International Journal of Forest, Animal and Fisheries Research (IJFAF)
ISSN: 2456-8791
[Vol-10, Issue-3, Jul-Sep, 2026]
Issue DOI: https://dx.doi.org/10.22161/ijfaf.10.3
Article DOI: https://dx.doi.org/10.22161/ijfaf.10.3.3

Climate Variability, Vegetation Dynamics, Crop Production Trends, and Farmers' Adaptation Strategies in South Darfur State, Sudan

Tahlil A. Farah[1], Nagla N. Suliman[1], Entisar-Elilah B. M. Ahmed-Elbadry [1], Ibrahim H. Abdalkreem[2,*]

[1]Department of Crop and Range Sciences, Faculty of Natural Resources and Environmental Studies, University of Kordofan, Elobied, Sudan.
[2]Department of Forestry, Faculty of Forestry and Range Sciences, University of East Kordofan, Abu Jubayhah, Sudan.
*Corresponding author: ibrahimhamad733@gmail.com

Received: 02 Jul 2026; Received in revised form: 31 Jul 2026; Accepted: 04 Aug 2026; Available online: 11 Aug 2026

Abstract**—** *Climate change poses a significant threat to rain-fed agricultural systems in arid and semi-arid regions, particularly in Sudan, where livelihoods largely depend on climate-sensitive agriculture. This study assessed long-term trends in climate variables, vegetation dynamics, crop production, and farmers' adaptation strategies in South Darfur State, Sudan. Climatic data, Normalized Difference Vegetation Index (NDVI), and crop production records covering the period 1992–2021 were analyzed using the Mann–Kendall trend test and Sen's slope estimator. In addition, a household survey of 180 farmers was conducted to examine socio-economic characteristics, agricultural practices, and climate change adaptation strategies. The results revealed significant increasing trends in NDVI ($\tau = 0.61$, $p < 0.001$), maximum temperature ($\tau = 0.32$, $p = 0.01$), and annual rainfall ($\tau = 0.29$, $p = 0.03$), indicating notable changes in vegetation conditions and climate over the study period. Among the major crops, millet showed a significant declining trend ($\tau = -0.26$, $p = 0.04$), whereas groundnut, sesame, and roselle exhibited no significant long-term trends despite considerable interannual variability. The decline in millet production is likely associated with increasing temperature, rainfall variability, and the prolonged socio-political conflict that disrupted agricultural activities in the region. Survey results showed that farmers have adopted several adaptation measures, including changing crop types, practicing crop rotation and agroforestry, using drought-tolerant crop varieties, improving soil fertility management, and adjusting planting dates based on indigenous knowledge. These practices have likely contributed to the relatively stable production of cash crops such as groundnut, sesame, and roselle. The findings demonstrate that while climatic conditions and vegetation productivity have generally improved, crop responses remain species-specific and are strongly influenced by both environmental and socio-economic factors. Strengthening climate-smart agriculture, improving access to extension services and climate information, and supporting locally developed adaptation strategies will be essential for enhancing agricultural resilience and ensuring sustainable food production in South Darfur under future climate change.*

Keywords**—** ***Climate change, NDVI, Crop production, Mann–Kendall trend analysis, Climate-smart agriculture, Farmers' adaptation, South Darfur, Sudan.***

I. INTRODUCTION

Climate change refers to long-term alterations in climatic conditions, including changes in temperature, precipitation, and wind patterns that characterize a region (Coolon et al., 2013). These changes may result from natural processes, such as volcanic activity, as well as anthropogenic activities that increase greenhouse gas emissions (Al-Akkad, 2009). The accumulation of greenhouse gases in the atmosphere has intensified the greenhouse effect, raising the Earth's average surface temperature and altering global climate systems (Le Treut et al., 2007). Human activities, particularly industrialization, transportation, and land-use change, have accelerated this process, leading to more frequent and intense extreme weather events, including droughts, heat waves, floods, and irregular rainfall patterns (Antero, 2019; Lu et al., 2007). According to Solomon et al. (2007), the Earth's climate has warmed by approximately 0.1°C per decade over recent decades, with significant implications for agriculture and food security. Agriculture is among the sectors most vulnerable to climate change because crop growth and productivity are highly dependent on climatic conditions. Temperature, rainfall, solar radiation, and humidity directly influence crop development, phenology, and yield (Helena and Costa, 2022). Each crop has specific climatic requirements, and deviations from these optimum conditions may reduce productivity or even prevent successful cultivation (Ali, 1994). Consequently, climate variability has become a major challenge to sustainable agricultural production, particularly in rainfed farming systems of developing countries.

Sudan is one of the countries highly vulnerable to climate variability due to its predominantly arid and semi-arid climate. Annual rainfall generally ranges from 300 to 700 mm, with desert conditions and minimal precipitation prevailing in the northern regions bordering Egypt. Most of the country's rainfall occurs during a short rainy season extending from June to September (Mahmoud, 2022). In addition to rainfall variability, Sudan has experienced a consistent increase in air temperature over recent decades (UNDP, 2020), further exacerbating agricultural risks. The Darfur region exhibits considerable climatic diversity, with higher temperatures in the northern areas and relatively cooler conditions toward the south (Ahmed et al., 2022). These spatial variations, together with increasing climate variability, have significantly affected agricultural production in the region (Elkhatim, 2017). Since agriculture in Darfur relies predominantly on rainfall, fluctuations in precipitation and temperature directly influence crop performance, household income, and food availability.

Millet (*Pennisetum glaucum*) is one of the oldest cereal crops and is well adapted to harsh environments characterized by limited water availability, high temperatures, and poor soils. Its resilience makes it an important staple crop for ensuring food security under changing climatic conditions (Prakash et al., 2023). Groundnut is the second most important crop in the Darfur States after millet and plays a crucial role in household income and nutrition (Mahendra et al., 2020). Similarly, sesame is an economically valuable oilseed crop widely cultivated by smallholder farmers, particularly on marginal lands where other crops perform poorly (Myint et al., 2020). Although these crops exhibit relatively high tolerance to environmental stress, their productivity is increasingly threatened by changing rainfall patterns, prolonged droughts, and rising temperatures associated with climate change. Climate change poses significant socio-economic challenges in Sudan, where approximately 60% of the population depends on rainfed agriculture for their livelihoods. Variability in rainfall and increasing temperatures threaten crop productivity, food security, and rural development. Despite growing evidence of climate change impacts, localized studies in South Darfur, particularly Nyala locality, remain limited. Therefore, this study assesses the effects of long-term changes in rainfall and temperature on the productivity of millet, groundnut, and sesame to provide evidence that supports effective adaptation strategies and sustainable agricultural development.

II. MATERIALS AND METHODS

2.1 Study area

The study was conducted in Nyala locality situated in the middle of South Darfur state (24º 53′ E latitude, 12º 03′N longitude) about 673 m a msl, approximately 1200 km south-west of Khartoum, the capital of

Sudan. The area inhabits about 0.6 million people whose major source of living is through farming. The average annual rainfall in south Darfur is about 400 mm, with an average summer temperature of 36 °C and 20°C during the winter (Elsheikh et al. 2014). The area experience notable hot days and heat wave events causing inter-annual variations in temperature (Mohamed et al. 2024). The main soil types in the region include sand dunes, clay plains, clay flats, and cracking clay, while vegetation patterns correspond to these soil types and the amount of rainfall, with a progression from scattered Acacia trees in the northern part of the state to dense forests in the south. In meantime, the population in the area grow millet, sorghum (durra), peanuts, watermelons as main crops, and vegetables. In addition, the locality has forest products, such as gum Arabic and other non-wood forest products (Siam and Abdalkreem, 2019).

2.2 Data collection

2.2.1 Sociodemographic data collection

A multistage sampling technique was used to select 180 farmers households. Localities were selected purposively based on agriculture relevance, while households were chosen by systematic random sampling. The sample size was determined using Yamane's formula for finite population. Participants were active farming households, recruited through household lists provided by local area leaders, and interviewed upon obtaining consent. Additionally, prior to the main survey, the questionnaire was pre-tested on a small sample group of farmers to identify unclear items and ensure that respondents understood the questions as intended. Nyala locality was stratified into two geographical regions, south and north Nyala based on population size and socio-economic characteristics. Approximately 60% of the sampled households (108 respondents) were allocated to South Nyala due to its larger farming population, while 40% (72 respondents) were allocated to North Nyala. Within each region, respondents were further stratified according to income level and education background to ensure representation of diverse socio-economic groups. In South Nyala, the sample included 40% low-income farmers with primary-level education, 30% middle-income farmers with secondary-level education, and 30% high-income farmers with university-level education. In North Nyala, the distribution consisted of 50% low-income farmers with primary-level education, 30% middle-income farmers with secondary-level education, and 20% high-income farmers with university-level education. Socio-demographic information such as age, gender, education, occupation, household size, income, farming experience was collected using a pre-tested, well-structured questionnaire. Additional data on the farmers' awareness of climate change, perceived impacts, and adoptive strategies were obtained through personal interviews and field observations.

2.2.2 Climatic and crops production data

Annual climate data, including rainfall and temperature data for Nyala locality, were obtained for a 30-year period covering annual data (1992 to 2022) from the Nyala meteorological station and compared with the World Bank Climate Change Knowledge Portal (2022). URL:

https://climateknowledgeportal.worldbank.org/.

2.2.3 Crops production data

Historical crop-yield and production of millet, sesame, roselle, and groundnut covering the period 1992-2022 were obtained from the Ministry of Agriculture and Forestry, South Darfur state, Nyala. While normalized difference vegetation index (NDVI) data of Landsat 8 is obtained from Climate Engine, using Google Earth Engine (Huntington et al. 2017).

2.3 Data analysis

The data collected from the farmers and crop yield from the Government sources, and the climate data from the knowledge portal were subjected were compiled for further analysis. Additionally, correlation analyses were performed between climatic factors, NDVI and crop yield, as well as between adaptation factors/strategies with the demographic factors. In addition to drought assessment, we conducted long-term trend analysis for rainfall and temperature to identify directional changes in climatic variables over the 30-year period. Trends in annual rainfall, maximum temperature and minimum temperature, NDVI, crops yield were evaluated using Mann-Kendal and Sen' Slope (Mann, 1945). Moreover, standardized precipitation index (SPI) was calculated using following McKee et al. (1993), where annual precipitation data from 1992 – 2021 were used to derive the long-term mean (μ) and standard deviation (σ) of annual precipitation as explained in Eq. (1). The analyses were carried out using Statistical Package for Social Sciences (SPSS, version 22.0), Origin 2025, and Microsoft Excel.

III. RESULTS AND DISCUSSION

3.1 Trends in climate variables, NDVI, and crop production

The Mann–Kendall and Sen's slope analyses revealed significant long-term changes in climatic and vegetation conditions in South Darfur during 1992–2021. NDVI showed a strong increasing trend ($\tau = 0.61$; $p < 0.001$) (Table 1), indicating gradual improvement in vegetation greenness and biomass. Maximum temperature also increased significantly ($\tau = 0.32$; $p = 0.01$) (Table 1), consistent with the warming pattern earlier observed in the study area. On the other hand, rainfall exhibited a positive and significant trend ($\tau = 0.29$; $p = 0.03$), although inter-annual variability remains high.

Among the major crops, only millet showed a significant decreasing trend ($\tau = -0.26$; $p = 0.04$) (Table 2), suggesting increasing vulnerability to heat load, dry spells, and the shifting onset of rainfall, which farmers also reported. On the other hand, the decreases on millet production in study area could be due to conflict from early 2000s in the region (Dosa, 2014) which may significantly influence production areas. Groundnut, sesame, and roselle exhibited no significant long-term trends ($p > 0.05$) (Table 2 and figure 1), although their year-to-year fluctuations correspond to rainfall variability and temperature extremes. The absence of significant decline in these crops may reflected the farmers' ongoing local adaptation practices such as adjusting planting dates, using drought-tolerant varieties, and indigenous soil fertility management. In contrast, due to demand in cash crops in recent year which significantly increase livelihoods income could result in stable production in groundnut, sesame, and roselle yield.

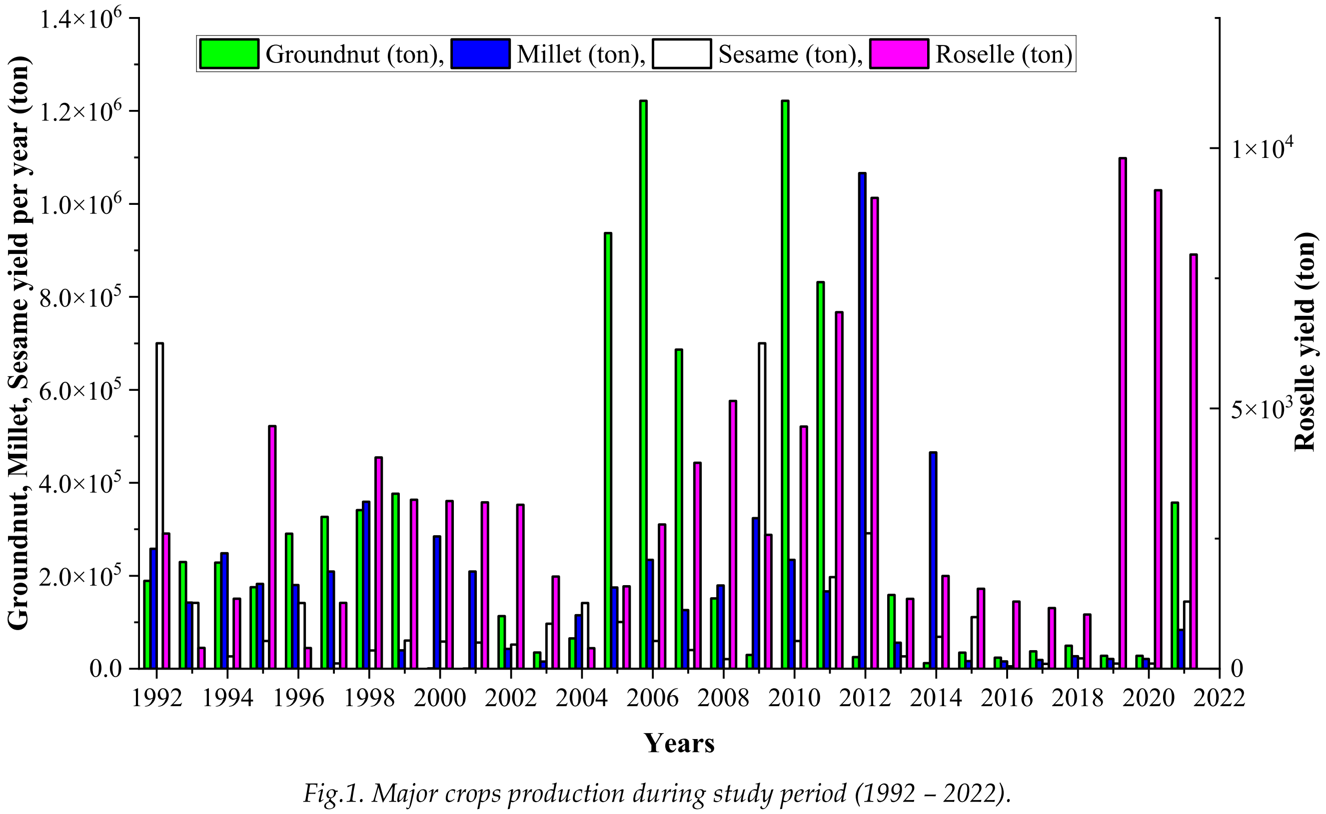

Fig.1. Major crops production during study period (1992 – 2022).

Table 1. Correlation between climatic factors, NDVI and crops yield during the study period

Variables	Min	Max	Rainfall	Groundnut	Millet	Sesame	Roselle	NDVI
Minimum	1.00							
Maximum	0.86***	1.00						
Rainfall	0.03	-0.12	1.00					
Groundnut	0.20	0.27	0.54**	1.00				
Millet	0.02	0.02	0.00	0.69***	1.00			
Sesame	-0.06	0.14	0.52**	0.11	0.34	1.00		
Roselle	-0.06	0.03	0.31	0.37*	0.26	0.00	1.00	
NDVI	0.14	0.12	0.62***	0.6**	0.54**	0.55**	0.61**	1.00

*, ** and ***. Correlation is significant at the 0.05, 0.01, and 0.001 level respectively

Table 2. Mann-Kendal and Sen' Slope of climatic variables and crop production across study year

Variable	Trend	Significance	Z-Statistic	P-Value	Tau (Ï„)	Slope (Theil-Sen)
NDVI	Increasing	Significant	4.77	<0.001	0.61	0.002
Max temp	Increasing	Significant	2.46	0.01	0.32	0.02
Min temp	No Trend	Not Significant	1.84	0.07	0.24	0.03
Rainfall	Increasing	Significant	2.21	0.03	0.29	2.97
Millet	Decreasing	Significant	-2.04	0.04	-0.26	-5498.96
Sesame	No Trend	Not Significant	-1.34	0.18	-0.18	-1857.30
Roselle	No Trend	Not Significant	1.04	0.30	0.14	66.56
Groundnut	No Trend	Not Significant	-0.86	0.39	-0.11	-3229.67

Note: Max: maximum, Min: minimum, and temp: temperature.

3.2 Socio-economic characteristics of respondents

3.2.1 Gender and marital status of the respondents

The gender of the respondents is a significant factor concerning crops production and knowledge about climate change, as individuals of all genders engage in agriculture. However, Abdullah and Osman, (2024) reported that socio-demographic factors, such as gender, play a role in activities to mitigate climate change. Simultaneously, may be necessary in case of developing strategies to enhance climate change education. The needs to meet household requirements often motivates many households to participate in agriculture. Additionally, the distribution of labor within a family is crucial in agricultural activities. However, our findings in (Figure 2) depict the gender composition of the respondents. It indicates that most respondents (55.6%) were male compared to (44.4%), were female.

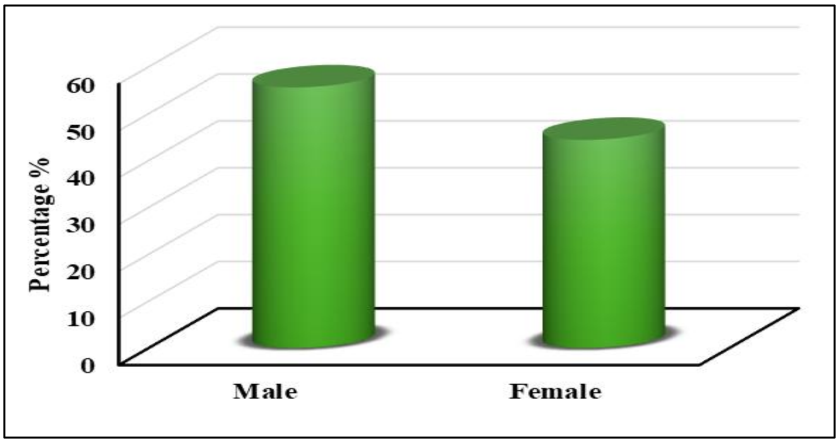

Fig.2. Gender of the respondents

3.2.2 Marital status of the respondents

Additionally, (Figure 3) shows that (44.4%) of respondents indicated that they are married. This suggests that a significant portion of the surveyed population is currently in a marital relationship. In addition (26.7%) of respondents reported being single. This category typically includes individuals who have never been married or are not currently in a committed relationship. Where (15.0%) of respondents stated that they are divorced. Moreover (13.9%) of respondents are widowed, meaning they have lost their spouse due to death. The result agree with umunnakwe, et al., (2013) who mentioned that the majority of rural youth in study district were married and from farming households, factors influencing involvement in both agricultural and non-agricultural livelihood activities included marital status, education level, employment status, fatalism-scienticism, mass media exposure, and extension contact. Understanding respondents' marital status can provide insights into demographic characteristics, family structures, social support networks, and potential influences on decision-making processes, including those related to agriculture, livelihoods, and household dynamics. Marital status can also be associated with socioeconomic factors such as income, access to resources, household responsibilities, and social roles within the community. These factors may influence respondent's perspectives, behaviors, and participation in various activities, including agricultural practices.

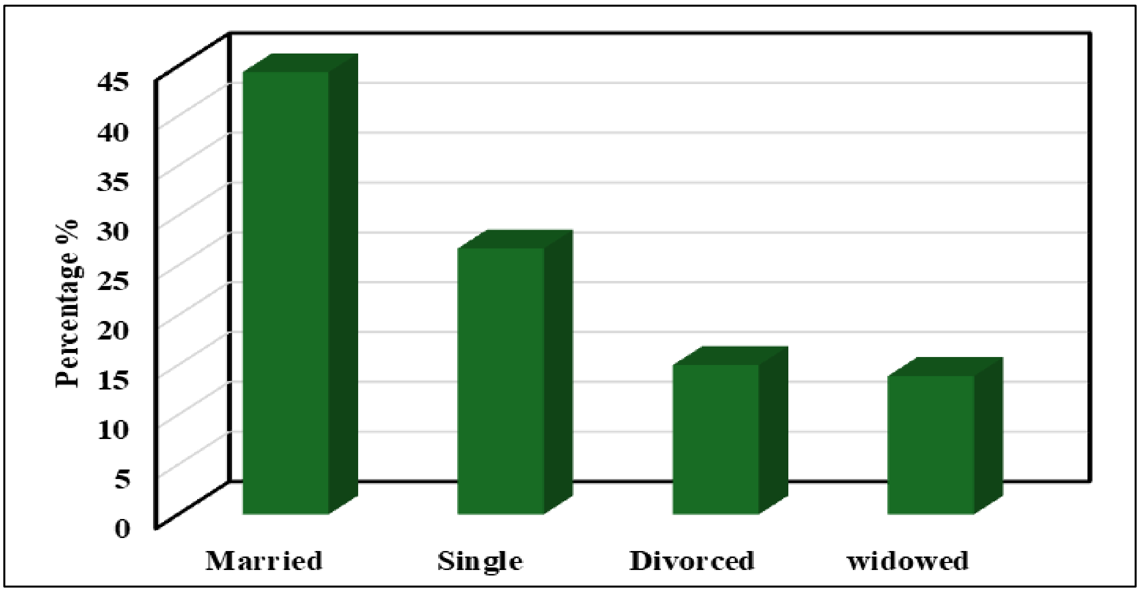

Fig.3. Marital status of the respondents

3.2.3 Occupation and experience in farming system of respondents

The result in (Table 3) shows respondents occupational distribution. We found that most respondents are involved in farmers (35%), followed by employees (32.2%) and free work (17.8%)as well as small percentage are in other categories. However, Khanal et al., (2021) stated that youth attitudes towards agriculture with respondents indicating different levels of agreement or disagreement. The results showed varying personal and economic attitudes towards farming among the study subjects, reflecting their enthusiasm and potential contribution to the economy through agriculture. Engaging in agricultural activity is simple because it's a traditional art passed down from one generation to the next, making it accessible and straightforward, as depicted in (Table 3).

Table 3. Occupation of the Respondents

Occupation	Frequency	Percentage %
Farmer	64	35.6
Employee	58	32.2
Free work	32	17.8
Other	26	14.4

3.2.4 Respondents experience in farming system

The results in (Table 4) highlight the diversity in experience levels among the respondents, ranging from newcomers to experienced farmers with decades of experience. Understanding the experience levels of individuals in the farming profession can be crucial for analyzing their practices, challenges, and potential areas for improvement in agriculture. Michael et al., (2023) explained that the responses is differed among farmers indicating years of experience, status and ownership can influence the perception of skill and satisfaction. Many respondents (35.0%) have been practicing farming for more than 5 to 10 years. This suggests that a significant portion are new to the farming profession. Additionally, 26.7% of the respondents have been practicing farming for 10 to 20 years, indicating experience in farming. Similarly Tahir, (2023) highlighted that the older farmers tended to have different levels of environmental knowledge compared to younger farmers.

Table 4. Respondents experience in farming system

Time	Frequency	Percentage %
Less than 5 years	35	19.4
5 - 10 years	63	35.0
10 -20 years	48	26.7
More than 20 years	34	18.9

3.2.5 Land ownership and total area owned by respondents' families

The results in (Figure 4) highlight the diversity in land ownership arrangements among the respondents, with some owning the land outright and others accessing it through rental agreements. Most respondents (51.7%) own the agricultural land they utilize for farming (Figure 4). This suggests that a significant portion of respondents have ownership rights, which can influence decision-making and investment in agricultural practices. On the other hand (48.3%) of respondents rent the agricultural land they use for farming. However, Hasson et al., (2023) stated that land ownership affects dietary diversity and food expenditure among smallholders. Where, informal land documents linked to higher food security outcomes for smallholders.

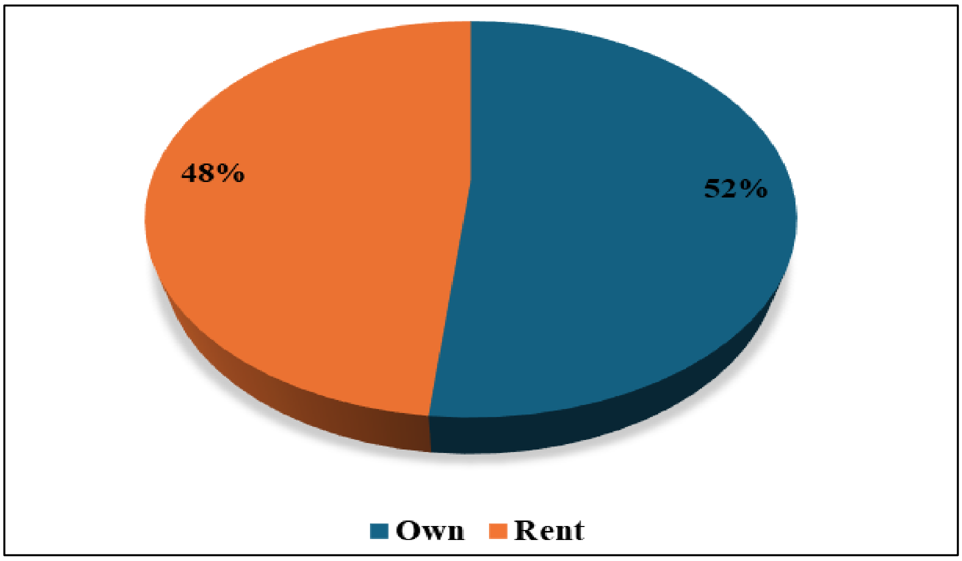

Fig.4. Respondents agricultural land ownership

3.3 Farming practices

3.3.1 The area of agricultural land owned by respondents' families

The distribution of agricultural land ownership among the respondents' families, many respondents (39.4%) own land in the 5-10 acre range, followed by 10-20 acre range (34.4%), and (17.8%) of respondents own more than 20 acres of agricultural land. suggesting a smaller but notable portion of respondents with larger land holdings, and smaller percentage (8.3%) of respondents own 5 acres, as showing in (Table 5). This matches the results of researcher (Jeremy et al., 2019) which indicate the extent of the spread of small-scale agricultural operations in the study area.

Table 5. Total area of agricultural land owned by respondents' families.

Area	Frequency	Percentage %
5	15	8.3
5- 10	71	39.4
10 - 20	62	34.4
More than 20	32	17.8

3.3.2 Type of agricultural soil and type of tillage used by respondents' in their farms

The largest group of respondents, comprising (46.7%), favor loamy soil for their farms. This type of soil, characterized by a balanced mix of sand, silt, and clay, is highly fertile and well-suited for a wide range of crops. Another (30.6%) of respondents prefer sandy soil, which drains well but may necessitate more frequent irrigation and nutrient control. Conversely, (22.8%) of respondents for clay soil, which retains water effectively but may require more careful drainage management as shown in (Figure 5). As reported in the research (Mullins et al., 1990) Clay soils have greater strength especially when dry and are also susceptible to waterlogging due to poor infiltration which results in poor aeration.

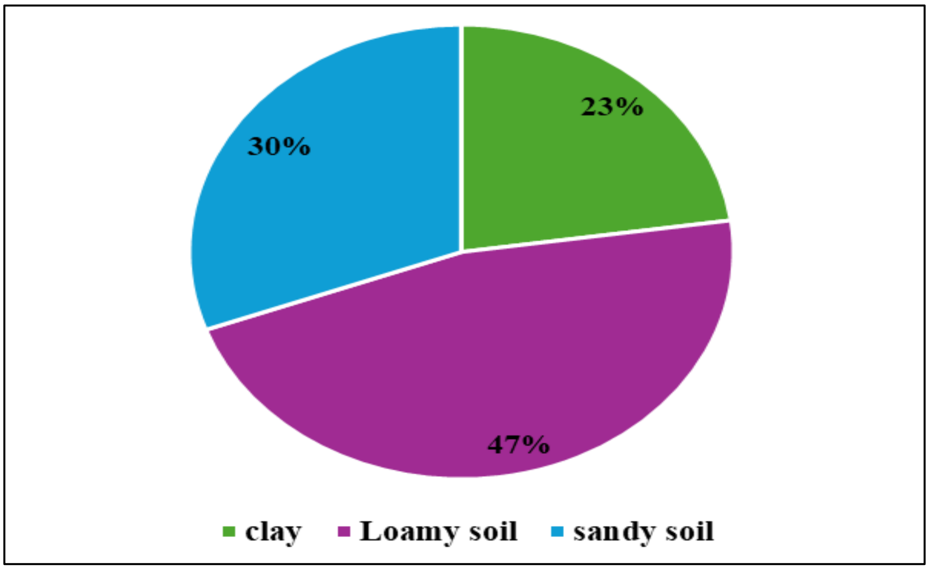

Fig.5. Type of soil for use respondents' farms.

3.3.3 Type of tillage used by respondents' in their farms

There are different methods of tillage employed by respondents on their farms. Most respondents (42.2%) use traditional plowing methods for tillage. Traditional plowing typically involves the use of animal-drawn or manually operated plows to prepare the soil for planting. Additionally, (36.1%) of respondents use machines operated by tractors for tillage. This method is more mechanized and efficient compared to traditional plowing as well as tillage larger areas within short of time. This is agreed with the results show that it was found that mechanized farming was labor and time saved technology more than the traditional and semi-mechanized farming (Wako, 2016). Mechanized and semi-mechanized farming played a significant role by reducing the operations hours of cereal crops, which have timeliness effect on production. It was found that the mechanized and semi-mechanized farming were more land and labor productive than the traditional farming (Wako, 2016). Although, (21.7%) of respondents perform tillage by hand, which can be labor-intensive but may be preferred for smaller plots or in areas where machinery is not accessible (Table 6).

Table 6. Type of tillage used by respondents' in their farms.

Type of tillage	Frequency	Percentage %
by hand	39	21.7
machine by tractor	65	36.1
traditional plowing	76	42.2

3.3.4 Fuel consumption of a tractor

The findings reveal that there is variation in the fuel usage of tractors among the survey participants. A noteworthy percentage of respondents (35.6%) reported fuel consumption ranging from 3 to 4 liters as well as 5 to 6 liters. This implies that a substantial number of tractors consume moderate amounts of fuel during their operation. Additionally, (21.6%) of tractors exhibit higher fuel consumption levels (above 7 liters) indicating respondents who operate tractors with greater fuel consumption per operation. These results are consistent with the findings (William, 2002) who stared that main machine components such as engine, pistons, piston rings, cylinder bores etc, require timely overhaul, reconditioning and maintenance. Therefore, these components are prone to wear due to high dust and dirts blown from the dry field operations. Hence, cylinder bore to piston clearance become increased which resulted to high blow by conditions. Performance efficiency of tractor and combine harvesters becomes low besides high rate of fuel consumption. On the other hand, (7.2%) of tractors show lower fuel consumption levels (1 to 2 liters) suggesting that a small fraction of respondents utilize tractors with lower fuel consumption rates (Table 7).

Table 7. Fuel consumption of a tractor

Fuel quantity	Frequency	Percentage %
1 - 2 liter	13	7.2
3 - 4 liter	64	35.6
5 - 6 liter	64	35.6
above to 7	39	21.6

3.3.5 Types of chemical and organic fertilizers used by respondents

There are several types of chemical fertilizers. Although, (42.2%) of respondents using "Other" fertilizers. This could imply that off-the-shelf fertilizers may not always meet the specific requirements of every farm, leading to the use of personalized fertilizer blends. The results show that phosphate fertilizers were the most commonly used among the respondents (27.2%) (Figure 6). However, Tilman et al., 2021; Roy et al., 2019) reported similarly to our findings and stated that phosphorus fertilizers are considered essential for crop production as well as strengthening intensive agricultural production could lead to increase the fertilizer demand. On the other hand, the reason of using phosphate could be widely available, affordable, or perceived as effective by farmers or gardeners. However, (20.0%) of respondents used Dab fertilizers suggests that this particular type has gained some popularity or recognition among users possibly due to its effectiveness or specific benefits. The rest (10.6%) of respondents used NPK fertilizers suggests a significant interest in balanced fertilization for various crops or plants as outlined in (Figure 6). However, Amtmann et al., (2008) reported that the potassium is one of the main plant nutrients, along with nitrogen and phosphorus. It influences many physiological processes affecting plant growth, yield and its quality, as well as plant resistance to pathogens, frost, heat and drought, pesticides and heavy metals (Römheld and Kirkby, 2010).

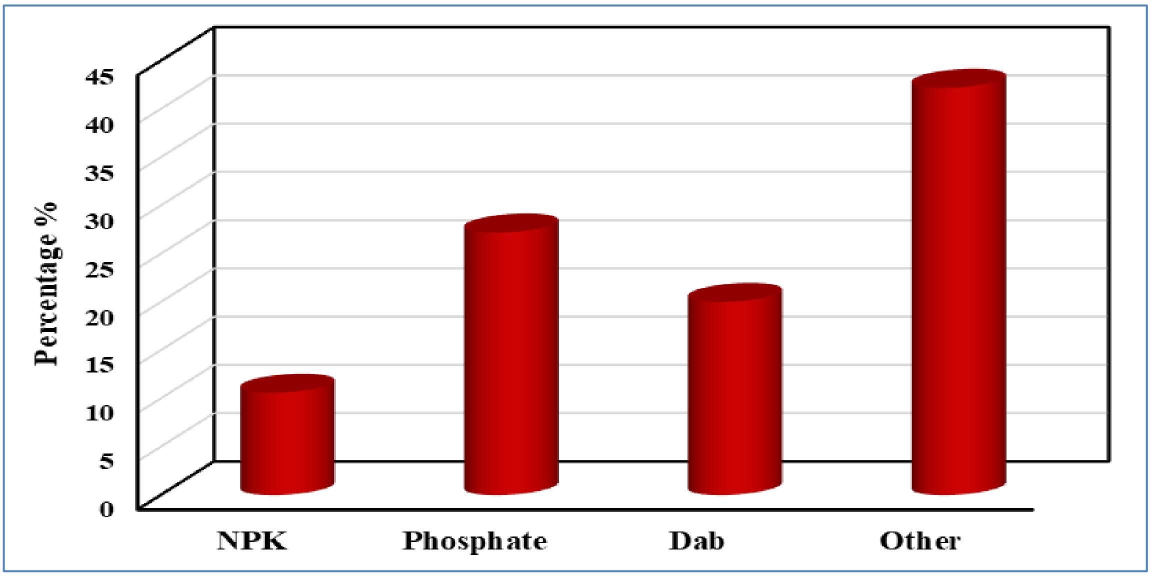

Fig.6. Types of chemical fertilizers used by respondents in farms

3.3.6 Types of organic fertilizers used by respondents

There are some organic fertilizer are commonly used by farmers in the study area. However, animal dung (cow and goat) was used by (28.9%), making it the most commonly used organic fertilizer in agricultural. However, traditional agricultural practices where animal manure is valued for its nutrient content and soil conditioning properties. Simultaneously, 27% are used urea thereby, indicates that urea traditionally considered a chemical fertilizer as well as being used as an organic option by a significant portion of the respondents. The other was used by (26.1%) of the respondents, showing a diversity of organic options beyond the commonly recognized ones like animal dung and plant remains. Plant remains such as compost were used by (17.2%) of the respondents (Table 8). This indicates recognition of organic value from plant sources in enriching soil fertility and promoting sustainable agriculture. However, Zamanov et al., (1990) stated that the full and efficient use of all resources of organic fertilizers simultaneously solves a number of economic tasks: obtaining maximum yields while maintaining and increasing soil fertility, protecting the environment from pollution by waste and waste from industry, public utilities, animal husbandry and crop production.

Table 8. Types of organic fertilizers used by respondents

Types of organic fertilizers	Frequency	Percentage %
Urea	50	27.8
Animal dung	52	28.9
Plant remains	31	17.2
Other	47	26.1

3.3.7 Types of pesticides used and types of crops cultivated by respondents

Pest and insect are dangerous to agriculture crops during growth, flowering and fruiting, however, farmers are used several type of pesticide (Table 9) to control and minimize the losses. Although, Other pesticide category used by the majority of respondents (53.9%), indicating a wide range of pesticide options being utilized beyond the ones explicitly listed. Additionally, 13.9% of respondents stated that used Glyphosate and Norford pesticide to control herbicide. Whereas Norford pesticide could refer to a specific brand or type of pesticide not commonly known, their equal usage percentage suggests they are prevalent choices among the respondents. We agreed with Milesi et al., (2021) who said that Glyphosate base herbicides (GBHs) are the most widely applied pesticides in the world. Trayseel and Takseel were used by (7.2%) and (11.1%) of the respondents respectively. These are specific pesticides that may have varying effects and target pests, indicating a diversity in pest management approaches among the surveyed group (Table 9). Consequently, these findings reflect diversity in the types of pesticides used by respondents, which could be influenced by factors such as pest types, crop varieties, local regulations, and availability of pest control products. The usage of specific pesticides like Glyphosate and Norford pesticide suggests that respondents are aware of different pesticide options and have access to a variety of pest control products.

Table 9. Types of pesticides used by respondents

Types of pesticides	Frequency	Percentage %
Glyphosate	25	13.9
Norford pesticide	25	13.9
Trayseel	13	7.2
Takseel	20	11.1
Other	97	53.9

3.3.8 Types of crops cultivated by respondents

Groundnut (also known as peanuts) is the most commonly grown crop among the respondents as stated by (34.4%) (Figure 7). Groundnuts are a significant source of protein and oil, making them an important crop in many agricultural systems. Additionally, Garba et al., (2021) reported that groundnut is cultivated in all the tropical zones throughout the world. However, in Niger, groundnut used in both as cash and food crop and is highly valued for its nutritional and economic qualities (Bakoye et al., 2019). Furthermore, millet is grown by (24.4%) where indicating a substantial but not dominant portion of the surveyed group. Although, millet is a drought-resistant cereal grain that is valued for its nutritional content and suitability for diverse climatic conditions. However, Tripathi and Vyas, (2023) stated that millet is an important crop with a long history of cultivation by humans as well as rich source of nutrients and adapt with low rainfall and harsh weather conditions (Tripathi and Vyas, 2023). In addition, rosella is mentioned by (23.3%) of the respondents. Thereby, rosella is cultivated for their daily consumption in from of tea, jams, and other products. In same line Mwasiagi and Phologolo, (2021) reported that roselle is an annual plant that has traditionally been used in human and animal diet as food, drinks, and medicine. As roselle can be grown in less than 6 months, it can be termed as an eco-friendly plant. Further, sesame is grown by (17.8%) representing a moderate but notable percentage

(Figure 7). Sesame seeds are valued for their oil content and used in cooking and food production. Rauf et al., (2024) explained that sesame seeds and their edible oil are highly nutritious and rich in mono- and polyunsaturated fatty acids. The results reflect a diversity in the types of crops grown by respondents, with a mix of grains (millet), oilseeds (groundnut, sesame), and specialty crops (rosella). However, this diversity is often indicative of varied agricultural practices, market demands, and local agro ecological conditions. Groundnut's high frequency suggests its economic importance and potential contribution to food security due to its nutritional value. Millet, sesame, and rosella also play roles in providing dietary diversity and agricultural livelihoods.

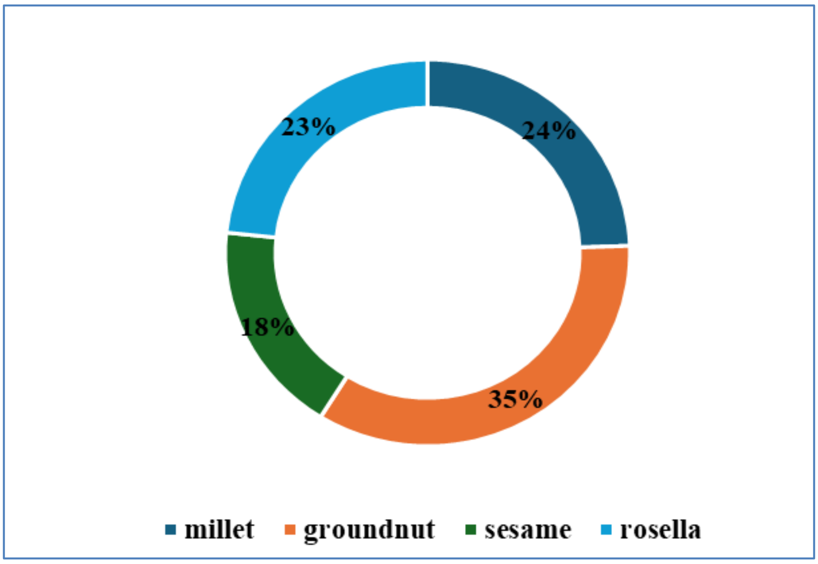

Fig.7. Types of crops cultivated by respondents

3.3.9 Sources from which respondents acquire seeds

Majority of the respondents (37.8%) acquire seeds from markets (Figure 10). Markets can include local agricultural, seed vendors, distributors, or retail outlets where seeds are readily available for purchase. This suggests that a substantial number of respondents prefer obtaining seeds through market channels. Another significant source of seeds is from fellow farmers, with (36.7%) of respondents acquiring seeds in this manner. This category likely refers to informal seed exchanges or transactions within farming communities. Similarly, Almekinders and Louwaars, (2002) reported that the large seed programs to replace the farmers' seed systems for a system in which farmers use seed as an external input, a major part of agricultural land in the world is still sown with seed that is informally produced by farmers. Farmers sharing seeds among themselves reflects a traditional and community-oriented approach to seed acquisition. Buy centers are a significant source of seeds (22.8%) of respondents acquiring seeds from these establishments. Buy centers may be local or regional outlets specializing in selling agricultural inputs including seeds. This indicates that a notable portion of respondents prefer purchasing seeds from dedicated centers. Only (2.8%) of respondents acquire seeds from organizations (Figure 8). This category likely refers to formal institutions such as agricultural cooperatives, government agencies, or seed companies. The low percentage suggests that a relatively small number of respondents rely on organized institutions for their seed procurement.

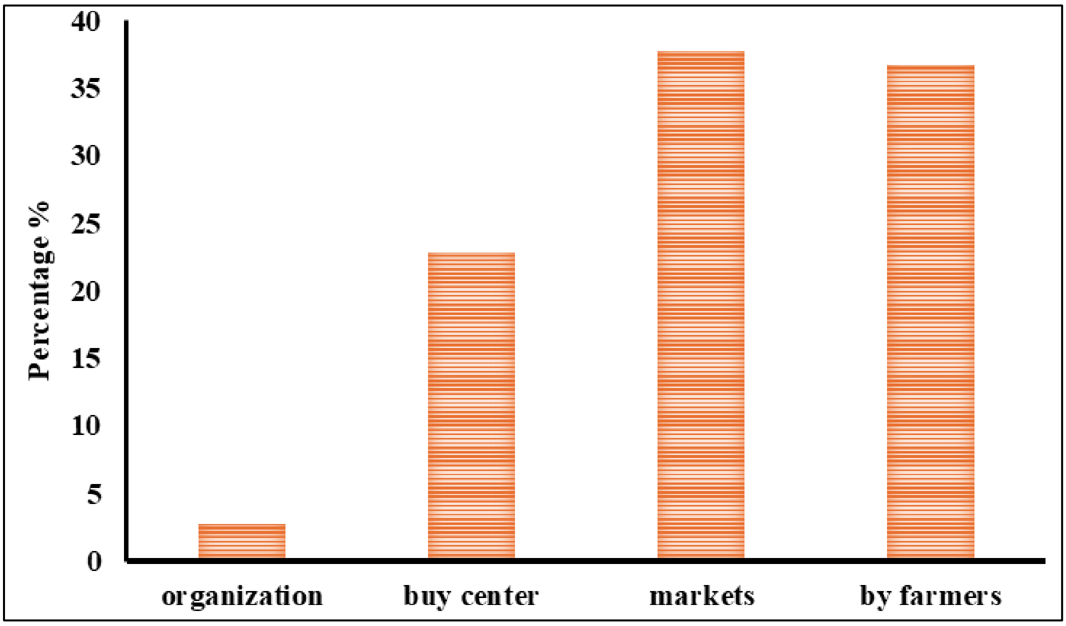

Fig.8. Sources from which respondents acquire seeds

3.3.10 Types of animals owned by respondents

A significant portion of respondents (50.6%) own other animals, indicating a wide variety of animal ownership other than cows, camels, and goats. Goats are popular for their milk, meat, and their ability to thrive in diverse environmental conditions whereas stated by (22.2%) respondent's. Cows are valuable for their milk production, meat, and use in agricultural activities such as plowing whereas (21.7%) of respondent's own cows. This is consistent with (Eik et al., 2008) who said livestock products not only provide high-value protein but are also important sources of a wide range of essential micronutrients such as iron and zinc, and vitamins such as vitamin A. In addition to milk and meat, manure is also an important by-product for farmers in this area and used to fertilize vegetable plots. Camels are often kept for their ability to survive in arid environments and are used for transportation, milk, and meat, a smaller percentage (5.6%) of respondent's own camels (Table 10). The results reflect diversity in the types of animals owned by respondents, suggesting varied livestock management practices based on factors such as climate, cultural preferences, and economic considerations. Livestock ownership, particularly of cows, camels, and goats, can play a significant role in the livelihoods of rural communities. These animals provide food, income through sales of milk or meat, and often serve as assets for agricultural activities.

Table 10. Types of animals owned by respondents

Types of animals	Frequency	Percentage %
Cow	39	21.7
Camel	10	5.6
Goat	40	22.2
Other	91	50.6

3.3.11 Methods used to remove weeds by respondents

The majority of respondents (53.9%) use mechanical methods to remove weeds. Mechanical weed control involves using tools or machinery such as hoes, weeders, plows, or cultivators to uproot or destroy weeds mechanically. However, Naïo, (2021) stated that proposed different types of weeding tools, including arrow- and tine-shaped, which can be mounted on a guided vehicle to perform weeding operations. We founnd (28.9%) of respondents remove weeds manually, indicating that a significant portion of weed control is done through manual labor. This method involves physically pulling or uprooting weeds by hand these also highlighted by Van et al, (2008) stating that hand-weeding is a common weed management practice, but it is time-consuming, high cost, labor-intensive, and more difficult due to labor shortage in the agriculture. Whereas (17.2%) of respondents use pesticides to control weeds (Figure 9). Pesticides are chemical substances designed to kill or inhibit the growth of weeds, and can be applied in various forms such as sprays, granules, or powders. Therefore, Bah et al., (2018) reported that the weeds exhibit uneven spatial distribution however; the traditional weed management method is that herbicides are usually applied uniformly across the field. The most herbicides are released into the environment through runoff and drift, which have an impact on the ecological environment and human health (Rani et al., 2021). Our findings reflect a mix of weed control strategies employed by respondents, including manual, mechanical, and chemical methods. The choice of method may depend on factors such as the scale of farming operations, weed species, labor availability, equipment access, and environmental considerations as well as area of farm and socioeconomic status of respondent.

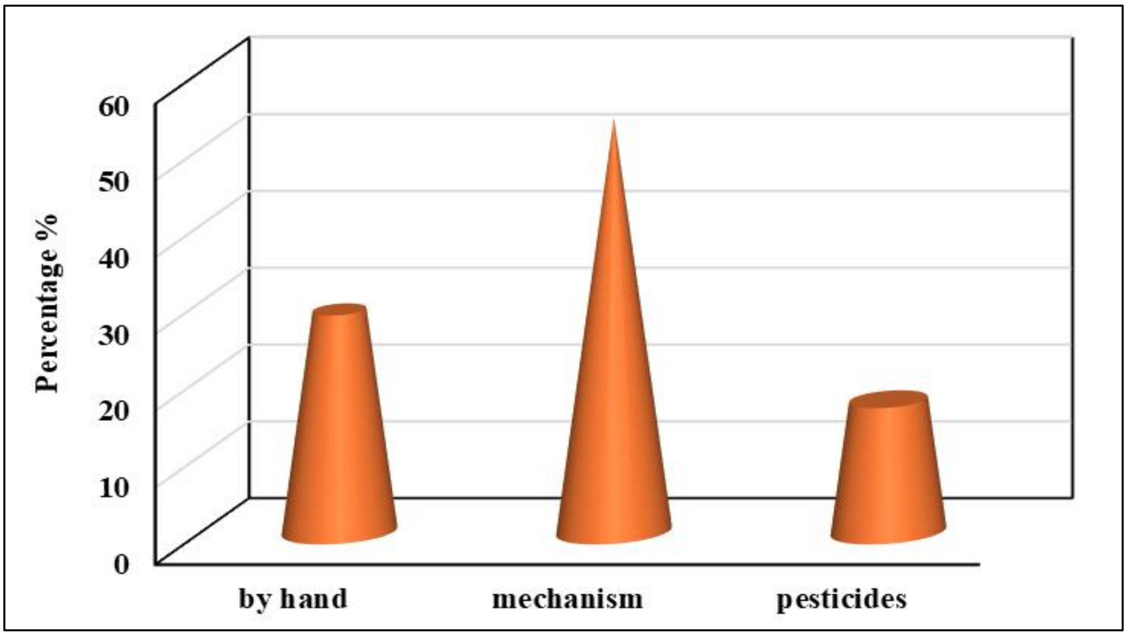

Fig.9. Methods used to remove weeds by respondents

3.4 Farmers' perception of climate change

3.4.1 Changes made to the cultivation method over the past 30 years

The majority of respondents (74.4%) indicated that they have not made changes to their cultivation methods over the past 30 years (Figure 10). This suggests a level of stability or continuity in agricultural practices among the surveyed group over the specified timeframe. Changes in cultivation method (25.6%) of respondents reported that making changes to their cultivation methods over the past 30 years (Figure 10). This indicates that a minority of respondents are actively modified their agricultural practices during this timeframe. This is consistent with (Mathews, 1992) who found that there was a varying degree of adoption of modern agricultural practices among farmers. Some farmers embraced new techniques, while others remained attached to traditional methods. The decision to make changes or maintain existing cultivation methods could be influenced by various factors such as technological advancements, changes in market demands, environmental considerations, access to resources, and traditional farming practices. Smith & Barbour, (2021) and Jones et al., (2022) reported that farmer behavior towards sustainability is shaped by a complex interplay of economic, environmental, social, and personal factors. Economic considerations often drive farmers towards sustainable practices when these can be shown to enhance profitability, either through increased yields, access to premium markets, or through reduced input costs associated with sustainable methods like organic farming or conservation agriculture. For respondents who have made changes, it reflects an openness to innovation, adaptation, and potentially a willingness to improve efficiency, productivity, or sustainability in agriculture. This can inform strategies for promoting sustainable agriculture, technology transfer, knowledge sharing, and capacity building among farmers.

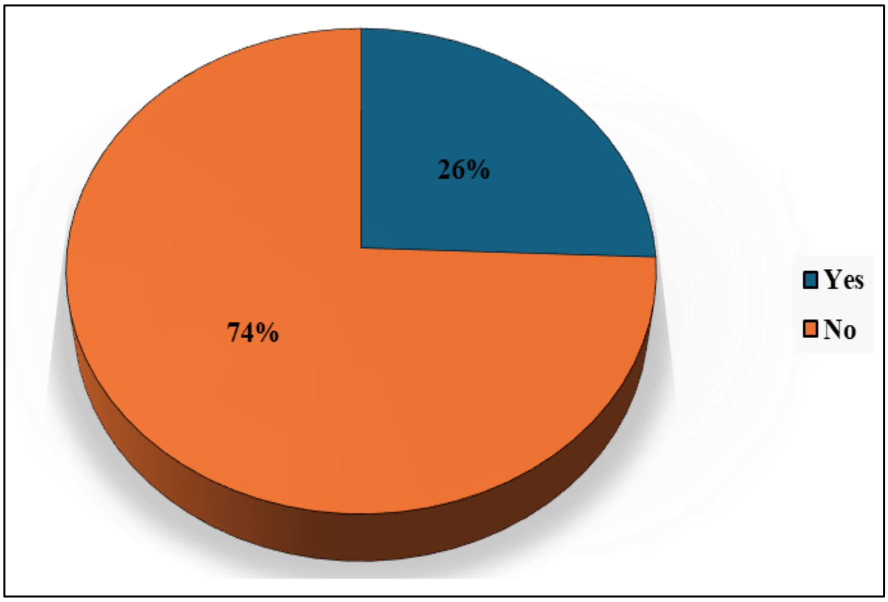

Fig.10. Changes made to the cultivation method over the past 30 years

3.4.2 Indicators whether there has been an increase or decrease in crop productivity over the past thirty years

Increased productivity (50.0%) of respondents reported an increase in crop productivity over the past thirty years. This suggests that a significant portion of respondents believe that advancements in agricultural practices, technology, or other factors have led to improved crop yields. Howevr, Jelliffe et al., (2024), stated that the major technological developments in farming over the last 60 years included the spread of green revolution crop genetic improvements, the use of manufactured inputs like synthetic fertilizers, agricultural chemicals, animal feed concentrates, and farm machinery greatly expanded. Decreased productivity (50.0%) of respondents reported a decrease in crop productivity, as observed in (Figure 11). This indicates that an equal number of respondents perceive a decline in crop yields, possibly due to factors such as soil degradation, climate change impacts, pest and disease pressures, or socio-economic challenges. Our findings agreed with Ortiz-Bobea et al., (2021) who reported that, future agricultural productivity could be affected by changes in yields resulting from a changing climate as well as relating climate change back to overall changes in TFP. The equal distribution between increased and decreased productivity indicates a variability in perceptions among respondents regarding changes in crop productivity could be from variability in farming practices, geographic regions, crop types, or individual experiences with agricultural production.

3.4.3 Strategies for climate change adaptation used by respondents

A majority of respondents (50.0%) have opted to change their crop type in response to shifting climate conditions, indicating a broad acknowledgment of the need to adapt to maintain productivity and sustainability (Table 11). The result agrees with Li, et al., (2021) which reported that these farmers are more likely to adapt to climate change by implementing strategies such as changing crop varieties, adjusting planting dates, and improving water management practices. Additionally, (20.0%) of respondents are involved in interplanting with trees, or agroforestry to benefit from shade, soil stabilization, and increased biodiversity as well as secondary sources of income from forest products. Another (20.0%) is focusing on growing climate-resistant crops to withstand extreme weather, pests, and diseases, showing a proactive approach to mitigating climate change impacts. Early agriculture practiced by (5.0%) of respondents, involves adjusting planting and harvesting times to avoid adverse weather, reflecting regional climatic adaptations. Lastly, (5.0%) use other unspecified strategies showcasing the diversity in approaches farmers are using to build resilience against climate challenges by combining traditional knowledge with modern agricultural advancements.

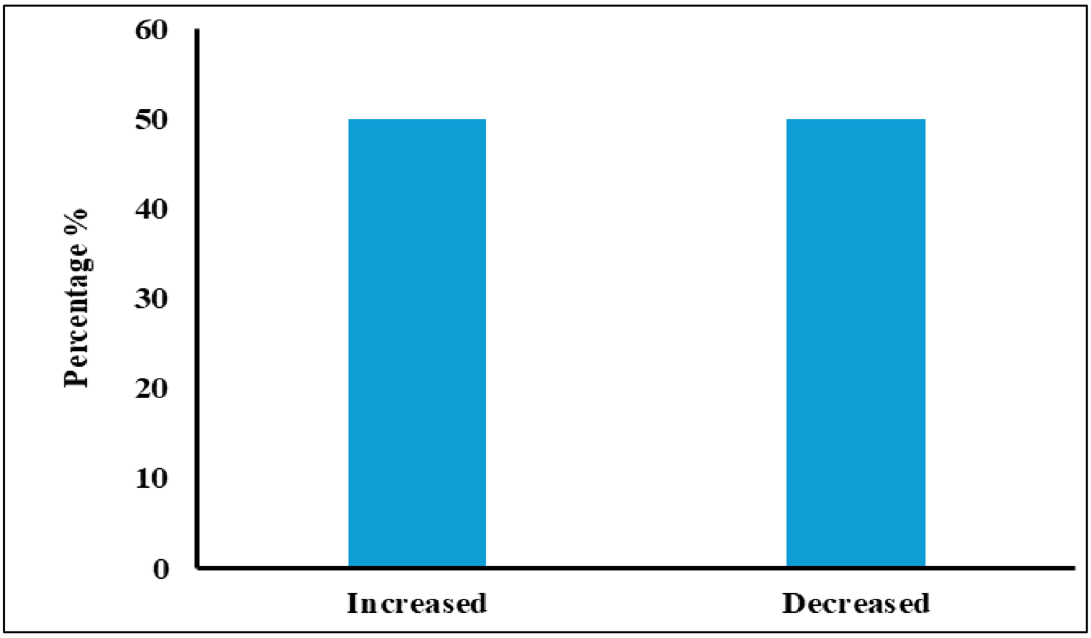

Fig.11. Indicators whether there has been an increase or decrease in crop productivity over the past thirty years

Table 11. Strategies for climate change adaptation used by respondents

Type of Activities	Frequency	Percentage %
Change in crop type	90	50.0
Interplanting with trees	36	20.0
Growing climate-resistant crops	36	20.0
Early agriculture	9	5.0
Other	9	5.0

3.4.4 Farmers' knowledge adaptation statement and possible strategies to cope-up with climate change

Farmers' perception about climate change and possible strategies to cope-up with climate change showed significant differences among the respondents (Table 12). However, these findings revealed that most of the respondents in the area use different strategies to cope with climate changes. Crops rotation, agroforestry, changing in sowing time and many other strategies are followed by farmers as adaptive strategies to improve major crop production for their daily needs and income generation (Table 12). These findings are in line with Yu et al. (2022) who reported that crop rotation is one of the strategies mostly used to reduce climate change effects. While Shah et al. (2021) reported that diversified crops rotation represents one of sustainable agriculture approached. Access to agricultural credit and insurance towards crop failure were the least popular strategies observed among the farmers of Nyala region of Sudan. Farmers in South Darfur already practice local adaptation measures that align with climate-smart agriculture (CSA). These include traditional pest and weed control, measure-based soil fertility improvement, crop rotation, early planting based on indigenous knowledge, and the use of drought-tolerant varieties of millet and sorghum. Some farmers also integrate trees into their filed to protect soil and improve microclimates. These locally developed practices form a strong foundation for CSA and show that future interventions should build on exiting community strategies rather than introducing entirely new approaches.

Table 12. Farmers' knowledge adaptation statement and possible strategies to cope up with climate change in South Darfur State, Sudan

Farmers' knowledge adaptation statement and possible strategies to cope up with climate change	Response (% of sample households)		
	Yes	No	Do not know
Adopting crop rotation	50.50	45.40	4.10
Using drought resistance crop variety/climate-smart crops	65.00	33.50	1.50
Changing sowing time & sowing intensity	75.00	22.40	2.60
Switching to minimal tillage	45.00	42.40	12.60
Switching to precision irrigation such as sprinkler/drip irrigation	15.50	75.50	9.00
Insect control through indigenous traditional knowledge	45.00	36.80	18.20
Changing fertilizer regime/ash management	25.40	56.00	18.60
Change to harvesting time	45.00	35.00	20.00
Adopting agroforestry practices	20.00	65.00	15.00
Growing trees on the field bunds/hedgerow	30.00	65.00	5.00
Adopting to mulching & soil conservation practices	25.50	64.50	15.00
Adopting to livestock rearing	45.00	45.00	10.00
Access to agricultural credit	15.00	84.00	1.00
Insurance towards crop failure	2.00	90.00	8.00

IV. CONCLUSION

Your findings indicate that South Darfur has experienced significant climatic and environmental changes over the past three decades. NDVI and rainfall increased significantly, while maximum temperature also showed a significant upward trend, reflecting continued regional warming. Millet was the only major crop to exhibit a significant decline, suggesting greater sensitivity to climate variability and socio-political disturbances, whereas groundnut, sesame, and roselle remained relatively stable due to farmers' adaptation practices and increasing market demand. Survey results further demonstrated that farmers have adopted several climate adaptation strategies, including changing crop types, agroforestry, crop rotation, drought-tolerant varieties, and indigenous soil management practices. These locally developed strategies provide a strong foundation for promoting climate-smart agriculture and improving the resilience of agricultural systems in South Darfur.

ACKNOWLEDGEMENT

This study forms part of a Master of Science (MSc.) thesis and is based on research supported by the Department of Crop and Range Sciences, Faculty of Natural Resources and Environmental Studies, University of Kordofan, Sudan. The first author gratefully acknowledges the valuable support provided by the department throughout the research process. Special thanks are extended to the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) for their generous financial assistance in the form of a scholarship for the award of the degree, which significantly contributed to the successful completion of this work.

DATA STATEMENT

Data available in article supplementary material.

CONFLICT OF INTEREST

The authors declare no competing interests

AUTHORS CONTRIBUTION

Tahlil A. Farah conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, writing-original draft; Nagla N. Suliman and Entisar-Elilah B. M. Ahmed-Elbadry conceptualization, methodology, supervision, validation, visualization, writing-reviewing and editing; Ibrahim H. Abdalkreem formal analysis, validation, visualization, writing-original draft, reviewing and editing. All authors read the final draft and approved for submission.

ETHICAL STATEMENT

This study was conducted in accordance with ethical research standards involving human participants. All respondents, including farmers, participated voluntarily after being fully informed about the purpose and nature of the research. Informed consent was obtained from all participants prior to data collection. The confidentiality and anonymity of all respondents have been strictly maintained, and no personally identifiable information has been disclosed in this manuscript.

REFERENCES

[1] Abdullah, Noor, Syafiqah., Kamisah, Osman. (2024). The effects of gender on knowledge, attitude and behaviour of science teachers towards climate change. International journal of Asian social science.

[2] Ahmed, Younis., N., J., Bello., A., O., Togun., G., Hamad., S., Aïssata., Siraj, Osman, Omer., Mustafa, Abdalla, Nasrealdin. (2022). Farmers' perceptions of climate change and its impact on gum Talha (Acacia seyal var. seyal) production in Bahar Alarab locality, East Darfur State, Sudan. Journal of Applied and Natural Science, 14(2):349-361. doi: 10.31018/jans.v14i2.3392

[3] Al-Akkad , Hanin ,(2009). climate change ,its causes and effects in Palestine , first edition , Development Action center for Publishing ,Gaza.

[4] Ali Hussein Musa (1994). Agricultural climate , Jawhar Alsham press , Damascus ,p. 9.

[5] Almekinders, C. J., & Louwaars, N. P. (2002). The importance of the farmers' seed systems in a functional national seed sector. Journal of new Seeds, 4(1-2), 15-33.

[6] Amtmann, J. A., Amtmann, K. A., & Spath, W. K. (2008). Lactate and rate of perceived exertion responses of athletes training for and competing in a mixed martial arts event. The Journal of Strength & Conditioning Research, 22(2), 645-647.

[7] Antero, Ollila. (2019). Challenging the Greenhouse Effect Specification and the Climate Sensitivity of the IPCC. Physical Science International Journal.

[8] Bah, M.D.; Hafiane, A.; Canals, R. (2018). Deep Learning with Unsupervised Data Labeling for Weed Detection in Line Crops in UAV Images. Remote Sens. , 10, 1690.

[9] Bakoye, O., Baoua, I., Sitou, L., Moctar, M. R., Amadou, L., Njoroge, A. W., ... & Baributsa, D. (2019). Groundnut production and storage in the sahel: challenges and opportunities in the Maradi and Zinder Regions of Niger. Journal of Agricultural Science (Toronto, Ont.), 11(4).

[10] Coolon, J. D., Jones, K. L., Todd, T. C., Blair, J. M. and Herman, M. A. (2013). Long-term nitrogen amendment alters the diversity and assemblage of soil bacterial communities in Tallgrass Prairie. PLoS ONE 8(6): e67884.

[11] Dosa, A.B. 2014. “The conflict and agricultural production in Darfur”. In Darfur's Political Economy (pp. 89-102). Routledge.

[12] Eik, L. O., Kifaro, G. C., Kiango, S. M., Nordhagen, Ø. M., Safari, J., & Mtenga, L. A. (2008). Productivity of goats and their contribution to household food security in high potential areas of East Africa: A case of Mgeta, Tanzania. African Journal of Food, Agriculture, Nutrition and Development, 8(3), 278-290.

[13] Elsheikh, A. E., El Khidir, S. O., & Zeinelabdein, K. A. E. (2014). Groundwater Resources Assessment for IDPs camps and Hosting Communities around Nyala Town, South Darfur State, Sudan. J Remote Sens GIS, 2(1), 46-51

[14] Garba, N. M. I., Toudou, A., Ibrahim, M. L. A., Soumana, I., & Bakasso, Y. (2021). Place of Groundnut in the Cropping System, Constraints, Local Taxonomy and Farmers' Criteria for Characterizing Groundnut Cultivars in

Niger. Asian Journal of Research in Crop Science, 6(1), 44-60.

[15] Hassoon, A. S., Kadhim, A. A., & Hussein, M. H. (2023). A Review in Medical, Pharmacological and Industrial Importance of Roselle Hibiscus sabdariffa L. In Medicinal Plants-Chemical, Biochemical, and Pharmacological Approaches. IntechOpen.

[16] Helena, Correia., D., Costa. (2022). Effect of Climate Change on Agricultural Production. Practice, progress, and proficiency in sustainability, 99-114. doi: 10.4018/978-1-7998-9557-2.ch006

[17] Huntington, J.L., K. C. Hegewisch, B. Daudert, et al. 2017. "Climate engine: Cloud computing and visualization of climate and remote sensing data for advanced natural resource monitoring and process understanding". Bulletin of the American Meteorological Society 98: 2397-2410. https://doi.org/10.1175/BAMS-D-15-00324.1

[18] Jelliffe, J., Fuglie, K., & Morgan, S. (2024). Productivity-led Pathways to Sustainable Agricultural Growth: Six Decades of Progress. Euro Choices.

[19] Jeremy, Bowles., Horacio, Larreguy., Shelley, Liu. (2019). census_agriculture.tab. doi: 10.7910/dvn/rexz8h/xtujye.

[20] Jones, P., & others. (2022). "Effects of conservation tillage on soil health and crop productivity." Agricultural Practices and Research, 28(1), 112-130.

[21] Khanal, Saugat., Pankaj, Dhital., Stephen, Christian. (2021). Farming the future: Youth enthusiasm and transforming Nepal's economy through agriculture. The Journal of Agriculture, Food Systems, and Community Development.

[22] Li, X., Cao, Z., & Shi, X. (2022). How do farmer's disaster experiences influence their climate change perception and adaptation?. *Climate and Development*, *14*(6), 523-536.

[23] Mathews, Godfrey, Muyekho. (1992). The transformation of traditional agriculture: A survey of webuye division, bungoma district, kenya.

[24] Michael, D., McManus., Cary, L., Rivard., Londa, Nwadike., Candice, A., Shoemaker. (2023). Grower experience affects business education needs for a profitable specialty crop farm operation in the central United States. Journal of Agricultural Education, 64(3):62-78.

[25] Milesi, M. M., Lorenz, V., Durando, M., Rossetti, M. F., & Varayoud, J. (2021). Glyphosate herbicide: reproductive outcomes and multigenerational effects. Frontiers in endocrinology, 12, 672532.

[26] Mohamed, A. A. A., Maharana, P., Phartyal, S. S., & Dimri, A. P. (2024). Projected change in precipitation and temperature over undivided Sudan and its major cities. Meteorology and Atmospheric Physics, 136(2), 11.

[27] Mullins CE, MacLeod DA, Northcote KH, Tisdall JM, Young IM (1990) Hardsetting soils: Behaviour , occurrence and management. Advances in Soil Science 11, 37-108.

[28] Mwasiagi, J. I., & Phologolo, T. (2021). Growing and uses of Hibiscus sabdariffa L.(roselle): a literature survey. Roselle, 43-52.

[29] Naïo Technologies. (2021). Autonomous Vegetable Weeding Robot—Dino. Available online: https://www.naio-technologies.com/en/dino/.

[30] Ortiz-Bobea, A., Ault, T., Carrillo, C., Chambers, R., & Lobell, D. (2021). Anthropogenic climate change has slowed global agricultural productivity growth. Nature Climate Change, 11, 306–312.

[31] Rani, L.; Thapa, K.; Kanojia, N.; Sharma, N.; Singh, S.; Grewal, A.S.; Srivastav, A.L.; Kaushal, J. (2021). An extensive review on the consequences of chemical pesticides on human health and environment. J. Clean. Prod. 283, 124657.

[32] Römheld, V.; Kirkby, E. (2010). Research of potassium in agriculture: needs and prospects. Plant and Soil, 335, 155–180.

[33] Roy, B.B.; Chowdhury, R.B.; Baroi, A.R.; Rahman, S.; Powers, S.M.; Milne, N.; Sujauddin, M. (2019). Unravelling the anthropogenic pathways of phosphorus in the food production and consumption system of Bangladesh through the lens of substance flow analysis. J. Ind. Ecol. 23, 1439–1455.

[34] Shah, K.K., B. Modi, H. P. Pandey, et al. 2021. "Diversified crop rotation: an approach for sustainable agriculture production". Advances in Agriculture 2021: 8924087. https://doi.org/10.1155/2021/8924087

[35] Siam, A. M. J. & Abdalkreem, I. H. (2019). Diurnal Photosystem II photochemical efficiency and biomass partitioning in Acacia mellifera and Acacia laeta seedlings under drying soil. Kastamonu University Journal of Forestry Faculty, 19 (1), 82-94. *(PDF) Diurnal Photosystem II Photochemical Efficiency and Biomass Partitioning in Acacia mellifera and Acacia laeta Seedlings Under Drying Soil*.

[36] Smith, L., & Barbour, E. (2021). "Organic farming adoption: Factors influencing farmer decision-making." Environmental and Agricultural Insights, 22(6), 701-715.

[37] Tahir, Mohammed, Layeeq. (2023). The level of environmental knowledge among farmers during farming practice in the Sharazur Plain - Sulaimani Governorate.14(1):1-16.

[38] Tilman, D.; Balzer, C.; Hill, J.; Befort, B.L. (2011). Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. USA , 108, 20260–20264.

[39] Tripathi, T., & Vyas, S. (2023). From ancient grains to modern solutions: A history of millets and their significance in agriculture and food security. Int. J. Home Sci, 9, 72-78.

[40] Umunnakwe, V., C., V., K., Pyasi., A., K., Pande. (2013). Comparing factors influencing involvement in agricultural and non-agricultural livelihood activities: Evidence from rural youth in Jabalpur district of Madhya Pradesh, India. International Journal of Agricultural Policy and Research.

[41] UNDP in Sudan ,(2020). Building resilience to climate change within systems traditional rain-fed agriculture and pastoral systems in Sudan. Annex 6 – (b) Environmental and social management Framework.

[42] Wako, K, A. (2016), Farm Mechanization of Small Farms in Ethiopia: A Case of Cereal Crops in Hetosa District, phD, Graduate School of Seoul National University, South Korea.

[43] William, (2002). Agricultural Machinery Management Data, St. Joseph, mach.: ASABE.

[44] Yu, T., L. Mahe, Y. Li, X. Wei, X. Deng, and D. Zhang. 2022. "Benefits of crop rotation on climate resilience and its prospects in China". Agronomy 12: 436. https://doi.org/10.3390/agronomy12020436

[45] Zamanov, P.B., Damirova, K.I., Vekilova, E.M., & Shakhmamedova, L.S. (1990). Improving soil fertility, protecting the environment from pollution, improving the environment by developing a technology for processing and using waste as organic fertilizers (p.20). Baku: Collection of Ecology of the BGK.