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Do We Listen or Ignore Indigenous Practices? The Machobane Farming System - An Indigenous Farming Practice of Lesotho

Sissay B. Mekbib [a*], Adesola O. Olaleye [b], Masia Johane [c] and Taddese Wondimu [d]

[a] *Department of Biology, National University of Lesotho, P. O. Roma 180, Lesotho.*
[b] *Department of Soil Science, Faculty of Agriculture, University of Eswatini, Eswatini.*
[c] *Department of Livestock Marketing and Registration, Ministry of Agriculture, Maseru, Lesotho.*
[d] *Department of Chemistry and Chemical Technology, Ontario Ministry of the Environment and Climate Change, Canada.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: To evaluate the adaptive capacity of the Machobane Farming System, an indigenous practice to improve soil fertility and maize productivity compared to other non-Machobane farming practices.
Study design: The study was conducted in four agroecological zones of Lesotho: Mountain, Foothills, low lands and Senqu river valley. Soil samples were collected at random from the non-Machobane farming practicing fields and Machobane farming practicing fields and the soil physicochemical and microbiological analyses were conducted to evaluate the soil quality.

**Corresponding author: E-mail: sbmekbib7@gmail.com; sb.mekbib@nul.ls;*

Structured and non-structured questionnaires were used to gather information from Focus Group Discussion (FGD) on the type of farming practices used and other demographic data.

Results and Discussion: The MfS were found to be less affected and resilient to climate change with multiple benefits such as moisture conservation, slow release of nutrients and cross migration of microorganisms to the intercropping plants in the field unlike other farming practicing fields. An increased number of soil fertility indicator microorganisms such as *Bacillus* spp and Nitrogen fixing bacteria were seen to have increased the production of food crops (P>0.05) almost all the year round. An intensive relay cropping of one acre would be sufficient to ensure food security for an average family of 5 members.

Conclusion: Currently, the Machobane Farming System (MfS) is adopted by many households in Lesotho using biochar and compost.

Keywords: Machobane farming system; soil fertility; food security; sustainable farming; biofertilizer; indicator microorganisms.

1. INTRODUCTION

Indigenous knowledge (IK) is deeply intertwined with landscape, culture, development, and human history, playing a crucial role in maintaining and restoring nature. However, human activities and poor resource management have led to climate change, exacerbating issues like drought, pest infestation, and the reduction of arable land. In Lesotho, only 9% of the land is arable, with the majority dominated by mountainous terrain and rangelands suitable for extensive livestock production [1]. These rangelands face aggressive invasion by exotic weeds like Salahalaha (*Seriphium plumosum* L. and *Felicia filifolia* L.) [2], negatively impacting animal husbandry by reducing forage quantity and quality, disrupting grazing patterns, and posing risks of poisoning to animals [3].

Climate change scenarios present a significant challenge by altering climatic and agro-ecological conditions, impacting resources such as water, agriculture, land use practices, and forests. Shifts in planting seasons have excluded certain crops and shortened cropping seasons, posing challenges for farmers with reduced yields and productivity. Additionally, the highest population pressure in lowland areas intensifies soil erosion and land degradation, further exacerbating agricultural challenges [1].

Rainfall patterns are erratic, with sporadic occurrences of drought, severe hailstorms, and harsh winters. Arable land estimates are dwindling due to thin soil layers and limited vegetation. Approximately 40 million tons of soil are carried away from Lesotho annually by wind and water erosion [4]. Weather plays a role in soil erosion, but poor land management and outdated land tenure systems also contribute significantly [5].

As per the IPCC (2007) [6], climate change poses ongoing challenges for communities in marginal lands. Lesotho responded by initiating the National Adaptation Program of Action (NAPA) on climate change in 2007 under the UNFCCC [7], which identified eleven adaptation technologies, primarily focusing on land and water management in agriculture [8]. The Machobane Farming System, developed in the 1940s by Machobane, exemplifies traditional farming practices in Lesotho known for its adaptability and resilience to climate change [9]. This mixed farming method involves intercropping plants between rows using natural resources like ash and manure. Successful implementation requires practical integrity, intensive soil work, input, and training for scalability, including expanding the system, establishing nurseries, water harvesting, and pest control methods for broader community application.

The study aimed to assess the technical aspects of the Machobane Farming System (MfS) and establish a scientific foundation to maximize its advantages compared to other farming systems. It also sought to create baseline data for the sustainable adoption of MfS among medium and small-scale farmers in Africa.

2. AGRICULTURE IN LESOTHO

2.1 Crop Farming Systems

“In Lesotho's diverse agroclimatic zones – Lowlands, Senqu River Valley, Foothills, and Mountain regions – crop production, mainly maize (63%), sorghum (28%), and wheat (12%), dominate. Beans and peas constitute smaller shares (5% and 3%, respectively). Precipitation and other climatic factors significantly influence crop production, with the southwestern lowlands being particularly vulnerable to erratic agro-climatic conditions in the region [10].

Lesotho currently employs six farming system practices: block farming [11], mono-cropping (traditional farming), conservation farming [12], keyhole gardening [13], double digging, and the Machobane Farming System [14]. Unfortunately, specific data on the percentage of farmers utilizing each system are unavailable. These systems are promoted to support rural livelihoods, conserve the environment, and generate income. However, their effectiveness in responding to climate change, as well as their adaptability and resilience, are crucial considerations in determining their suitability as best practices for rural livelihoods in Lesotho.

Crop production and yields on cultivated lands in Lesotho are highly erratic, closely tied to rainfall patterns. Soil infertility, insufficient organic fertilizer use, and inefficient technologies contribute significantly to this variability. Untimely planting, inadequate land preparation, poor weeding practices, and delayed harvesting further compound challenges faced in crop production

The Machobane Farming System demonstrates superior adaptability and resilience to climate change, ensuring high crop yields while preserving soil fertility and moisture year-round on a designated plot. Refer to Table 1(a) [1] for the distribution of crop production by district across Lesotho's four agroecological zones.

2.2 Animal Husbandry

In Lesotho, livestock production is vital for economic and social reasons, alongside crop production. This sector contributes significantly to the agricultural gross domestic product (30%), with cattle (25%), sheep (45%), and goats (30%) being the primary contributors. Refer to Table 1(b) [1] for the distribution of livestock population by district across Lesotho's four agroecological zones.

Livestock in Lesotho are typically kept near homesteads for half of the year, primarily due to seasonal changes, management practices (e.g., shearing, dipping), and security concerns. Consequently, stock often face inadequate rations for extended periods due to poor fodder and forage quality, exacerbated by a lack of traditional dry fodder preservation methods such as silage or hay. This leads to insufficient dry matter intake, particularly in remote areas, where rangelands remain under-grazed due to their isolation. Village pasture areas, supporting high stocking rates, suffer severe degradation. Overstocking, illustrated in Figs. 1 and 2, contributes to rangeland deterioration, negatively impacting livestock productivity alongside issues like inadequate feeding, disease control and breeding practices [15].

Table 1(a). Crop Production (mt) by District and Type, 2019/2020 Agricultural Census

	Type of Crop				
District	**Maize**	**Wheat**	**Sorghum**	**Beans**	**Peas**
Botha-Bothe	3,571.0	15.0	621.6	143.0	0.5
Leribe	12,651.7	425.8	1,490.5	695.0	4.7
Berea	9,186.2	406.8	1,520.9	983.1	11.2
Maseru	9,893.2	405.8	894.6	2,684.4	12.8
Mafeteng	5,444.4	76.0	975.9	555.2	17.0
Mohale's Hoek	3,469.7	1,157.5	400.6	608.8	15.3
Quthing	2,080.3	203.5	299.2	509.9	20.5
Qacha's Nek	1,253.2	147.2	154.0	343.0	7.8
Mokhotlong	1,743.6	549.8	61.0	306.0	52.8
Thaba-Tseka	1,722.9	319.5	141.8	201.9	16.9
Total	**51,016.3**	**3,706.9**	**6,560.1**	**7,030.4**	**159.6**

Key: *Agroecological locations of districts in Lesotho: Botha-Bothe (Lowlands, Foothills); Leribe (Lowlads, Foothills), Berea (Lowlands), Maseru (Lowlands), Mafeteng (Lowlands), Mohale's Hoek (Lowlands), Quthing (Lowlands), Qacha's Nek (Lowlands, Mountain), Mokhotlong (Mountain) and Thaba-Tseka (Lowlands, Foothills).*
Source: www.fao.org

Table 1(b). Livestock holdings by District and Type, 2019/2020 Agricultural Census, Lesotho

	Type of Livestock				
District	**Cattle**	**Sheep**	**Goats**	**Pigs**	**Chicken**
Botha-Bothe	7,438	4,937	3,409	2,806	6,143
Leribe	18,996	12,032	8,210	7,121	14,532
Berea	16,704	10,242	7,085	7,487	11,253
Maseru	20,766	11,665	10,22 5	10,034	13,960
Mafeteng	15,022	13,167	4,894	5,780	10,157
Mohale's Hoek	12,474	11,463	7,177	4,953	9,672
Quthing	9,116	7,981	6,728	3,542	6,828
Qacha's Nek	5,047	3,917	3,373	1,648	4,322
Mokhotlong	10,486	10,296	7,082	579	7,465
Thaba-Tseka	9,668	8,701	6,761	1,283	6,399
Total	**125,718**	**94,399**	**64,944**	**45,232**	**90,731**

Key: *Refer the legend under Table 1a.*
Source: www.fao.org

Fig. 1. The range land under severe livestock pressure: Horses and mules are the main means of transport in the rural Lesotho [17]

Fig. 2. The range land under severe livestock pressure, Lesotho: Sheep and goat for wool and mohair- contributed 30% of the National Export Revenue [18]

"The livestock subsector in Lesotho is less susceptible to erratic climatic conditions compared to arable agriculture. Adequate rainfall positively impacts rangelands and water sources crucial for livestock. However, subsector productivity suffers due to a failure to maintain a balance between range resources and animal population, often stemming from adherence to traditional management practices" [16].

2.3 Climate Change Impacts on Farming Systems in Lesotho

Naturally, Lesotho faces critical vulnerability to climate change due to its agroecological positioning. Rainfall, primarily during the summer season, varies greatly in quantity and timing due to climate shifts. Typically, Lesotho receives 85% of its annual rainfall between October and March. However, data from the Lesotho Meteorological Services (2006) [19] revealed a concerning trend: September rainfall, the start of the planting season, was 57% below average. Although late rains arrived in October and persisted through December, precipitation dwindled in January 2007 and drastically decreased in February and March compared to the 30-year average for Lesotho[20].

Farmers living in all (four) agroecological zones have noticed that climate is changing. Long period of drought, exceptionally heavy rain fall and drought have been noticed by all focus group participants. In the mountains (Mantsonyane), people used to experience early frost due to climate changes, but, which they thought could be due to the construction of Mohale dam, such problem is now a bit improved. In the other agro- ecological zones, they have noticed the change in climate by a shift in sawing season, early frost, wet and dry seasons and extremely high temperatures.

The shift in planting seasons has led to the exclusion of certain crops like peas and beans in mountainous areas due to changing climate conditions. Yield reductions occur due to poorly developing buds, pest infestations, droughts, floods, and hailstorms. In villages practicing the Machobane Farming System in the Mountains and Foothills, resilience to climate change is observed, attributed to sustained soil fertility and moisture conservation. However, in the Senqu River valley, participants note the susceptibility of all crops to climate change, with shifting precipitation patterns leading to unpredictable planting and harvesting seasons, potentially resulting in disastrous outcomes. Historical data analysis from 1961 to 1994 predicts warmer future climatic conditions in Lesotho, with lower spring and summer precipitation and higher precipitation in winter and autumn [1].

Alternatively, an increase in winter precipitation may signal heightened activity in frontal systems, potentially leading to heavier snowfall and strong, devastating winds, posing significant risks for agricultural production in Lesotho. Annually, 40 million tons of soil are eroded from Lesotho due to wind and water erosion [20]. While rainfall is more abundant in the mountains, benefiting animal farming, the cropping season is notably shorter due to early frost onset, hindering plant growth and maturity. Conversely, lowland areas experience significant dryness, leading to frequent crop failures from drought.

2.4 Adaptation Strategies Made by the Communities to Climate Changes

Specific adaptation measures to climate change vary across villages. In mountainous regions, farmers conduct crop trials to identify suitable crops for shifting and shortened growing seasons. In the dry Senqu River valley, mulching and returning crop residue to fields are observed as effective moisture conservation methods (Table 2). Additionally, proposals for water harvesting and small dam construction for irrigation during dry periods are suggested. In the foothills at Pitseng, adaptive measures include plowing land with plant residue intact, refraining from burning residue to conserve soil moisture and nutrients, establishing optimal planting seasons for various crops, and timing maize planting for late July.

2.5 The Machobane Farming System and Its Requirements

The following are key features of the Machobane Farming System, signifying its basic behavioral and technical requirements to adopt as an agricultural farming system.

2.5.1 Behavioral requirements

The Machobane farmer has the following behavioral quality: self reliance; appreciation of resource base, readiness to do hard work, learning and teaching by doing, technology sharing, and helping their neighbors.

Table 2. Coping strategies to the effect of climate change

Protection	Climate change controlling strategies							
	Flood protection (%)	Crop substitution (%)	Crop diversification (%)	Intercropping (%)	Settlement restriction (%)	Mulching (%)	Livestock restocking (%)	Replanting (%)
Crop loss	35.4	24.2	36.9	46.7	4.8	44.2	3.8	63.4
Livestock mortality	5.8	6.1	8.1	1.0	7.3	1.5	23.7	1.0
Property loss	8.1	5.1	3.3	1.0	2.3	1.0	2.3	0.5
Fertility loss	21.2	8.3	10.6	19.2	5.3	15.4	0.8	8.8
Pest infestation	8.6	15.2	21.7	21.5	0.8	8.1	1.8	16.7
Evaporation or freezing	13.4	4.5	6.8	6.6	0.5	11.9	1.8	4.5

2.5.2 The technical bases

The following activities are considered vital technical bases for MfS practices: the use of organic fertilizers, preparation of perennial vegetation cover (mulching), introducing adequate cropping pattern to the varying climate, natural pest control, and relay harvesting allowing for almost year-round harvest.

2.5.3 Use of organic fertilizers

The Machobane Farming System utilizes animal manure and wood ash as fertilizers, with approximately 7,500 kg of manure applied for initial land preparation. Depending on soil type, varying mixtures of organic materials are used each cropping season. After four years, reduced organic fertilizer is needed as soil fertility improves. Plant leaf litter and/or mulching can also effectively cover soil, maintaining moisture and supplying decomposing materials to plants (see Fig. 4).

2.5.4 Perennial vegetative cover

The Machobane Farming System maintains year-round crop cover: winter crops (e.g., wheat and peas) are planted in April–May for January–March harvest, while summer crops (e.g., maize, beans, and sorghum) are planted in August–October for November–December harvest. With minimal tillage, complete plowing occurs once every 5 years to reduce soil disturbance. Crop residues left in the field help maintain soil nutrient content.

2.5.5 Cropping pattern adapted to varying climate

Lesotho experiences a temperate climate, characterized by warm summers and cool winters, often accompanied by late or early frosts, hail, and seasonal drought. The Machobane system accommodates the planting of cool-weather crops like peas, wheat, and potatoes, which thrive in winter conditions. During summer, maize, beans, pumpkins, and other crops are intercropped (refer to Figs. 3 and 5). To mitigate the risk of crop failure during summer droughts, drought-resistant crops like sorghum, known as the "camel of the plant kingdom", are also cultivated.

Fig. 3. Machobane Farming System: double row of wheat and vegetables

2.5.6 Seedbed preparation and planting

In the initial planting phase, the 0.4 ha (1 acre) field is plowed and subsequently harrowed or disked for soil preparation. Furrows or rows for seed planting are created using a spade or hoe. In April, winter crops such as wheat and peas are sown. Wheat is planted in double rows with a 30 cm spacing between them. Following a 2 m gap, double rows of peas are planted, also with 30 cm spacing between rows. This alternating pattern continues with double rows of wheat and peas, each separated by 2 m gaps (refer to Fig. 3).

Fig. 4. Potato cultivation under Machobane Farming System: mulching

In August, the first batch of potatoes is planted in the 2-m gaps between rows of wheat and peas, covering half the field initially. From November, the remainder of the field is planted with a second batch of potatoes. In October, summer crops like maize, beans, sorghum, pumpkin, and watermelon are intercropped in a complex pattern. Single furrows are dug in the 30-cm spaces between double rows of wheat and peas. Maize and beans are planted in these furrows, with 30 cm spacing for maize plants and 15 cm spacing for beans. Every 4 m, two pumpkin seeds are added to maize and bean hills. Alternating rows feature watermelon instead of pumpkin. Finally, sorghum is sown along the entire furrow (see Fig. 5).

In the Machobane Farming System (MfS), intensive cropping on one acre provides food security for an average family of 5, using only 1/3 of the conventional area. Seven staple crops are typically grown in Lesotho: maize, potatoes, sorghum, wheat, peas, beans, and cucurbits (pumpkins and melons) (see Fig. 5). These crops are relay-intercropped in a 1-acre plot, allowing for nearly year-round food production. To mitigate crop failure and boost productivity, the MfS incorporates the following basic technical applications:

2.5.7 Crop management practices

2.5.7.1 Tillage

Minimum tillage is employed for field crops, utilizing a spade, hoe, or hand-pushed ripper (refer to Fig. 6). This method enables furrows to be opened for planting summer and winter crops without disturbing standing crops, facilitating continuous planting cycles.

Fig. 5. Maize intercropping with pumpkin and watermelon: Mountains (Mantsonyane)

Fig. 6. A hand push ripper to open the furrow

2.5.7.2 Weeding

Weeds in the field can harbor pests and compete with plants for moisture, light, and nutrients. The initial weeding, performed with a hoe immediately after crop emergence, aerates the soil and eliminates weeds. A second weeding occurs when crops are approximately one month old. Crop residues are retained in the field, enhancing soil fertility and suppressing weed growth.

2.5.7.3 Earthing the potatoes

The first earthing is conducted when potatoes reach their initial flowering stage, with a minimal amount of soil gathered around the plant. Subsequent earthings occur at successive budding stages: the second earthing involves slightly more soil being ridged around the plant, followed by the third earthing covering half of the plant with soil at the third budding. During the fourth earthing, approximately two-thirds of the plant is covered with soil.

2.5.7.4 Natural pest control

Natural pest control is emphasized in the system, discouraging the use of chemical pesticides. Intercropping of certain crops acts as natural repellents to specific insects, aiding pest control. Deliberate crop rotation disrupts insect pest life cycles. Continuous weeding throughout the year also helps manage pests and diseases. Additionally, plants like pumpkin, with irritant hairs, serve as home remedy pest control measures.

2.5.7.5 Relay intercropping

Relay intercropping optimizes land use by staggering crop planting times to minimize competition during growth. This practice enhances soil preparation for subsequent crops and maximizes land productivity by cultivating multiple species simultaneously.

2.5.7.6 Relay harvesting

In relay harvesting, manual methods replace machinery. The relay intercropping system enables staggered crop harvesting throughout the year. For instance, peas can be harvested as green peas in November and as grains in March, while wheat harvesting begins in January. The first batch of potatoes is harvested from late November to March, and the second batch from April onwards. Potatoes are harvested when leaves and stems have dried using a spade or digging fork.

3. MATERIALS AND METHODS

3.1 The Study Area

The study area covers the four agroecological zones of Lesotho: the Highlands, Foothills, Lowlands and Senqu River Valley as depicted in Fig. 7.

3.2 Farmers Focus Group Discussion and Interview

Structured and non-structured questionnaires were used to gather information from Focus Group Discussion (FGD) on the type of farming practices used and other demographic data.

3.3 Soil Physicochemical Analyses

Undisturbed soil samples were collected from mini-pits at a depth of 0-20cm in selected farmers' fields: Machobane and Non-Machobane. These samples were analyzed for bulk density [21] and moisture content [22]. Additionally, physicochemical and microbiological analyses were conducted based on pedological horizons determined by area slope. Data on vegetation type, mini-pit position on the slope, parent material type, and soil texture were recorded following USDA methods [23.

3.4 Determination of Soil Microbiota as Soil Fertility Indicators

Soil samples from five locations within Machobane and Non-Machobane farming plots were collected in brown paper bags and transported to the Microbiology laboratory at NUL for analysis. Samples were stored at 4°C until processing. Soil fertility indicator microorganisms were isolated and quantified following methods described by Foldes *et al* (2000) [24] and Kennedy *et al* (2004) [25].

4. RESULTS AND DISCUSSION

4.1 Soil Texture

Silt and clay were identified as the predominant fractions of soil texture, crucial for soil nutrient retention (see Figs. 8, 9, and 10). Sites were categorized into two groups based on silt content: those with >40% silt (e.g., PMFS, PNMFS, TNMFS) and those with <30% silt (e.g., MHNMFS, QNMFS, QMFS, TMFS, MHMFS, BBMFS, BBNMFS). Sand content across all sites fell into three classes: >50% sand (MHMFS, BBMFS, BBNMFS), 35-48% sand (QMFS, TMFS, TNMFS, QNMFS), and ≤35% sand (PNMFS, MHNMFS, PMFS) (Fig. 8). Clay content grouped sites into >30% clay (TMFS, PNMFS, PMFS, MHNMFS) and <25% clay (MHMFS, BBMFS, TNMFS, QMFS, BBNMFS, QNMFS). Notably, the sites exhibited significant variations in sand, silt, and clay contents.

Fig. 7. The study area: agro –ecological zones of Lesotho

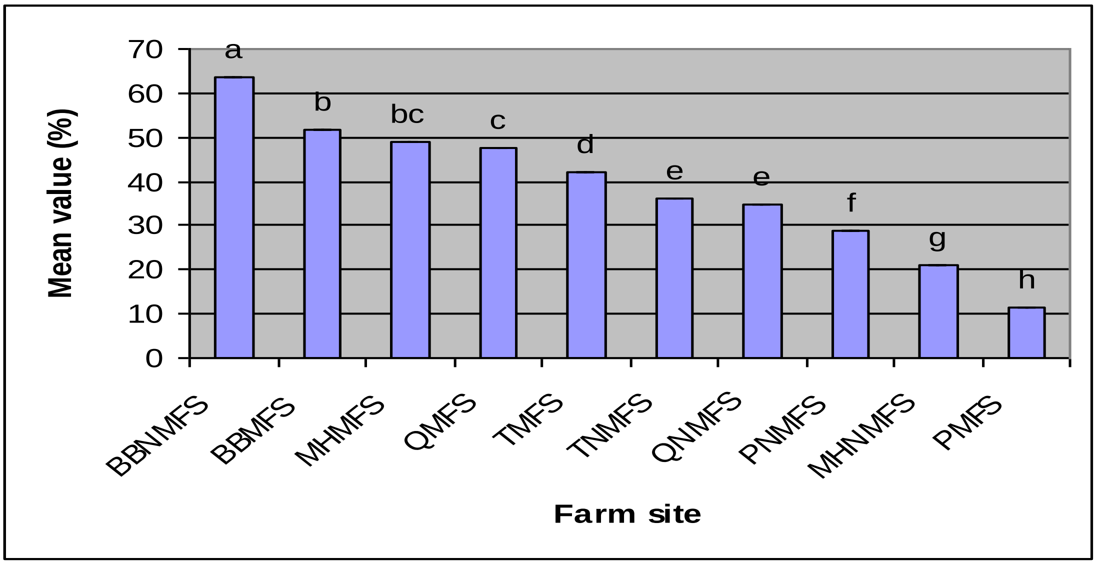

Fig. 8. Sand fraction of different farm sites

**Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (P< 0.05)*

Legend: Acronyms stands for the following representation: BBNMFS = Butha Bothe Non Machobane Farming System, BBMFS = Butha Bothe Machobane Farming System, MHMFS = Mohale's Hoek Machobane Farming System, QMFS = Quthing Machobane Farming System, TMFS = ThabaTseka Machobane Farming System, TNMFS = ThabaTseka Non Machobane Farming system, QNMFS = Quthing Non Machobane Farming System, PNMFS = Pitseng Non Machobane Farming System, MHNMFS = Mohale's Hoek Non Machobane Farming System, PMFS = Pitseng Machobane Farming System.

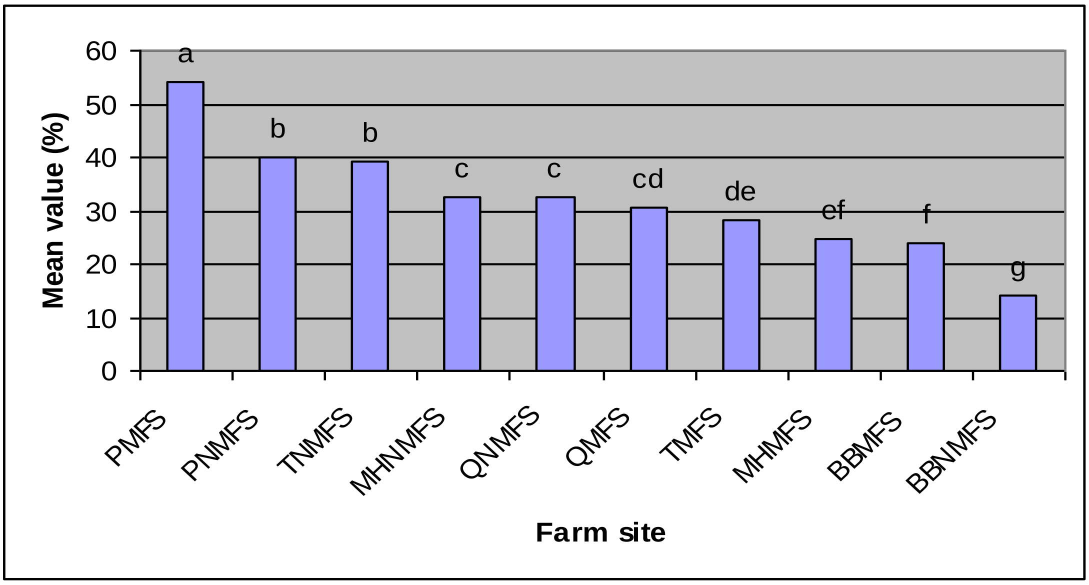

Fig. 9. Silt fraction of different farm sites

**Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (P< 0.05). Legend: refer to Fig. 8*

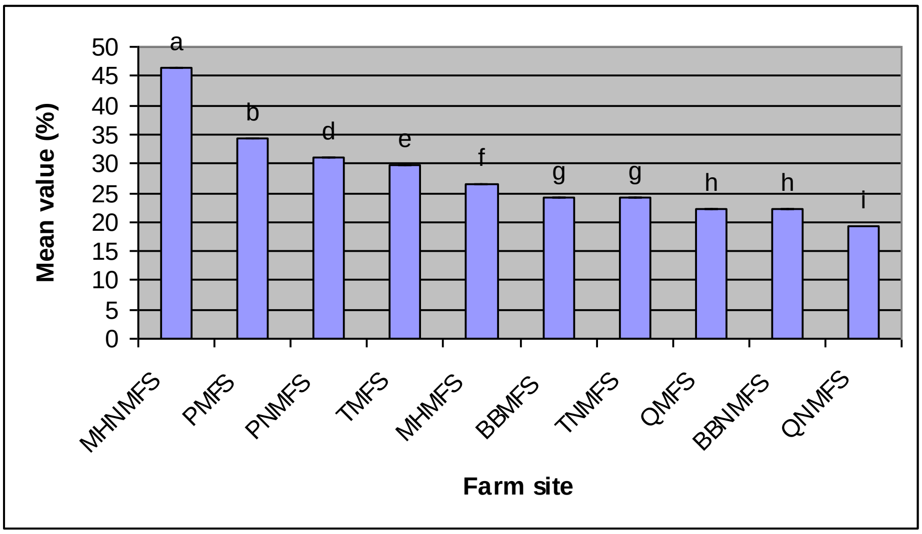

Fig. 10. Clay fraction of different farm sites

**Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (P< 0.05). Legend: refer to Fig. 8*

4.2 Soil pH

Soil pH can be classified into two groups: those with pH >6.0 (TNMFS, QNMFS, MHMFS, MHNMFS, TMFS, QMFS) and those with pH < 5.0 (PNMFS, BBMFS, BBNMFS, PMFS) (see Fig. 11). These sites exhibited significant variations in acidity and alkalinity levels.

4.3 Organic Carbon

Organic carbon content can be categorized into two groups: those with organic carbon < 1% (BBNMFS, PNMFS, BBMFS, QNMFS) (refer to Fig. 12), and others with organic carbon > 1.5%. These sites exhibited significant variations in organic carbon levels.

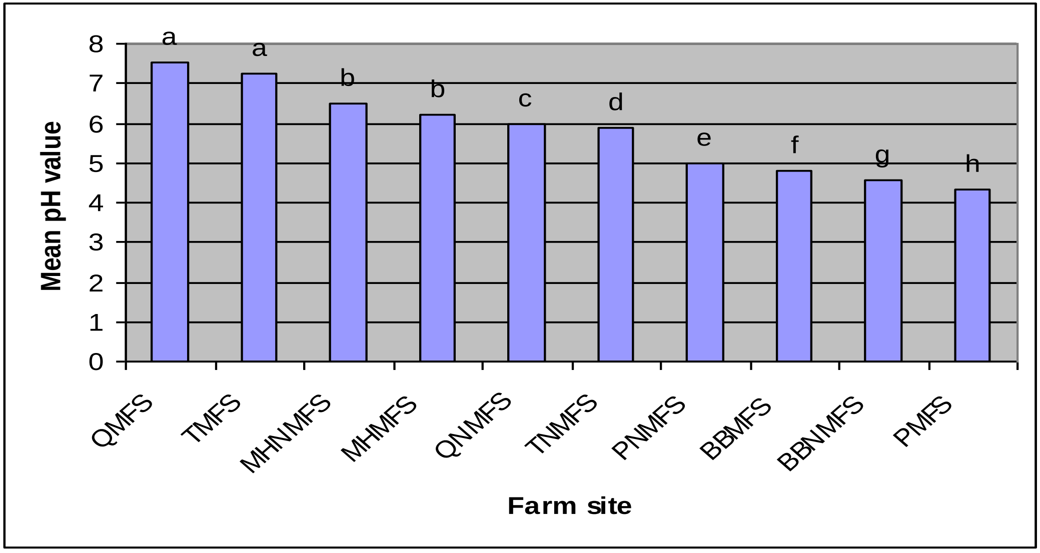

Fig. 11. Soil pH of different farm sites

**Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (P< 0.05). Legend: refer to Fig. 8*

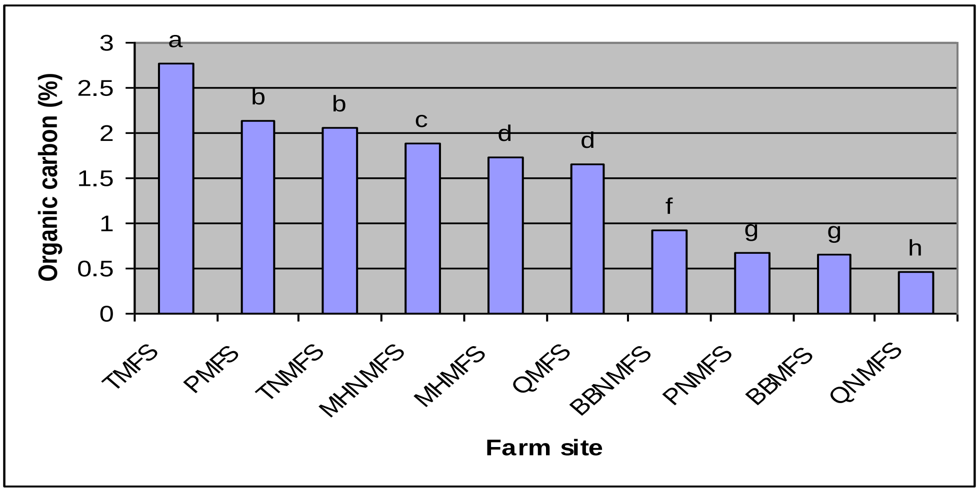

Fig. 12. Organic carbon contents of soils practicing different farming systems

Means with the same letter are not significantly different at Duncan's Multiple Range Test and grouping (P< 0.05). Legend: refer to Fig. 8

4.4 Available *P*

Available phosphorus levels were generally low, grouped into two categories: those with available P >10 mg/kg (BBNMFS, MHMFS, QMFS), and those with <5 mg/kg of P (BBMFS, TMFS, PMFS, PMMFS, TNMFS, MHNMFS, QNMFS). Sites exhibited significantly varied levels of available phosphorus (P) (see Fig. 13).

4.5 Lime Rate

Results indicate two categories based on lime requirements: sites with lime rates >15,000 kg/ha (PNMFS, BBMFS, BBNMFS, TNMFS) and those with lime rates <10,000 kg/ha (MHNMFS, QNMFS, MHMFS, TMFS, QMFS, PMFS) (see Fig. 14).

4.6 Determination of Soil Microbiota as Soil Fertility Indicators

Soil samples from Machobane Farming plots showed higher levels of soil fertility indicator microorganisms compared to non-Machobane Farming System soils. The total count of free-living Nitrogen Fixing (NF) bacteria was 5.4 x 105 cells/ml, followed by Bacillus spp. at 1.96 x 105 cells/ml (refer to Figs. 15 and 16). Nutrient-rich soils not only increase microbial population but also enhance microbial diversity [25,26]. The presence of Bacillus spp. is associated with nitrogen fixation in nitrogen-deficient soils [27], contributing to soil pH improvement (see Fig. 11). Bacillus spp., known as Plant Growth Promoting Rhizobacteria (PGPR), directly affect plant growth by producing phytohormones, solubilizing inorganic phosphate, enhancing iron nutrition through siderophores, and releasing volatile compounds that influence plant signaling pathways [28]. They are also recognized for their role in disease suppression and can migrate to plant aerial parts [29].

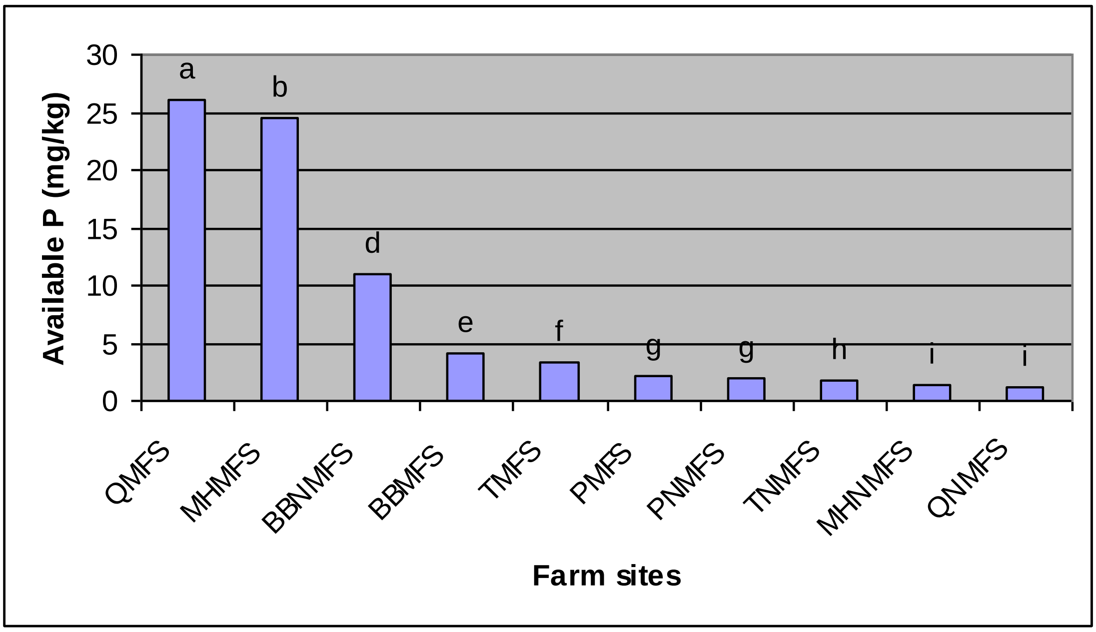

Fig. 13. Available Phosphorus (*P*) in soils of Machobane and Non- Machobane Farming practicing fields. Means with the same letter are not significantly different at Duncan's *Multiple Rang Test and grouping (P< 0.05). Legend: refer to Fig. 8*

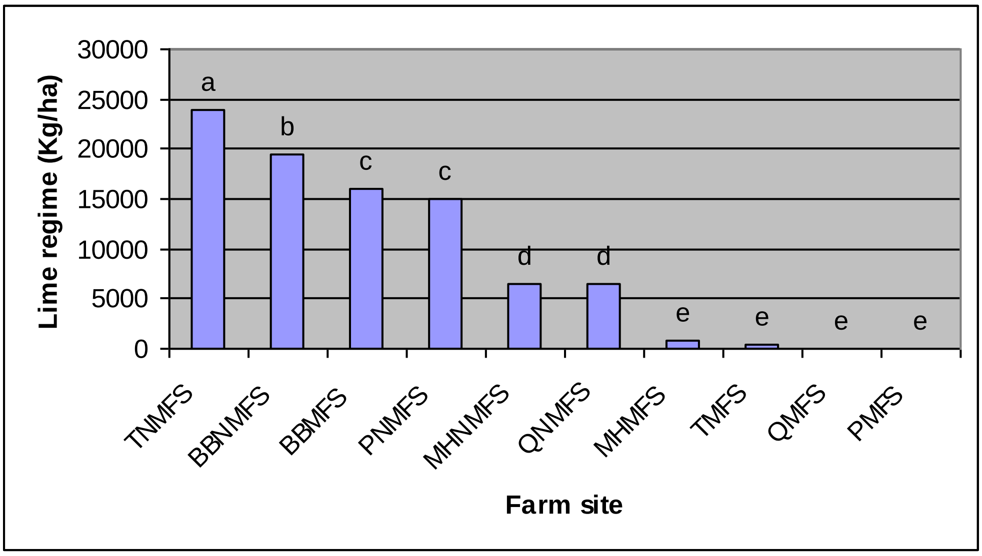

Fig. 14. Lime Regime (Kg/ha) in different soils practicing farming sites
**Means with the same letter are not significantly different at Duncan's Multiple Range Test and groupings (P< 0.05). Legend: refer to Fig. 8*

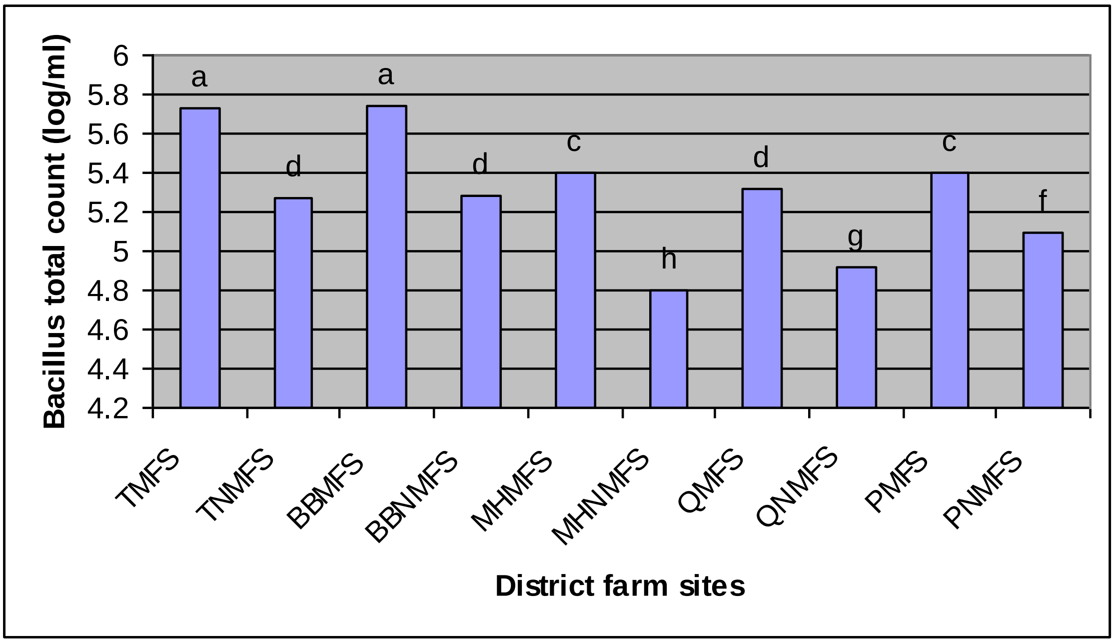

Fig. 15. Total *Bacillus* count. Mean with the same letter are not significantly different by Duncan grouping at (*P*<0.05). Legend: refer to Fig. 8

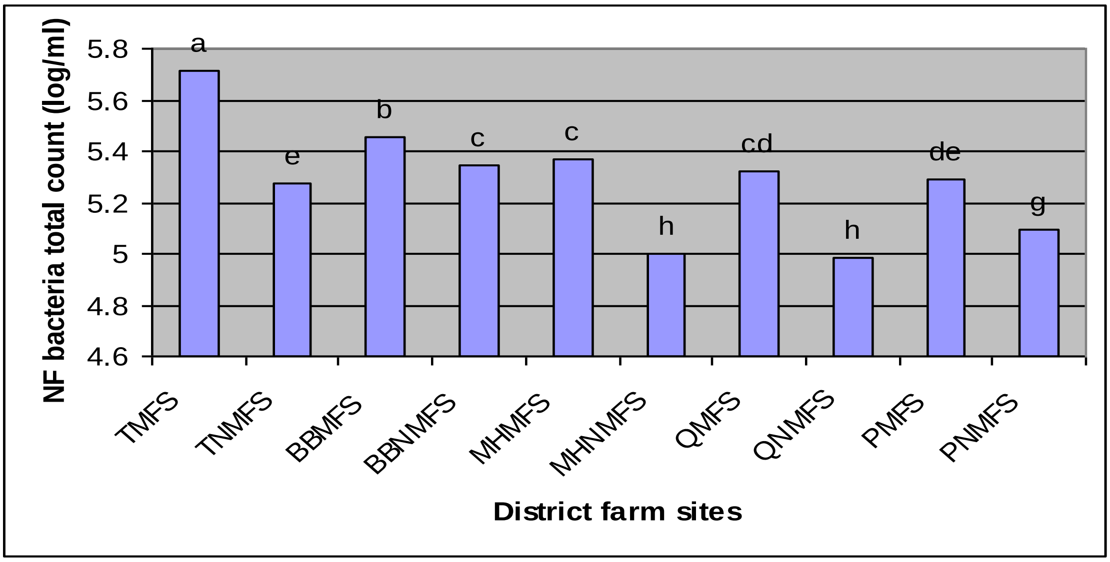

Fig. 16. Total Nitrogen Fixing (NF) bacteria count. Mean with the same letter are not significantly different by Duncan grouping at (*P*<0.05). Legend: refer to Fig. 8

4.7 Pest Prevalence and Control

Insects emerged as the primary pests, with fungal and bacterial infections also causing significant damage to crop plants (see Fig. 17). The Stock Borer (*Busseola busca*) and Bagrada Bug (*Bagrada hilaris*) were identified as major insect pests, with Aphids inflicting considerable damage to both leaf (>55%) and stem (51.5%) parts of crops, respectively.

Pest control strategies varied among the communities. Approximately 44% of respondents reported using commercial pesticides, while 30% used traditional pesticides on their farms. Additionally, during the Focused Group

Table 3. Different crops grown and pests/ diseases that commonly affecting them in the agroecological zones given

Agroecological zone (village)	Crops	Pests and environmental factors	Pest control method
1.Senqu valley (Mokanametsong)	• Maize • Sorghum • Wheat • Beans • Vegetables	• Cut worm (*Agrotis spp*)and stalk borer (*Busseloa busca)* • Aphids (Hoaba* and Boroku*) • Rust and smuts • Blight	- *Tigatus minuta* and *Aloe*, Onion and Pepper concoction - They also claim using pharmaceuticals such as Acaricides (Dezzel NF*), Fast take, Avalanche* and Cut worm. They used these chemicals as pesticides to control animal diseases such as sheep scab as well.
2. Mountains (Mantśonyane)	• Maize • Sorghum • Wheat • Beans • Peas • Lentils • Vegetables	• Cut worm (and stalk borer (*B. busca)* • Drought • Drought • Frost • Frost • Frost	- These crops are grown in all farming systems. - All farming systems are said affected by disease and pests - Herbicides used on small areas like gardens - Use of *Aloe*, soap lather, seholobe*, moroko oa joala*, seholobe and mosali mofubelu* - Using concoction of smelling types of herbs mixed with chillis • The concoction is applied during pest outbreaks • Main advantage of this mixture lies in its being non-poisonous. • also some buy commercial pesticides for field crops such as sorghum, wheat and maize
3. Foothills (Pitseng)	• Maize • Sorghum • Wheat • Beans • Potato • Tomato • Beet root • Green pepper • Spinach • Cabbage	• Cut worm (*Agrotis* spp) • Cut worm (Observation is that Sorghum was not affected by worms in the previous years) • Gradabug* (on vegetables) • Aphids (on vegetables)	• Farmers use any pesticides as per their economy for application from the near by available markets whenever there is an outbreak. • Theses days, however, the application frequency and dose of pesticides increased from time to time. • They also use a mix of plant concoction (different herbs) such as *Aloe*, *Rhamnus prinoides.*

** = Vernacular name.*

Discussion, participants described the formulation of concoctions using various plant materials and other inputs (refer to Table 3).

The different types of crops that are grown at different agroecological zones and the types of disease/pest that commonly affect them are also listed in Table 3.

4.8 Meteorological Data Trend Analysis

Fig. 18 illustrates the precipitation levels in Lesotho from 1923 to 2006, showing the highest recorded precipitation between 1954-1962. However, precipitation fluctuated irregularly from 1963 to 2006. Fig. 19 depicts the decadal changes in rainfall, with the highest changes observed from 1944-1953 gradually decreasing over the years to the lowest between 1974-1983. The lowest precipitation change was recorded between 2003-2006.

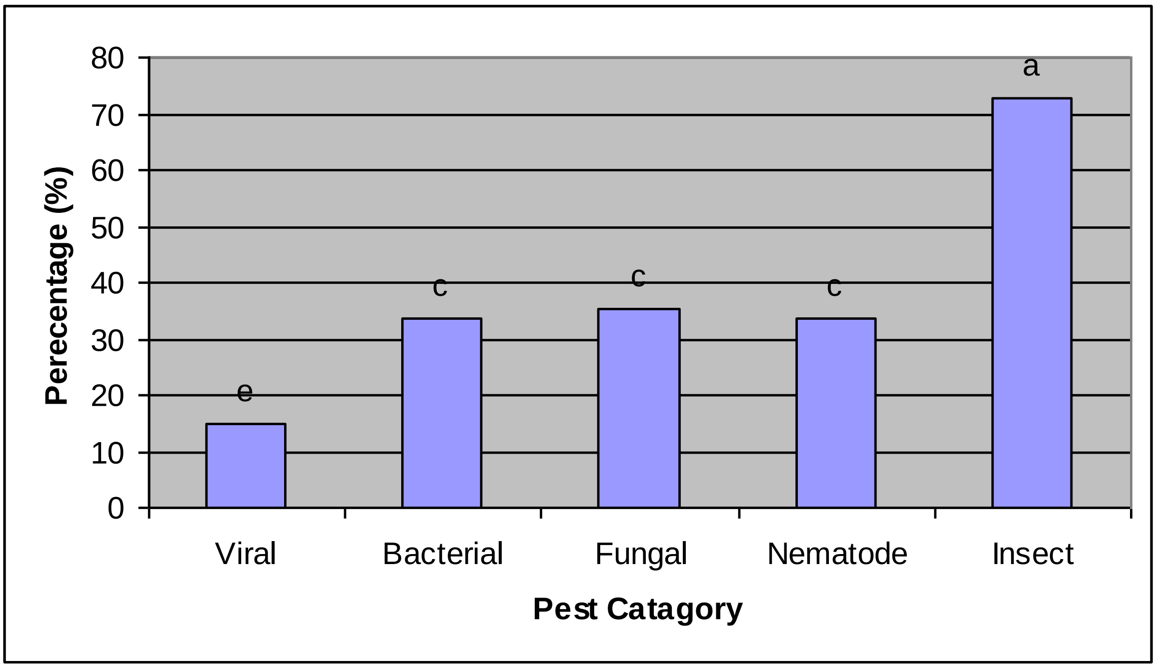

Fig. 17. Differnent Pest Categories in Crop

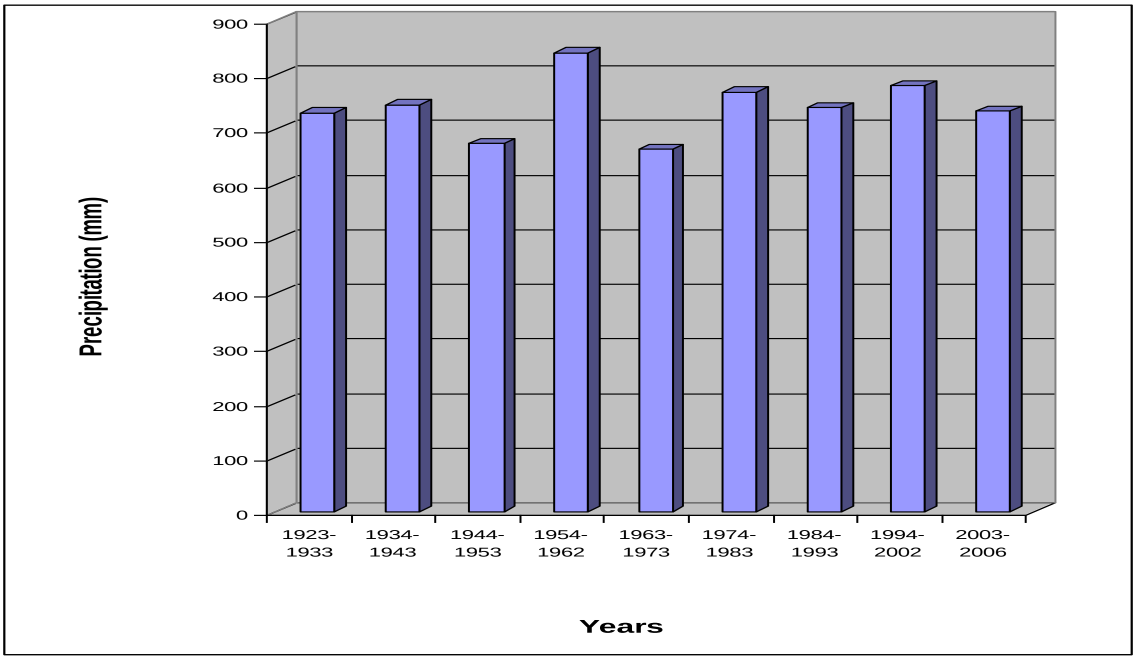

Fig. 18. Precipitation trend in Lesotho since 1923-2006

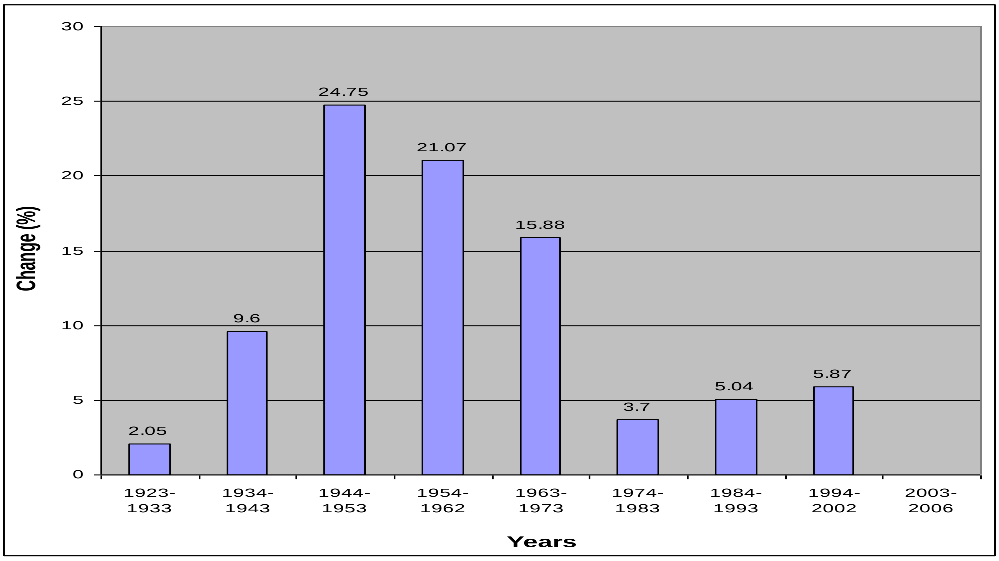

Fig. 19. Percentage change of precipitation over years in Lesotho (1923 – 2006)

4.9 Current Application of the Machobane Farming System in Different Agroecological Zones of Lesotho

A new approach is being implemented in Machobane Farming System fields in Lesotho, specifically in Qachasnek (Ha-Thaba), Mohale'shoek (Taung Ha Moletsane), Butabute (Manamela), and Mafteng (Ha-Makhakhe). This approach involves using biochar instead of ash and compost instead of manure to intensify agriculture. Backyard experiments conducted at NUL in 2021 demonstrated promising outputs (see Fig. 20), paving the way for further adoption of these practices in Lesotho's agricultural intensification efforts.

Lead farmer households from each of Lesotho's agroecological zones, in collaboration with the Machobane Agricultural Development Foundation (MADF) in Maseru, have been selected to discuss and implement intensification agriculture experiments in their fields. The appropriate application rates of biochar vary based on soil quality, crop type, and amendment availability. Previous experiences reported by farmers highlighted three main advantages of the Machobane Farming System: (i) increased land productivity, (ii) significant cash revenue from potato intercropping, and (iii) sustained greenery in fields during drought compared to non-Machobane fields. Recent field trials in Tabang, Mokhotlong, Lesotho, demonstrated high performance in maize and beans mixed farming with the application of 40% biochar and compost (see Fig. 21).

Fig. 20. Machobane farming system backyard experiment with biochar and compost Project, NUL (Courtesy: Mekbib, 2021)

4.10 Long-Term Technical Sustainability

The Machobane Farming System, an indigenous practice, integrates cropping and livestock rearing activities, emphasizing the importance of understanding land and crop management. Its adoption involves the application of biochar and compost, with biomass availability varying across agroecological zones.

In the mountains, extensive pasturelands are available, although many are degraded due to overgrazing. Typically, households own 30 to 50 small ruminants (sheep and goats) for wool and mohair, and 3 to 6 cattle primarily for traction and reproduction. To support widespread adoption of the Machobane system, animal dung combined with decomposed plant litter and agricultural residues (such as maize and sorghum stalks), along with invasive range land weed biomass like Salahalaha (*Seriphium plumosum* L. and *Felicia filifolia* L. ver.) [2], can serve as feedstock for biochar, enhancing both food security and environmental sustainability.

Fig. 21. Seven maize cobs in 40% biochar and compost treated soil, Tabang, Mokhotlong, Lesotho. (Curtesy: Mrs Mpolokeng, 2023; lead farmer and owner of the field).

5. CONCLUSION and RECOMMENDATION

Lesotho's experience reveals that amidst climate change, fields employing the Machobane Farming System (MfS) remained resilient and consistently green throughout the year. This system demonstrates notable benefits, enhancing soil moisture retention and fostering an increase in soil fertility indicator microorganisms. Consequently, MfS emerges as a preferred farming system for year-round crop cultivation.

For widespread adoption of the Machobane Farming System, government policies and support are crucial. Encouraging the use of animal dung, decomposed plant litter, agricultural residues [30], and invasive range land weed biomass as feedstock for biochar production can maximize the benefits of Machobane farming practices for food security and environmental protection [31].

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CONFLICT OF INTEREST STATEMENT

No author of this work has a conflict of interest, including specific financial interests, relationships, and/or affiliations relevant to the subject matter or materials in this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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