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Major soil fertility and management gaps in sorghum production in Lesotho

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Sorghum is an important staple crop in Lesotho, following maize and wheat. The objective of this study was to assess soil fertility and management gaps in the country and their impact on sorghum production. In July 2022, an interview involving 320 Basotho farmers was carried out in 8 districts across Lesotho. The survey indicated that sorghum yield across the nation is low (< 1 ton/ha), with the major limiting factors being poor soil fertility, soil management practices, prevalence of weeds, diseases and insects. Farmers consider financial constraints, dry and hard soils, noxious weeds, wetlands, and clay pan as the most serious problems in tillage. Most of the land is cultivated (57.8%), while 42.2% is left fallow. Most farmers perceive their land to be fertile based on yield, and no soil test has been carried out in nearly 90% of the farms. Periodical training is vital to raise their level of awareness. Except for soil erosion control, there appear to be no significant differences among the districts in the parameters considered. Farmers can boost sorghum production through scaling up organic and inorganic fertilizer additions and interventions such as crop rotation, fallowing, cover cropping and conservation agriculture.

Key words: Basotho, organic fertilizers, fallowing, crop rotation, cover crops, conservation agriculture.

INTRODUCTION

Sorghum is the fifth most widely consumed crop worldwide and is rich in proteins, minerals, vitamins, unsaturated lipids, and other essentials. It is a very important crop for the livelihood of Basotho farmers in Lesotho, especially for those who live in low-rainfall areas where maize production is low (Sekoli and Morojele,

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2016). Sorghum is the most cultivated cereal before the introduction of maize in sub-Saharan Africa. Its production is believed to ensure food security for the rural population of Lesotho, due to its tolerance to a wide range of climatic conditions (Sekoli and Morojele, 2016). It is also a great source of diet for farming communities in Africa and Asia because it can be prepared in the form of porridge, bread, brewed in a drink and prepared in other traditional dishes. It is also a good source of animal feed, especially during the dry seasons (Ashok et al., 2011).

Sorghum production in Lesotho is generally affected by drought and floods, poor soil fertility, early frost, late planting, weeds, and insect pests (BOS, 2019). Soils in the sorghum-producing areas in Lesotho, especially in the Senqu River valley and the southern plains, are of poor fertility and are also eroded. Consequently, the average sorghum production never exceeded 1 ton per hectare (BOS, 2014, 2017, 2019). This is generally low by world standards and even by South African standards. Studies conducted in the southern region of Africa have shown that levels of adoption of improved fertilization techniques for soils cultivated with sorghum and millet have been very low (Sito, 2005).

The major soil fertility problems in Lesotho are insufficient levels of macro- and micronutrients (N, P, K, Fe, Zn, etc) and widespread soil acidity, which ordinarily could be rectified through appropriate soil management practices (Caule, 1986). The major causes of low soil fertility are large-scale soil erosion, land degradation and poor soil management. According to (Rehman et al., 2022), application of P and K on Aridisols, significantly improved sorghum fodder yield, which is important for sustainable livestock production. A study that compared the microbial community under a legume (sun hemp) and sorghum, found out that there was higher microbial community under sorghum, which is indicative of the potentials of sorghum to improve soil fertility, if beneficial microorganisms are introduced (Eo et al., 2015).

In a study conducted in Nebraska, sorghum rotating with soybean (*Glycine max*) had a significantly higher yield than sorghum in continuous cropping (Yamoah et al., 1998). Sorghum has also been used as a novel ingredient for sustainable aquafeeds (Zarei et al., 2022). Treatment of wastewater may represent an important tool to enhance and stabilize the biomass of energy crops by recycling scarce quality water and nutrients otherwise lost in the environment (Maucieri et al., 2016).

Some open-pollinated sorghum cultivars produced more vegetative biomass and more grain per plant, compared to commercial hybrids when grown with arbuscular mycorrhiza (AM) fungi and no fertilization (Cobb et al., 2016). Compost application could contribute to increased food availability in the Sahel (Ouédraogo et al., 2001).

It is very crucial that Basotho farmers are provided with relevant education on soil fertility problems and their management to boost sorghum production in Lesotho. Raising the level of awareness of farmers on land degradation and training them on two soil and water conservation measures in northern Burkina Faso promoted a quick adoption of these technologies (Sidibe, 2005). Another study from West Africa discusses the importance of blending knowledge from farmers' organizations with external training as a better approach to fostering agroecological techniques to the farming community than traditional practices alone (Iyabano et al., 2023a).

Scaling up sorghum intake in the diet of Basotho farmers would ensure better food security, balanced nutrition, and health. The objective of this study is to assess the actual soil fertility and management gaps in Lesotho so that workable strategies could be adopted that could increase sorghum crop yield and sustain the productivity of the land.

MATERIALS AND METHODS

Survey and sampling

The survey was conducted in July/August 2022, in specific villages of 8 of the 10 districts of Lesotho, where sorghum is believed to be grown (Table 1). Prior to the survey, a structured questionnaire was developed encompassing questions under several categories pertaining to social, agronomic, crop protection, nutritional and soil fertility aspects of sorghum production. This study particularly focuses on the results of interviews regarding the major soil fertility and management constraints that limit sorghum production in those districts. The survey tool used was KoboCollect. KoboCollect is an open-source Android application for collecting survey data. KoboCollect is a Kobo mobile application. The sampling was both purposive and random in nature. It was purposive because it particularly targeted the sorghum growing districts (Figure 1) and only the sorghum growing farmers. The respondents that were interviewed were randomly selected from among the sorghum growing farmers, with the help of extension officers in the respective areas. The exact number of respondents interviewed from each district is seen on Table 1.

Household number, educational background, and land possession of respondents

A total of 320 respondents were interviewed in the above districts. The median number of household members was 5. 6. Only 1% of respondents had primary education, while 22.8% had secondary education. About 10% of them never had formal education, while 5.3% had high school education, 3.4% tertiary education and 0.31% fall under others. About 84.1% had their own crop land, while 15.3% rented land and 0.6% had no land.

Data analysis

Comparison of districts in response to a few selected parameters is made using the STATA Statistical Software, release 18 (StataCorp. 2023). Similar responses for each question were grouped under each district to determine the statistical differences between districts. Where more responses were given for a particular question, they were grouped together as 'combined responses' and

Table 1. Districts and specific locations in Lesotho where the interview was carried out.

No.	Districts	Specific locations	Respondents	Percentage
1	Berea	Sefikeng, Mapoteng, and Corn exchange	48	15.00
2	Botha Bothe	Ha Selomo, Ha Nquabeni, and Tlokoeng	38	11.88
3	Leribe	Mphosong, Matlameng, and Pela tsoeu	53	16.56
4	Mafeteng	Thabana Morena and Motsekuoa	16	5.00
5	Maseru	Nyopa-tsoeu and Nazaretha	34	10.63
6	Mohale's Hoek	Phamong, Brakfotein, and Holy cross	60	18.75
7	Quithing	Qomo, quomong and Askopo	27	8.44
8	Thaba Tseka	Koma Koma, Litsoetse, and Hama Kunyapane	44	13.75
Total			320	100

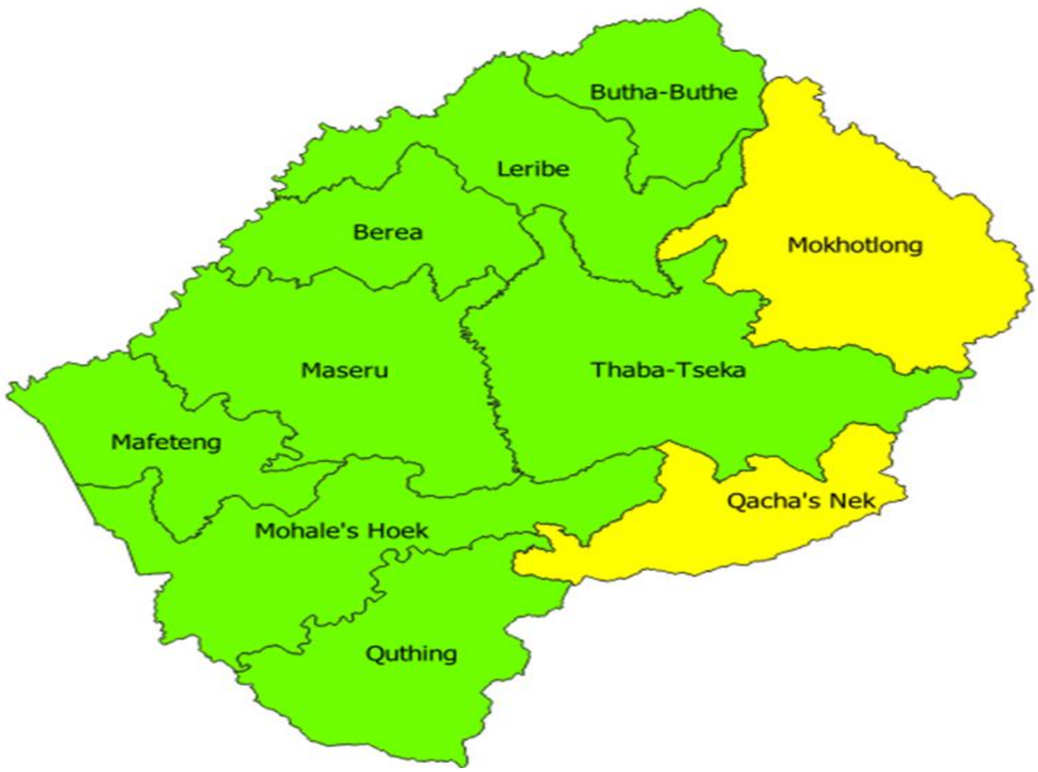

Figure 1. Map of Lesotho showing the 8 districts (in green) where sorghum is grown.

their means were determined as one group. Where a few other responses were given including no-responses, they were collectively described as 'others'. A non-parametric statistical analysis was conducted using the Chi-square test (X^2). The Kruskal-Wallis non-parametric test was carried out for multiple-group analysis.

RESULTS

Data on crop yields and soil fertility

Respondents ranked the fertility status of their farms based on the yields they obtained. Accordingly, 21.3% ranked their soil as very good, 47.2% as good, 29.1% as poor, and 2.5% as very poor (Figure 2). There is no significant difference in the ranking of soil fertility levels across the eight (8) districts (Table 2). Most respondents across the districts considered the soil fertility as good while very few perceived very poor. However, within each district, the frequencies of the respondents across the four soil fertility levels were significantly different. The study also found that most of the land was under cultivation (96.9%). Of the 310 who responded, most mentioned that their land was under cultivation for over

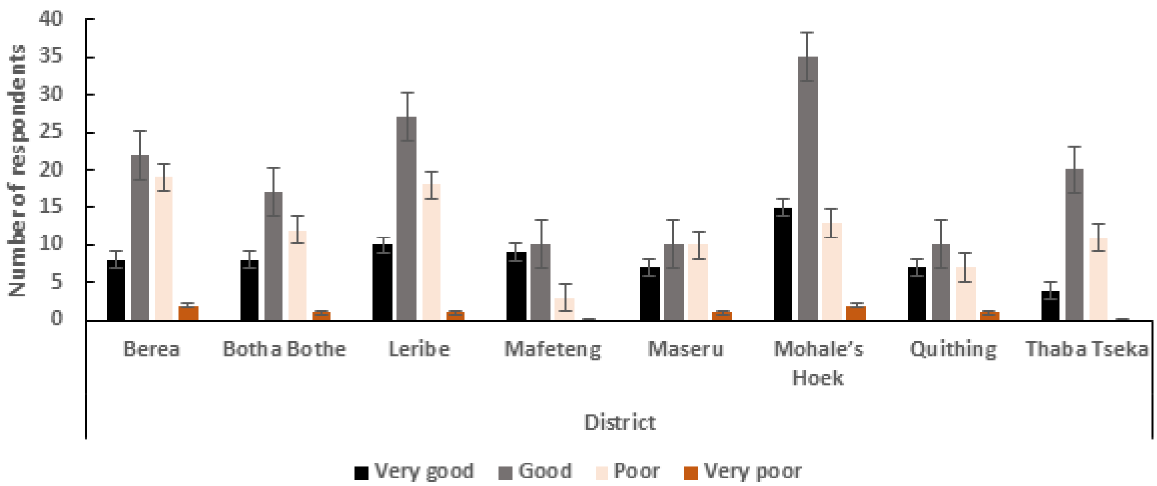

Figure 2. Farmers' perception of soil fertility levels of their croplands based on crop yields.

Table 2. Farmers classified their land into different levels of soil fertility based on crop yields.

Soil fertility level	District										
	Berea	Botha Bothe	Leribe	Mafeteng	Maseru	Mohale's Hoek	Quithing	Thaba Tseka	Total	$\chi^2(21)$	Pr
Very good	8	8	10	9	7	15	7	4	68		
Good	22	17	27	10	10	35	10	20	151	18.09	0.643
Poor	19	12	18	3	10	13	7	11	93		
Very poor	2	1	1	0	1	2	1	0	8		
Total	51	38	56	22	28	65	25	35	320		

ten years (71%), while 8.7% of the respondents said their land was cultivated between 5 to 10 years. A few of them (13.2%) said they cultivated it for less than 5 years. About 7.1% do not have accurate knowledge of how long the land was cultivated.

Land ownership and utilization

Most of the interviewed farmers owned land for over 20 years (65.8%), 7.1% of them for 15-20 years, 9.3% for 10 – 15 years, 11.2% for 5 to 10 years, and 6.7% for 0-5 years. Most of the land was cultivated (57.8%) while 42.2% was left fallow. Out of 320 respondents, only 132 responded. Those who responded said they left their land fallow, because of lack of inputs, such as seeds or fertilizers (67.4%), high tillage costs (44.7%), poor rainfall (33.3%). Only 14.4% of them said they left it to improve the productivity of the land.

Problems related to tillage

Regarding the significant problems farmers encountered during tilling, they enumerated their problems in the following descending order: financial problems, dry and hard soils, noxious weeds, wetlands, others, and clay pan (Figure 3). There appears to be no significant difference between districts regarding tillage related problems (Table 3).

Soil testing and soil acidity problems

When asked whether they ever had their soil tested, most said that it was never tested (89.7%), 8.4% said only one time, a few of them (1.9%) said they got it tested more than one time. When asked why they never got their land tested, only 287 out of 320 responded. Out of those who responded, most (60.6%) answered that they were not even aware that soil could be tested, 52.6% do not know where soils are tested, and 13.6% said that testing soil is quite expensive. 65.2% of the respondents said that their yields were not reduced due to soil acidity, while 34.8% of them said their yields were reduced due to soil acidity. Nearly 2/3 of them did not respond to the question pertaining to the management practice they use to rectify the acidity problem. 62.2% of those who responded said they did nothing to improve the acidity problem. 25.2%

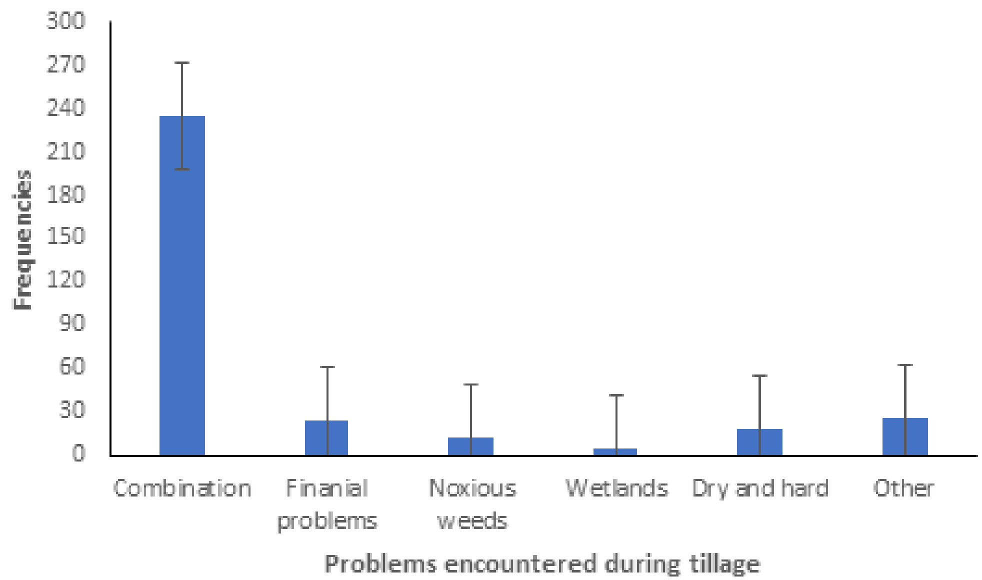

Figure 3. Farmers' responses to problems they encountered during land operation.

Table 3. Farmers' responses to problems they encountered during tillage.

Tillage related problem	Districts								Total	$\chi^2(35)$	Prob
	Berea	Botha Bothe	Leribe	Mafeteng	Maseru	Mohale's Hoek	Quithing	Thaba Tseka			
Combination (financial. noxious weeds. clay pan etc.)	72.5	71.1	71.4	90.9	71.4	69.2	80.0	74.3	73.4		
Financial problems	13.7	5.3	12.5	9.1	-	6.2	4.0	2.9	7.5		
Noxious weeds	2.0	5.3	3.6	-	7.1	7.7	-	-	3.8	47.35	0.079
Wetlands	3.9	2.6	-	-	3.6	-	4.0	-	1.6		
dry and hard soil	3.9	2.6	-	-	7.1	12.3	-	14.3	5.6		
Others	3.9	13.2	12.5	-	10.7	4.6	12.0	8.6	8.1		

of them applied ash to improve the acidity problem while 13.5% of them limed their fields to correct soil acidity. Farmers' lack of proper perception about soil fertility and acidity and reluctance to get their soils tested in labs is indicative of the need of periodical focussed trainings on soil fertility and management at farm level.

Types of artificial fertilizers used, and proportions applied on crops

On the use of organic or inorganic fertilizers, 41.7% of 319 respondents indicated that they use both organic and inorganic fertilizers, 24.1% said they use only organic fertilizers, 22.9% said they use only inorganic fertilizers, while 15.7% said they do not use any of the fertilizers. When asked which of the organic fertilizers they use, 72.4% of the 87 who responded to the question, said they use kraal manure, while 20.7% use compost,2.3% said others, 2.3% said chicken manure, 1.1% use sheep manure, and finally 1.1% use effective microorganisms. When asked which inorganic fertilizers they use, 73 of them responded. Out of those who responded, 56.2% said 6:2:1(31), 32.9% said 2:3:2(22); 9.6% said 3:2:1(25) and 1.4 said 2:3:4(30) indicating the N:P: K proportions in each fertilizer.

Only 12 responded when asked on which crop 3:2:1(25) N:P: K is applied. 50.0% said they use it on maize, 33.3% on sorghum, 8.3% on beans and 8.3% on others. The median size of land they used for sorghum was 1 acre, from which on average they produced 4 bags of sorghum.

There were 72 responses for the question on which crops they applied 6:2:1(31) N:P: K. It appeared that they applied almost equally on maize and sorghum fields, while very few applied on beans. 48.6% of the responses indicated that 6:2:1(31) is applied on sorghum, followed by maize (47.2) and very few responses (4.2%) indicated on beans. From the 35 responses, it was possible to find out that on average farmers used 2 acres of land for sorghum and harvested on average 5 bags per acre. Of the 47 responses to the question on which crops 2:3:2(22) N:P: K is applied, most said on sorghum (48.9%), followed by maize (36.2%) and few mentioned beans (14.9%). The average field size used for sorghum was 2.61 acres per farmer and an average of 7.1 bags of sorghum were harvested from each acre, using this fertilizer.

It appears farmers do not apply 2:3:4 (30) N:P: K fertilizer as much as the others. Only one person responded that he/she applied 2:3:4(30) N:P: K on both sorghum and maize. He/she mentioned that on average he/she used 8 acres of land for sorghum, at a rate of 1 bag per acre. It appears the same farmer utilized about 9 acres for maize, with an average yield of 1 ton/acre.

Erosion problems and measures taken to tackle them

Most farmers (63.4%) could identify some signs of erosion on their fields, while some of them (36.6%) didn't observe any signs of erosion at all. Farmers mostly tried to tackle erosion problems by constructing diversion furrows (46%), while a few used loose stones and conservation structures (12.4%), some applied conservation agriculture (10.4%): others reverted to area closure for animal grazing (4.4%), others planted trees (4.4%), or used other measures (4.4%); while a few took no measures at all (18%) (Figure 3). There is a significant difference between districts regarding the soil erosion control measures they used (Table 4). A multiple-parameter comparison using the Krukal-Wallis test also indicates that there is a nearly significant difference between districts only for the ways farmers used to control soil erosion (Table 5).

Most farmers (66.3%) happen to have used conservation agriculture (CA) at one time or another, while some (33.8%) of them never used conservation agriculture at all, to control soil erosion. Of those who used CA, a significant number (45.5%) of them applied minimum tillage, and a good number of them (40.9%) dug potholes (Likotjana), while a few of them (13.6%) combined both minimum tillage and pot-holes (Figure 4).

From among the few respondents that replied to the question which compared the CA practises, 46.7% of them believe that a mixture of potholes and tillage is the most effective measure; while some of them (33.3%) believe minimum tillage is most effective: whereas 20% of them think pot-holes are most effective. Most farmers (65.5%) do not use any soil cover to protect soils; while some (19.5%) leave crop residues on field to cover the soil. A few (10.7%) grow green manure crops, while very few of them (4.3%) combine green manure with crop residues.

DISCUSSION

Over 2/3 of sorghum growing Basotho farmers believe they have fertile soils based on yields they obtain. Although farmers may claim their land is fertile, sorghum yields in Lesotho are generally low (< 1 ton/ha). Most farmers never got their soils tested and hence there is no proof to warrant good soil fertility. There are reports indicating that the soils of Lesotho are impoverished of nutrients, due to the large-scale land degradation. Sorghum production in Lesotho may also be limited because of bird attack, infestations with stem borers, weeds, and other adverse environmental causes as well.

Although most farmers possessed their lands for many years, their soils are exhausted because they are usually cultivated and rarely left fallow for soil nutrient recuperation. Even those who left the land fallow for some time, didn't do so for the replenishment of soil nutrients but mainly because of lack of agricultural inputs (such as seeds or fertilizers) or because of high tillage costs and poor rainfall. Only few farmers seem to be aware of the benefits of fallowing for improving soil fertility. Rotations with leguminous crops could also improve soil productivity. Greater profits could be achieved by using rotations with soybean because of higher sorghum yields and lower fertilizer costs, usually under favorable rainfall and temperature regimes (Yamoah et al., 1998).

Another obstacle to productivity in the farmlands is due to practises related to tillage. Just the same with other

Table 4. Farmers enumerated different measures to control soil erosion.

Farm practices	Districts								Total	$\chi^2(35)$	Prob
	Berea	Botha Bothe	Leribe	Mafeteng	Maseru	Mohale's Hoek	Quithing	Thaba Tseka			
Erosion control											
Conservation Agriculture	-	-	1.8	-	7.1	1.5	-	8.6	2.2		
Combination (diversion furrow CA., etc.)	13.7	5.3	12.5	18.2	10.7	29.2	20.0	20.0	16.9		
Constructed diversion furrow	15.7	26.3	35.7	27.3	42.9	18.5	28.0	25.7	26.3	51.98	**0.032**
None	15.7	7.9	17.9	4.5	10.7	15.4	12.0	20.0	14.1		
Others plus blank	52.9	55.3	30.4	45.5	28.6	35.4	40.0	22.9	38.8		
Planting trees	2.0	5.3	1.8	4.5	-	-	-	2.9	1.9		
Conservation measures											
Combined	3.9	2.6	3.6	-	3.6	10.8	8.0	5.7	5.3		
Minimum tillage	13.7	26.3	14.3	18.2	10.7	9.2	16.0	17.1	15.0	23.37	0.325
Nothing	66.7	60.5	76.8	59.1	71.4	58.5	72.0	65.7	66.3		
Pothole	15.7	10.5	5.4	22.7	14.3	21.5	4.0	11.4	13.4		
Soil Cover											
Combination	3.9	2.6	1.8	13.6	3.6	6.2	12.0	2.9	5.0		
Crop residues	13.7	15.8	25.0	18.2	10.7	20.0	40.0	8.6	18.8	29.55	0.101
Green manure	15.7	15.8	8.9	4.5	7.1	6.2	-	14.3	9.7		
Nothing	66.7	65.8	64.3	63.6	78.6	67.7	48.0	74.3	66.6		

Table 5. Kruskal–Wallis equality of populations rank test.

Farm practice	Districts								$\chi^2(7)$	Prob
	Berea (n=51)	Botha Bothe (n=38)	Leribe (n=56)	Mafeteng (n=22)	Maseru (n=28)	Mohale's Hoek (n=65)	Quithing (n=25)	Thaba Tseka (n=35)		
Soil fertility	7240.0	5965.5	8638.5	4513.5	4330.0	11216.5	4165.0	5291.0	9.17	0.241
Erosion control	7165.5	5331.5	10036.5	3163.5	5008.5	10148.0	3802.0	6704.5	12.61	0.082
Tillage problems	8882.0	5746.0	8514.0	3463.0	4398.5	11398.0	3530.0	5428.5	4.91	0.671
Conservation measures	8146.5	6639.5	8146.5	3825.5	4244.5	10887.0	3796.0	5674.5	3.70	0.814
Soil cover	8337.5	6283.5	9231.5	3505.5	3964.0	10187.5	4543.5	5307.0	3.20	0.865

farmers in developing nations, financial problems seem to be the biggest problem in tillage. Additionally, soil drying and formation of hard impenetrable clay pans, incidence of noxious weeds, prevalence of wetlands in some localities, etc. happen to compound tillage problems. Formation of hard clay pans may affect drainage and water infiltration. Reduced but adequate tillage has been found to be highly useful in

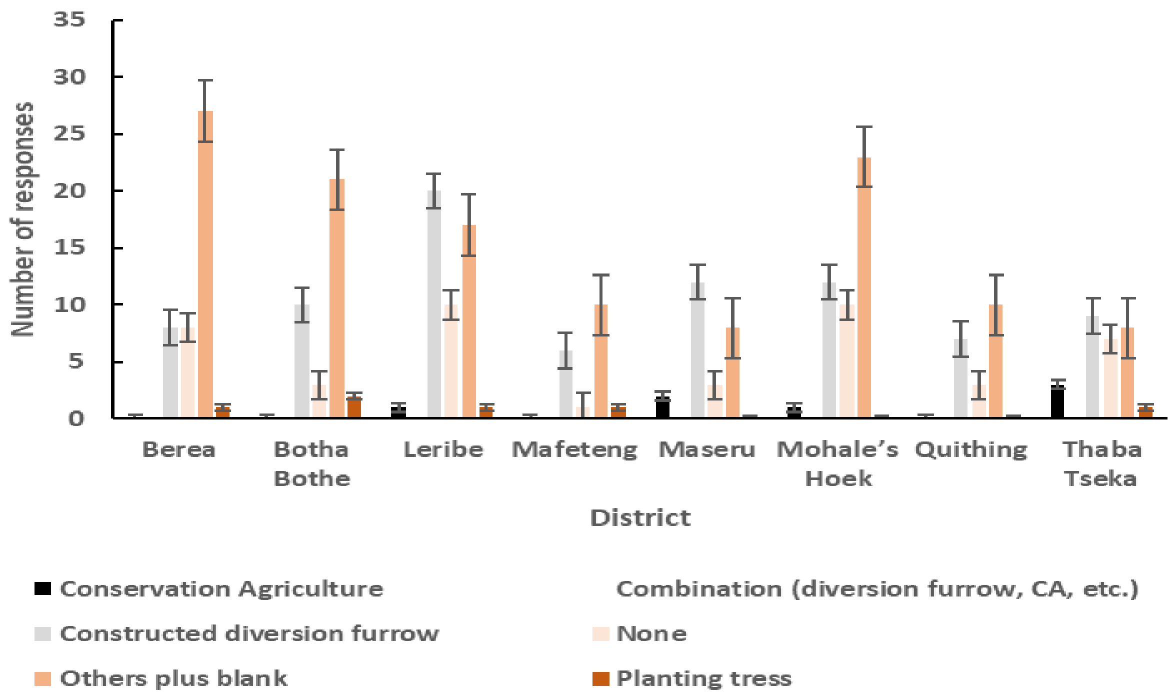

Figure 4. Farmers applied these measures to control soil erosion.

improving soil physical conditions and crop yield and concurrently conserving soil and water (Busari et al., 2015). Several studies indicate deep tillage significantly reduces bulk density and increases soil porosity and soil infiltration in sorghum production (Lopez-Fando et al., 2007; Rocateli et al., 2021).

Most farmers appear to be adept with practises such as Kraal manure and compost application on their farms to improve their land productivity and yield. Little use is made of sheep or chicken manure. It appears also that most are not aware of the benefits of applying microorganisms to improve soil fertility. Hence, it should be an area that should be given emphasis in future. Application of organic manures from different sources and liquid organic manures have been found to increase dry matter yield of sorghum (Lubas and Kumagai, 2007; Potadar et al., 2023). Growth of sorghum and microbial activity was enhanced with application of biochar (Hairani et al., 2016).

Most also happen to apply artificial fertilizers, frequently 6:2:1(31) N:P: K. This fertilizer is applied almost equally on sorghum and maize crops. It is applied less on beans. They generally allocate between 1 to 3 acres of land for sorghum cultivation and usually obtain between 4 to 7 bags/acre of yield. Nearly about two thirds of the farmers are aware of incidence of soil erosion on their farms. They usually tackle it by digging diversion furrows and less frequently by using other conservation structures and conservation agriculture, among others. Most of the farmers that practise Conservation Agriculture do quite often apply minimum tillage practices and dig pot-holes (Likotjana). In addition to direct effects on crop stand, erosion may affect yields by influencing soil properties, microclimate, and the interaction between them. The magnitude of the effect of erosion on yields also varies among soils, crops, and management systems (Lal, 1987). Conservation agriculture helps in reducing many negative effects of conventional agriculture such as soil erosion, soil organic matter decline, water loss, soil physical degradation, and fuel use. Conservation Agriculture helps improve biodiversity in the natural and agro-ecosystems (Saha et al., 2022).

Keeping the soil covered most of the time with crop residues or periodically growing green manure crops would ideally help retain soils from being eroded and to also enable re-stocking of nutrients removed. Generally, most farmers in Lesotho do not practise leaving cover crops on the field or growing green manure crops (Figure 5).

Cover crops are widely used elsewhere to improve soil properties and reduce weed infestation and soil erosion (Eo et al., 2015). Both non-leguminous and leguminous cover crops improve the chemical and physical properties of the soil such as the organic matter content and water-holding capacity (Ramos et al., 2010). Cover crops affect the activity, biomass, and composition of the soil microbial community by supplying root exudates and debris during their growth period (White and Weil, 2010).

For such interventions to permeate into the knowledge system of farmers, coordinated trainings by Farmers'

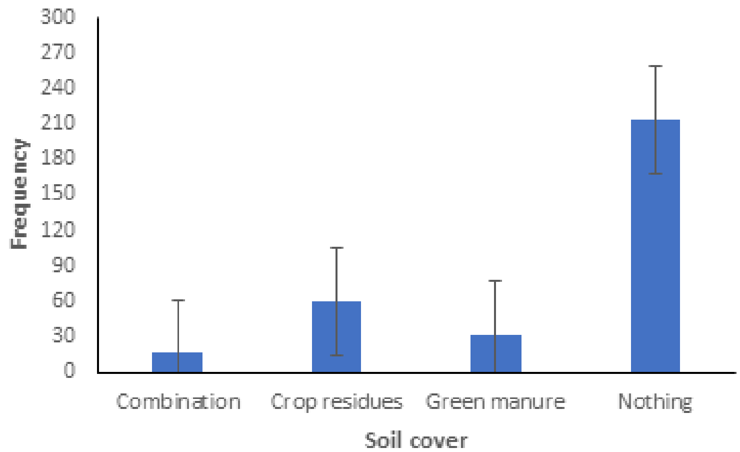

Figure 5. Few farmers appear to be using soil cover as a measure of erosion control.

Organizations, NGOs, educational institutions such as NUL could expedite adoption of sustainable agricultural technologies in a shorter period. Experience from other regions also clearly shows the importance of the above (Iyabano et al., 2022, 2023b; Ochieng et al., 2021). It is believed that the recent trainings on sorghum and Pearl millet production in Lesotho, which were offered to extension officers, will cascade down to benefit farmers across the nation.

CONCLUSIONS AND RECOMMENDATIONS

Although most sorghum farmers claim that their soils are fertile, their claim is not based on soil analysis. Actually, the soils are quite impoverished and require additional nutrient amendments. Moreover, they tend to practice monoculture of sorghum for years, which exhausts their soils. It is hence very crucial that they scale up practices such as the application of organic fertilizers from different sources, crop rotation, and fallowing, integrated pest management, etc., to increase the yield of sorghum, which currently amounts to less than 1 ton/ha. The application of biochar may also improve growth and microbial activity in soils. Hard clay pans and dry soils may also be obstacles to crop production, which could be rectified through reduced but deep tillage practices.

Soil erosion is also suggested as a major problem. Practices such as conservation agriculture and employing cover crops and leaving crop residues in the soil are believed to improve the current situation. Sorghum is important for its nutritional values and medicinal effect from low gluten. Hence, it is advisable to scale up sorghum production in Lesotho with some of the interventions suggested above. Concerted trainings by Farmers' Organizations, NGOs, and higher education institutions in the future will help improve the adoption of technologies. Future studies should include an assessment of the impact of such trainings on farmers' adoption of improved technologies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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