

The distribution of the CVI is approximately normal, with a mean of 0.539 (Figure 75). Overall, this indicates that the system's viability is moderate.

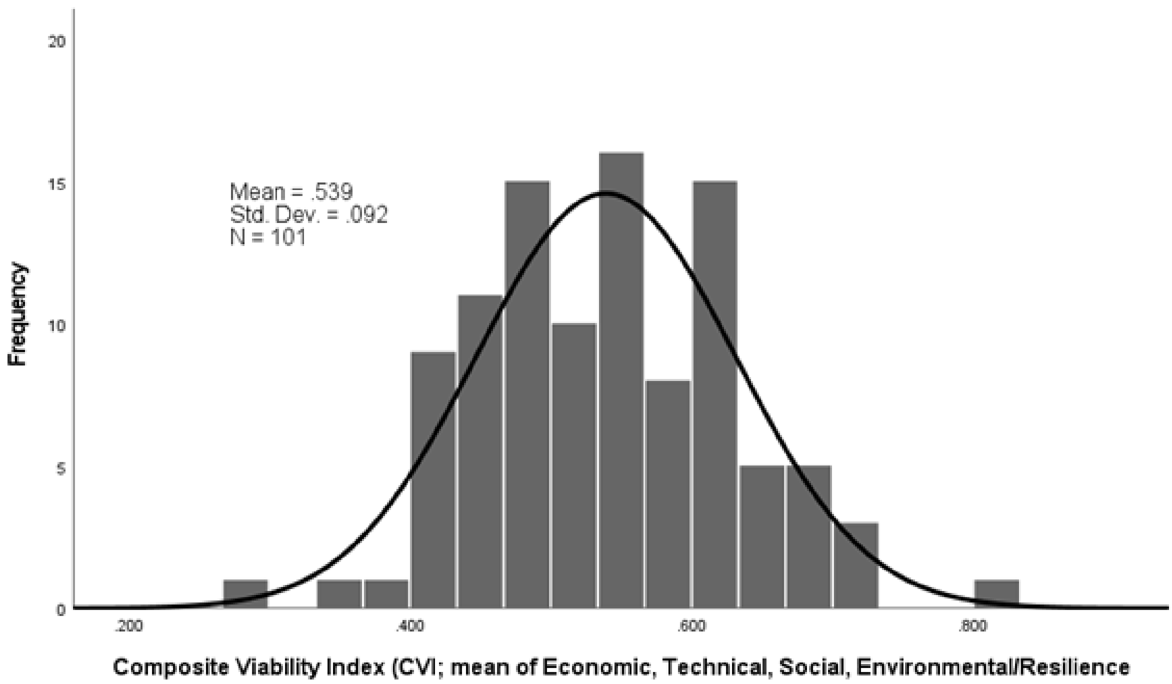


Figure 75: Distribution of Composite Viability Index (CVI) Scores Among Respondents

Discussion

The Composite Viability Index indicates that the overall viability of the agricultural system within the study area is moderate, with a score of 0.54 (54%). The distribution of scores within the system is approximately normal, with most farms near the middle of the viability index and a few at the high or low ends. Thus, the system is functioning at a steady, even level, but not yet at a strong, consolidated level of performance.

Regarding the four dimensions of viability, results indicated that the system fared best in economic viability, followed by environmental and resilience viability, social viability, and technical and production viability. Thus, the system shows gains in economic and environmental factors but not in its technical components, indicating a potential area for future improvement.

For each sub-indicator, the results were mixed. Environmental sustainability scored best in land degradation management and soil and water resilience, but produced moderate results in livestock diversification. The need for grazing land by livestock on the farms indicates that the farm system is still in the early stages of implementing changes to its production system.

The general interpretation of the results in relation to the qualitative data from interviews with individual farmers indicates that there are benefits to the farming practices currently implemented by those farmers, but there are also constraints on their ability to be expanded. The constraints most frequently mentioned by the farmers included a lack of training on these practices, inadequate water infrastructure, and weak market linkages for agricultural products.

The findings of this study therefore suggest that the agricultural system in the study area is at a middle stage of practice development. While gains are being made in the economic and environmental aspects of the system, its technical components still face constraints. Thus, the system exhibits a moderate level of readiness to scale these practices and gains, as the gains being made are still emerging, fragile, yet promising.

3.9.5 Observations on Adoption, Scaling, and Effectiveness

The level of adoption of climate-smart sorghum and teff is moderate. While the system is currently functioning, several factors limit its full potential. The CVI of 0.54 indicates that the benefits adopted by smallholder farmers are insufficient to scale up these practices. The distribution of viability also indicates that adoption is gradual and not yet complete.

The most influential factors in the adoption of climate-smart practices across all wards are access to water and training. These factors are the most influential as enabling factors in wards where they are available and as constraining factors where they are lacking. The high proportion of smallholder farmers who responded to the survey (68%-88%) underscores their critical role in adopting climate-smart practices.

Several other factors influence the scaling up of adoption. The limited availability of seeds for planting climate-smart sorghum and teff limits smallholder farmers' ability to establish these crops effectively. In addition, limited market access for both sorghum and teff is a constraint on their adoption, as it limits smallholder farmers' ability to cultivate these crops beyond subsistence needs. The lack of inclusion of women and youth in the adoption of climate-smart sorghum and teff also affects their scaling up. Various environmental stresses, such as soil degradation, crop pest damage, and rainfall variability, also affect the scaling up of these practices. The weak integration of livestock into the adoption of climate-smart sorghum and teff presents another constraint on their scaling up. Finally, the lack of effective support programs for the adoption of these crops also limits their scaling up.

The analysis of these factors indicates that smallholder farmers are experiencing a level of economic viability from adopting climate-smart sorghum and teff practices, but to a much lesser extent in relation to technical and production viability.

Field experiences indicate that the main factors constraining the adoption of climate-smart sorghum and teff practices vary across wards. In Burat, the scarcity of water resources and the lack of training in adopting these practices are the most influential factors. In Kiina, the constraints to the adoption of climate-smart sorghum and teff by smallholder farmers are market- and gender-related. In Ngaremara, environmental stresses constrain the adoption of these practices.

The findings on these factors indicate moderate viability of climate-smart sorghum and teff adoption on smallholder farms. While adoption and benefits from these crops are evident, broader adoption is constrained by various factors. Enhancing the viability and scalability of climate-smart sorghum and teff adoption will require improving the factors affecting smallholder farms.

4.0 CROSS-CUTTING POLICY IMPLICATIONS

System transformation is needed, based on evidence from each of the seven thematic areas. The shift from participation to inclusion in agriculture is needed, especially for women and youth.

The disparities among the wards indicate the need for decentralized approaches to agricultural development and interventions. Not all areas within the wards have the same resources and conditions for agriculture; thus, interventions need to be targeted toward each of these areas.

The gaps in the existing systems and the inconsistencies in the benefits they provide to smallholder farmers indicate the need for improvements in these systems. Currently, interventions focused on strengthening these systems will have positive impacts on smallholder farmers' agricultural yields, incomes, and food security.

The livelihood and food security challenges faced by smallholder farmers in Isiolo County indicate the need to improve market integration. Smallholder farmers need to benefit more from their agricultural production if markets in their countries are strengthened.

The interdependence among crop production, livestock production, and environmental sustainability underscores the need to integrate agricultural development interventions that account for each of these aspects of smallholder farms. For instance, implementing dual-purpose crop systems will allow smallholder farmers to simultaneously increase their livestock and crop yields while reducing environmental impact.

The constraints on smallholder farms underscore the importance of enabling systems for smallholder farmers. Improving small-scale water infrastructure, local seed systems, and access to technology will increase smallholder farmers' productivity and the adoption of improved agricultural technologies.

The climate-related issues affecting small-scale farmers in the ASALs underscore the need to implement strategies to enhance their resilience to climate change. Strategies such as diversifying crops, feed, and agricultural products, and implementing improved storage systems for these products, will help smallholder farmers better withstand the impacts of climate variability.

It is important to ensure that agricultural development in Kenya and the region is sustainable into the future. While the outcomes have been positive for smallholder farmers, implementing strategies to improve the sustainability of agriculture in these regions will help ensure they are not adversely affected by environmental conditions.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The findings of this study demonstrate the significant potential of climate-smart sorghum and teff farming systems to improve food security and livelihoods in ASALs, yet this potential remains unrealized because of structural constraints in these contexts.

The study also reveals that climate-smart sorghum and teff farming interventions that focus on a single component of the agricultural system are unlikely to yield the desired results. Interventions that consider the various systems within agriculture and across ASALs as a whole are required to address the complex challenges in these regions.

The interventions should move beyond providing farmers, especially women and youth, with a sense of agency within the agricultural systems. The interventions must account for the different conditions across the wards of ASALs. Furthermore, interventions to improve access to resources essential for implementing these climate-smart systems must be undertaken.

The sustainability of these farming systems will depend on the ability of existing policies to account for the complex conditions within ASALs. Considering these findings, future interventions should focus on coordinated efforts to improve various aspects of agricultural systems in ASALs, enhancing the sustainability of these crops and the livelihoods of the smallholder farmers who grow them.

5.2 Recommendations

- In order to develop a successful agricultural policy, the following recommendations can be made based on the information gathered during the study of the state of the agricultural sector in Kenya:
- County Governments should implement ward- and context-specific planning and implementation. Each County can develop agricultural programs tailored to the environment and resources of each ward within that County. Each County also has the resources to collect the data required to manage and monitor its own agricultural programs.
- Establish integrated agricultural services within the Public and Non-State Sectors. The extension services for these sectors should be continuous, focused on the agricultural

practices required for agricultural sustainability, and include strategies for both crop and livestock management.

- Increase the availability of foundational agricultural enablers, including small-scale water infrastructure, seed systems, and mechanization.
- Implement policies that increase the availability of agricultural resources and management strategies for women and youth farmers, thereby enhancing their ability to participate in the production and management of agricultural resources in Kenya.
- Invest in developing the agricultural markets in Kenya to increase the availability of infrastructure for sorghum and teff production, processing, and storage.
- Encourage the development of integrated crop and livestock agriculture and management systems within Kenya. Both systems are necessary for sustainable agricultural production, and the management of Kenya's rangelands will significantly contribute to that goal.
- Promote agricultural diversification and the implementation of infrastructure to store agricultural products. Both food and feed crops can benefit from increased development of storage infrastructure for Kenyan farmers.
- Implement additional strategies to improve the sustainability of agriculture in Kenya, especially in areas that are at risk of environmental challenges to their agricultural systems.
- Reform and strengthen the existing agricultural support systems for farmers to improve the sustainability and effectiveness of those programs.

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7.0 ANNEXES

Annex 1: Demographic profile of respondents

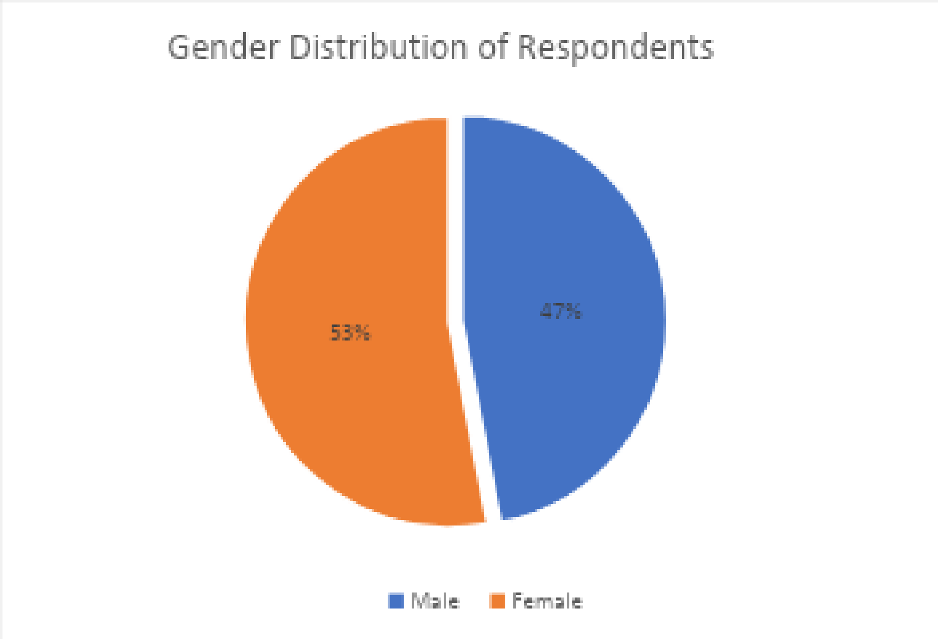

Figure 1: Distribution of respondents by gender

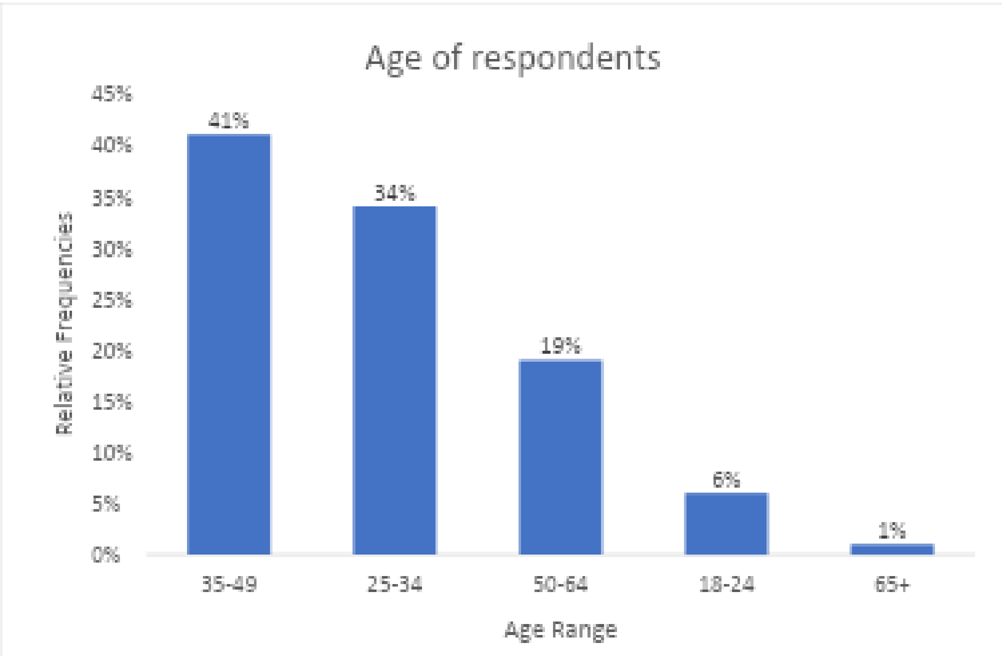

Figure 2: Age Distribution of Study Respondents

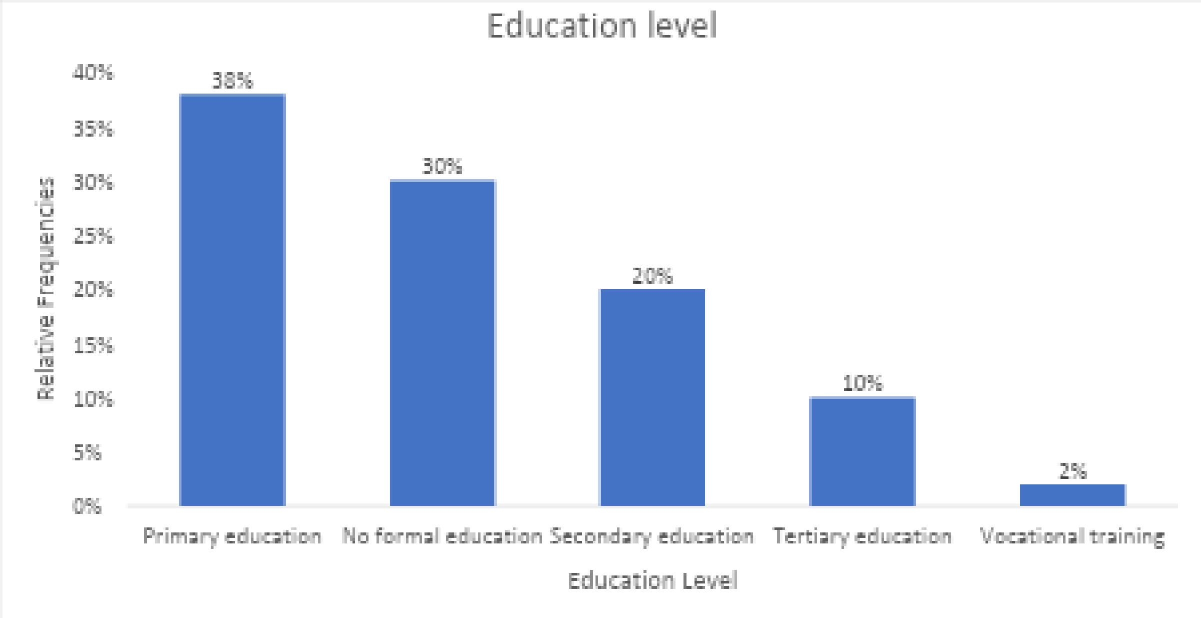

Figure 3: Education Level of Respondents

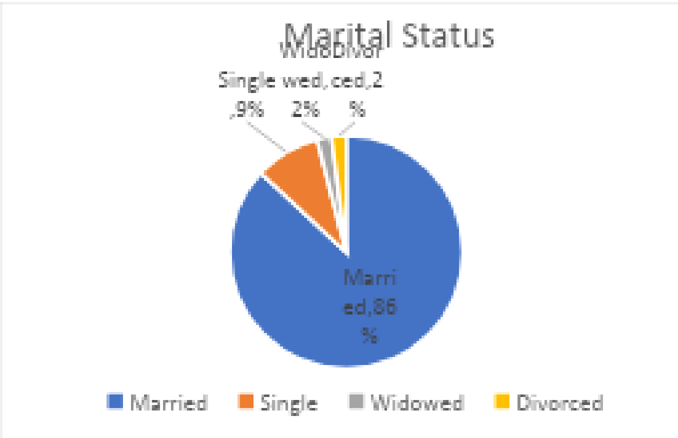

Figure 4: Marital Status of respondents

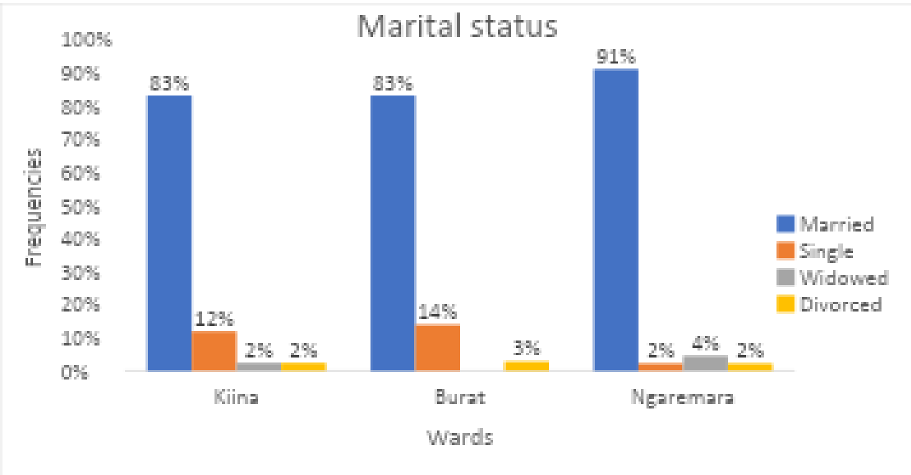

Figure 5: Marital Status of respondents by Ward

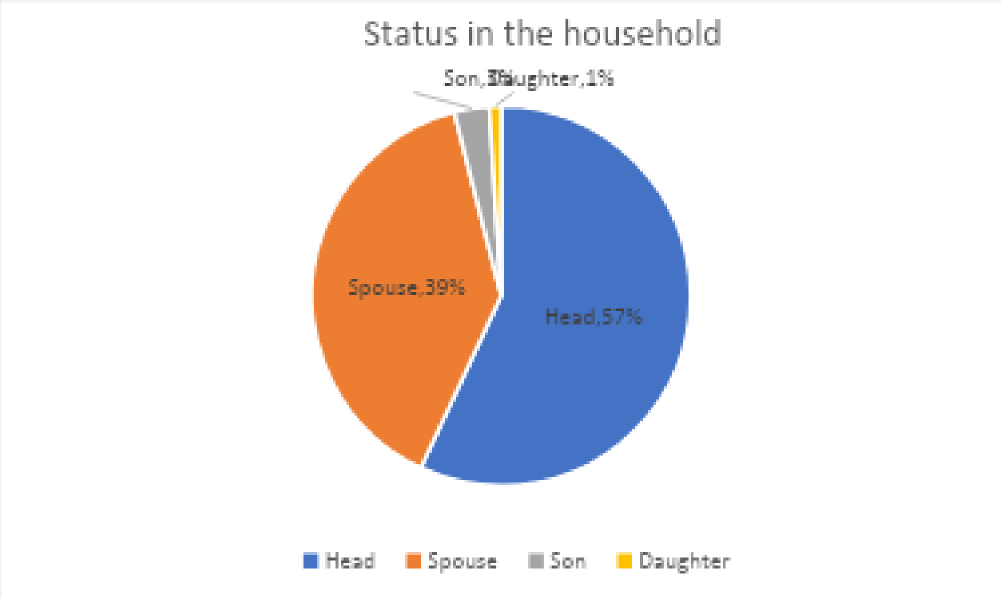

Figure 6: Relationship of Respondents to the Household Head

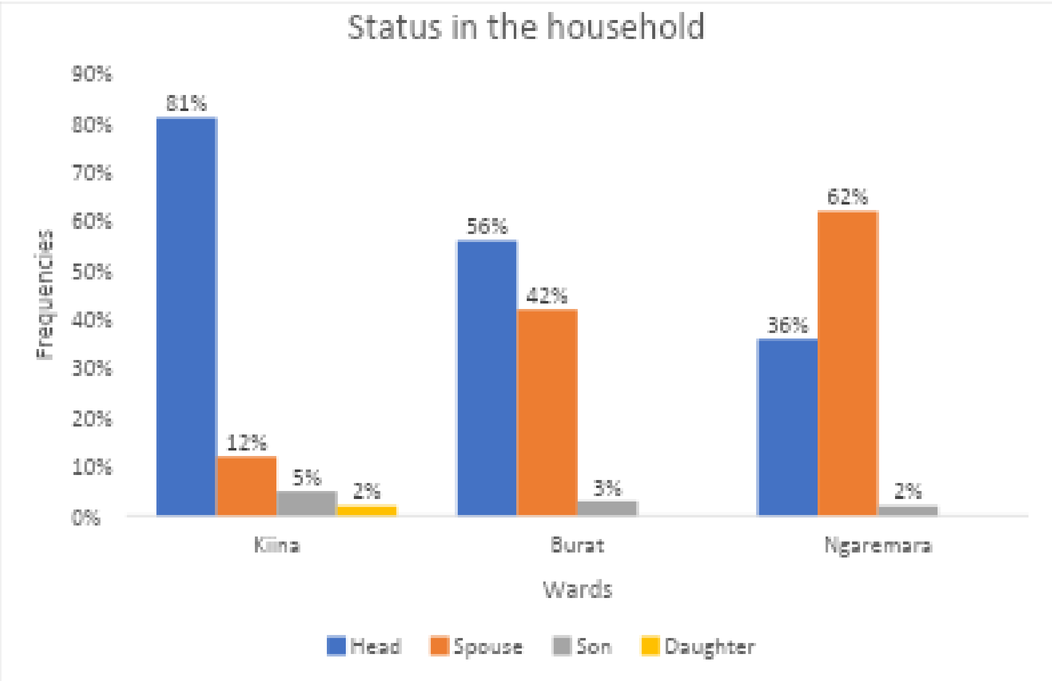

Figure 7: Relationship of Respondents to the Household Head by Ward

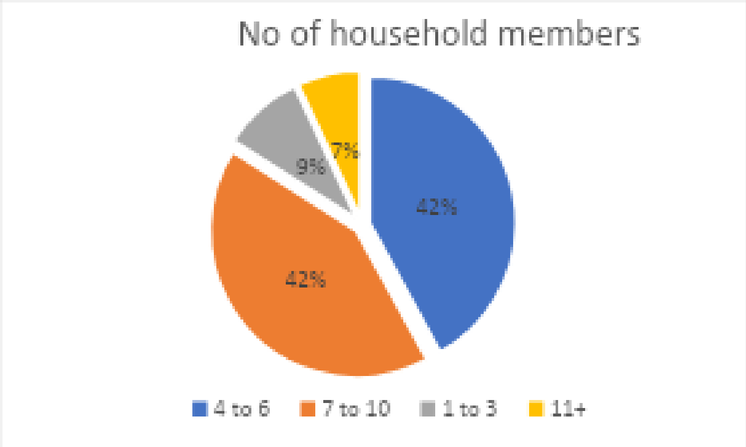

Figure 8: Household Size Distribution of Respondents

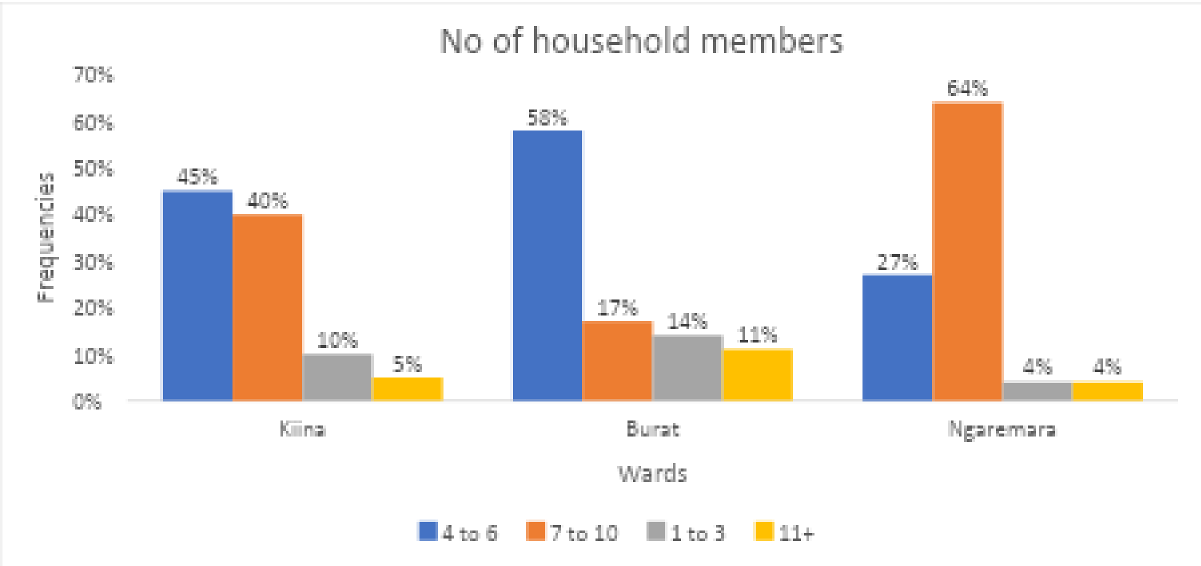

Figure 9: Household Size Distribution of Respondents by Ward

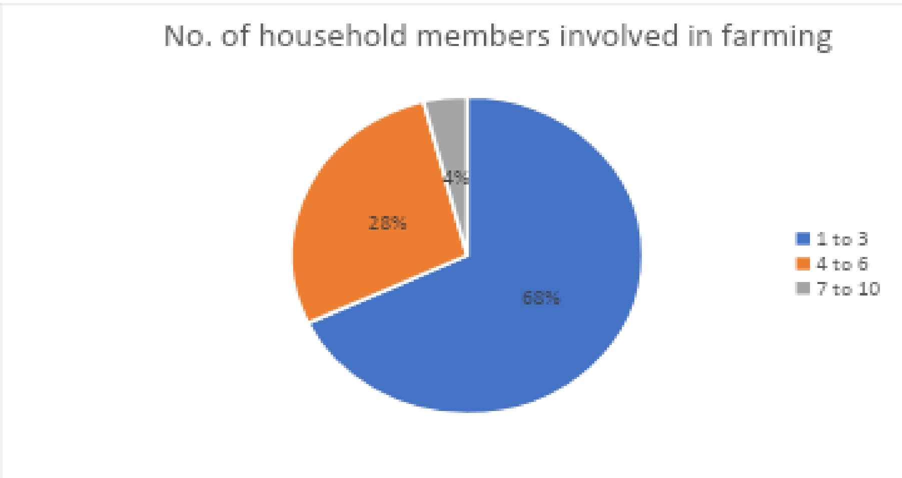

Figure 10: Household members actively involved in farming

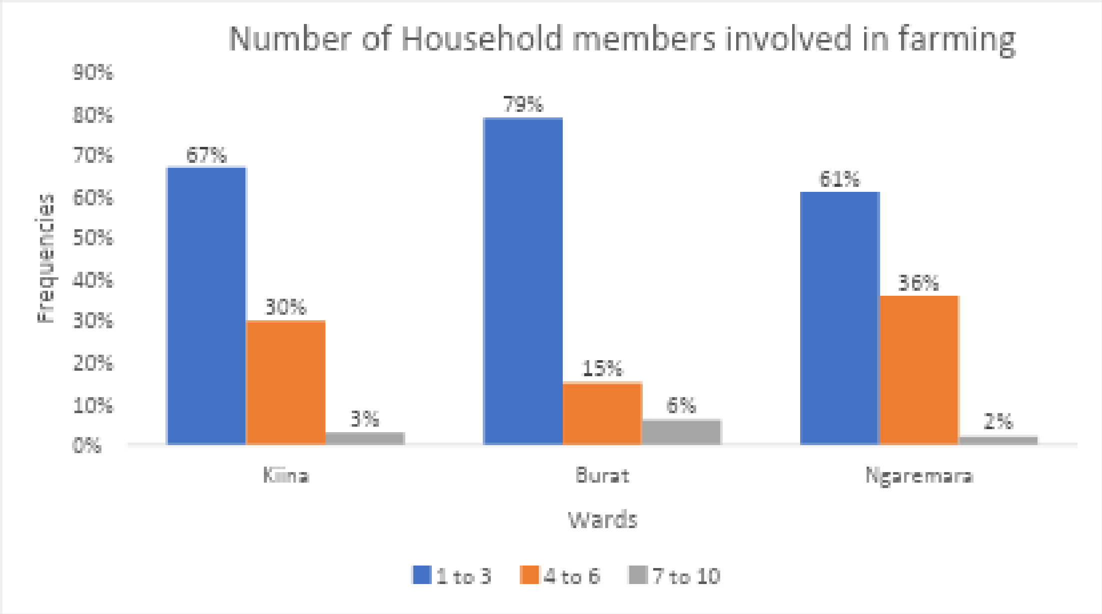

Figure 11: Household members actively involved in farming-ward level

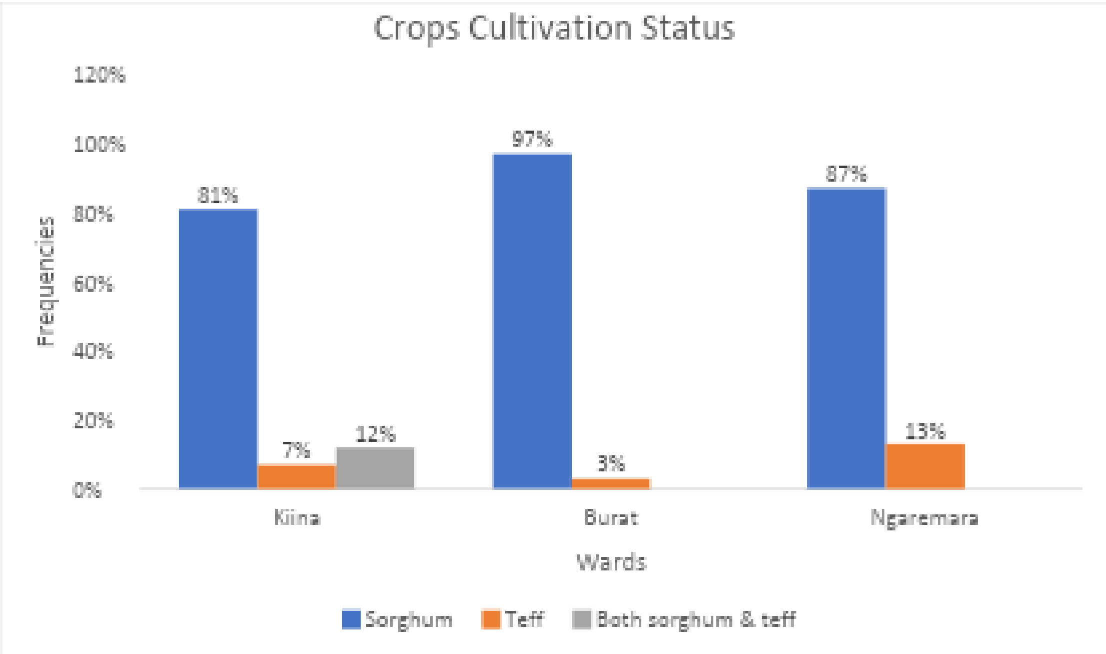

Figure 12: Sorghum and/or Teff Cultivation Status by Ward

Annex 2: Women & Youth Inclusion

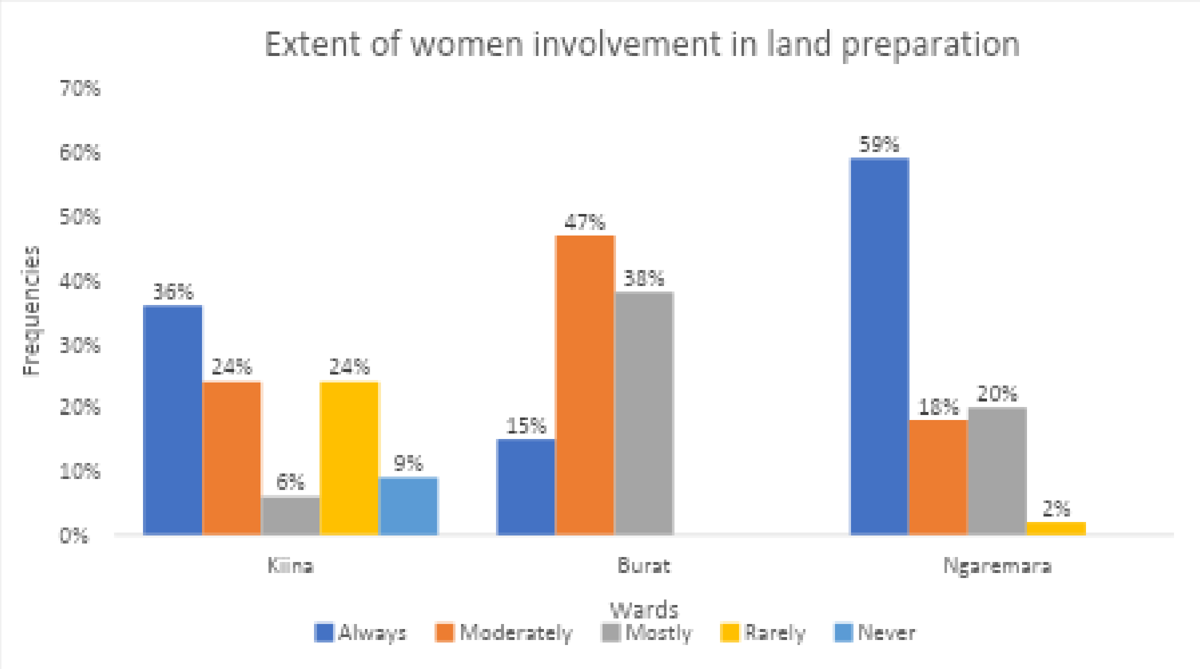

Figure 1: Women's Participation in Land Preparation by Ward

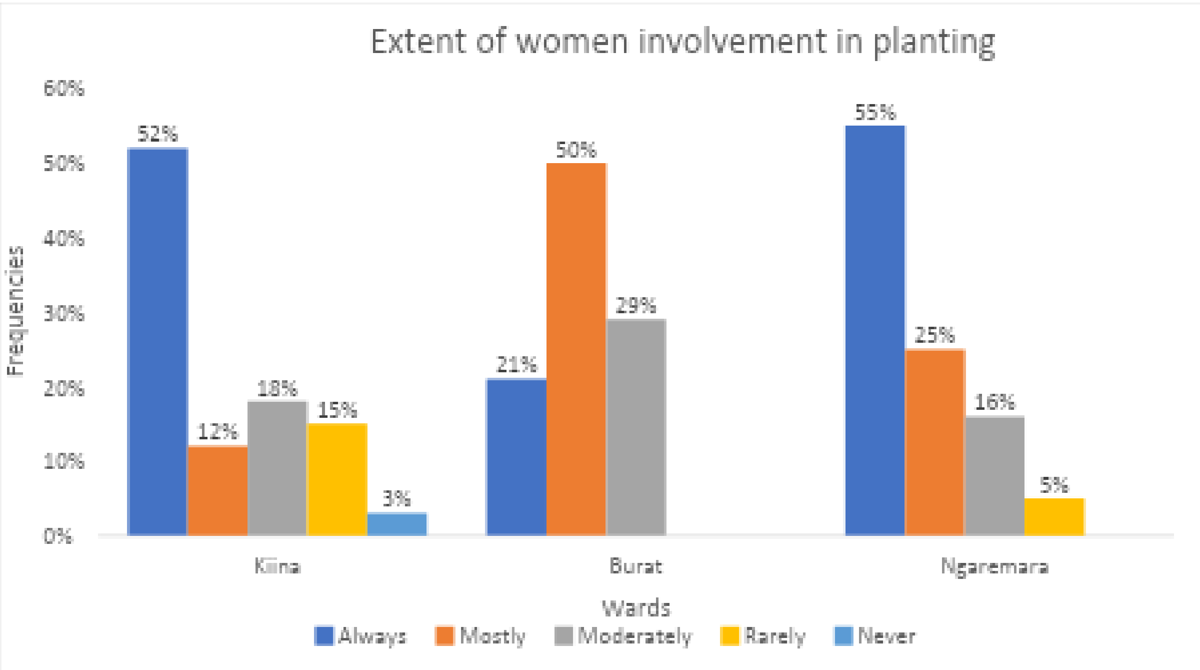

Figure 2: Women Involvement in Planting by Ward

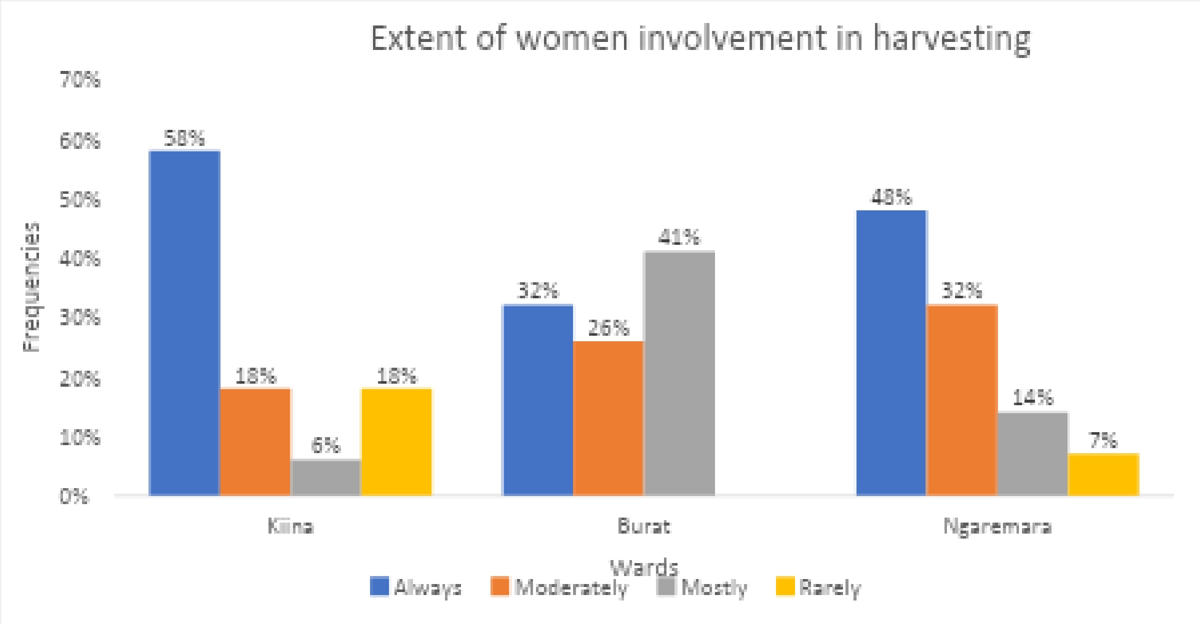

Figure 3: Women Involvement in Harvesting by Ward

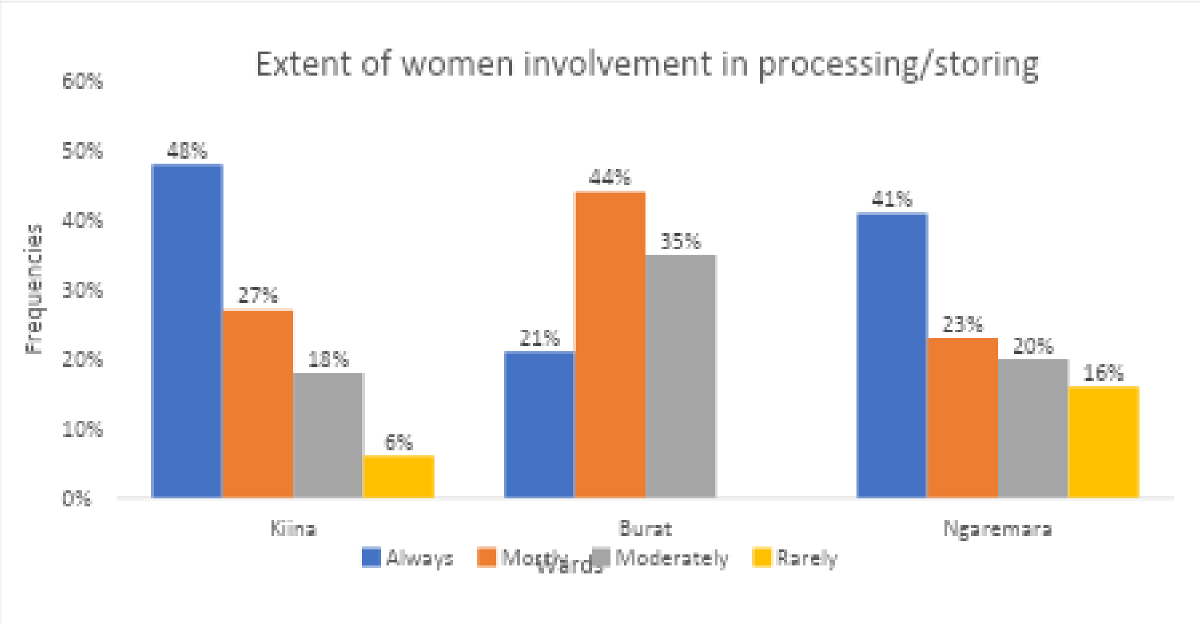

Figure 4: Women Involvement in Processing by Ward

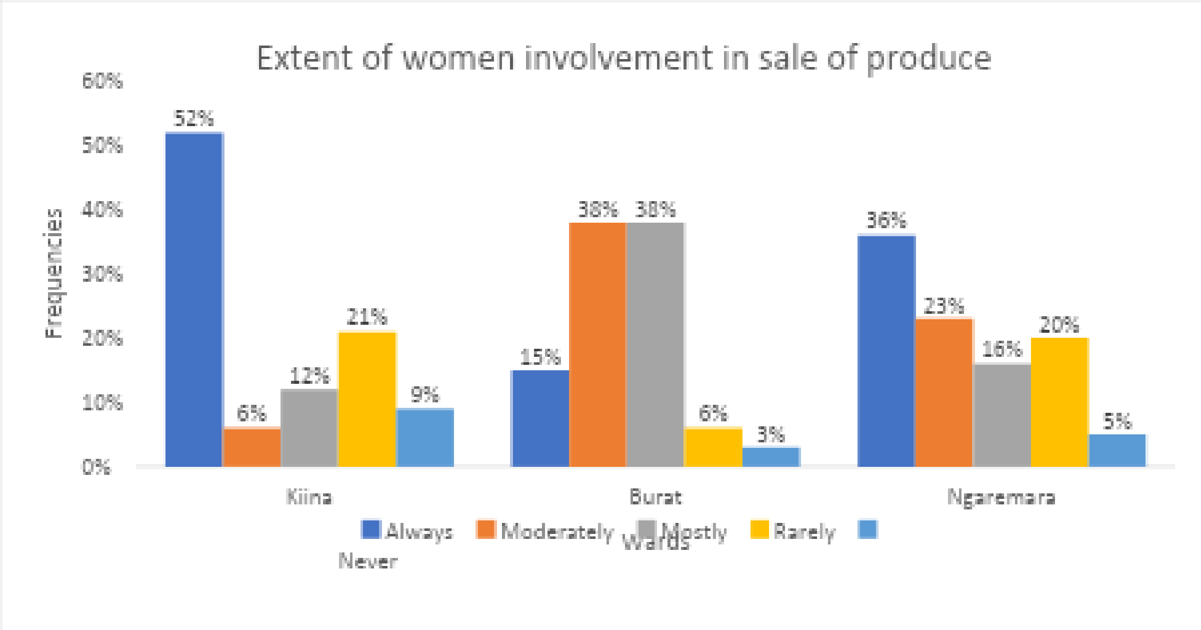

Figure 5: Women Involvement in sale of produce by Ward

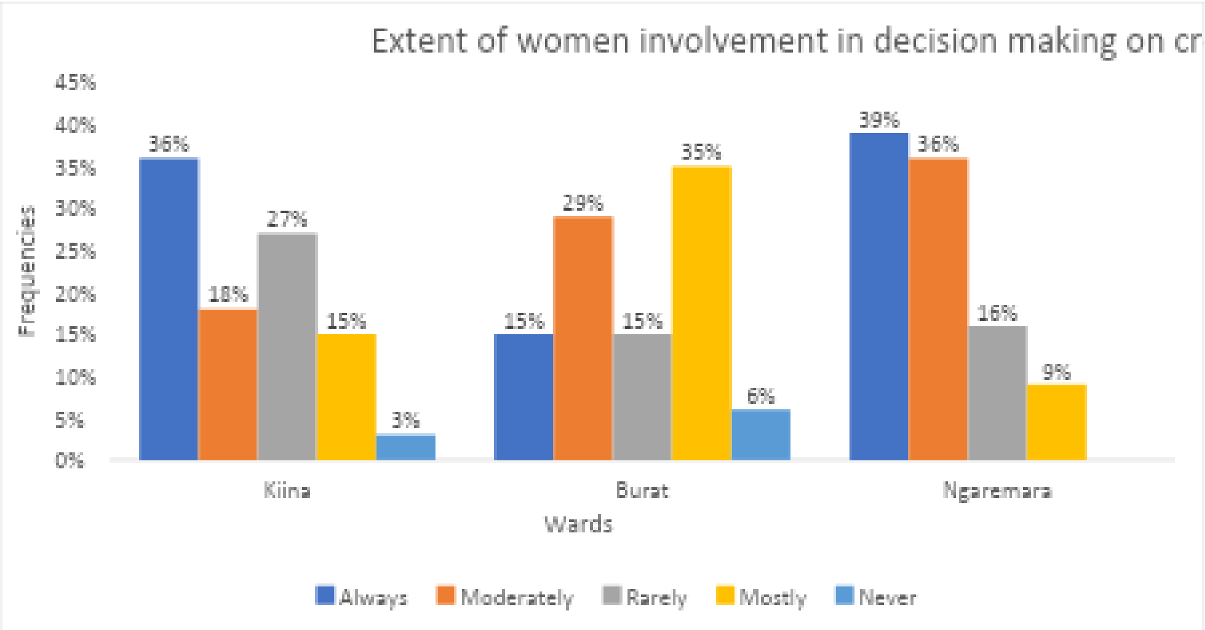

Figure 6: Women Involvement in decision making on crop use by Ward

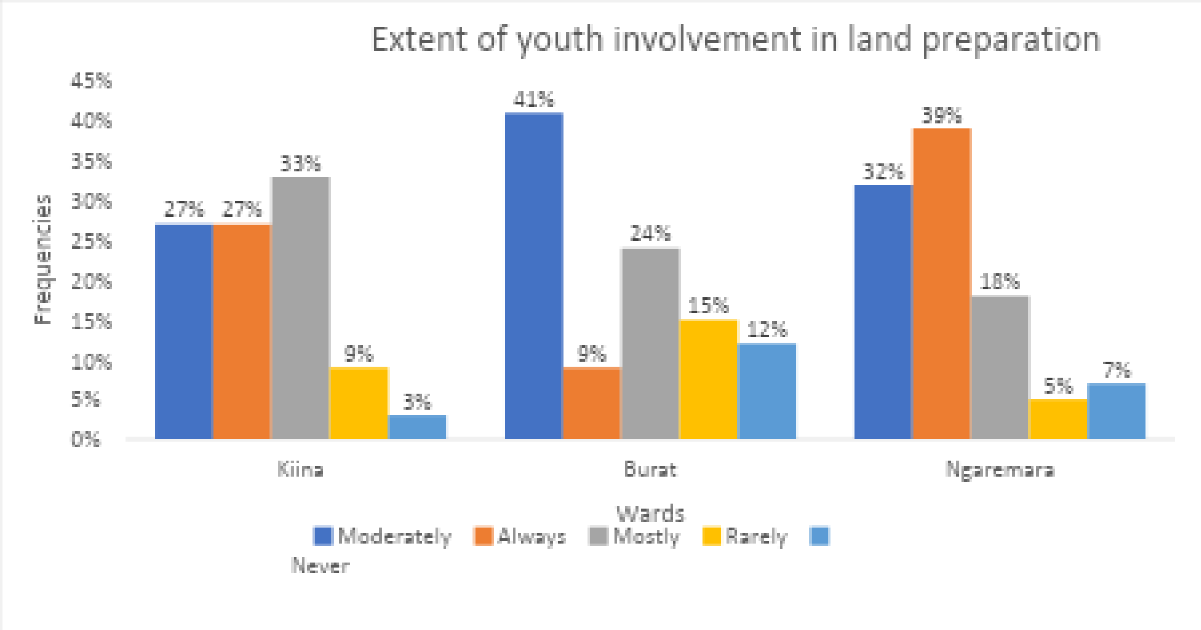

Figure 7: Youth Involvement in land preparation by Ward

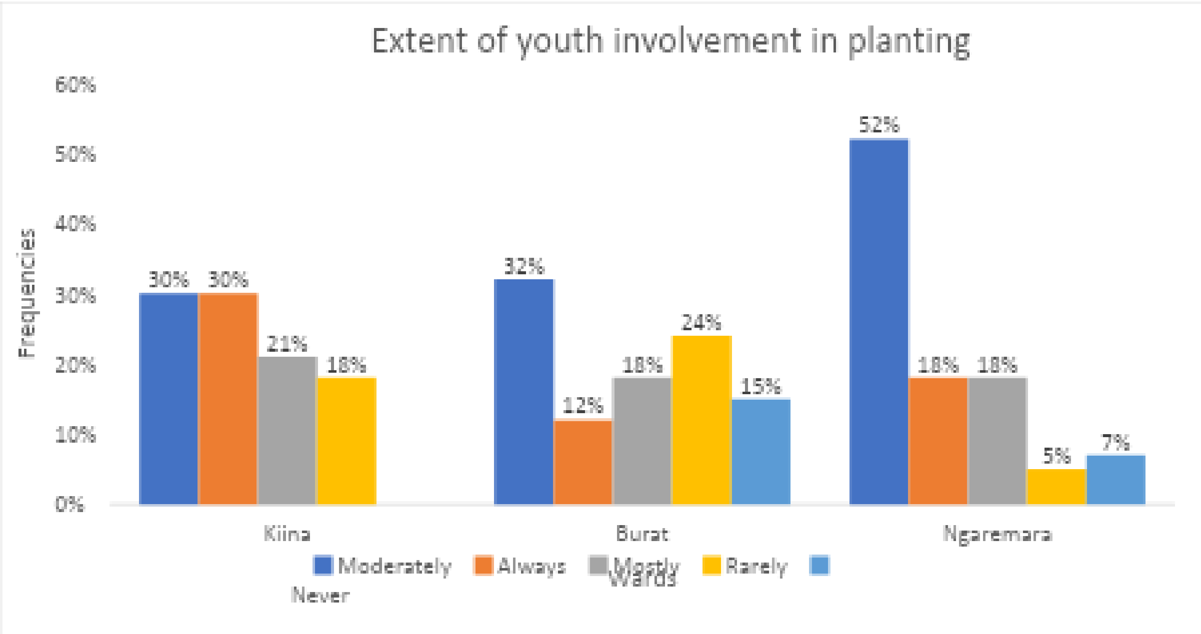

Figure 8: Youth Involvement in Planting by Ward

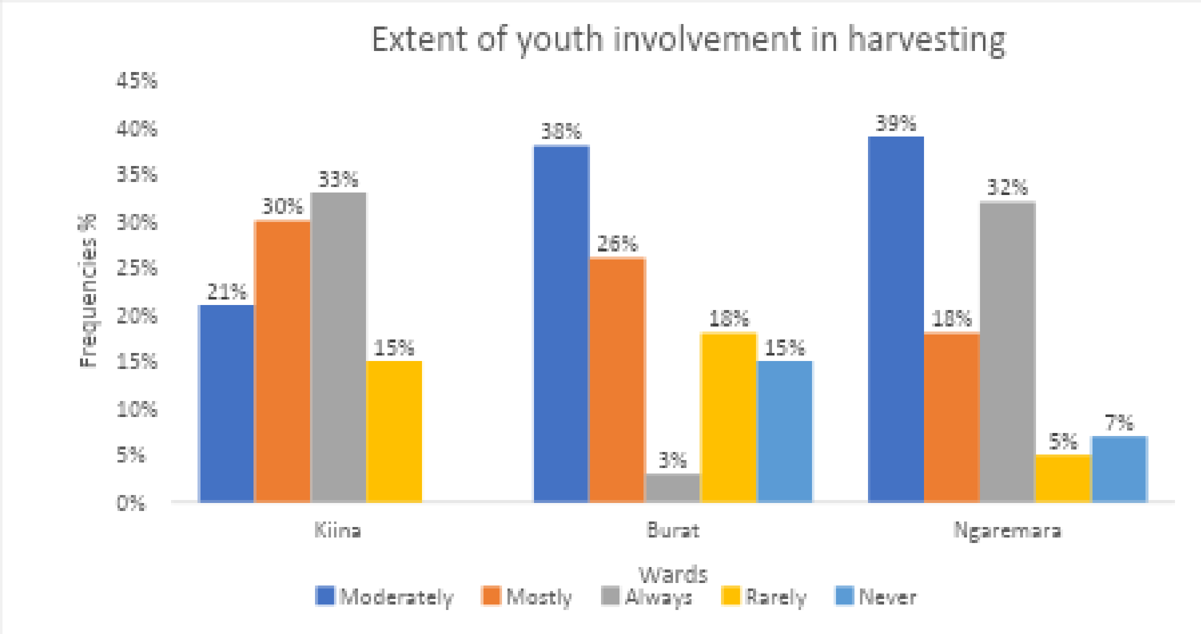

Figure 9: Youth Involvement in Harvesting by Ward

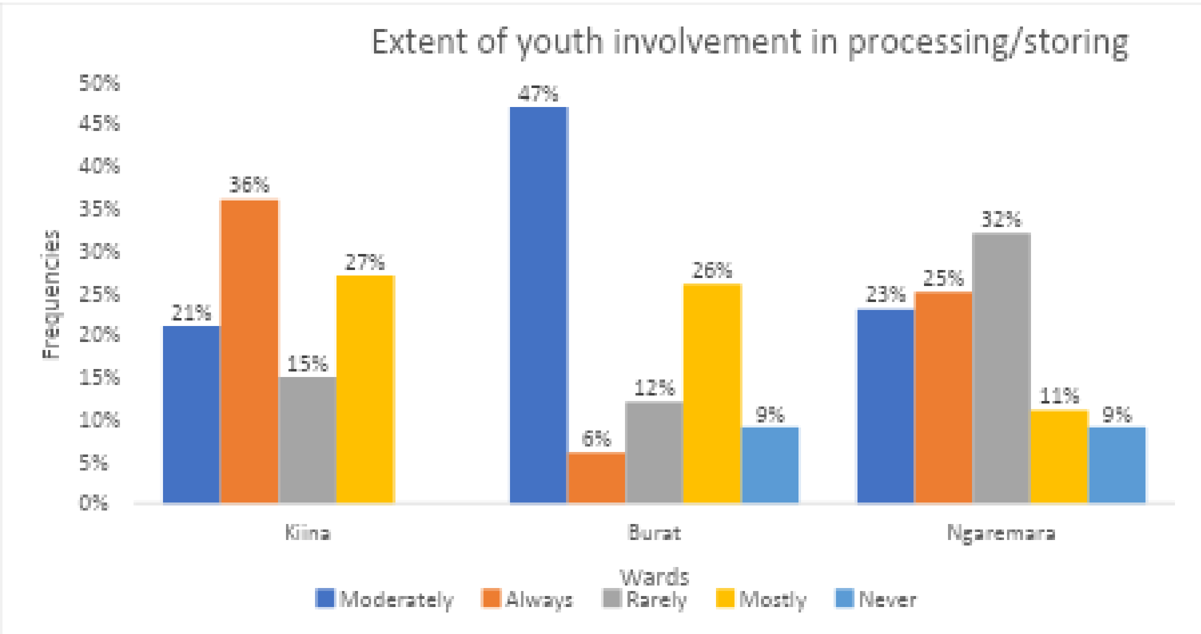

Figure 10: Youth Involvement in Processing by Ward

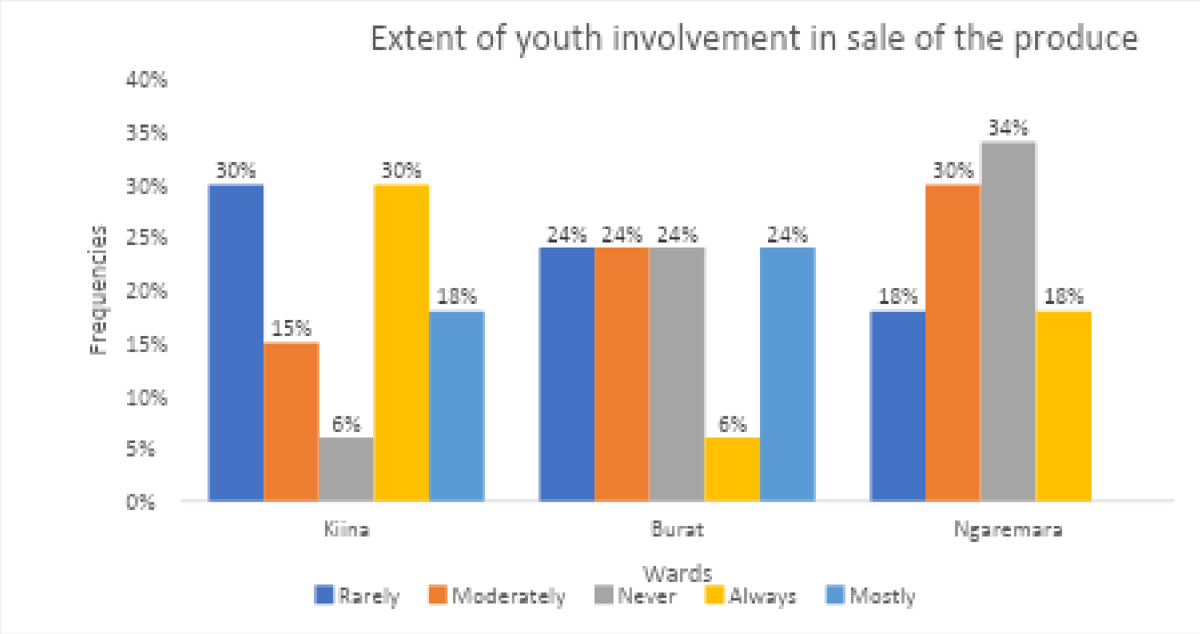

Figure 11: Youth Involvement in the Sale of Produce by Ward

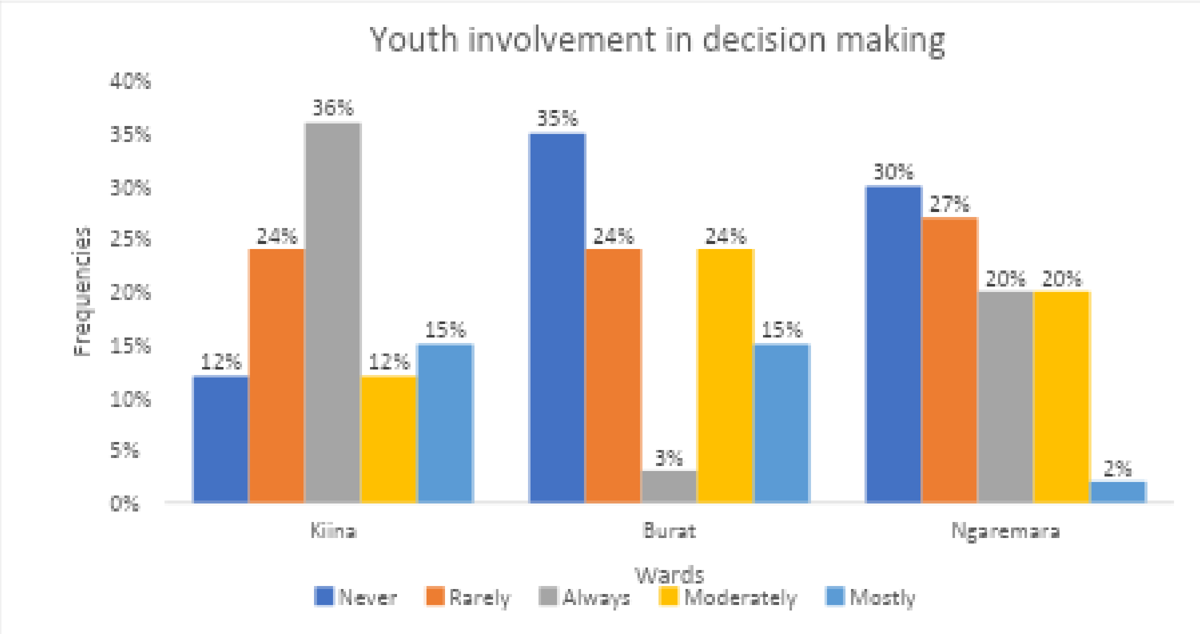

Figure 12: Youth Involvement in decision making on crop use by Ward

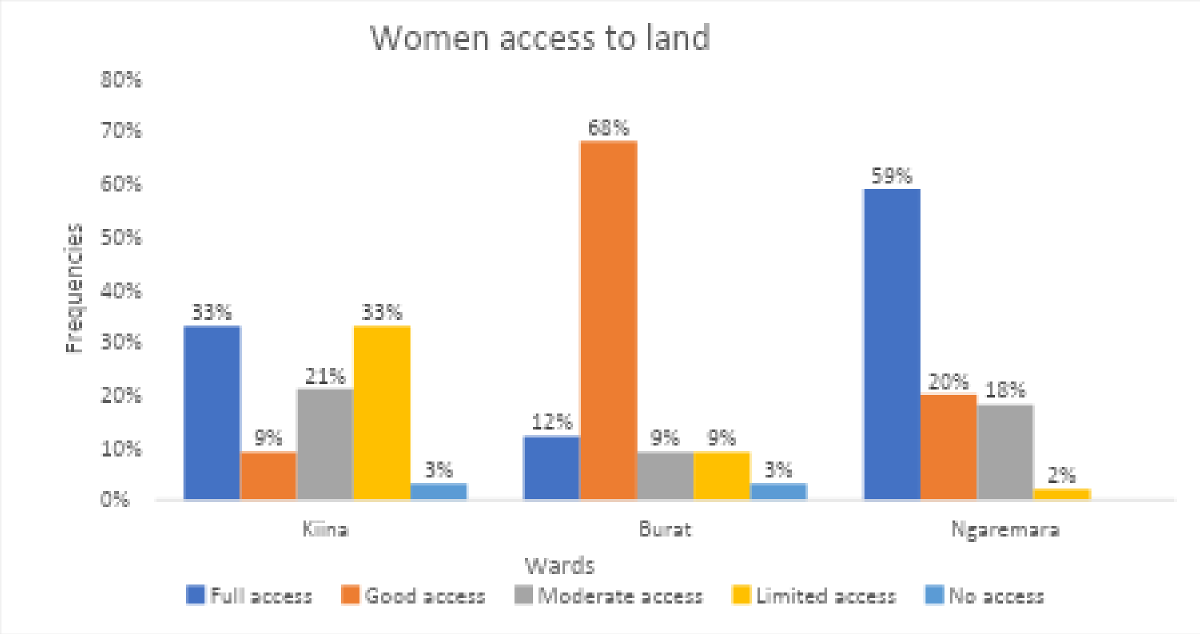

Figure 13: Women Access to land for cultivation by Ward

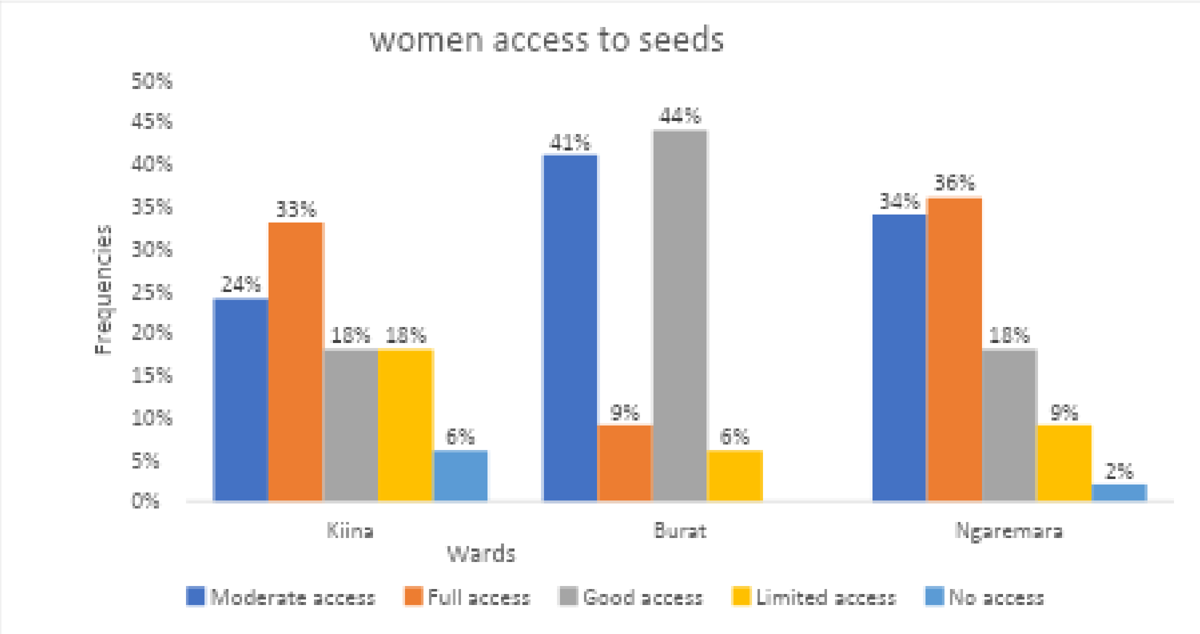

Figure 14: Women Access to seeds (Ward-Variation)

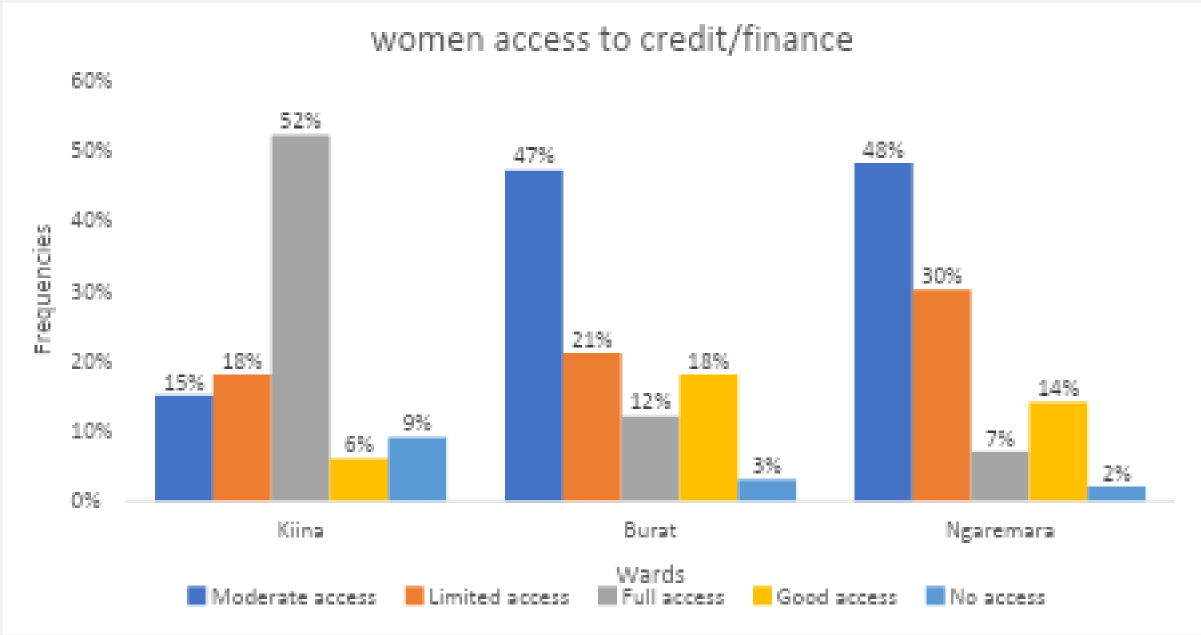

Figure 15: Women Access to credit/finance by Ward

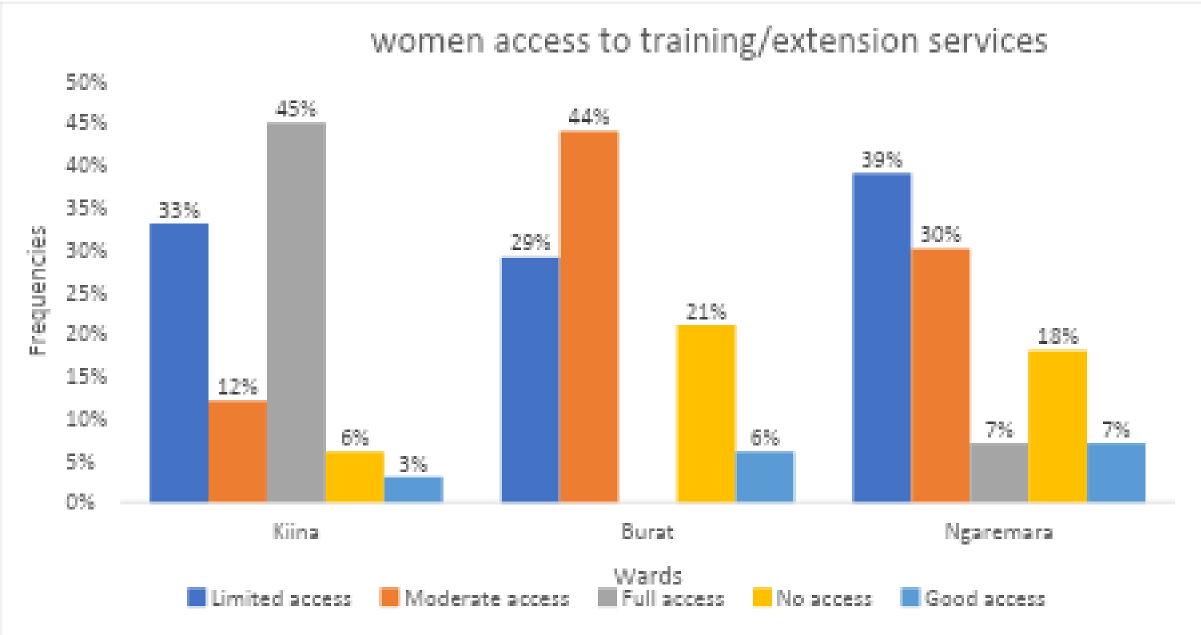

Figure 16: Women Access to training/extension services by Ward

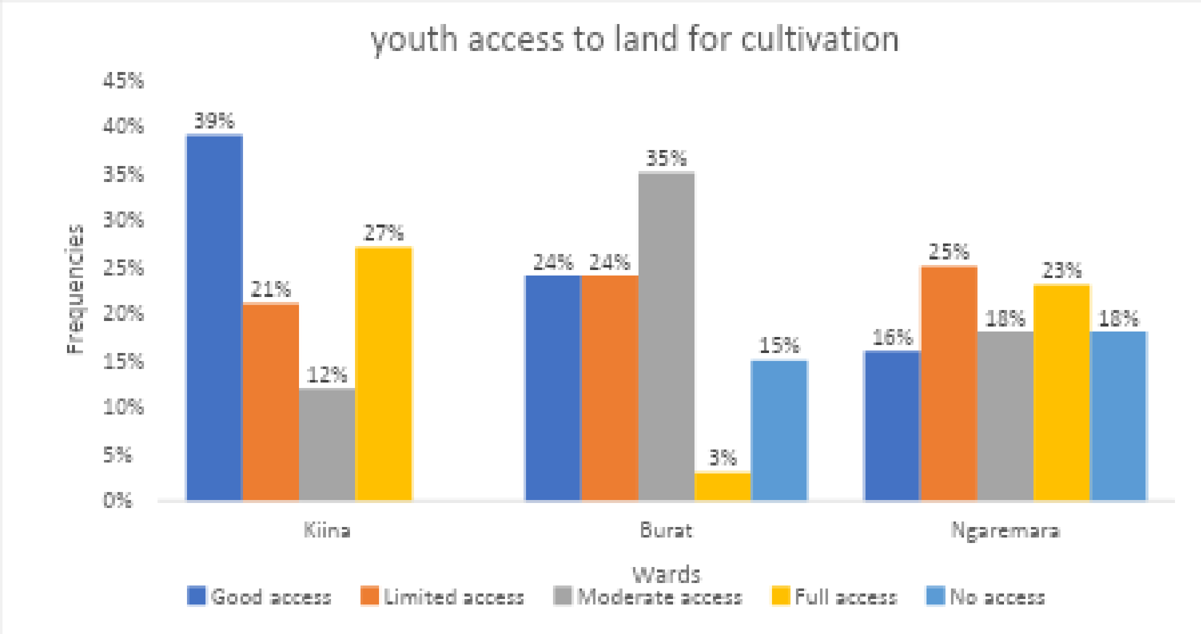

Figure 17: Youth Access to land for cultivation by Ward

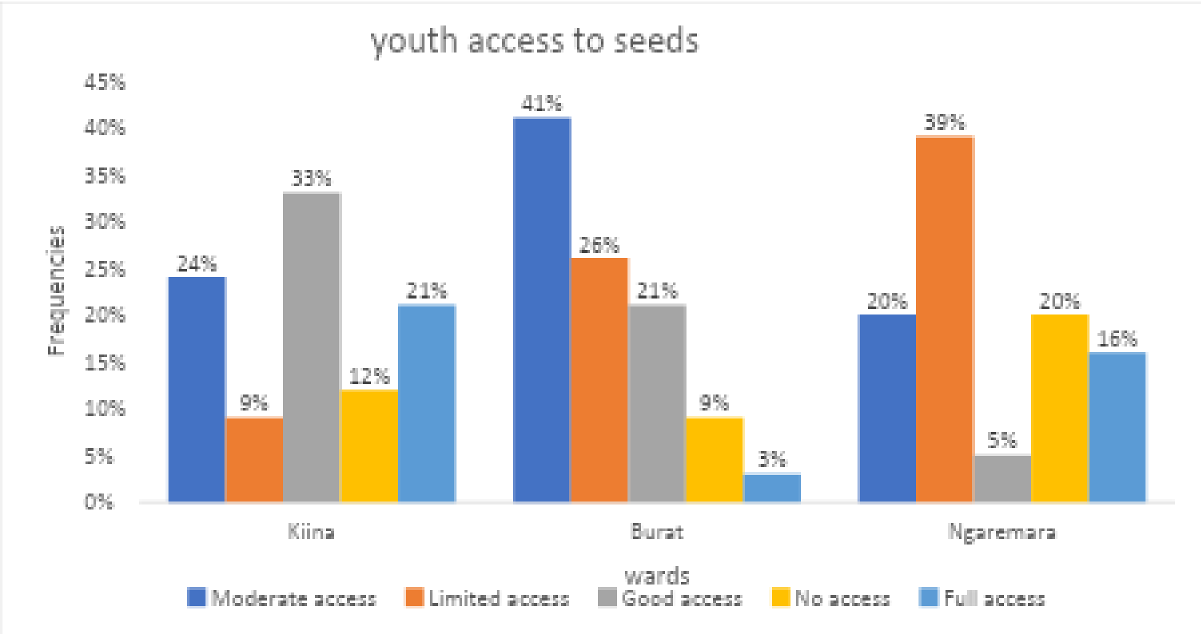

Figure 18: Youth Access to seeds by Ward

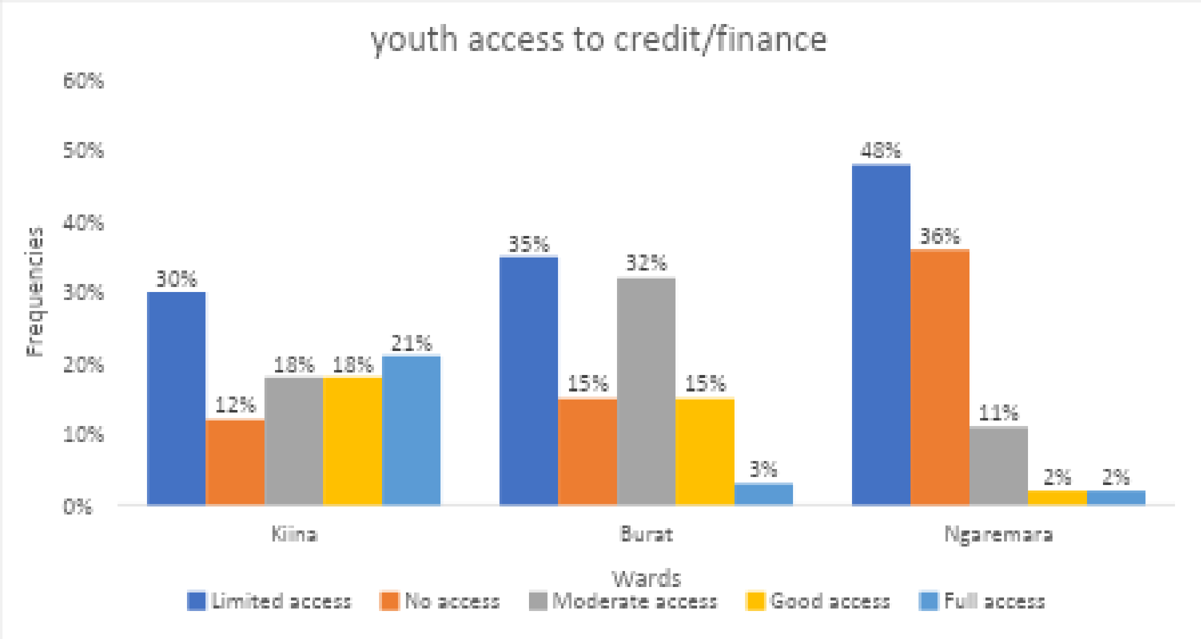

Figure 19: Youth Access to credit/finance by Ward

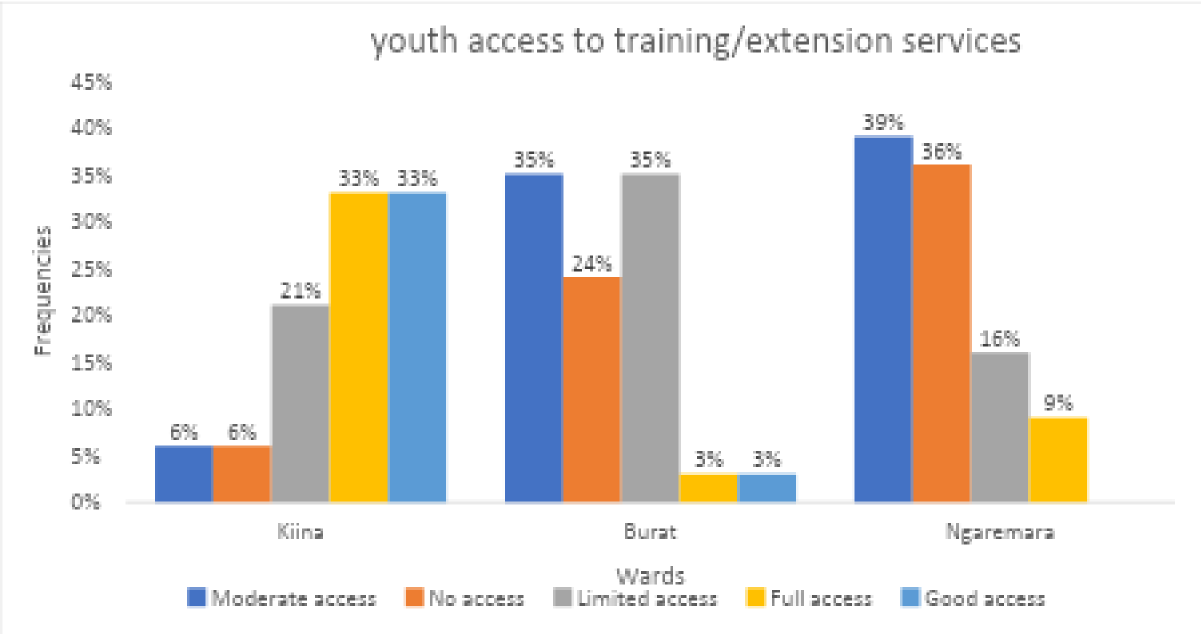

Figure 20: Youth Access to training/extension services by Ward

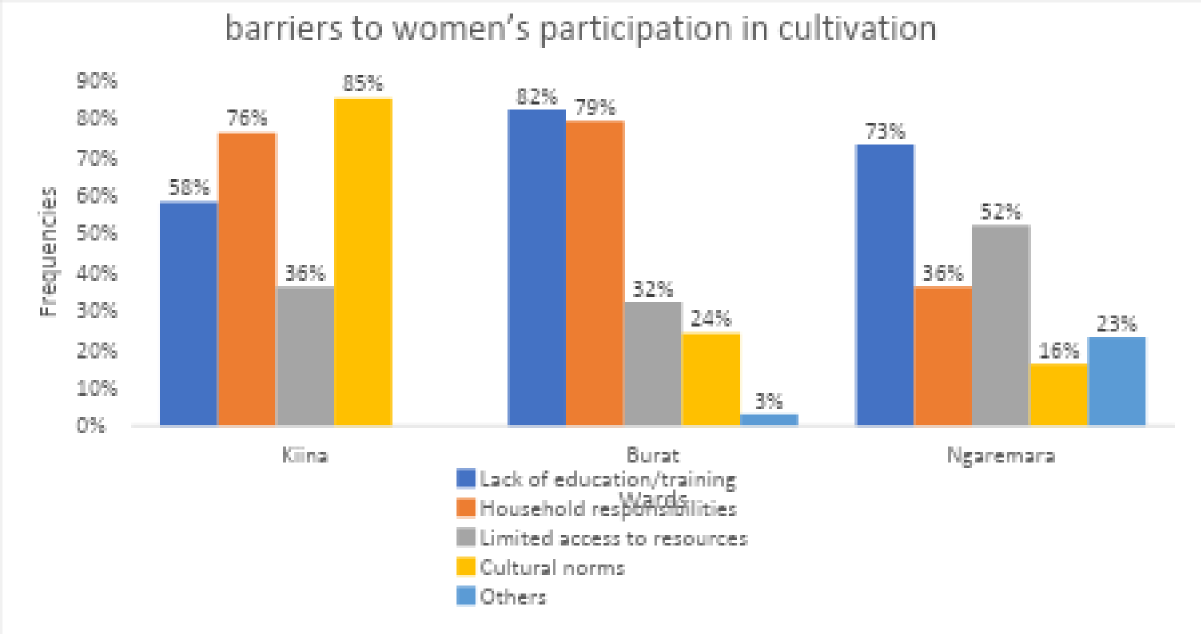

Figure 21: Barriers to women participation in sorghum/teff cultivation by Ward

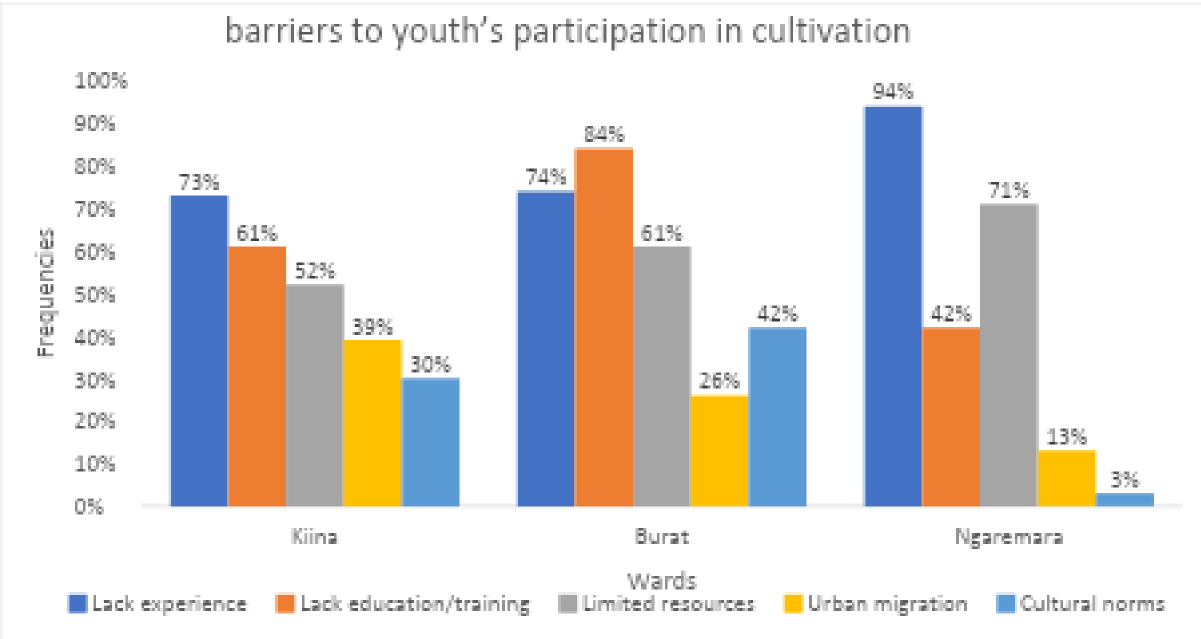

Figure 22: Barriers to youth participation in sorghum/teff cultivation by Ward

Table 1: Ward Differences in Community Perception of Women's Involvement in Sorghum and Teff Activities (Likelihood Ratio Test of Perception)

Ward	Low Perception N (%)	High Perception N (%)	Total N
Kiina	7 (21.2%)	26 (78.8%)	33
Burat	2 (2.6%)	75 (96.2%)*	77*
Ngaremara	3 (6.8%)	41 (93.2%)*	44*
Total	12 (10.8%)	99 (89.2%)	111

Kiina recorded a lower proportion of high perception (78.8%) compared to Burat and Ngaremara (93.6%).

Table 2: Ward Differences in Community Perception of Women's Involvement in Sorghum and Teff Activities (Likelihood Ratio Test of Perception)

Ward	Low Perception N (%)	High Perception N (%)	Total N
Kiina	6 (18.2%)	27 (81.8%)	33
Burat	17 (50.0%)	17 (50.0%)	34
Ngaremara	18 (40.9%)	26 (59.1%)	44
Total	41 (36.9%)	70 (63.1%)	111

Note: Kiina recorded the highest proportion of positive perception (81.8%), followed by Ngaremara (59.1%), while Burat showed the lowest and most evenly split responses (50.0% high vs 50.0% low). The Likelihood Ratio test confirmed the result ($\chi^2(2)=8.252$, $p=.016$).

Table 3: Activity-Level Means: Women's Involvemen by Ward

Activity	Kiina M (SD)	Burat M (SD)	Ngaremara M (SD)	Total M (SD)
Land preparation	3.36 (1.432)	3.68 (0.727)	4.36 (0.865)	3.86 (1.111)
Planting	3.94 (1.273)	3.91 (0.712)	4.30 (0.904)	4.07 (0.988)
Harvesting	4.03 (1.237)	4.06 (0.776)	4.02 (1.045)	4.04 (1.026)
Processing/storing	4.18 (0.950)	3.85 (0.744)	3.89 (1.125)	3.96 (0.972)
Selling of produce	3.76 (1.501)	3.56 (0.927)	3.59 (1.300)	3.63 (1.257)

Decision-making	3.55 (1.325)	3.38 (1.101)	3.70 (1.153)	3.56 (1.188)

Note: Land preparation showed the greatest ward variation (range: 4.36 to 3.36); harvesting was most uniform (range: 4.06 to 4.02). Decision-making recorded the lowest overall mean (M=3.56).

Table 4: Activity-Level Means: Youth Involvement by Ward

Activity	Kiina M (SD)	Burat M (SD)	Ngaremara M (SD)	Total M (SD)
Land preparation	3.73 (1.069)	3.03 (1.114)	3.77 (1.217)	3.53 (1.182)
Planting	3.64 (1.113)	2.88 (1.225)	3.36 (1.059)	3.30 (1.157)
Harvesting	3.82 (1.074)	2.85 (1.077)	3.64 (1.183)	3.45 (1.181)
Processing/storing	3.85 (1.093)	3.09 (0.996)	3.11 (1.351)	3.32 (1.215)
Selling of produce	3.36 (1.365)	2.65 (1.252)	2.50 (1.439)	2.80 (1.400)
Decision-making	3.39 (1.499)	2.26 (1.189)	2.57 (1.469)	2.72 (1.460)

Note: Kiina recorded the highest mean on all activities. Youth selling (M=2.80) and decision-making (M=2.72) were the only items below the scale midpoint of 3.0.

Annex 3: Agricultural Production & Land Use

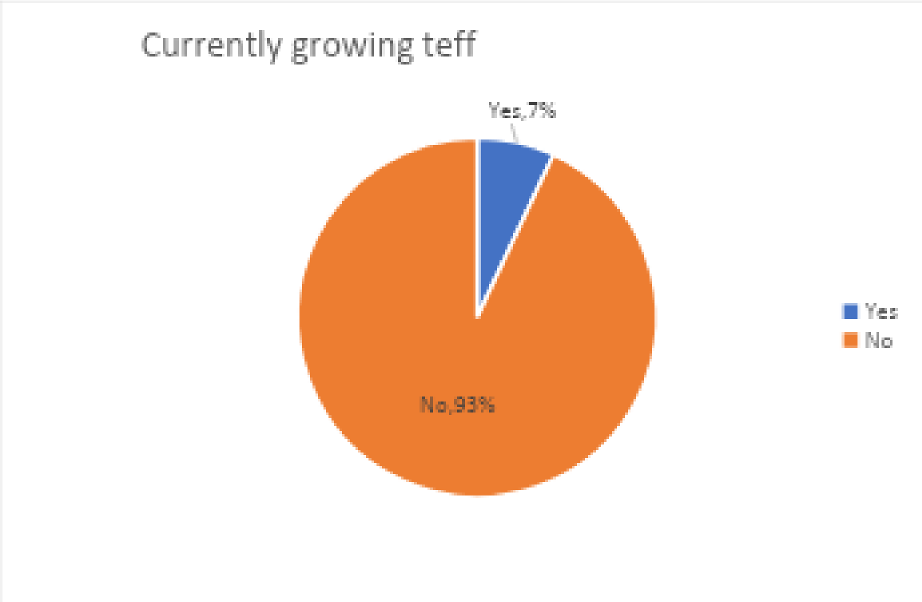

Figure 1: Households currently growing Teff

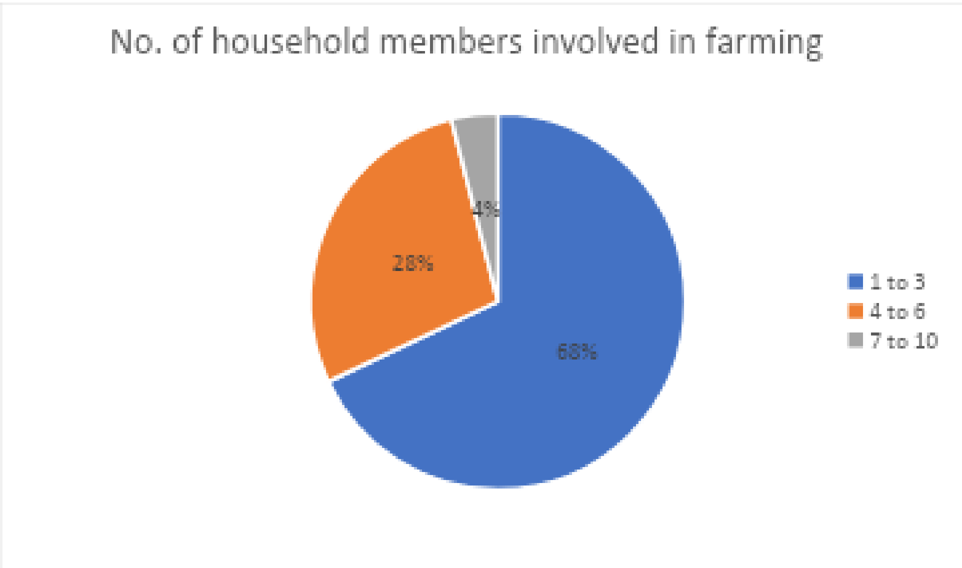

Figure 2: Proportion of household members involved in farming

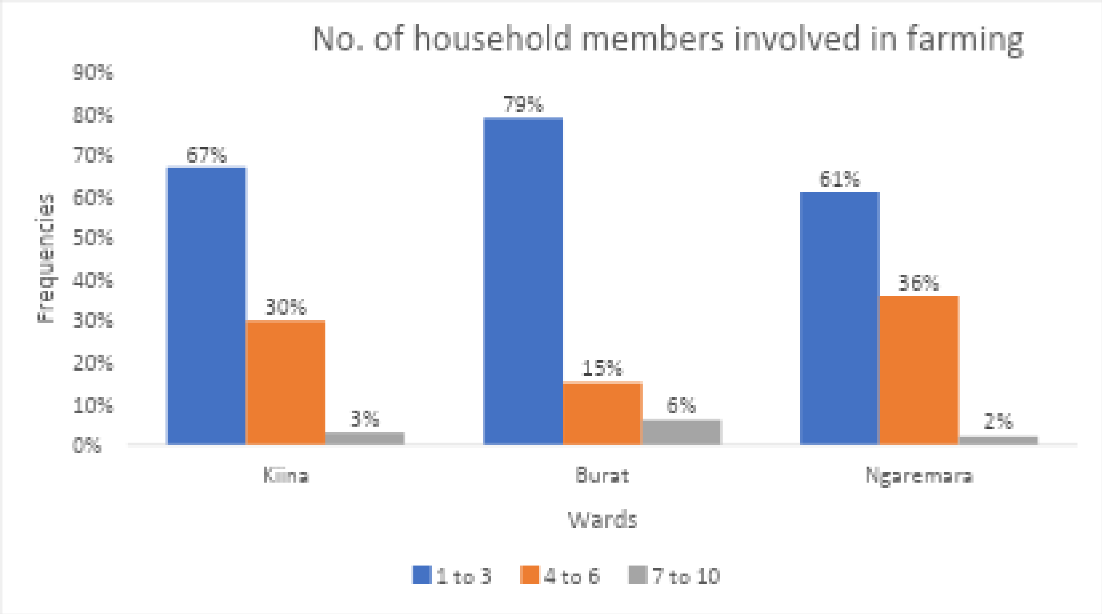

Figure 3: Proportion of household members involved in farming (ward level)

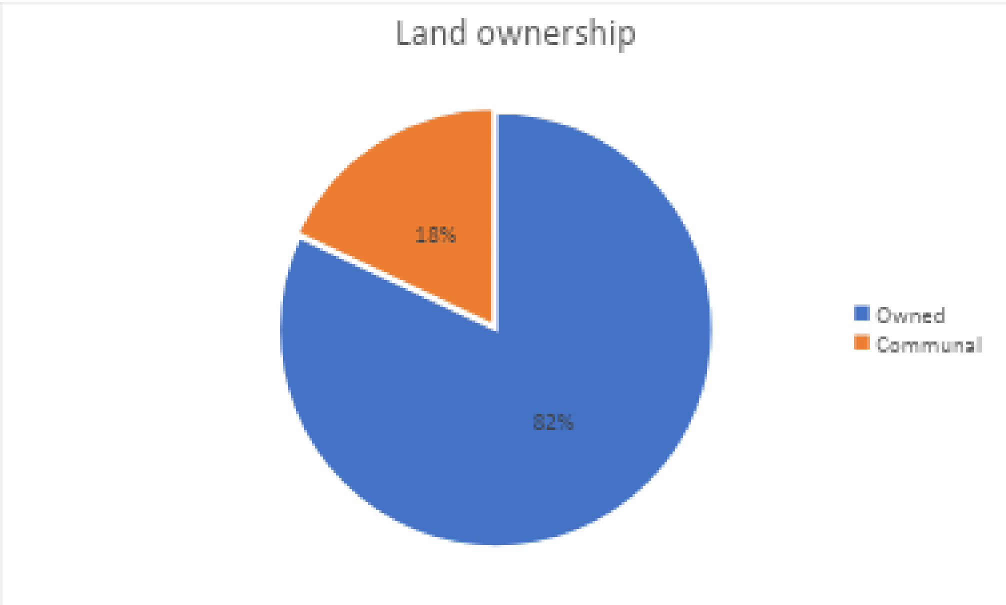

Figure 4:Land ownership

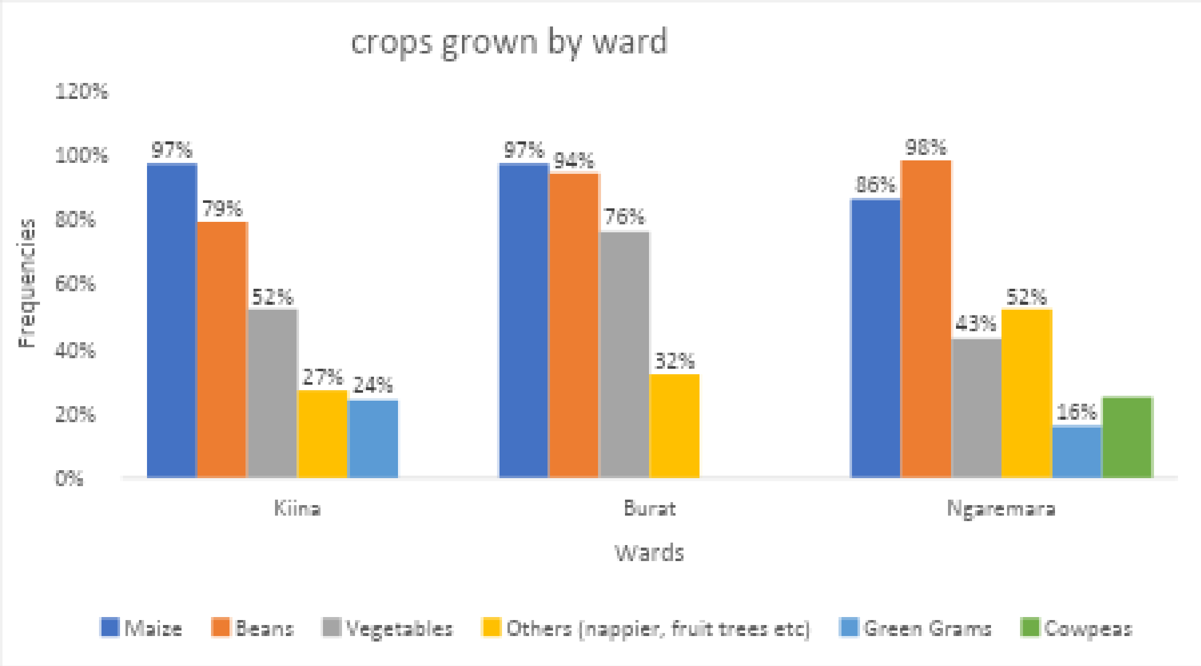

Figure 5: Other Crops Grown by Respondents (Ward Level)

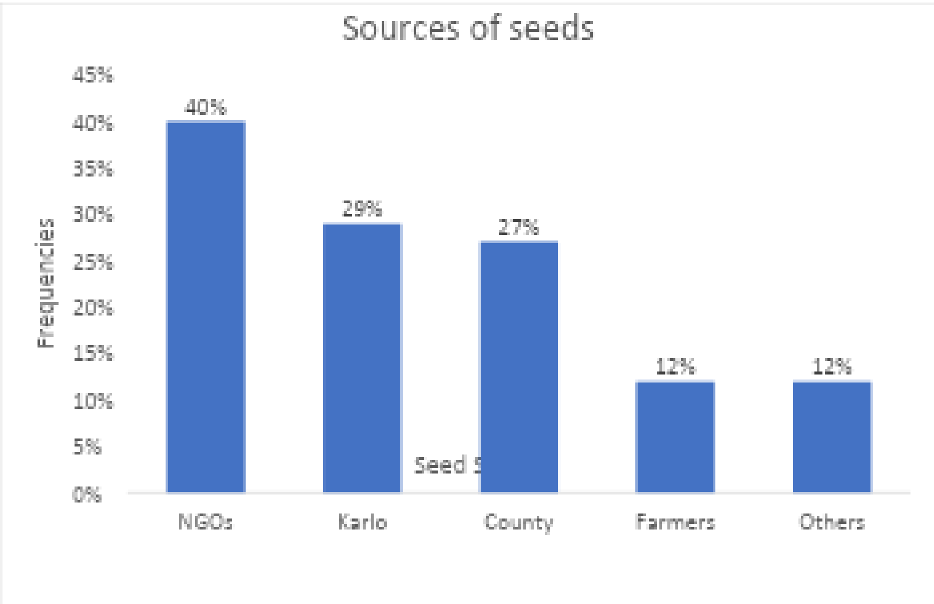

Figure 6: Sources of sorghum/teff seeds

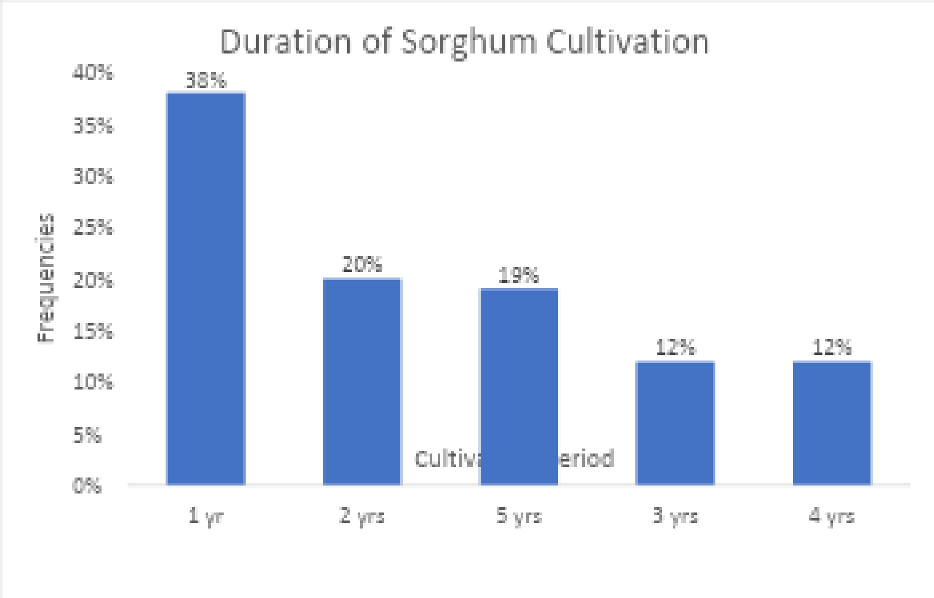

Figure 7: Duration of sorghum cultivation

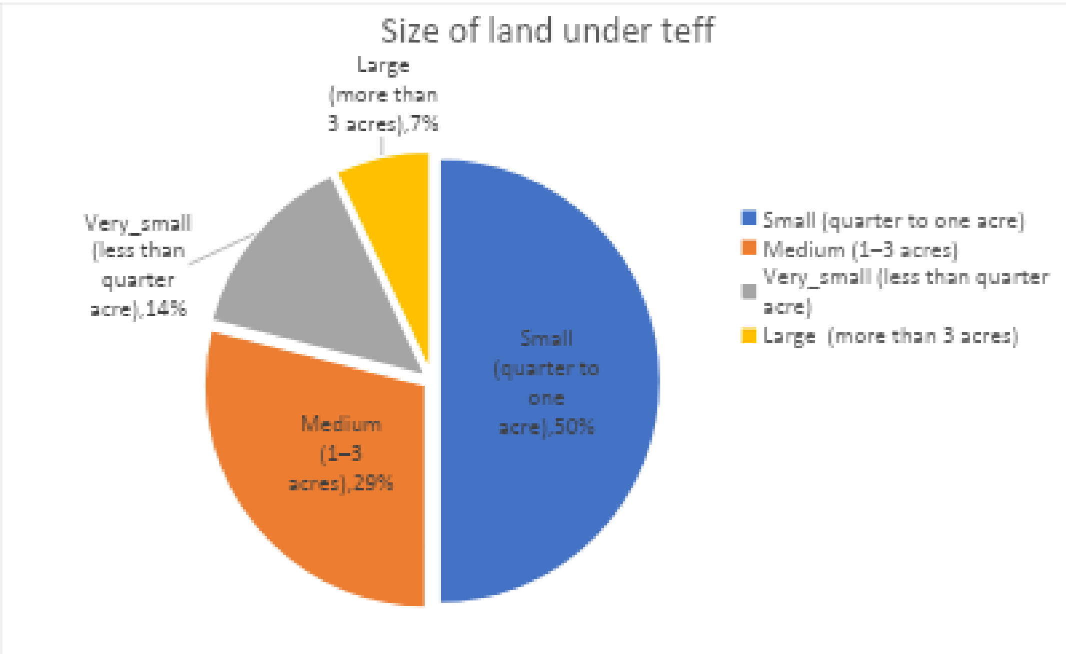

Figure 8: Land allocated to teff cultivation

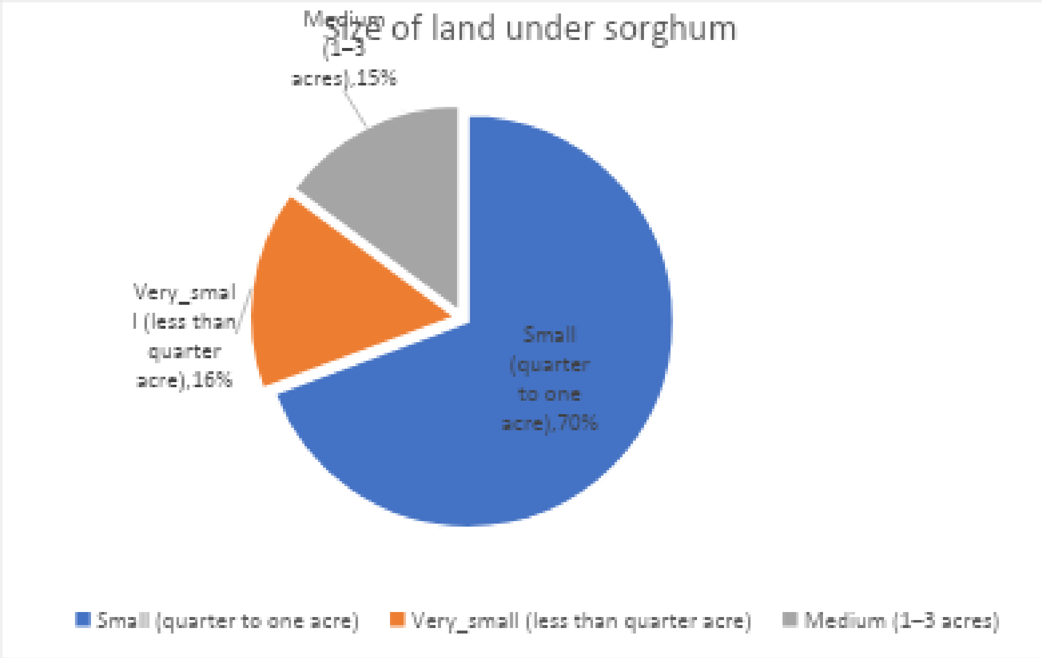

Figure 9: Land allocated to sorghum cultivation

Table 1:Ward Differences in Teff Adoption (Chi-Square)

Test	Value	df	p-value
Pearson Chi-Square (3-ward)	6.997	2	.030
Fisher's Exact (Kiina vs Burat+Ngaremara)	—	1	.026
Cramér's V (collapsed)	0.228	—	.016

Interpretation: The wards were collapsed for 2×2 comparison (Kiina versus Burat+Ngaremara combined) and used as the primary test. Fisher's Exact test indicated a significant difference, p = .026, V = .228 (moderate effect), confirming that Kiina respondents were significantly more likely to be growing teff.

Annex 4: Livelihoods & Economic Sustainability

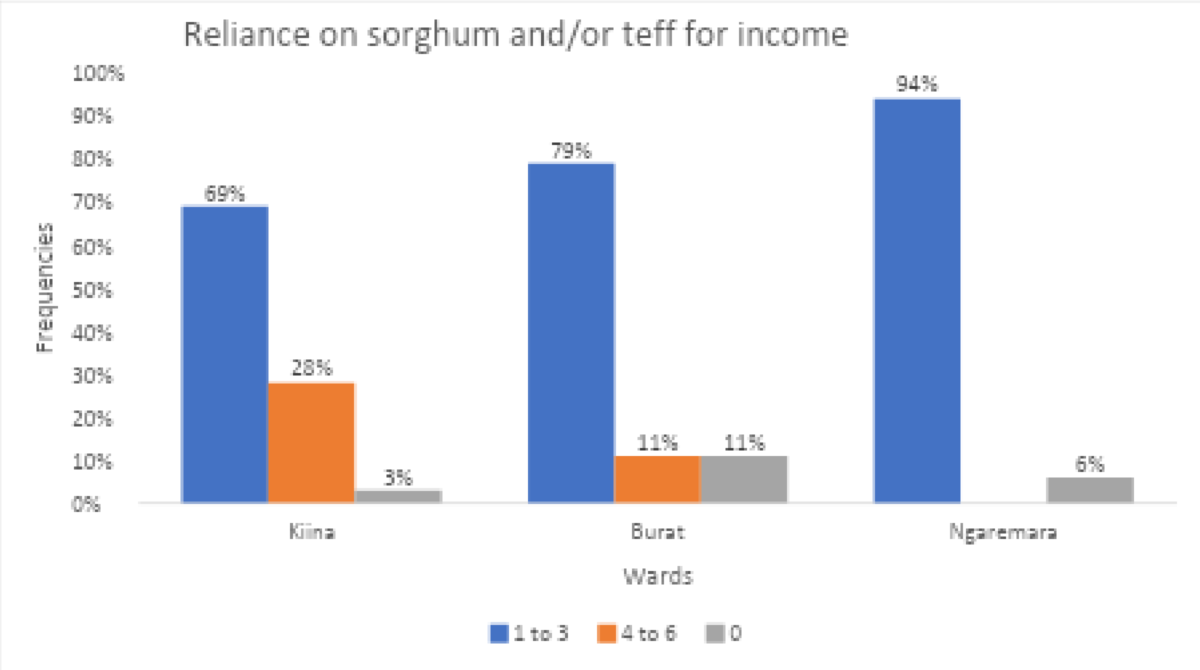

Figure 1: Number of months households rely on sorghum and/or teff for income

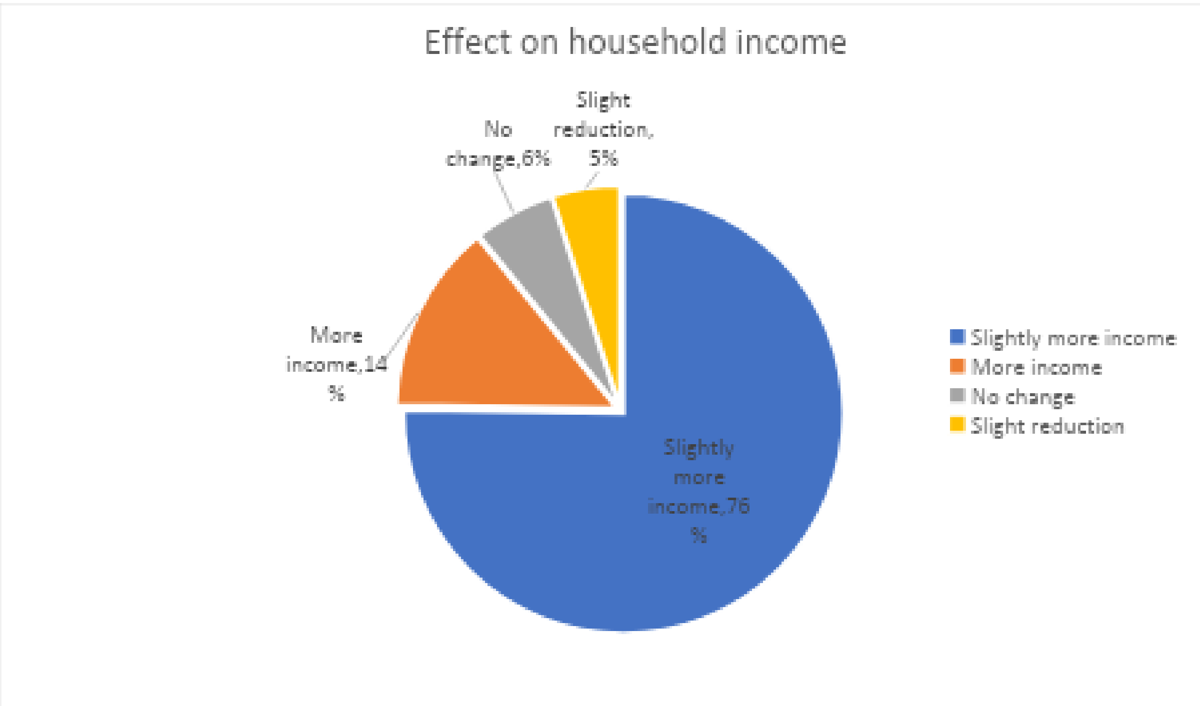

Figure 2: Effect of sorghum/teff cultivation on household Income

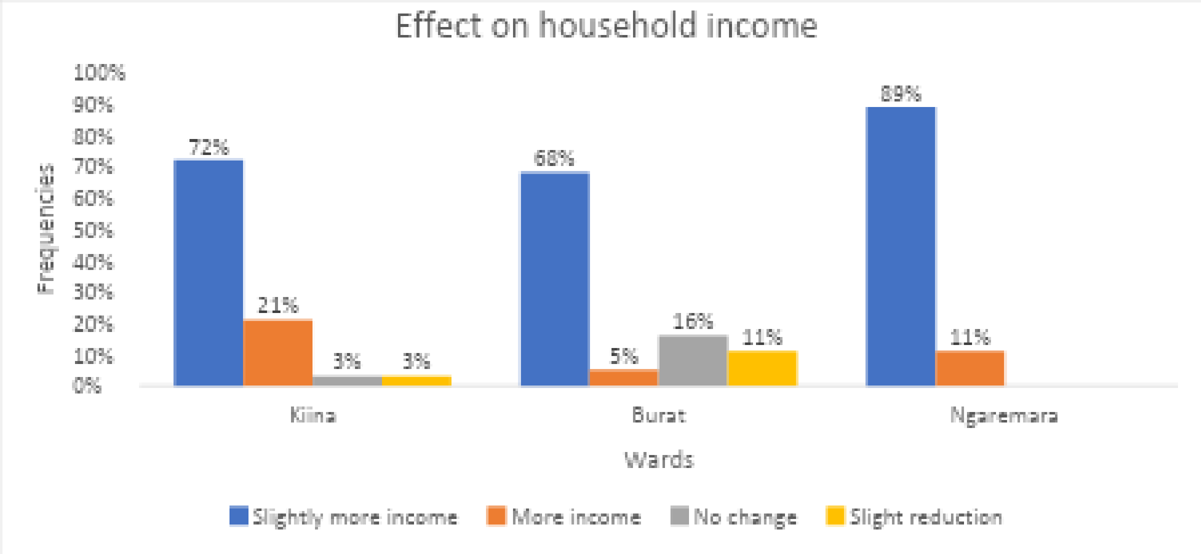

Figure 3: Effect of sorghum/teff cultivation on household Income (ward level variation)

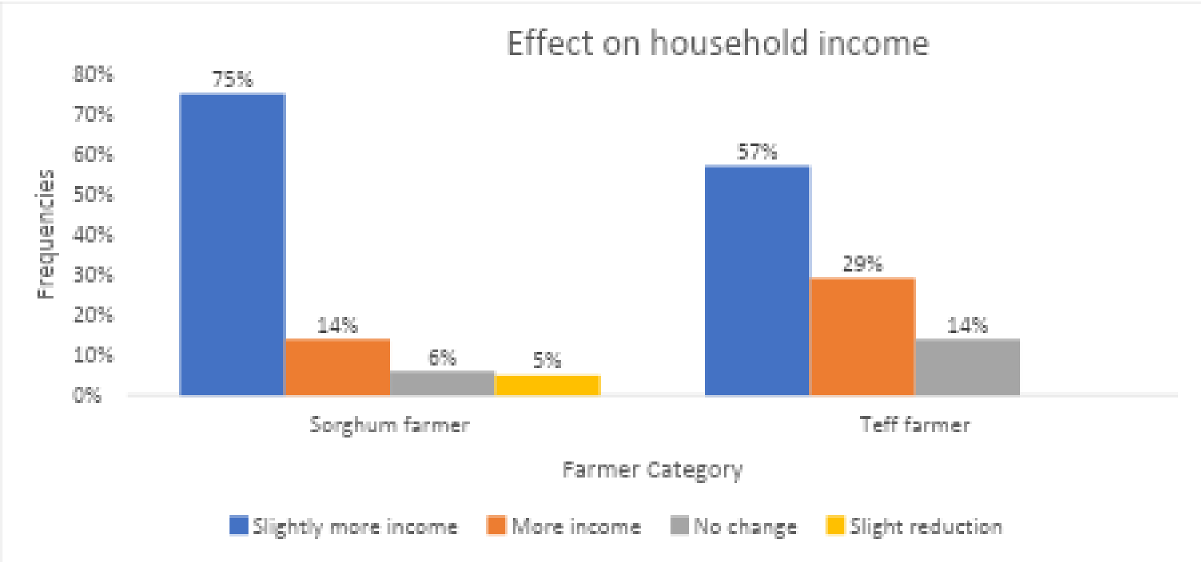

Figure 4: Effect on household Income (Crop level differentiation)

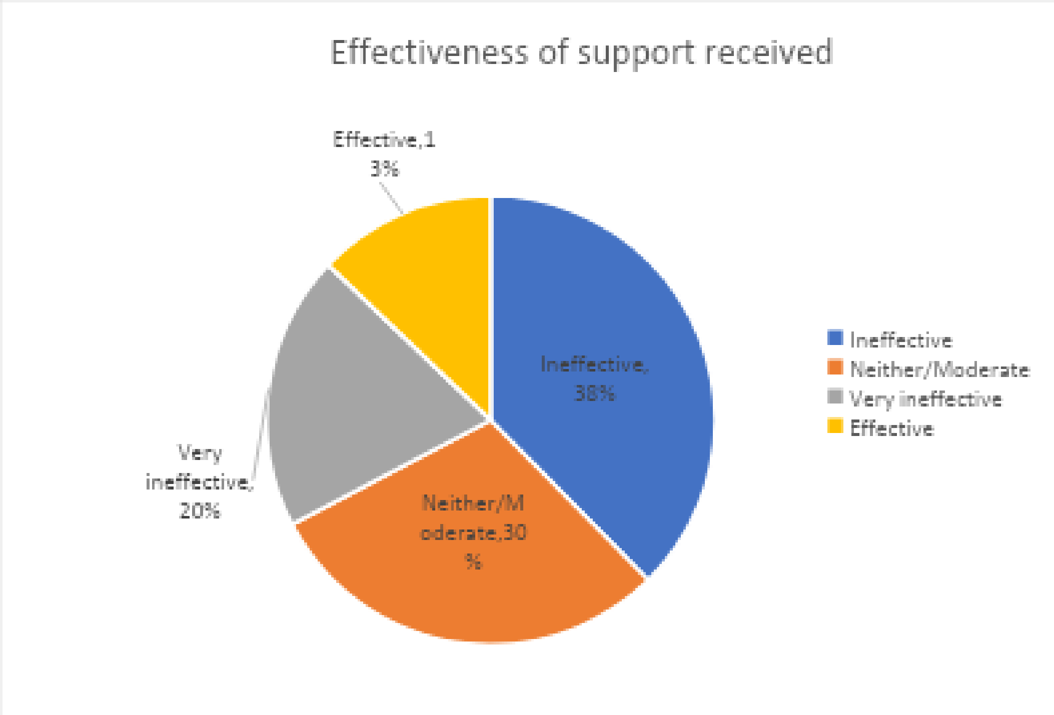

Figure 5: Effectiveness of support received

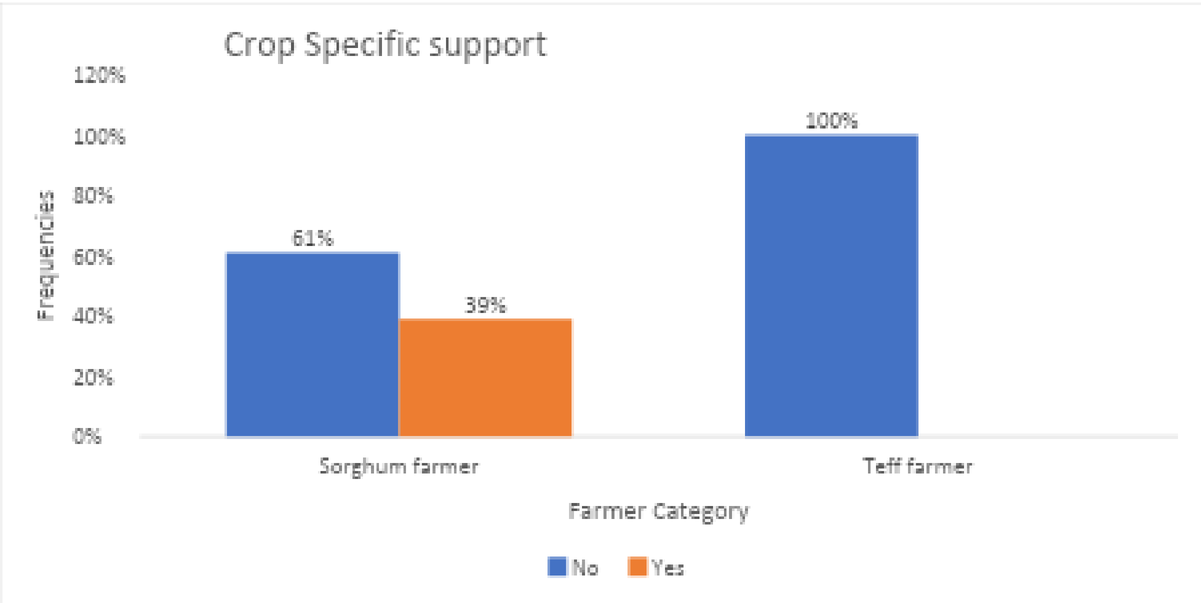

Figure 6: Support offered towards cultivation of sorghum/teff

Annex 5: Food Security Impacts of Sorghum and Teff Cultivation

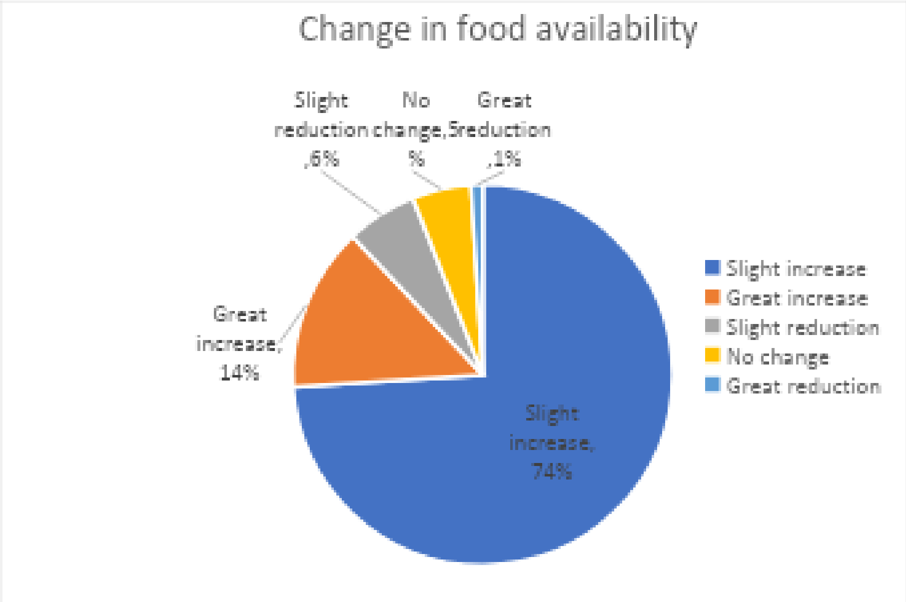

Figure 1: Change in Household Food Availability Attributed to Cultivation of Sorghum and Teff

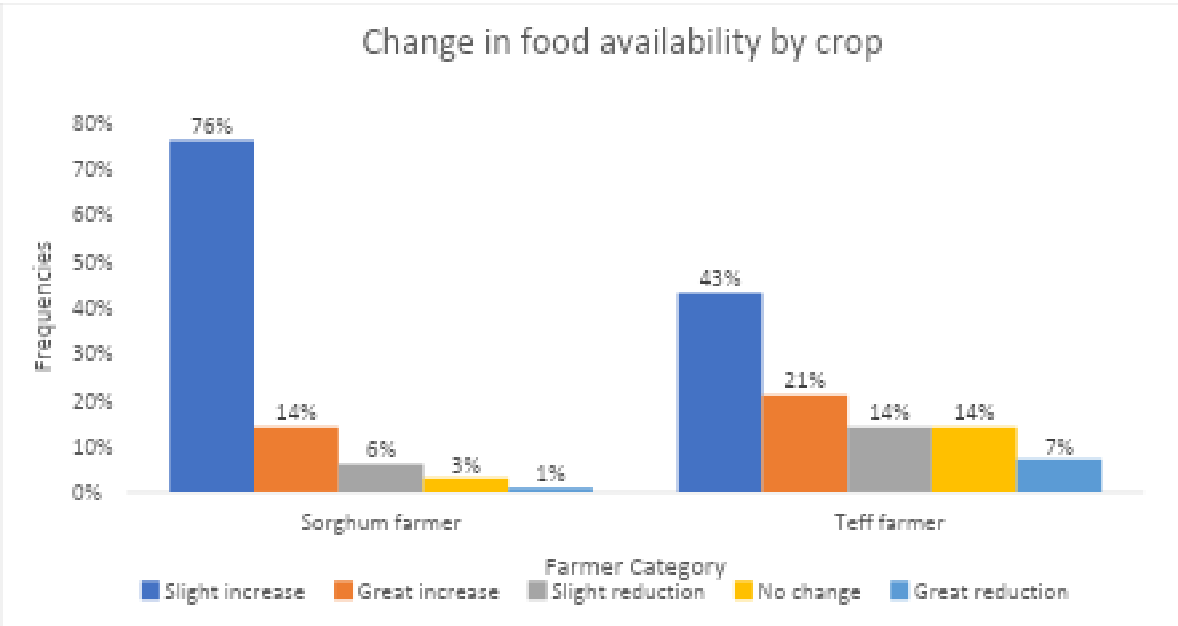

Figure 2: Change in Household Food Availability by crop

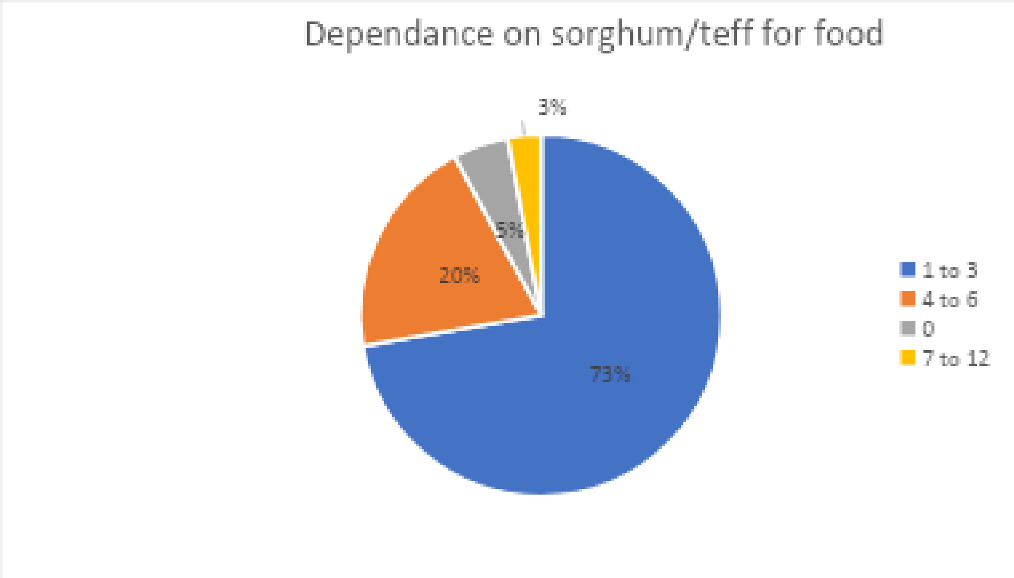

Figure 3: Duration of Household Reliance on Sorghum and Teff for Food Supply

Annex 6: Feed Security & Crop–Livestock Integration

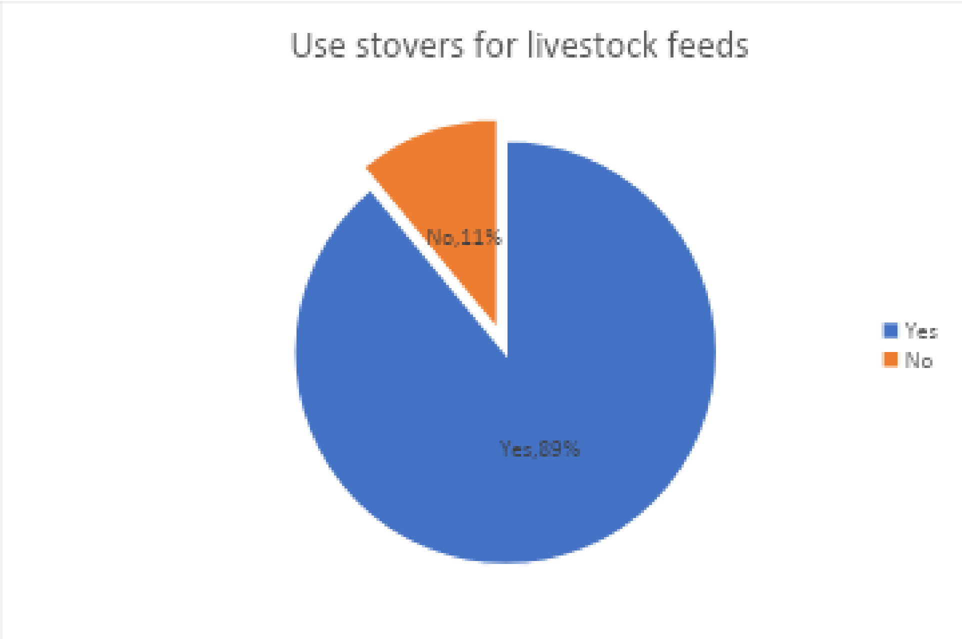

Figure 1:Household use of stovers for livestock feeds

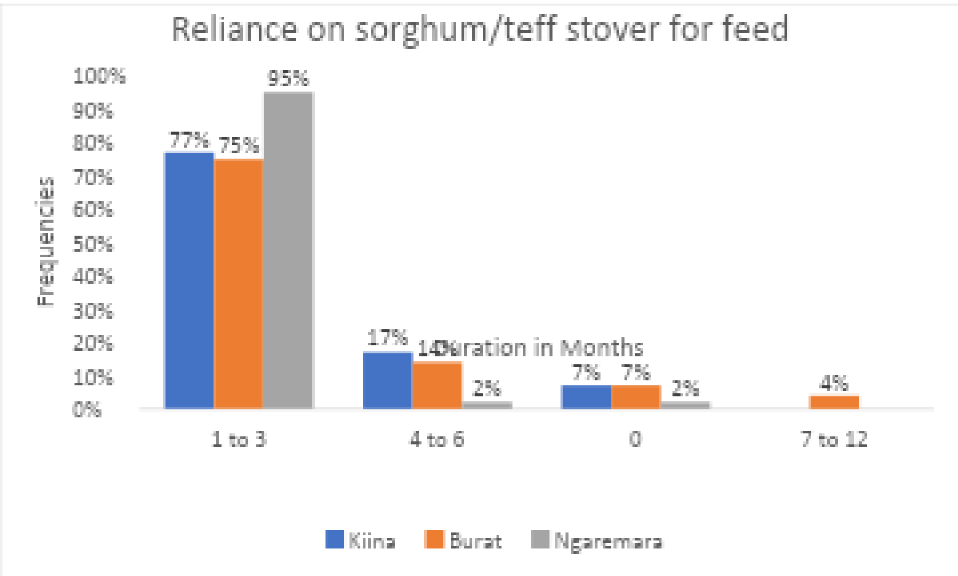

Figure 2: Months relied on sorghum/teff stover for feed

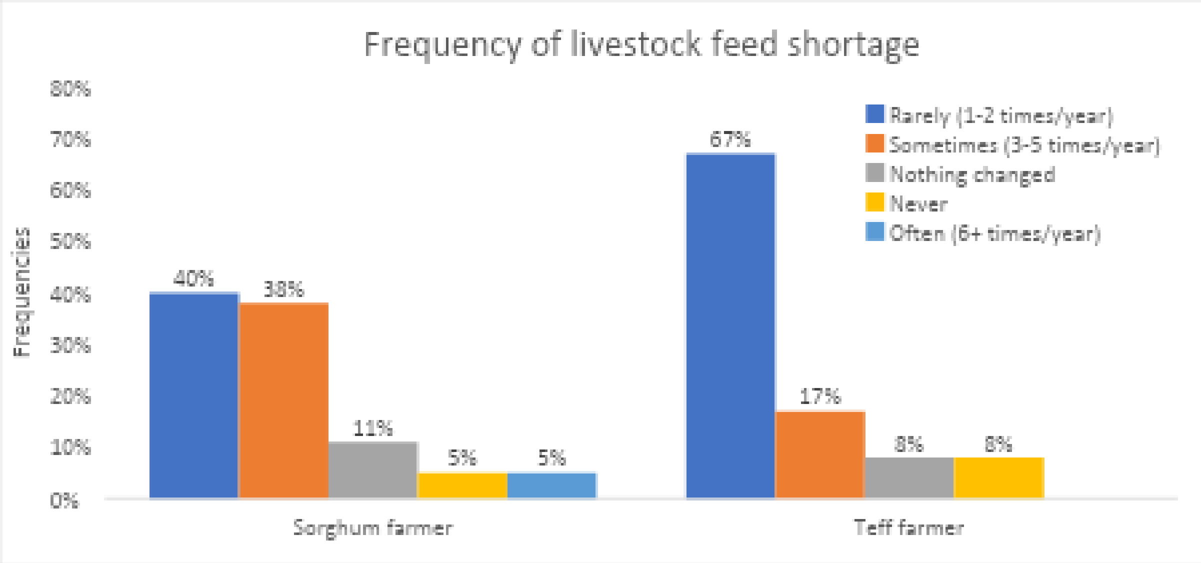

Figure 3: Frequency of livestock feed shortages (Crop specific)

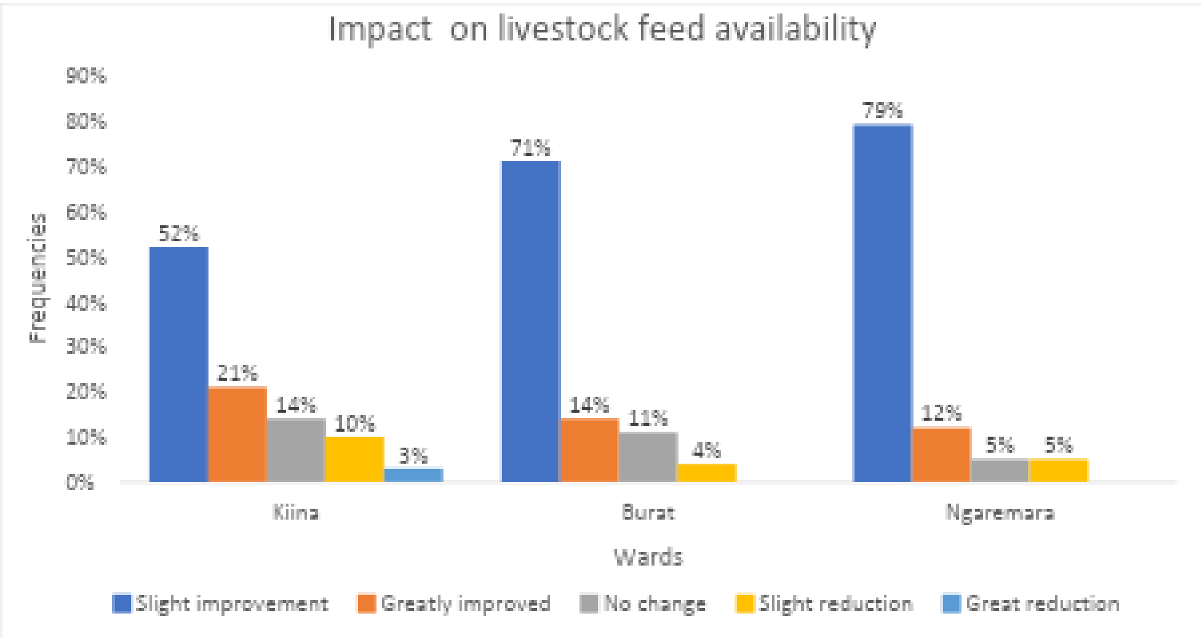

Figure 4: Impact of sorghum/teff cultivation on livestock feed availability (Ward level specific)

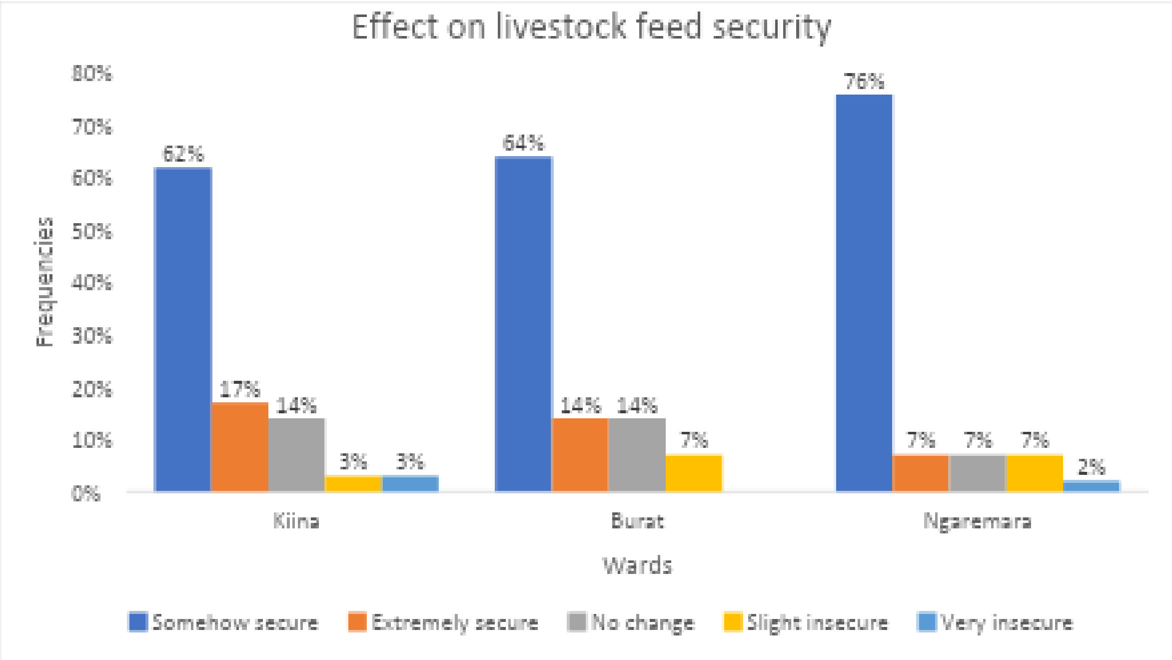

Figure 5: Effect of sorghum/teff cultivation on feed security

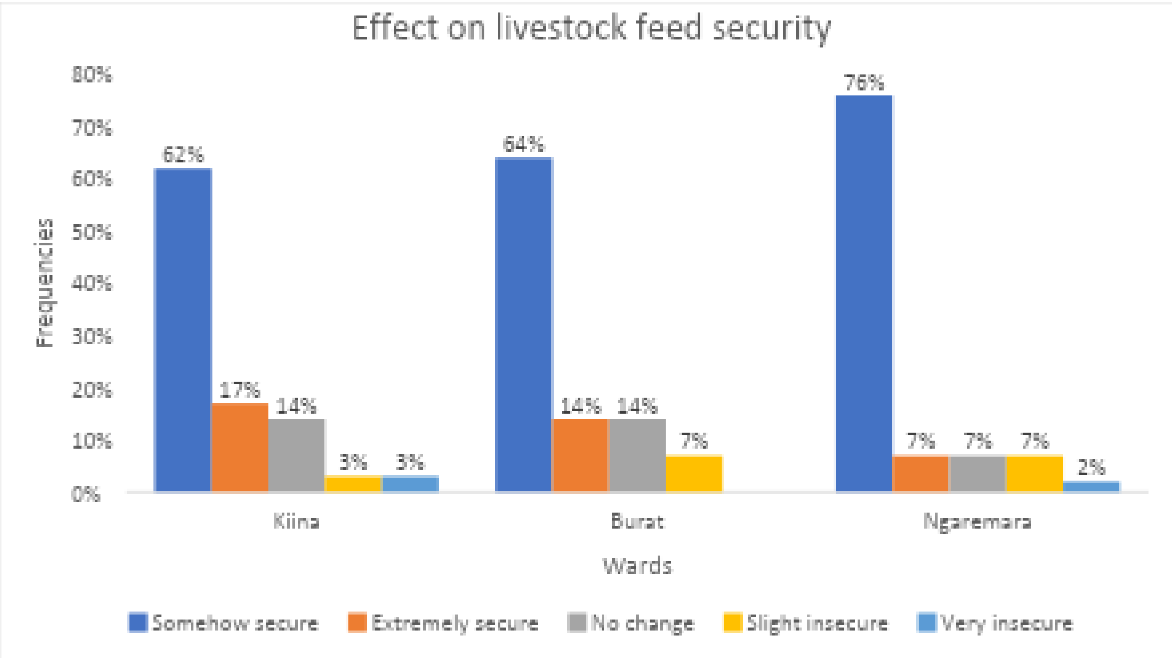

Figure 6: Effect of sorghum/teff cultivation on livestock feed security (Ward variation)

Annex 7: Environmental and climate effects of sorghum/teff cultivation

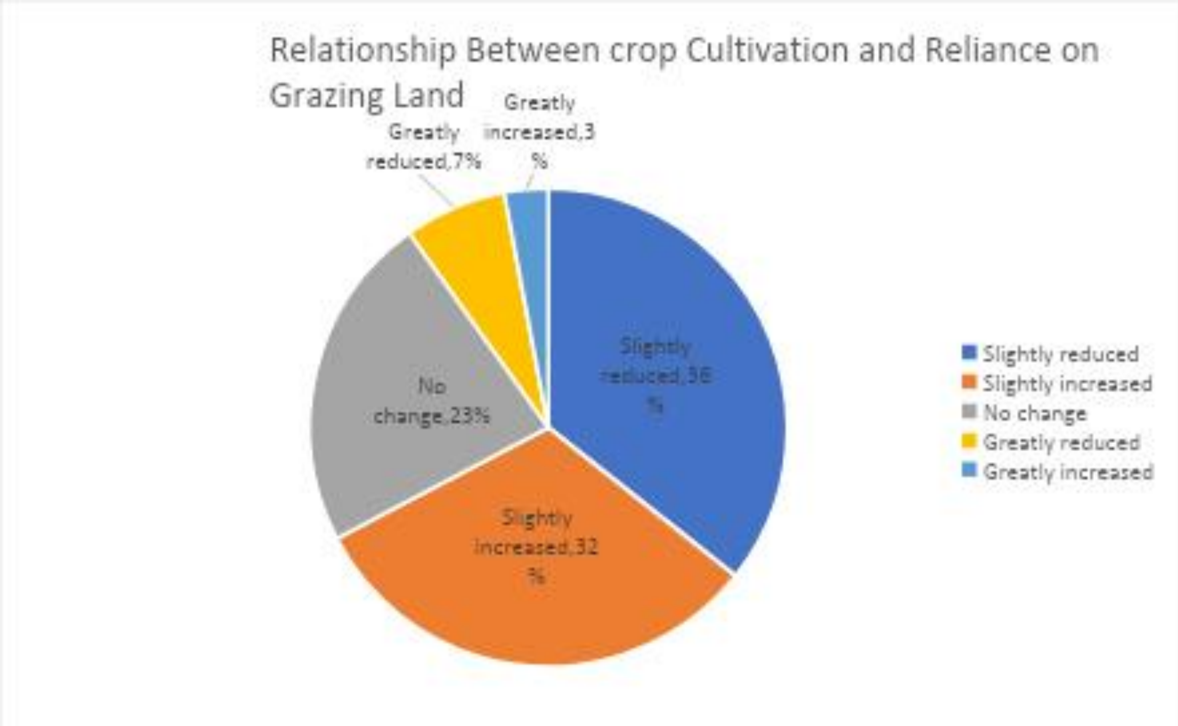

Figure 1: Relationship Between Sorghum/Teff Cultivation and Reliance on Grazing Land

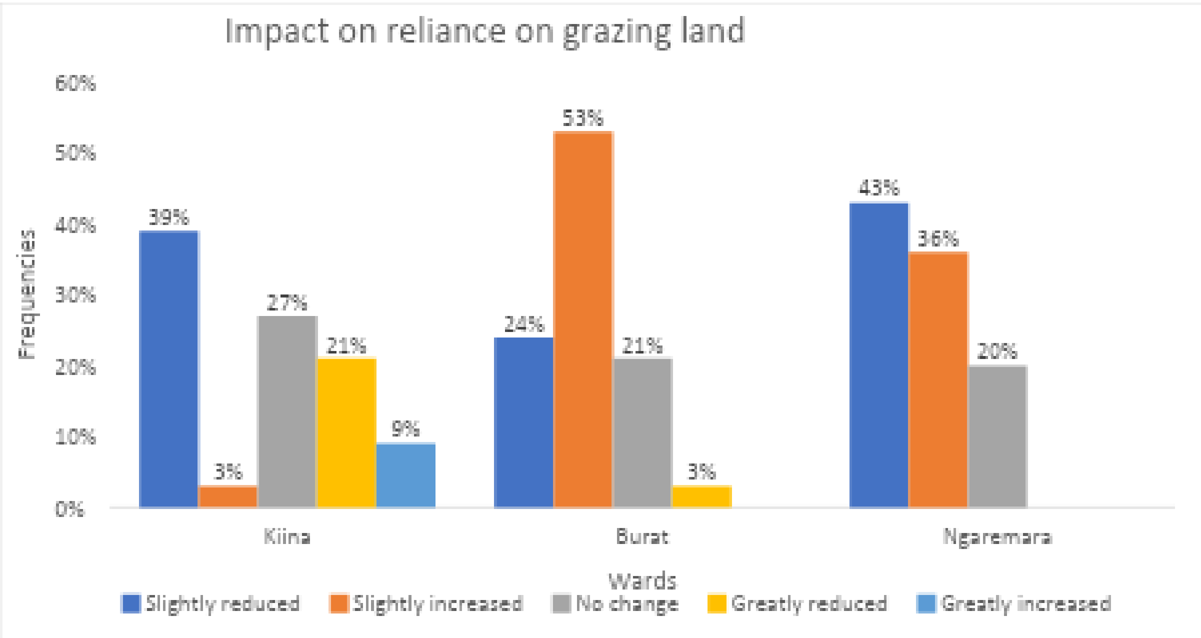

Figure 2: Relationship Between Sorghum/Teff Cultivation and Reliance on Grazing Land(Ward level)

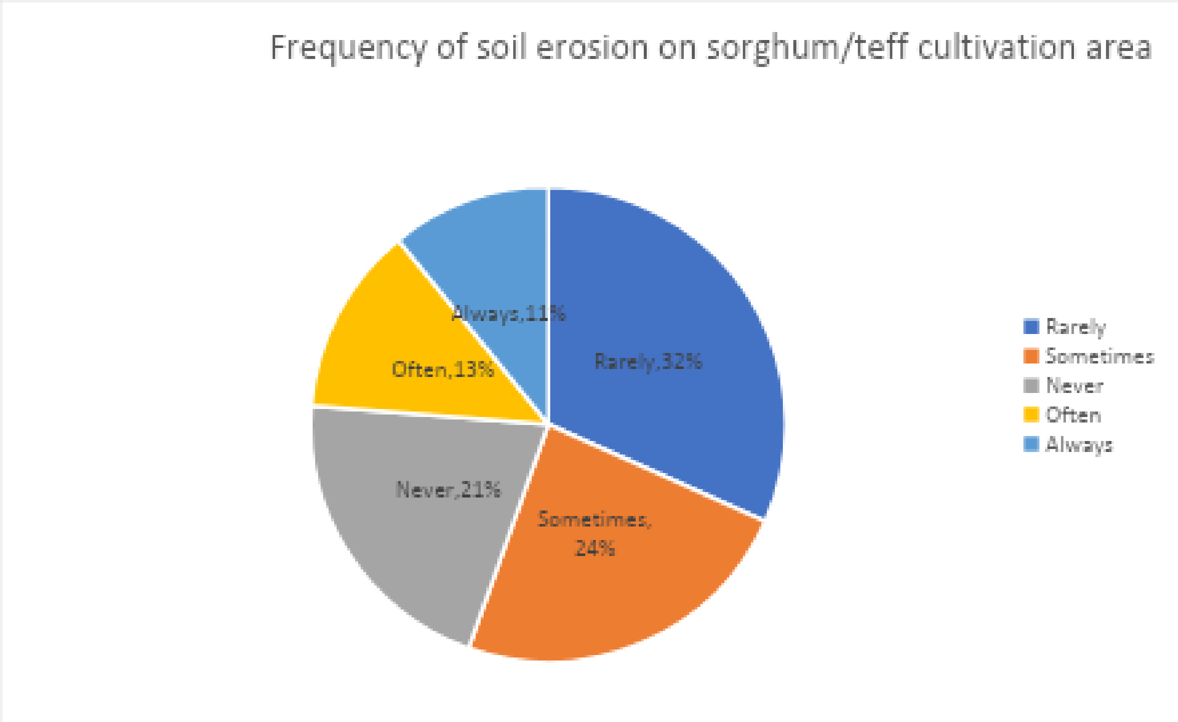

Figure 3: Frequency of soil erosion on sorghum/teff cultivation area

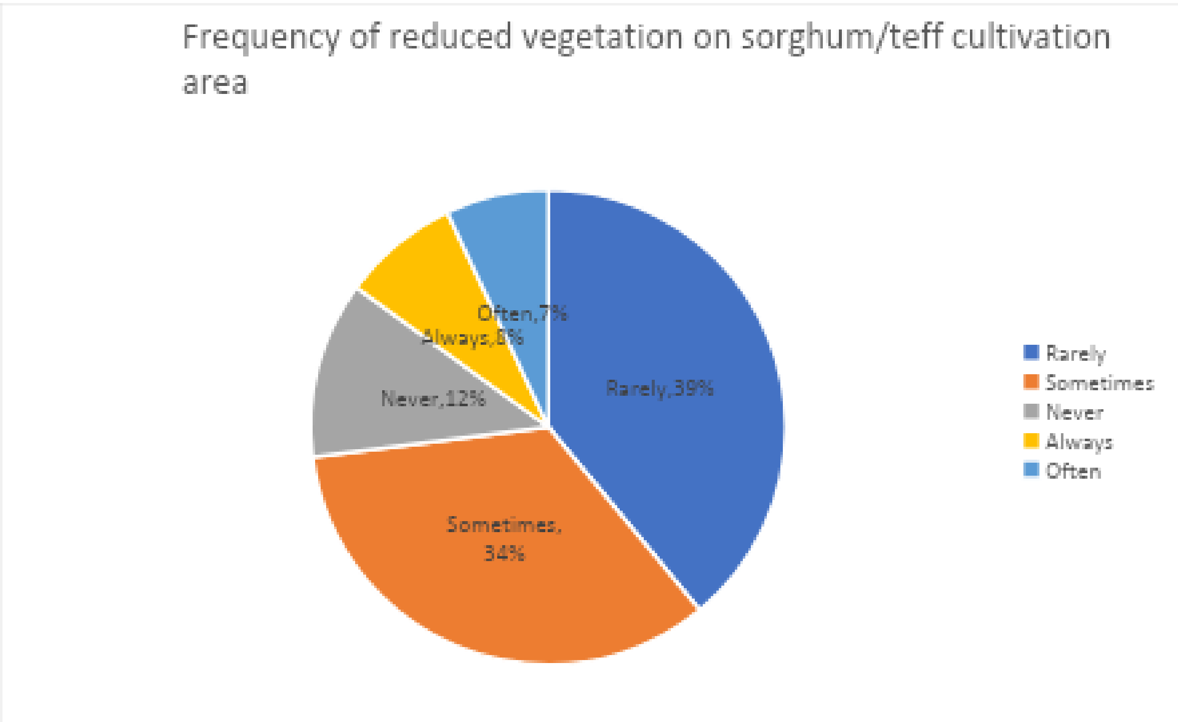

Figure 4:Frequency of reduced vegetation on sorghum/teff cultivation area

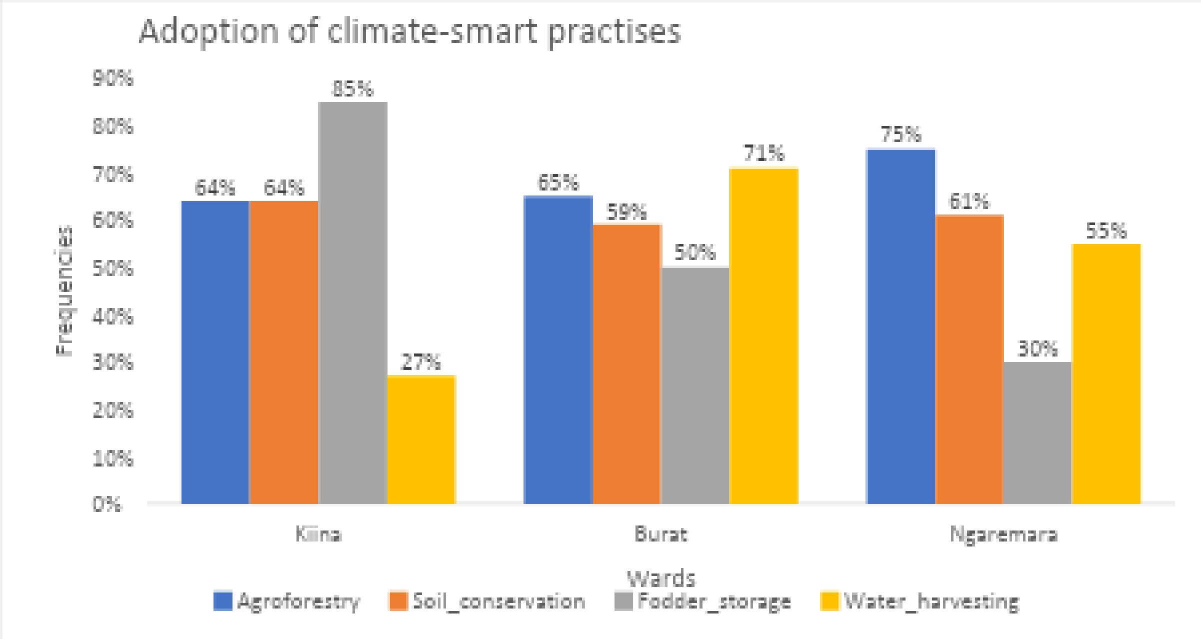

Figure 5: Adoption of climate-smart practises alongside sorghum/teff cultivation(Ward level)

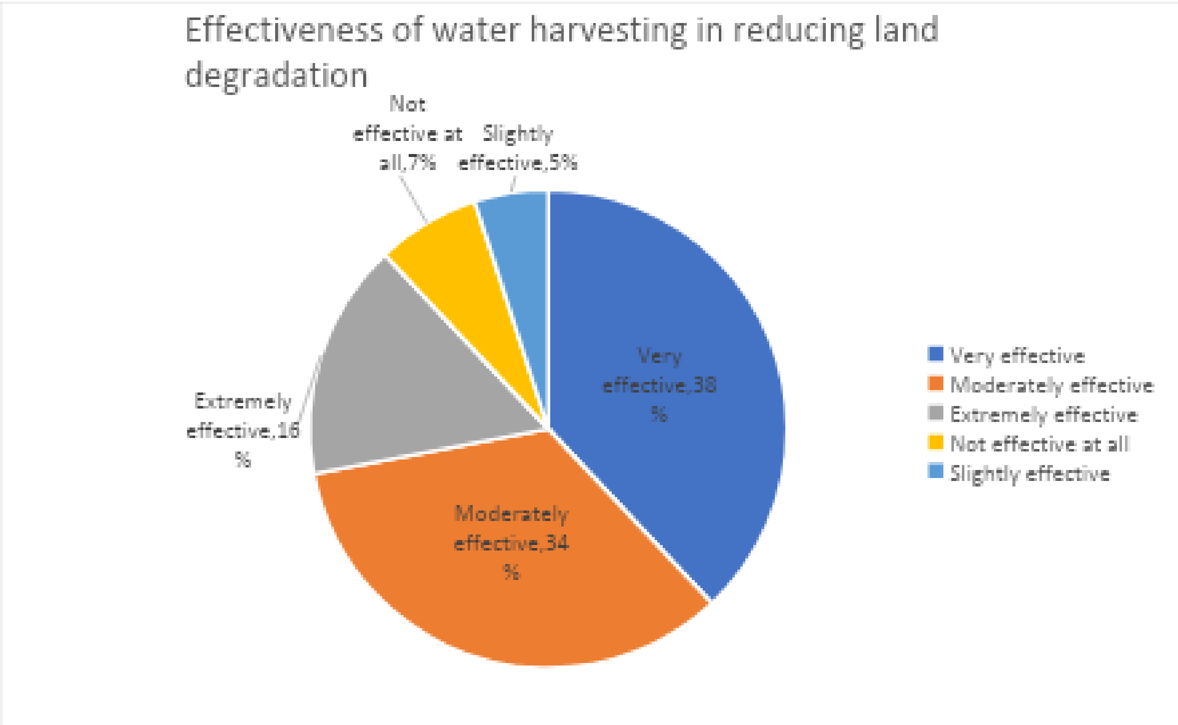

Figure 6: Perceived Effectiveness of Water Harvesting in Reducing Land Degradation

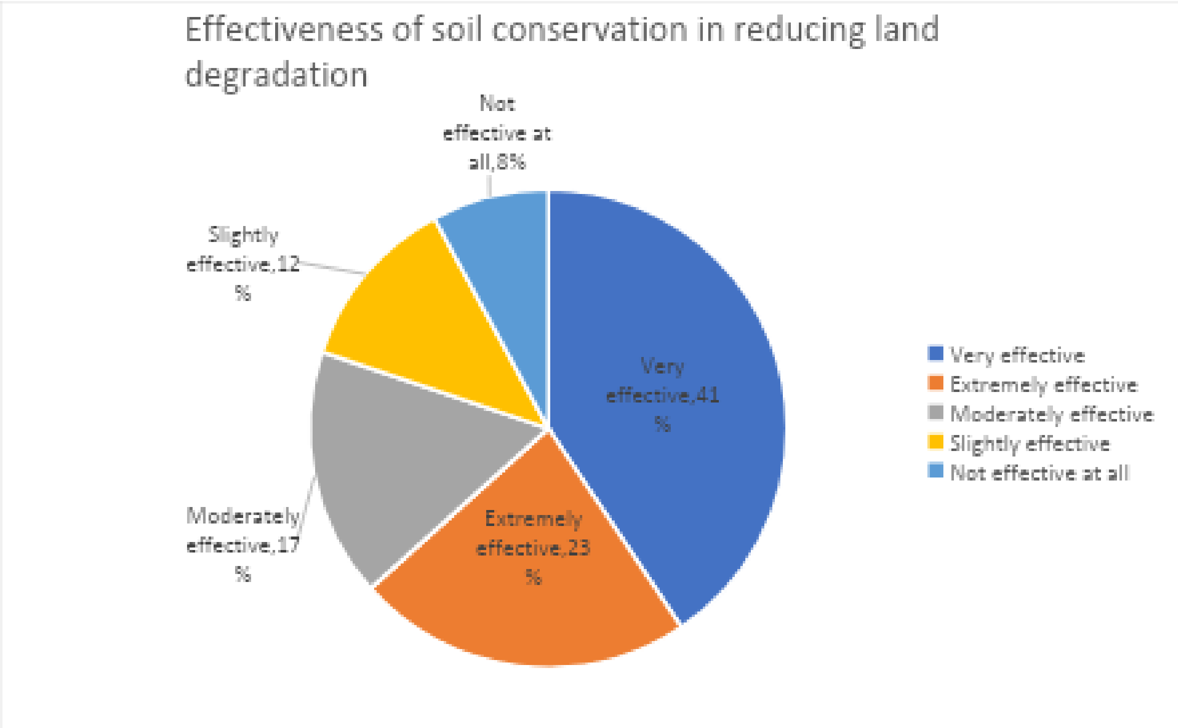

Figure 7: Perceived Effectiveness of Soil Conservation techniques in Reducing Land Degradation

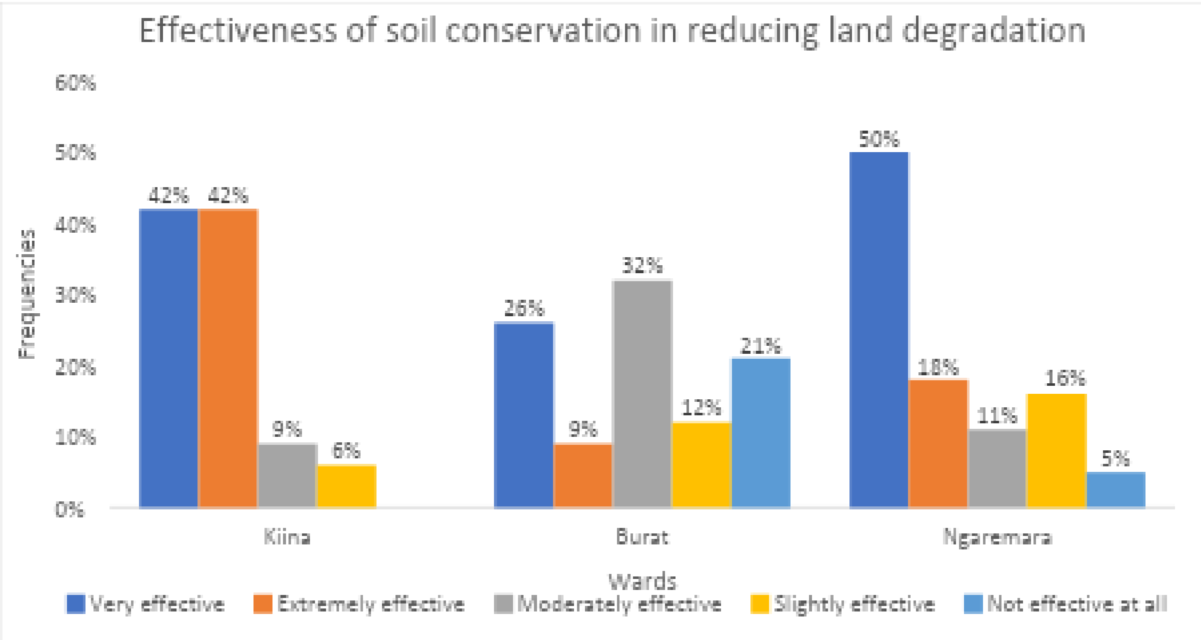

Figure 8: Perceived Effectiveness of Soil Conservation techniques in Reducing Land Degradation (Ward level)

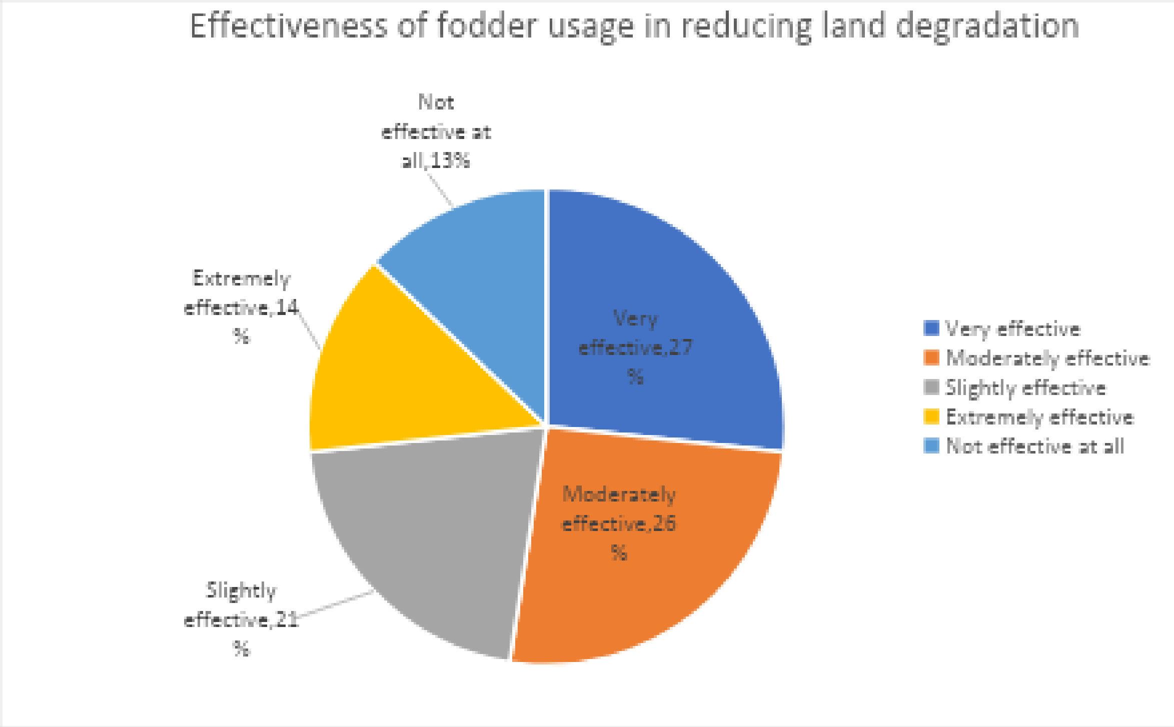

Figure 9: Effectiveness of fodder usage in reducing land degradation

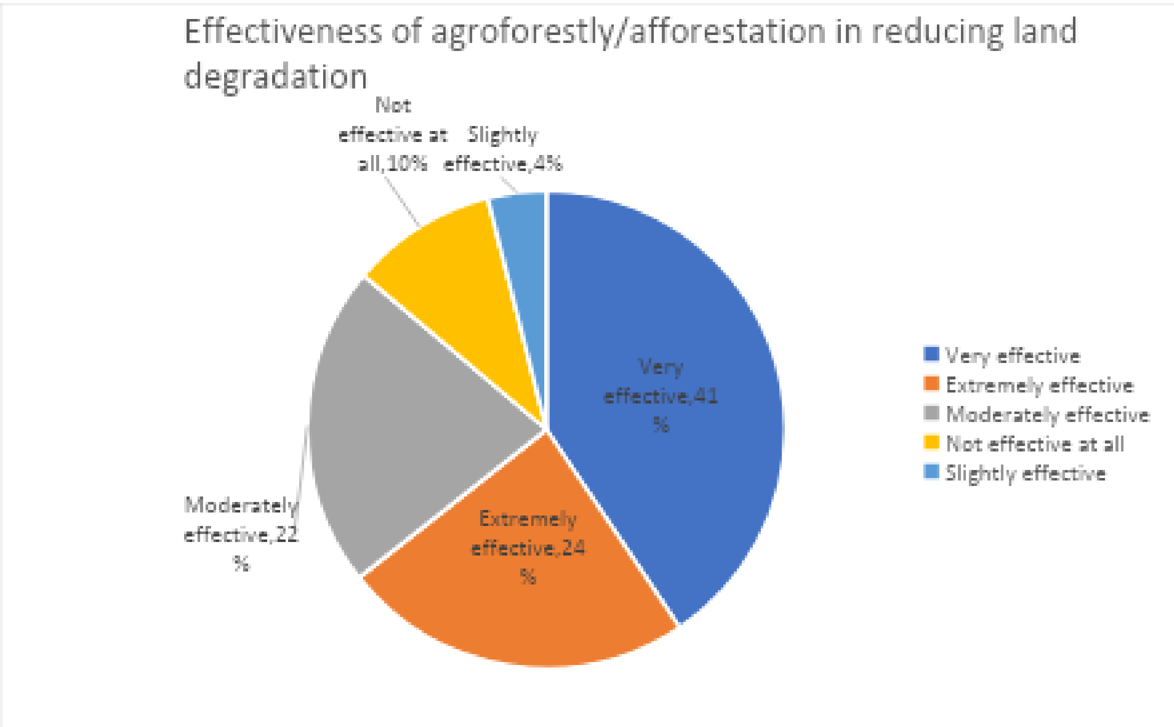

Figure 10:Effectiveness of agroforestly/afforestation in reducing land degradation

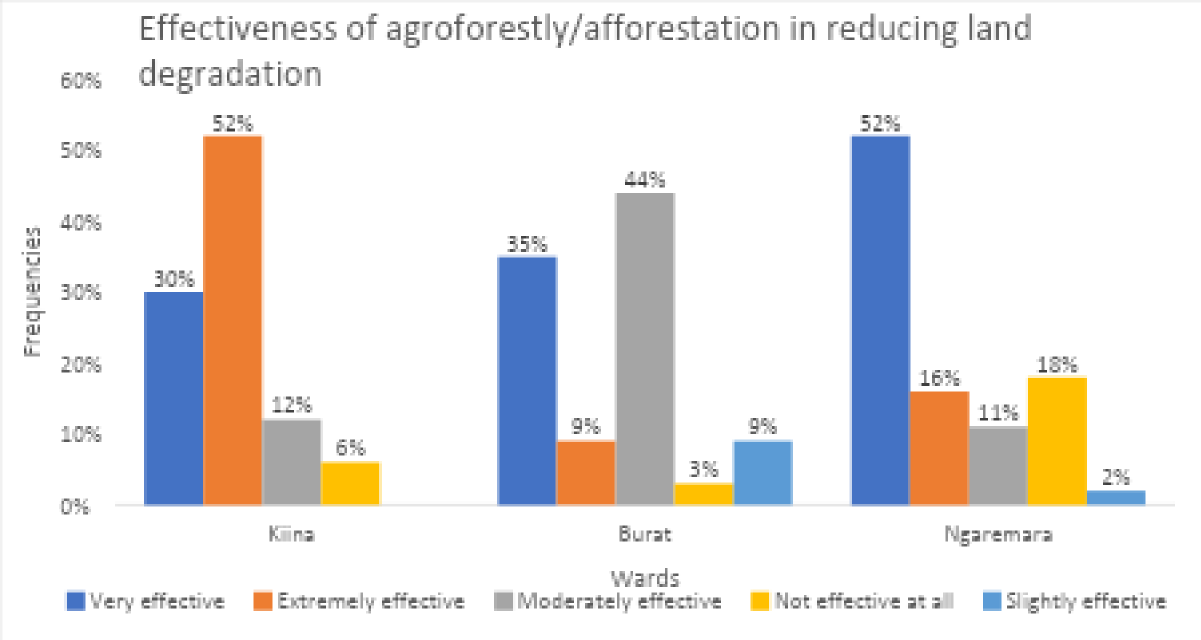

Figure 11: Effectiveness of agroforestly/afforestation in reducing land degradation(Ward Level)

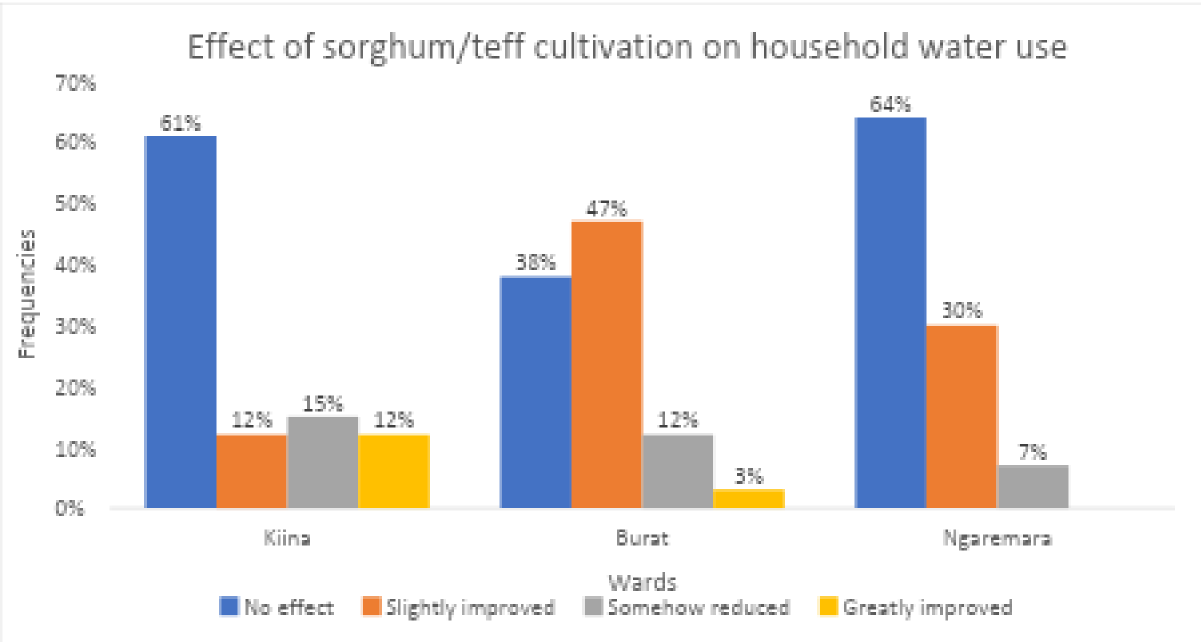

Figure 12: Effect of sorghum/teff cultivation on household water use efficiency (Ward level)

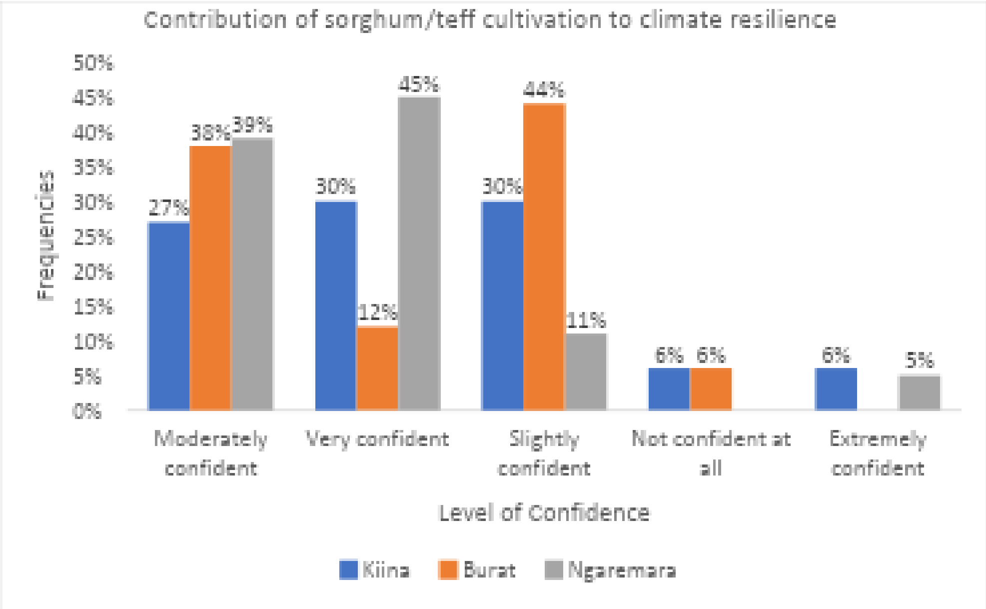

Figure 15: Level of confidence in sorghum/teff cultivation in improving community's resilience to climate change (Ward level)

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