Original Research Article

Do we listen or ignore indigenous practices? The Machobane Farming System - an indigenous farming practice of Lesotho for enhancing soil fertility, pest control, crop production and irrigation water management

ABSTRACT

Aim: To examine various technological farming practices as part of the country's adaptation and/or mitigation strategy to improve soil fertility and enhance maize plant growth and reduce its vulnerability to drought and climate change.

Study design: The study was conducted in four agroecological zones of Lesotho: Mountain, Foodhills, 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. 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 conservation of moisture, 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>005) 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) agricultural practice is adopted by many households in Lesotho and the use of biochar and compost showed promising results at backyard experiments and field studies under APPSA (Agricultural Productivity Programme for Southern Africa).

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Keywords: *Machobane Farming System, Soil fertility, Food security, Sustainable farming, Biofertilizer, Indicator microorganisms.*

1. INTRODUCTION

An indigenous knowledge has a deep root to the landscape/agroecology, culture, develpment and history of human kind. The IK has paramount importance in maintaining and restoration of nature[1]. However, negative impacts of human activities and poor resource management, caused climate change, which intensify drought, pest ~~infestation and~~infestation and shrinks the arable land. Currently, in Lesotho only 9% of the land area is arable, while the rest of the country is dominated by a mountain (59%), most of which are rangelands, which is suitable for extensive livestock production[2]. The rangeland however is agressively invaded by exotic weed biomass known as Salahalaha: *Seriphium plumosum* L. and *Felicia filifolia* L. ver.[3], which impacts negatively the animal husbandry practice in the country.

Climate change scenarios has brought a serious challenge by inducing a shift in climatological conditions that is bound to lead to a shift in agro-ecological conditions, which in turn could have serious impacts on various economic sectors such as water, agriculture, land use change, forestry and health. The eminent shift in planting season has also excluded certain crops and the cropping season is getting much shorter and remained to be a huge challenge to farmers with low yield and productivity. Such an impact has also brought the highest population pressure in the lowlands of the country, where the estimated arable land is concentrated. This again is compounded by the problem of serious soil erosion and land degradation[2].

Rainfall is also sporadic and drought, hailstorms and winters can be quite severe. Even the estimated arable land is declining because of the thin layer of soil, limited vegetation and farmers dying of AIDS. Wind and water carry 40 million tons of soil from Lesotho every year[4]. Weather is partly to blame for the soil erosion, but poor management and an ancient land tenure system has also played their part. As a result, Lesotho has been described as one of the least forested countries in the sub-Saharan Africa where trees are cut down for firewood and new shoots are eaten by animals, causing further soil erosion and making even less land available for agriculture. The soils of the Senqu River valley is an example which remained the most unproductive in the region[5].

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The Intergovernmental Panel on Climate Change (IPCC)[6] report published in early 2007 confirmed that global climate change is already happening and that communities living in marginal lands are among the most vulnerable to climate change. This phenomenon made them to develop valuable knowledge to adapt climate change. But, the magnitude of future hazards may exceed their adaptive capacity, especially given their current conditions of marginalization.

To avert such a challenge, Lesotho has developed the National Adaptation Program of Action (NAPA) on climate change under the UNFCCC in 2007[7] and identified eleven adaptation technology options, most of which address land and water management in agricultural production[8].

The Machobane Farming System is one of the traditional farming practices in Lesotho develped in 1940s by ~~Dr~~ Machobane with high adaptability and resilience to climate change. The farming practice is a mixed farming by intercropping plants between rows using natural resources: ash and manure[9]. The practice demand high practical integrity to work on the soil and its intensive activity requires input and training to expand the system, to build nurseries, to harvest water and pest control methods for wider application of the system to the vast community.

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The objectives of this study was to evaluate the technical features of MfS and develop scientific ground to exploit its full benefits in comparison with other farming systems and develop a baseline information for sustainable use of the MfS as its principle can be applicable to smallholder and medium farmings in Africa.

2. AGRICULTURE IN LESOTHO

2.1 Crop farming systems

Crop production is one of the most important components of the farming systems in Lesotho throughout all livelihood zones dominated by maize (63%) of the area planted followed by sorghum (28%) and wheat (12%), whereas beans and peas accounts for (5%) and (3%) share of area planted[2]. The North and South western Lowlands, the Senqu River Valley, the Foothills and Mountain regions are the main cropping regions in the country. The amount and distribution of precipitation and other climatic conditions of the area is an important factor in crop production activity. The south western lowlands are the more susceptible areas to erratic agro-climatic conditions in the region.

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Currently, six farming systems or technologies are practiced in Lesotho, namely: block farming[10], mono-cropping (traditional farming), conservation farming[11], keyhole garden[12]

(Taylor, 2008), double digging [a 24 inch (610 mm) deep trench] and the Machobane Farming Systems[13]. Data depicting the percentage of farmers engaged in each farming system are not available. The farming systems are promoted with the obvious goal of assisting the rural livelihoods, conserving the environment, and generating income. However, their response to climate change impacts, adaptability and resilience property remained a crucial factor for consideration of the farming systems as a best farming practice in the rural livelihood of Lesotho.

Maize is the basic staple food crop of the people as it contributes 40% to the daily diet. Sorghum is the next important cereal used in preparation of porridge, traditional beer brewing and preparation of animal feed. Beans and peas have been grown for long as cash crops and are major sources of protein in the local diet. The area under cultivation, production, and yields are very erratic and closely related to rainfall figures. Other factors such as soil infertility, inadequate use of organic fertilizers, inefficient technologies that are characterized by untimely planting, poor land preparations inadequate weeding, and delayed harvesting are also major factors that affect greatly crop production in Lesotho.

2.2 Animal husbandry

In Lesotho, the livestock production plays an important role for both economic and social reasons next to crop production and it contributes 30% to agricultural gross domestic product[14]. The sub sector consists mainly of cattle (25%), sheep (45%) and goats (30%)[15]. Other livestock kept include horses, donkeys, pigs and poultry. Cattle are mostly raised for subsistence livelihoods including draught power, milk, fuel (dung), and meat. The 1996 distribution of livestock population at different agroecological zones is depicted in Table 1.

Table 1. Agricultural activities in the four agroecological regiona of Lesotho[2]

Parameter	Mountains		Foothills	
Main crops	Maize, wheat, peas, potato	Maize, wheat, beans vegetables	Maize wheat, peas, fodder crops and potatoes	Maize, sorghum, beans, few trees in valleys
Vegetation	Denuded grassland indigenous shrubs in some river, valleys, stunted peach trees near homesteads	Crop stubble, reforestation on some hills, fruit trees near homesteads	Poplar and willow trees along streams and gullies, crop stubble, a lot of fruit trees near homesteads	Denuded dry shrubs, brush, few trees in valley
Summer grazing	High mountain cattle posts	Around village	Around villages	Unsuitable, too dry
Percent of total livestock population	(%)	(%)	(%)	(%)
Cattle	32	26	31	11
Sheep	19	10	58	13
Goats	19	20	45	16
Horses	18	19	49	14
Donkeys	39	23	25	13

Livestock are reared around homesteads for half of the year due to seasonal changes (onset of winter), management practices (shearing, dipping) or to minimize the risk of theft. ~~Thus~~Thus, most stock have inadequate ration during long periods of the year in terms of poor nutritive value of fodder and forage. Farmers have no tradition of fodder husbandry on arable land or conserving fodder as silage or hay. This leads to insufficient dry matter intake for livestock. Though in some remote areas, rangelands are under-grazed due to remoteness, most village pasture areas support high stocking rates and are severely degraded. The range land deterioration as a result of overstocking (Figure 1 and 2), in turn affects the livestock productivity amongst other factors such as lack of proper feeding, disease control, poor breeding practices and stock theft.

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The livestock subsector is less prone to erratic climatic conditions as compared to the arable agriculture. Good rains positively affected rangelands and the water flow in streams and rivers on which livestock depend. However, the productivity of the subsector is severely affected by failure to maintain an appropriate balance between range resources and animal population and by adherence to traditional management practices[1]. A trend of declining in the number of livestock and its out put is attributed to declining of animal nutrition that has mainly resulted from degrading and overgrazing of rangelands[16].

Figure ~~1.The~~1. The range land under severe livestock pressure, Lesotho: Sheep and goat for wool

and mohair- contributed 30% of the National Export Revenue[17] .

Figure 2. The range land under severe livestock pressure: Horses and mules are the main means of transport in the rural Lesotho[15].

2.3 Climate change impacts on farming systems in Lesotho

Naturally, Lesotho is critically vulnerable to climate change scenarios because of its ~~agroecologicl~~agroecological location. Rainfall occurs mainly during the summer season but is extremely variable in quantity and time due to climate changes. Lesotho usually receives 85% of its annual rainfall between the months of October and March. Data from Lesotho Meteorological Services reported that rainfall levels in September 2006, the beginning of the planting season, were 57% lower than average. Although late rains commenced in October and remained constant through December, rainfall amounts started to decline in January 2007 and decreased dramatically during February and March as compared to the 30-year average for Lesotho[18].

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,~~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 eminent shift in planting season has excluded certain crops like peas and beans in the mountain areas. The changing climate has also decreased yield because of poorly developing buds; pest infestation, drought, flooding and hail storms. In the Mountain and the Foothill villages practicing Machobane Farming System noticed that it is less affected by a climate change. Sustenance of fertility from the soil that slowly release nutrients to the farm and conservation of the moisture content in Machobane Farming System make its resilience to climate change noticeable. In the Senqu River valley, participants noticed that no particular crop was resistant to climate change. A shift in precipitation patterns ultimately brings a shift in sawing and harvesting seasons to which unexpected disastrous situations could happen before crops harvested in the field. Assessment of historical data since 1961 to 1994 predict warmer future climatic conditions over Lesotho being lower precipitation in spring and summer and a higher precipitation in winter and autumn[2].

On the other hand, an increase in precipitation in winter may suggest an increase activity in frontal systems which may result in heavier snowfall and strong devastating winds often bring disasters and human suffering posing significant risks for agricultural production in Lesotho. Every year, wind and water carry 40 million tons of soil from Lesotho[19]. Rainfall is higher in the mountains and foothills and may favor the animal farming, ~~but,~~but the cropping season is much shorter due to the early outset of frost which will be exacerbated by climate change. The lowlands areas are significantly drier and crop failure from drought is very common.

2.4 Adaptation strategies made by the communities to climate changes

Specific measures taken against changing of climate conditions have varied from one village to the other. In the mountains some participants mentioned that they were running trials to find out as to which crops would be more suitable to the shifting and short growing period. In the dry Senqu River valley, mulching and returning residue on to the fields was observed to be the best way of conserving moisture (Table 3). They have also proposed water harvesting and construction of small dams for irrigation during dry period as an effective adaptive measure towards climate change. In the foothills at Pitseng village participants mentioned several adaptive measures such as:

- Ploughing the land while the plant residue is still there
- Avoid burning of plant residues in order to conserve soil moisture and not destroy the nutrients.
- Establishment of appropriate sawing season for different crops in response to the shifting sawing season to cope with a climate change.
- They used to saw maize in August but, due to the climate variability, they established the sawing season for maize to be towards the end of July.
- They still run trials for other crops and vegetables.

There have been no unique (innovative) measures implemented in Senqu River valley agroecological zones. In the mountains and foothills, on farm trials by farmers are ongoing to establish appropriate crops that can cope with shifting sawing season.

Table 2. Coping strategies to the effects of climate change

Protection to	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 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

i) ~~self reliance~~self-reliance; farmers must be convinced that can achieve food security without external assistance: it is their will that makes the difference

ii) appreciation of the resource bas; farmers must be convinced that they can improve crop production by fully exploiting their resource base;

iii) readiness to do hard work

iv) learning and teaching by doing; farmers must be trained on their own fields and farmer trainers must be ready to do work along with them

v) spontaneous technology spreading; farmers learn from their farmers

vi) Machobane farmers have the duty to help their neighbors.

In Lesotho mountain areas, most crops are grown on permanently terraced land. Due to poor soil structure, inadequate soil fertility management and erratic rainfall,

land productivity is low and subject to wide fluctuations. According to Machobane, these constraints can be overcome by rational exploitation of the resource base and minimizing the need for purchase inputs. In the MFS, it is considered that intensive cropping of one acre is sufficient to ensure food security for an average family of 5 members (1/3 of the area conventionally thought necessary). Commonly, seven basic crops are grown in Lesotho: maize, potatoes, sorghum, wheat, peas, beans and curcubits (pumpkins and melons). These crops are relay-intercropped in a 1-acre (0.4 ha) plot and the cropping pattern allows food crops to be produced almost all the year round. To reduce the likelihood of total crop failure, and increase productivity the Machobane farming system takes the following basic technical applications into account:

2.5.2 The technical bases

i) The use of organic fertilizers.

ii) Perennial vegetation cover.

iii) Cropping pattern adequate to the varying climate.

iv) Natural pest control,

v) Relay harvesting allowing for almost year-round harvest.

Although the specifics of this farming system may be appropriate only in the temperate climate of Lesotho, many of the principles outlined here are also applicable to smallholder farming areas in tropical Africa.

2.5.3 Use of organic fertilizers

The Machobane Farming System uses animal manure and wood ash as fertilizer. For the initial land preparation, approximately 300 wheelbarrowfuls are used per hectare (120 per acre; one wheelbarrow contains about 25 kg). Depending upon the type of soil, different mixtures of organic material are applied as required. About the same amount of organic matter is applied to the field before each cropping season. By the fourth year, the fertility of the soil will have improved, and less organic fertilizer will be needed each cropping season then after. Plant leaf litter and/ or remains (mulching) can also be used as effective soil cover to maintain moisture and decomposing material to the plant (Figure 4).

2.5.4 Perennial vegetative cover

The Machobane Farming System ensures complete crop cover throughout the year, because winter crops (e.g., wheat and peas) are planted in April–May (for harvest in January–March), and summer crops (e.g., maize, beans and sorghum) are planted in August–October (for harvest in November–December). Because the system uses minimum tillage (complete plowing of the field is only done once every 5 years), soil movement is minimized. Crop residues are left in the field, allowing humus to build up. Because there are always crops in the field, grazing of livestock is not possible.

2.5.5 Cropping pattern adapted to varying climate

Lesotho's climate is temperate, with a warm summer and a cool winter. Late or early frosts, hail and seasonal drought are not uncommon. The Machobane system allows for the planting of cool-weather crops, such as peas, wheat and potatoes, which perform well in the winter conditions. In the summer months, maize, beans, pumpkins and other crops are intercropped (Figure 3 and 5). However, because Lesotho can experience drought in the summer, drought-resistant crops like sorghum (aptly known as the "camel of the plant kingdom") are also planted to reduce the risk of crop failure.

2.5.6 Seedbed preparation and planting

In the first planting season, the 0.4 ha (1 acre) field is ploughed. The plot is then harrowed or disked to prepare the soil completely. A spade or hoe can be used to make the furrows or rows where the seed is to be planted. In April, the winter crops (wheat and peas) are planted. A double row of wheat is planted, with 30 cm between the two rows. Then a gap of 2 m is left, and a double row of peas is planted, again with 30 cm between the rows. Then comes another gap of 2 m, followed by a double row of wheat, a 2-m gap, another of peas, and so on (Figure 3).

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

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

In August, the first batch of potatoes is planted in the 2-m gaps between the rows of wheat and peas; only half of the field is planted at this time. Starting in November, the rest of the field is planted with a second batch of potatoes. In October, the summer crops are planted in a complex intercropping pattern of maize, beans, sorghum, pumpkin and watermelon. In the 30-cm spaces between the double rows of wheat and peas, a single furrow is dug. Maize and beans are planted in this furrow, with 30 cm between the maize plants, and 15 cm between the beans. Every 4 m, two pumpkin seeds are added to the maize and bean hill. In every other row, watermelon is planted rather than pumpkin. Finally, sorghum is sown along the entire furrow (Figure 5).

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

2.5.7 Crop management practices:

2.5.7.1 Tillage

Once the crops are in the field, minimum tillage is done using a spade or a hoe. A hand-pushed ripper (Figure 6) can also be used to open the furrow to plant the summer and winter crops. New crops can then be planted without harming the standing crops.

2.5.7.2 Weeding

Weeds in the field should be controlled as they can harbor insects and pests, and can also compete with plants for moisture, light and nutrients. The first weeding is done with a hoe immediately after crop emergence to break up and aerate the soil around the crops and to kill the weeds. The second weeding is done when the crops are about 1 month old. Crop residues are left in the field, helping to improve soil fertility and hindering weed growth.

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

2.5.7.3 Earthing the potatoes

The first earthing is done when the potatoes are at their first stage of flowering. A very small quantity of soil is gathered around the plant at this time. The second earthing is done at the second budding: a little more soil is ridged around the plant. The third earthing is done at the third budding, and ridging is done to cover half the plant with soil. With the fourth earthing, two-thirds of the plant is covered with the soil.

2.5.7.4 Natural pest control

Natural pest control is encouraged in the system, while chemical pesticides are discouraged. Since some crops act as natural repellents to certain insects, the intercropping practice contributes to pest control. The deliberate crop rotation helps to break the life-cycle of insect pests. Regular weeding throughout the year helps to control pests and diseases. Also, some plants can create an unsuitable environment for insects; for example, the pumpkin plant has hair which is irritating. Pest-control home remedies may also be used.

2.5.7.5 Relay intercropping

The relay intercropping practice offers many advantages. For example, because the crops are sown at different times there is little competition during the growing period. Time spent weeding one crop helps prepare the soil for the crop that will follow. Available land is maximized with the production of several species.

2.5.7.6 Relay harvesting

The relay intercropping system allows for staggered harvesting of crops throughout the year, manually. No machinery is used for harvesting. The winter crop of peas can be harvested in November (as green peas) and in March (as grains). Wheat is harvested starting in January. The first batch of potatoes is harvested from late November to March; the second batch is harvested starting in April. The potatoes are harvested as soon as the leaves and stems have become dry using a spade or digging fork.

Harvesting the large number of summer crops begins late in the year. Green maize can be harvested in December–January, and green beans in December–February. Watermelons can be harvested starting in February. From March to May, pumpkins should be harvested. Beans in grain form are harvested from April to the end of June; rape, cabbage, and spinach can be harvested during the same period. Grain or dry maize and sorghum are harvested in June–July.

3. MATERIALS AND METHODS

3.1 The study area

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

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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

From each of the selected farmers' fields (Machobane and Non-Machobane), undisturbed samples were collected from the mini-pits at the depth of 0-20 cm to determine the bulk density[20] and water reaction[21]. Samples were collected according to pedological horizons based on slope/ relief of the area for both physicochemical and microbiological analyses. Data about type of vegetation around each mini-pit, position of the mini pit on the slope, type of parent materials in the area and soil texture was recorded according to USDA method.

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

4. RESULTS AND DISCUSSION

4.1 Soil texture

Silt and clay were found to be the most important fractions of the soil texture as shown in (Figures: 8, 9 and 10). The silt and clay contents are very important for soil nutrient retention. These sites can be grouped into two categories those with silt contents of > 40% (i.e. PMFS, PNMFS & TNMFS) and those with silt contents < 30% silt contents (i.e. MHNMFS, QNMFS, QMFS, TMFS, MHMFS, BBMFS & BBNMFS). However, the sand content from all these sites can be grouped into three classes. Those with sand contents >50% (i.e. MHMFS, BBMFS & BBNMFS); those with sand contents between 35-48% (i.e. QMFS, TMFS, TNMFS, QNMFS) and those with sand contents ≤35% (i.e. PNMFS, MHNMFS & PMFS) (Figure 8). Furthermore, the clay contents from all these sites can also be grouped into two groups. Those with clay contents >30% (i.e. TMFS, PNMFS, PMFS & MHNMFS) and those with clay contents < 25% (i.e. MHMFS, BBMFS, TNMFS, QMFS, BBNMFS & QNMFS). These sites had significantly different levels of sand, silt & clay contents.

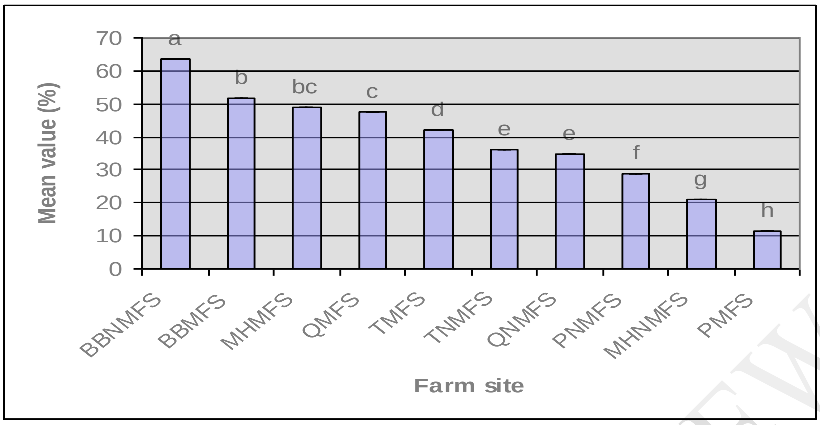


Figure 8. Sand fraction. Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (*P*< 0.05).

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.

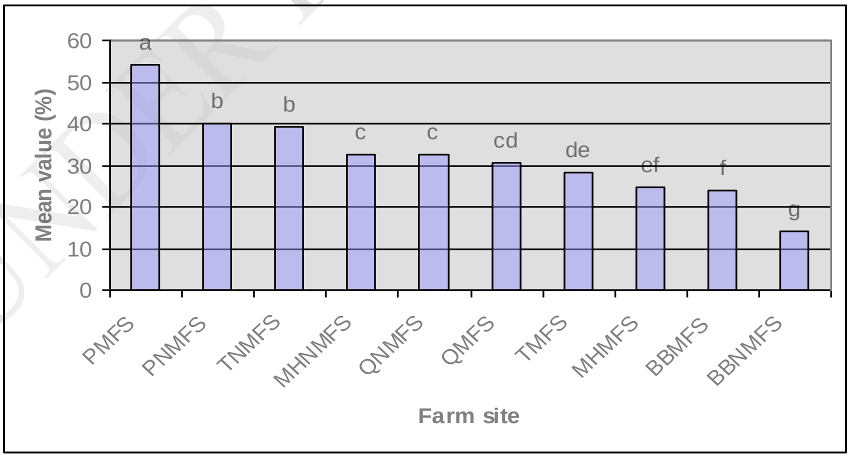


Figure 9. Silt fraction. Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (*P*< 0.05). Legend: refer to figure 8.

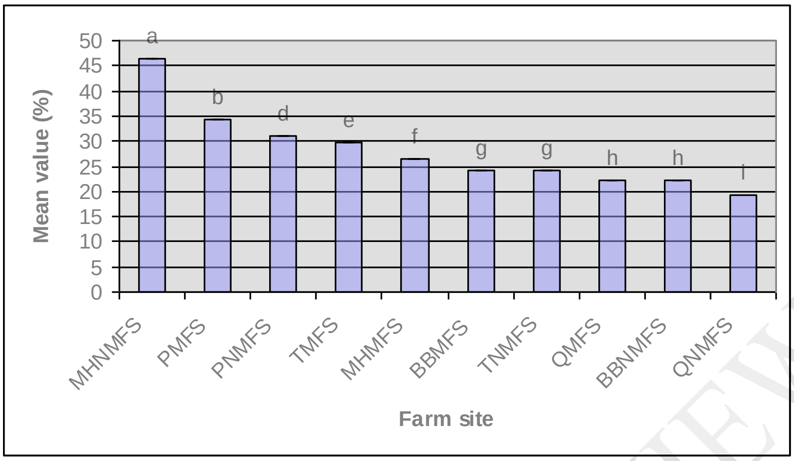


Figure 10. Clay fraction. Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (*P*< 0.05). Legend: refer to figure 8.

4.2 Soil pH

Generally, the soil pH can be grouped into two classes. Those with pH >6.0 (i.e. TNMFS, QNMFS, MHMFS, MHNMFS, TMFS & QMFS) and those with pH < 5.0 (i.e. PNMFS, BBMFS, BBNMFS & PMFS) (Fig 11). These sites had significantly different levels of acidity & alkalinity.

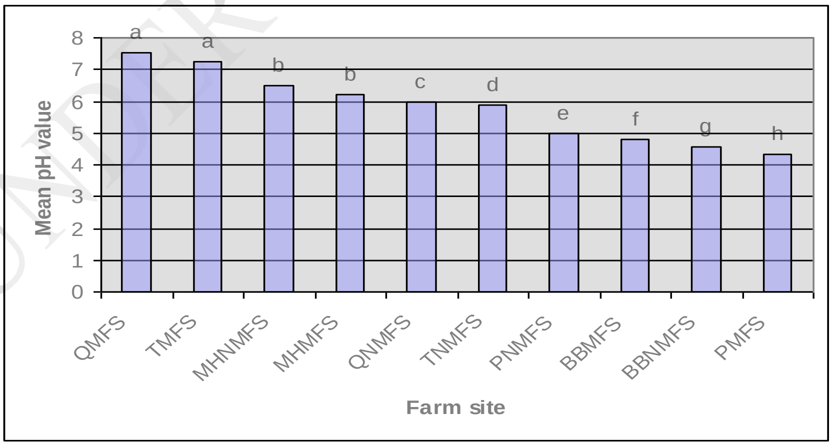


Figure 11. Soil pH. Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (*P*< 0.05). Legend: refer to figure 8.

4.3 Organic Carbon

The organic "C" can be grouped into two classes. Those with org C < 1% (i.e. BBNMFS, PNMFS, BBMFS & QNMFS) (Fig 12). In addition, others had org C > 1.5%. These sites had significantly different levels of organic carbon.

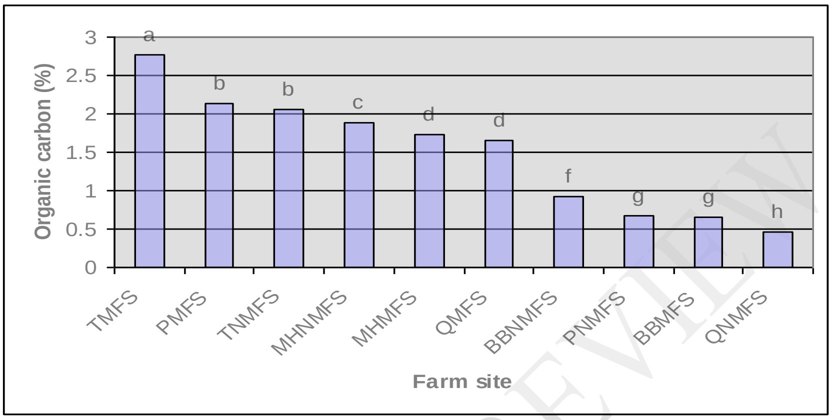


Figure 12. Organic carbon contents of soils practicing different farming systems. Means with the same letter are not significantly different at Duncan's Multiple ~~Rang Test~~Rang Test and grouping (*P*< 0.05). Legend: refer to figure 8.

4.4 Available *P*

The available *P* were generally low and these could be grouped into two classes. Those with available *P* of >10 mg/kg (i.e. BBNMFS, MHMFS & QMFS) and the others had <5 mg/kg of *P* (Fig 13). These sites had significantly different levels of available prosperous (*P*).

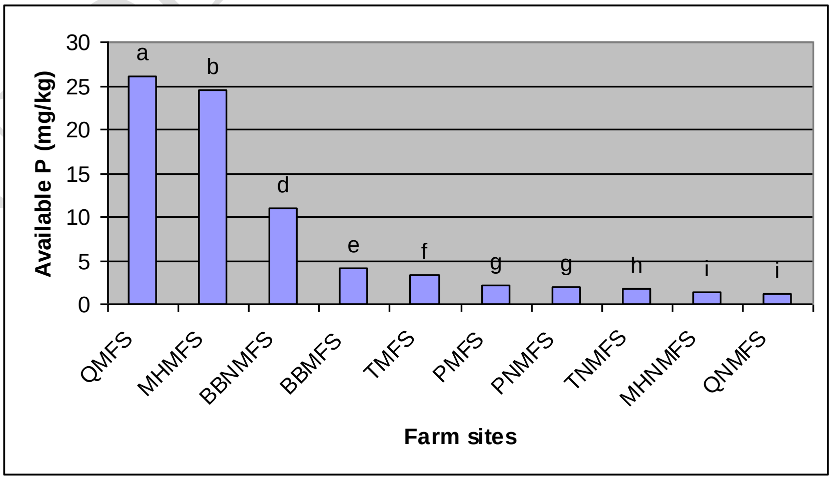


Figure 13. Available Phosphorus (*P*) in soils of Machobane and Non- Machobane Farming practicing fields. Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (*P*< 0.05). Legend: refer to figure 8.

4.5 Lime rate

Results showed that sites can be grouped into two categories based on their lime requirements. These are sites with lime rate >1,500 kg/ha (i.e. PNMFS, BBMFS, BBNMFS & TNMFS) and those with lime rates < 10,000 kg/ha (MHNMFS, QNMFS, MHMFS, TMFS, QMFS & PMFS) (Figure 14).

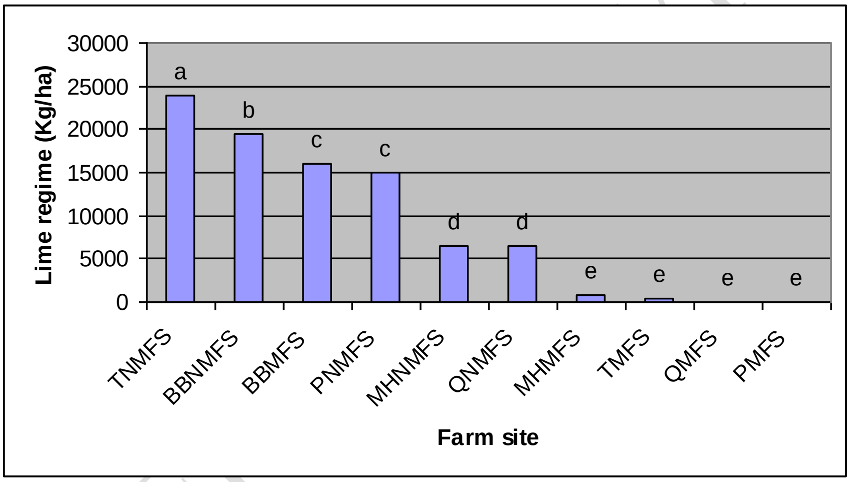


Figure 14. Lime Regime (~~K~~kg/ha) in different soils practicing Machobane and non-Machobane Farming Systems. Means with the same letter are not significantly different at Duncan's Multiple Rang Test and grouping (*P*< 0.05). Legend: refer to figure 8.

4.6 Determination of soil microbiota as soil fertility indicators

Soil samples from different ~~agrolecological~~agroecological zones of Lesotho were collected from five locations of Machobane and Non-Machobane farming plots using (A4 size) brown paper bags. The samples were kept at 4°C in the fridge until processing. As good indicator for soil fertility, the population dynamics of *Bacillus* strains as plant growth promoting rhizobacteria (PGPR) and strains of non-symbiotic nitrogen fixing bacteria (NFB) were determined using the methods described by Foldes *et al* (2000)[22]and Kennedy *et al*. (2004)[23], respectively.

Soil samples brought from Machobane Farming practicing plots exhibited higher number of soil fertility indicator microorganisms compared to the non-Machobane Farming System soils. The total count of ~~free living~~free-living Nitrogen Fixing (NF) bacteria was 5.4 x 10^5 cells/ml followed by *Bacillus* spp (1.96 x 10^5cells/mL~~l~~) (Fig 15 and 16). Soils rich in nutrients and carbon sources, not only increase number of microbial population, but also diversity of microorganisms[24,25]. An increase in number could also be associated with the ability of the *Bacillus* spp to fix nitrogen in nitrogen deficient soils[24] and has an over all ameliorative effect to the soil pH. Significant differences were observed in soil pH improvement in some Machobane Farming System practicing farms (Fig. 11). The *Bacillus* spp as Plant Growth Promoting Rhizobacter (PGPR) has also known to exert a direct effect on plant growth by production of phytohormones, solubilization of inorganic phosphate, increased iron nutrition through iron chelating siderophores and volatile compounds that affect the plant signaling pathways[26]. They have also known for their migration to the aerial parts of the plant for the mediation of disease suppression activity[27].

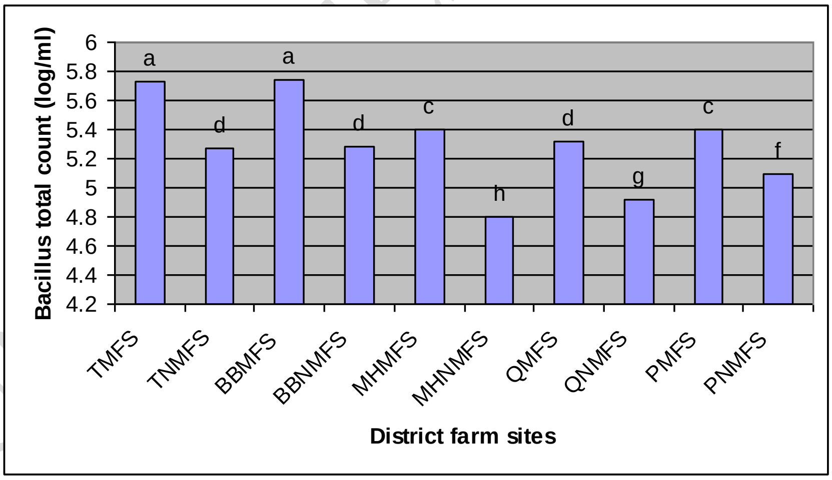


Figure 15. Total *Bacillus* count. Mean with the same letter are not significantly different by Duncan grouping at (*P*<0.05). Legend: refer to figure 8.

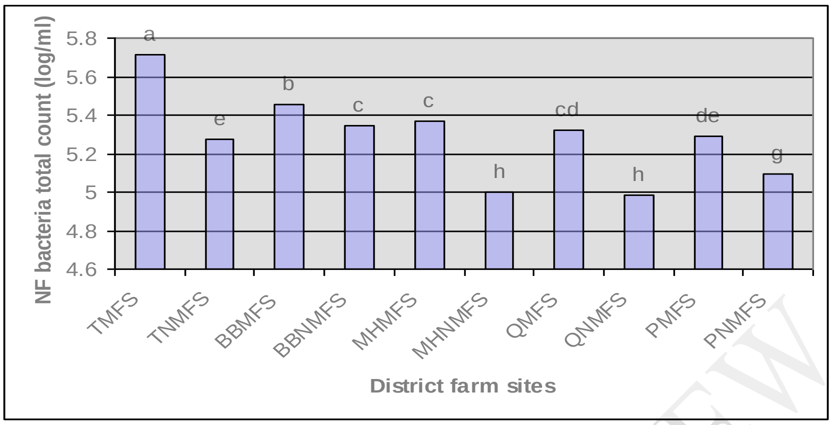
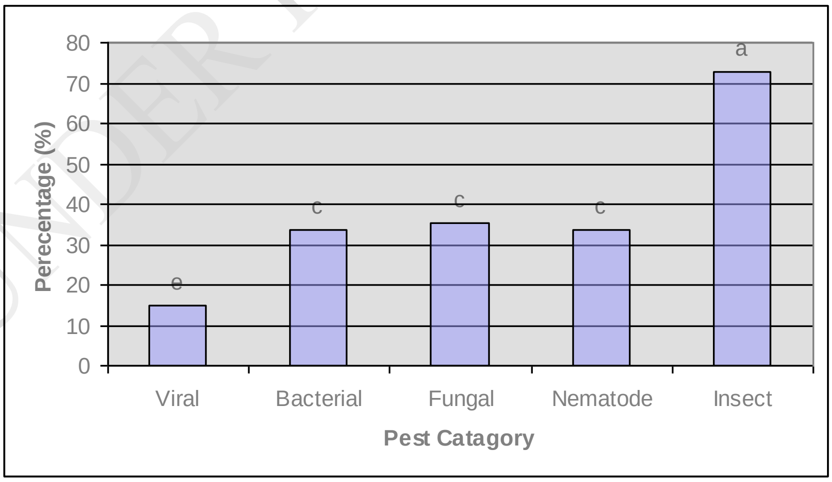


Figure 16. Total Nitrogen Fixing (NF) bacteria count. Mean with the same letter are not significantly different by Duncan grouping at (*P*<0.05). Legend: refer to figure 8.

4.7 Pest prevalence and control

Insects were identified as the major pests followed by fungal and bacterial infections that cause great damage to their crop plants (Figure 17). Stock Borer (*Busseola busca*), and Bagrada Bug (*Bagrada hilaris*) were identified as the major insect pests followed by Aphids that causes great damage to the leaf (>55%) and stem (51.5%) parts of their crops, respectively.



~~Figure 17~~Figure 17. Crop pest category.

To control pests, about 44% of the respondents showed the application of commercial pesticides, where as (30%) the respondents showed the use of traditional pesticides in their farm. The formation of concoction using various plant materials and other inputs has also been explained in the Focused Group Discussion (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.

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

Agroecological zone (village)	**Crops**	**Pests and environmental factors**	**Pest control method**
			• 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.

4.8 Meteorological data trend analysis

The amount of precipitation and percentage change over years (1923 – 2006) in Lesotho is depicted in Fig 18 and 19 below. Highest precipitation was recorded between 1954-1962 and this fluctuates irregularly as from 1963 to 2006 (Fig. 18). Results of the decadal change in rainfall were highest for periods of 1944-1953 and this trend decrease successively over years to the lowest between1974-1983 and the lowest precipitation change was recorded between 2003-2006 (Fig. 19).

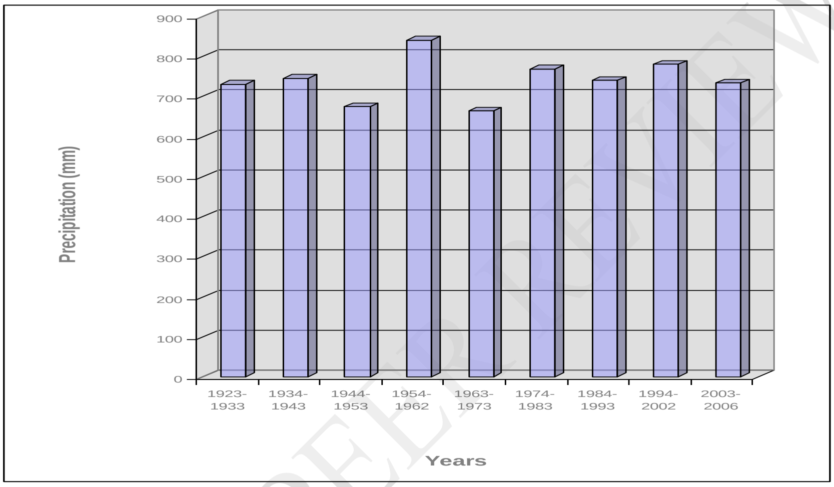


Figure 18. Precipitation trend in Lesotho since 1923 – 2006.

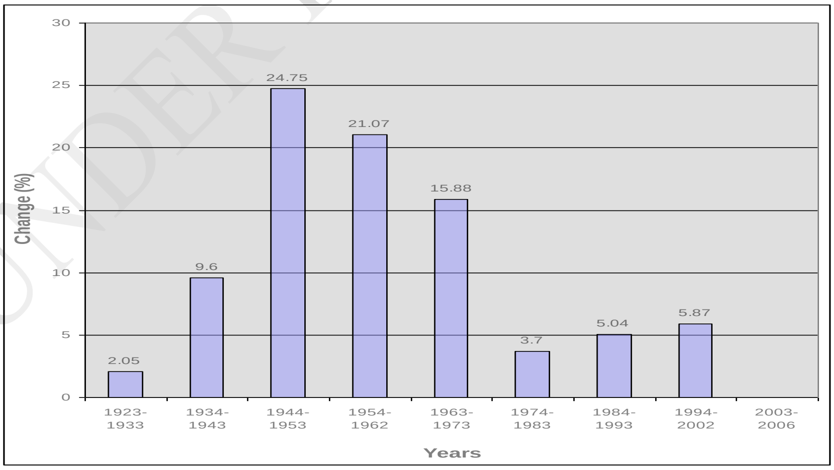


Figure 19. Percentage change of precipitation over years in Lesotho (1923 – 2006).

4.9 Current application of the Machobane Farming System in different agroecological zones of Lesotho

Currently, a new apporach using biochar instead of ash with manure is underway for intensification agriculture in fields practicing the Machnobane farming System: Qachasnek (Ha-Thaba) (mountains), Mohale'shoek (Taung Ha Moletsane) and Butabute (Manamela) (Foothills) and (Mafteng (Ha-Makhakhe) (Lowlands). Backyard experiments undertaken in 2021 with biochar and manure application at NUL shows promissing output (Figure 20) to be used in an intensification agriculture experimentsats at the selected Machobane farming practicing fields in Lesotho.

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

Appropriate application rates of bichar may vary, depending on soil quality, crop, and availability of amendments. Lead farmer households from each of the agroecological zones of Lesotho who have understood and accepted the principles of MfS have been selected in collaboration with the Machnobane Agricultural Development Foundation (MADF), Maseru to discuss and impliment the intensfication agriculture experiment in their fields. From the previous experience, farmers have reported three main advantages of the system: (i) intensification = much higher land productivity, (ii) potato intercropping = large cash revenue, and (iii) their fields are green even when non-Machobane fields are dry in case of drought. In recent field trials, the application of 40% biochar and compost has shown high performance in maize and beans mixed farm at Tabang, Mokhotlong, Lesotho (Figure 21).

Figure 21. **Seven maize cobs in 40% biochar and compost treated soil, Tabang, Mokhotlong, Lesotho. (Curtesy: Mrs Mpolokeng, 2023[28], lead farmer and owner of the field).**

4.10 Long-Term Technical Sustainability

The Machobane technology is a farming practice approach that pivots around the integration of cropping and livestock rearing activities, and requires a good understanding of land and crop management requirements using biochar and compost. Its widespread application

~~need~~needs sufficient organic manure in the form of compost and biochar feedstock, which may be vary in the lowlands and the mountain areas of Lesotho.

In the mountains, large areas of pasture land are available, albeit some in serious state of degradation due to overgrazing. On average, a household would own some 30 to 50 small ruminants (sheep and goats, reared for the wool and mohair and occasional slaughtering for meat consumption), and 3 to 6 cattle (essentially kept for animal traction and reproduction). Well over half of the dung collected in the *kraals* is consumed as fuel. To sustain a large scale application of the Machobane system, animal dung with decomposed plant litter agricultural residues/ waste (maize, sorghum stalk, etc. and the invasive range land weed biomass, Salahalaha: *Seriphium plumosum* L. and *Felicia filifolia* L. ver.[3] can be used as a feedstock for biochar to maximize the benefit for food security and environment.

5. CONCLUSION and RECOMMENDATION

In order to either take full advantage of new opportunities and potential that may come with climate changes, or avert human sufferings that may be associated with its adverse effects, more robust national coordinated mitigative and adaptive development policies should be in place for the best advantage of the poor.

To sustain a large scale application of the Machobane farming system, polices and support has to be in place for the use of animal dung with decomposed plant litter, agricultural residues/ waste (maize, sorghum stalk, etc. and the use of an invasive range land weed biomass, Salahalaha: *Seriphium plumosum* L. and *Felicia filifolia* L. ver.[3] as a feedstock for biochar production to maximize the benefit of the Machobanae farming practice for food security and environment protection.

More effort has to be done with strength towards improvement of productivity by way of several indigenous farming practices. From Lesotho’s experience, in due course of climatic change, some of the agricultural fields practicing the Machobane Farming System remained unaffected and appeared green throughout the year. However, no data have been collected to explain why the Machobane fields are green when other fields are dry in years of poor rainfall and neither explanation is provided on the impact of the MfS on the soil's capacity for retaining moisture and making it available for plant growth. Thus, being a good farming practice, knowing the impacts of the MfS on the soil's capacity for retaining moisture and increase the soil fertility indicator microroganisms, making it a choice of farming practice to be used widely for fmaily food security and envimronment in Lesotho.

In developed countries, application of such a farming practice may require a change in policy systems to support an ecologically sound, socially responsible, economically viable agriculture that support more farmers who are committed to taking care of the land for the long-run benefit of society as well as ~~themselves as~~themselves as ~~highlighted by~~highlighted ~~Ikerd~~by Ikerd, J. (2024)[29].

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