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Microbial and physico-chemical evaluation of soils from different farming systems practicing fields in Lesotho and the adaptive capacity of Machobane Farming System to climate change

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In Lesotho, agriculture remains a major source of income for more than 80% of rural population. The arable land accounts for about 9% of the total land area and the current crop yields are half the level achieved in the late 1970s. Despite its contribution to Lesotho's development, the rural economy has been languishing due to poor land management and farming practices, declining soil fertility, poor weather conditions and poor management of water resources. Communities living in marginal lands and whose livelihoods are highly dependent on natural resources are among the most vulnerable to climate change. In Lesotho, about six farming technologies, namely, block farming, mono-cropping, conservation farming, keyhole garden, double digging and the Machobane Farming systems are practiced. We assessed the distribution and diversity of *Bacillus* spp., the non-symbiotic Nitrogen Fixing Bacteria (NFB) and physico-chemical variables including soil texture, pH, organic carbon, and available phosphorus as quality indicators of soils from various farming systems in Lesotho in an attempt to elucidate the adaptive capacity of various farming systems to climate change. Amongst the six farming systems assessed, the Machobane Farming System (MFS) practicing fields exhibited significant level of soil quality improvement in microbial composition and physico-chemical property compared to other farming systems. These findings provide, for the first time, scientific evidence that the MFS, which combines indigenous knowledge and technology, may show better resilience to climate change for high and sustainable production of variety of crops throughout the year.

Key words: Indigenous farming technology, adaptability, traditional knowledge, farming practices in Lesotho, soil microorganisms, soil fertility.

INTRODUCTION

The Kingdom of Lesotho is a country located in the southern part of Africa at an elevation of between 1,500 m and 3,482 m above sea level with a land area of 30,355 sq km (Flannery, 1977). The country is divided into four agro-ecological zones (Figure 1) based on climate and elevation: Lowlands (17%), Senqu River Valley (9%), Foot-hills (15%) and Mountains (59%) (Cauley, 1986). During the last 4 decades, the arable land area declined from 15% to about 9% of the total land area, the remainder of the country being dominated by rangeland suitable for livestock production (Bureau of Statistics and Planning, 2002). The highest population pressure is found in the lowlands of the country, where the estimated arable land is concentrated and this is compounded by the problem of serious soil erosion, land degradation and increasing population pressure (Bureau of Statistics and Planning, 2007).

Naturally, the agro-ecological location of the country made it so vulnerable for many climatic changes. Rainfall has been sporadic and precipitation highly variable both temporally and spatially during the last 50 years, probably as a result of climate change. Studies indicate that rising trend in temperature and declining trend in rainfall, combined with late rains, early frosts, and erratic hailstorms have enormous implications for the agriculture of Lesotho (LMS, 2011). In pursuit of commitments under the Climate Convention, Lesotho has developed the National Adaptation Program of Action (NAPA) on climate change under the UNFCCC in 2007 (MoNR, 2007) and identified technology needs in agriculture, which is the most important contributor to the national economy and livelihoods to a high proportion of the population (LMS, 2004).

It is therefore imperative for Lesotho to examine various technological options in agriculture that will form part of the country’s adaptation strategy to reduce its vulnerability to climate change. Physico-chemical and microbial characterization of soils may shed light on the degree of resilience to climate change of the different farming systems. The Machobane Farming System (MFS) (Robertson, 1994; Machobane and Robert, 2004) is one of the farming practices in Lesotho developed for smallholder farmers using existing natural resources. Successful adaptation reduces vulnerability and it depends greatly on the adaptive capacity of an affected system to cope with the impacts and risks of climate change. The MFS is an intensive cropping scheme based on self-help philosophy to ensure self-reliance. This farming system combines crop rotation, relay cropping, intercropping practices and self-discipline to allow year-round crop production. Reliance of rural communities on adequate agricultural produce still remains inevitable in Lesotho and the MFS appears to be a viable option but, to our knowledge, no assessment of the resilience of farming systems in Lesotho was done in terms of microbial and physico-chemical variables. The aim of the present study was to assess the adaptive capacity of farming systems to climate change in the four agro-ecological zones of Lesotho based on physico-chemical, and microbial analysis of farm soils and open and closed-ended questionnaires.

MATERIALS AND METHODS

Study area

The study area covers selected farm lands in the four agro-ecological zones of Lesotho that practice Machobane Farming System MFS and non-Machobane Farming System (NMFS): the Highlands: Thaba-Tseka (Mant’sonyane) (2000-3480 m.a.s.l.), Foothills: ButhaBothe (1800-2000 m.a.s.l.), Lowlands: Mohale’s Hoek (1200-1800 m.a.s.l.) and Quithing (Senqu River Valley) (1000-1200 m.a.s.l.) as depicted in Figure 1.

Questionnaire survey

Informally structured questionnaires that comprised of four major parts: household characteristics; food security and poverty alleviation practices; climate change and adaptation practices; and government and civil society’s intervention to provide support at community level were used for field work data collection. In total, 400 households [100 from each of the four agro-ecological zones of Lesotho] were interviewed.

Collection of soil samples

Undisturbed soil samples were collected from MFS and NMFS practicing fields of five districts [ThabaTseka- Mants’onyane (Mountain), Leribe-Pitseng (Wet lowland), Butha- Bothe (Foothill), Quthing (Senqu River valley) and Mohale’s Hoek (Dry lowland)] of the four agro-ecological zones in Lesotho and samples were labeled as follows: Pitseng Machobane Farming System (PMFS), Pitseng non-Machobane Farming System (PNMFS); ThabaTseka Machobane Farming System (TMFS), ThabaTseka non-Machobane Farming System (TNMFS), Butha Bothe Machobane Farming System (BBMFS), ButhaBothe non-Machobane Farming System (BBNMFS), Mohale’s Hoek Machobane Farming System (MHMFS), Mohale’s Hoek non-Machobane Farming System (MHNMFS), Quthing Machobane Farming System (QMFS) and Quthing non-Machobane Farming System (QNMFS) (Figure 2). From each of the selected farmers’ fields, samples were collected from the mini-pits at the depth of 0 to 20 cm to determine the bulk density (Blake and Hartge, 1986) and water reaction (Klute, 1986). The pedological horizons of soil were assessed based on slope/ relief of the area. 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 methods.

Soil physico-chemical analyses

Air dried samples were used to determine the proportion of gravel (>2 mm) in the soil. The <2 mm fraction was determined using hydrometer method as an index of soil micro-aggregate stability. The soil pH, texture, organic carbon, available phosphorus (*P*) and lime rate (cation exchange capacity) were determined using the method described by Badamchian (1984).

Soil microbiological analyses

Soil samples from different agro-ecological zones of Lesotho were collected from five locations of Machobane and non-Machobane farming plots using (A4 size) brown paper bags.

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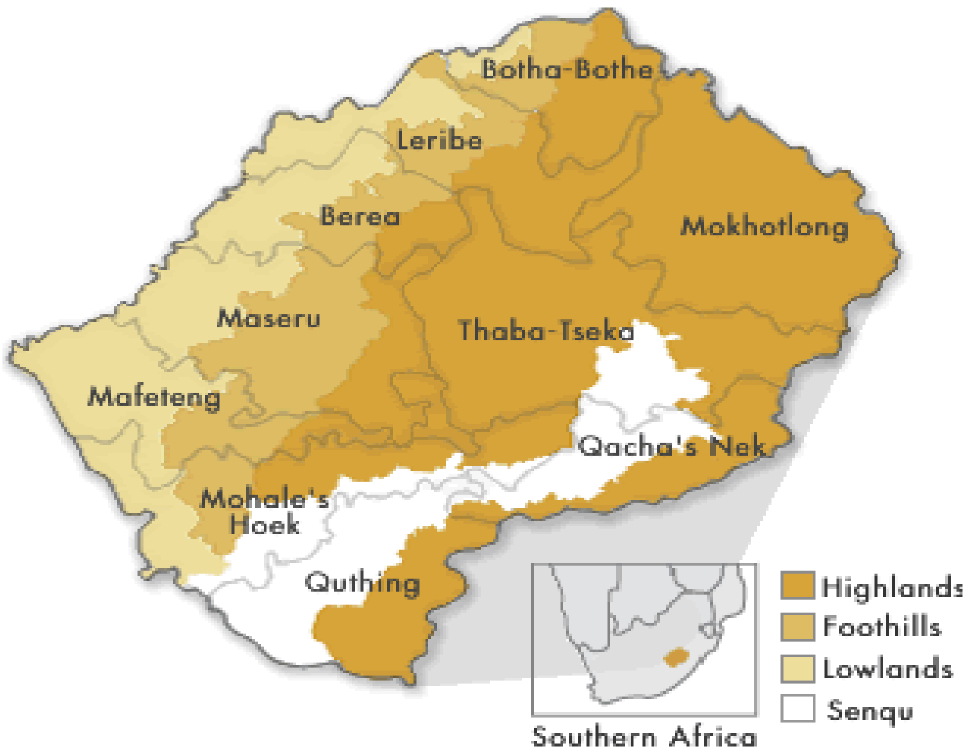

Figure 1. Agro –ecological zones of Lesotho: the study area.

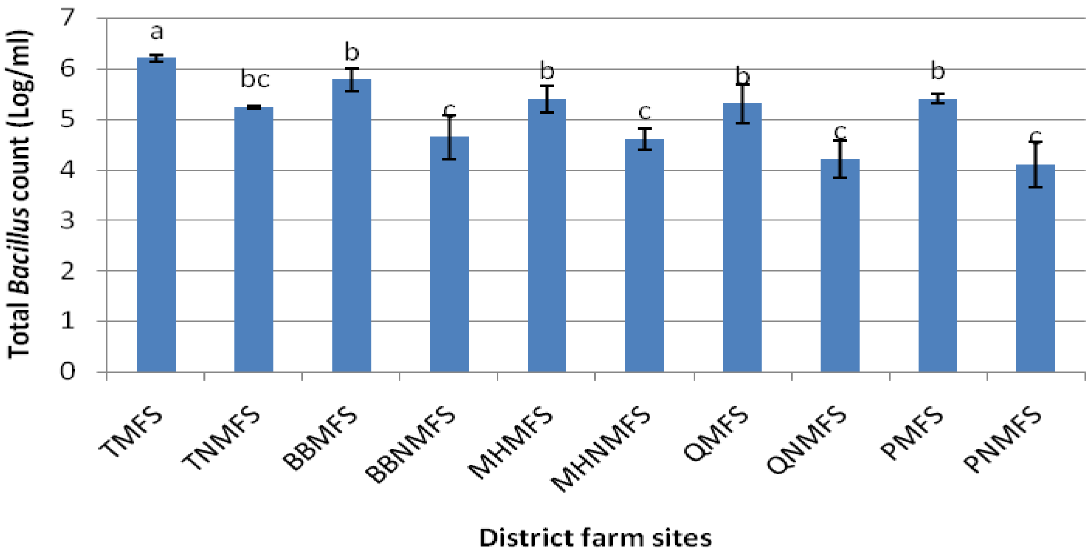

Figure 2. Total *Bacillus* count. Mean with the same letter are not significantly different by Duncan grouping at (P<0.05).

The samples were kept at 4°C in the fridge until processing. As good indicator for soil fertility, the distribution and diversity of *Bacillus* spp. and the non-symbiotic nitrogen fixing bacteria (*NfB*) were determined using the methods described by Foldes et al. (2000) and Kennedy et al. (2005), respectively.

Statistical analyses

Summary statistics – CV, standard errors, and skewness were used to summarize all soil data collected. Student's t-test was used to compare the difference between the soil properties at each section

Table 1. Respondent gender cross tabulation with Farming Systems.

Respondent	Response	Respondent gender		Total
		Male	Female	
Do you use a Machobane Farming System?	Yes	132 (51%)	127 (49%)	259 (66.8%)
	No	56 (43.4%)	73 (56.6%)	129 (33.2%)
Total		188	200	388

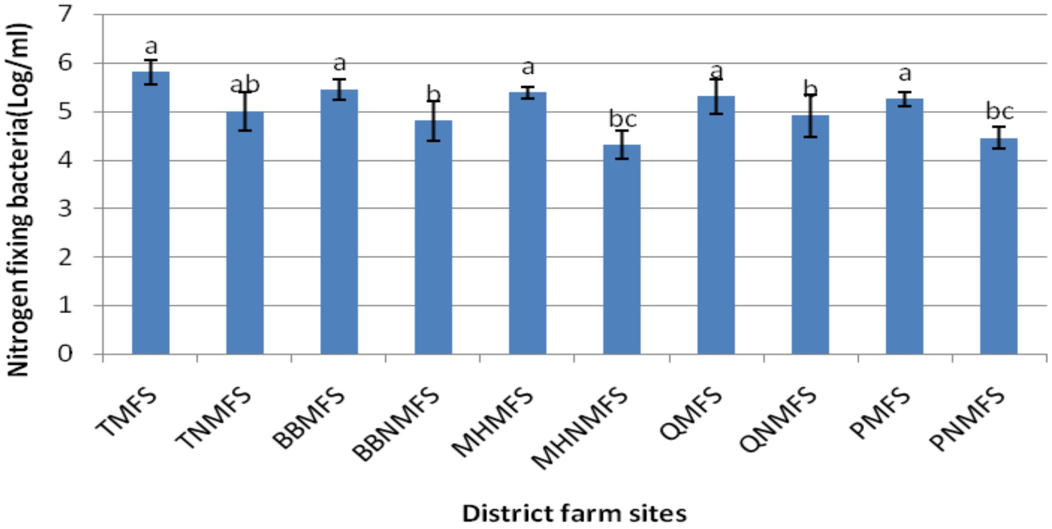

Figure 3. Total non- symbiotic Nitrogen Fixing Bacteria (N*f*B) count. Mean with the same letter are not significantly different by Duncan grouping at (P<0.05).

of the slope positions using the SAS PROC statistical analysis systems (SAS Version 8, 2001). The subsets of topography and soil fertility data were analyzed and summarized by the principal component analysis (PCA) using the PRINCOMP procedure of SAS. Principal components (PC's) were calculated based on the correlation matrix. The mean separation analyses were conducted using Duncan's Multiple Range test at P<0.05.

RESULTS

Respondents gender cross tabulation with farming systems

More than 66% of the respondents, 51% male and 49% female, practiced the Machobane Farming System. The remaining respondents, about 56% female, practiced the non-Machobane Farming System (Table 1). This could be due to its intensive nature of farming practice that requires more labor compared to other farming practices.

Soil microbiota as soil fertility indicators

Soil samples brought from MFS practicing plots exhibited higher number of soil fertility indicator microorganisms compared to the NMFS soils. The total count of *Bacillus* spp. ranges between 7.8 x 10^5 - 3.1 x 10^6 cells/ml in MFS soils and 1.1 x 10^4 to 2.6 x10^5 in NMFS practicing soils followed by free living Nitrogen Fixing Bacteria (NFB) ranges between 6.7 x 10^5 to 2.9 x 10^6 in MFS soils and 2.1 to 1.3 x 10^5 cells/ml in NMFS practicing soils (Figures 2 and 3).

Physico-chemical characteristics of soil

Soil pH

Generally, the soil pH can be grouped into two classes. Those with pH > 6.0 (that is, TMFS, MHMFS, QMFS, and QNMFS) and those with pH < 5.0 (that is, BBNMFS and PNMFS) (Figure 4). These sites had significantly different levels of acidity and alkalinity.

Soil texture

Silt and clay were found to be the most important

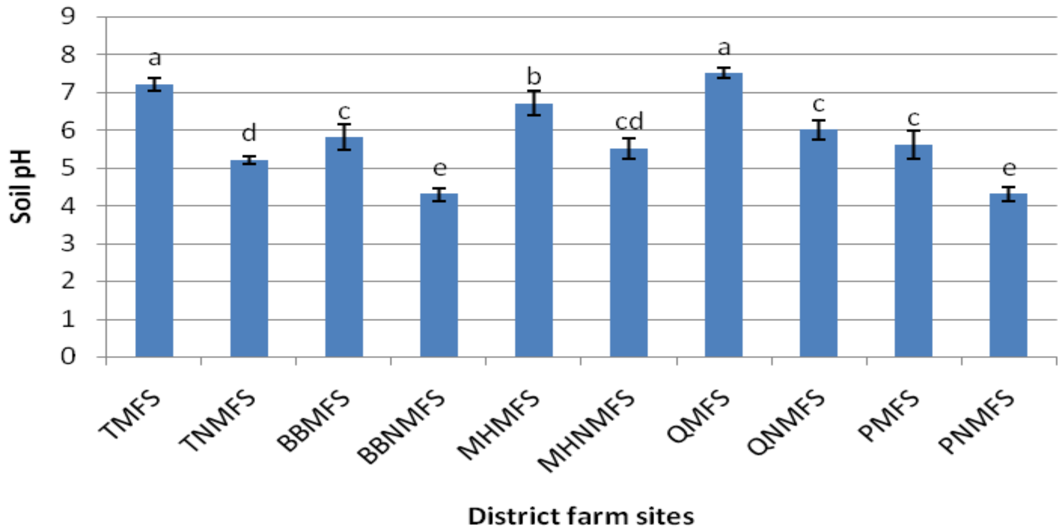

Figure 4. Soil pH. Means with the same letter are not significantly different at Duncan's Multiple Range Test and grouping (P< 0.05).

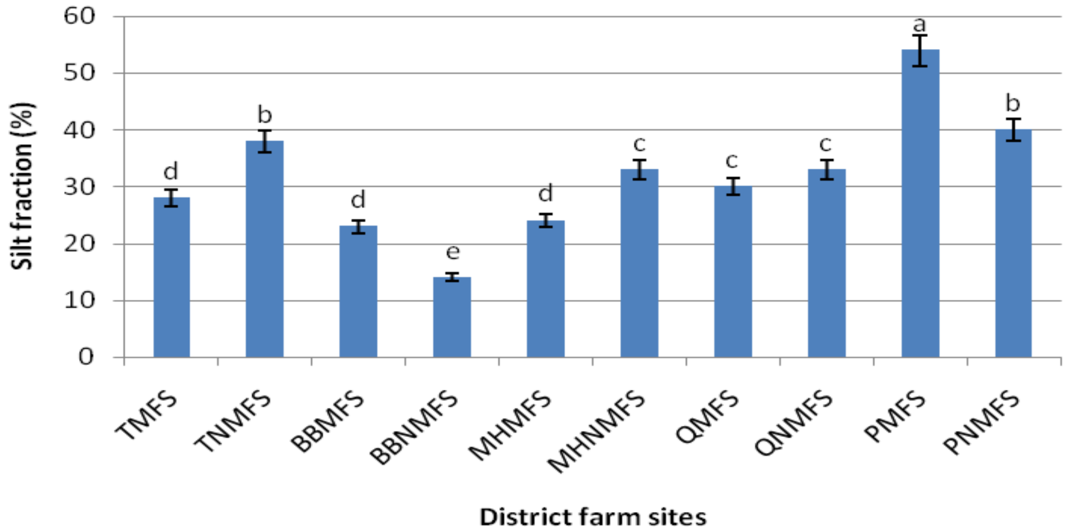

Figure 5. Silt fraction. Means with the same letter are not significantly different at Duncan's Multiple Range Test and grouping (*P*< 0.05).

fractions of the soil texture as shown in (Figures 5 and 6). These sites with silt content can be grouped into two categories: those with silt contents of > 40% (that is, PMFS and PNMFS; and those with silt contents < 30% (that is, TMFS, BBMFS, MHMFS, BBNMFS, MHNMFS and QMFS (Figure 5). However, the sand content from all these sites can be grouped into three classes. Those with sand contents >50% (that is, BBMFS and BBNMFS); those with sand contents between 35 to 48% (that is, TMFS, MHNMFS, QMFS and QNMFS) and those with sand contents ≤35% (that is, TNMFS, MHMFS, PMFS and PNMFS) (Figure 7). Furthermore, the clay contents from all these sites can also be grouped into two categories as clay contents >30% (that is, MHMFS, MHNMFS, PMFS and PNMFS) and < 25% (that is, TNMFS, BBMFS, BBNMFS, QMFS and QNMFS) (Figure 6). These sites had significantly different levels of sand, silt and clay contents.

Organic carbon

The organic "C" can be grouped into two classes. : those with org C < 1% (that is, BBNMFS, QNMFS and PNMFS)

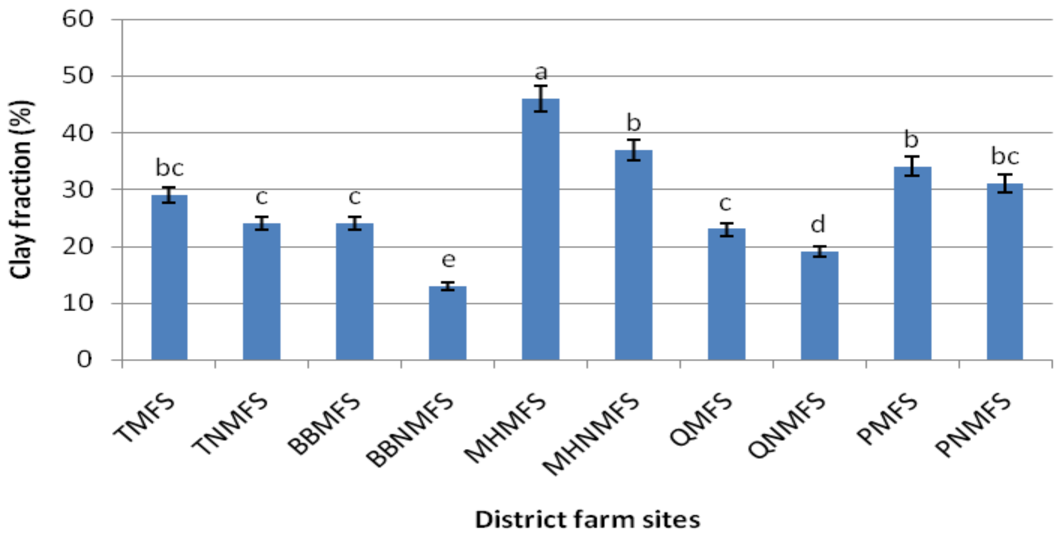

Figure 6. Clay fraction. Means with the same letter are not significantly different at Duncan's Multiple Range Test and grouping ($P< 0.05$).

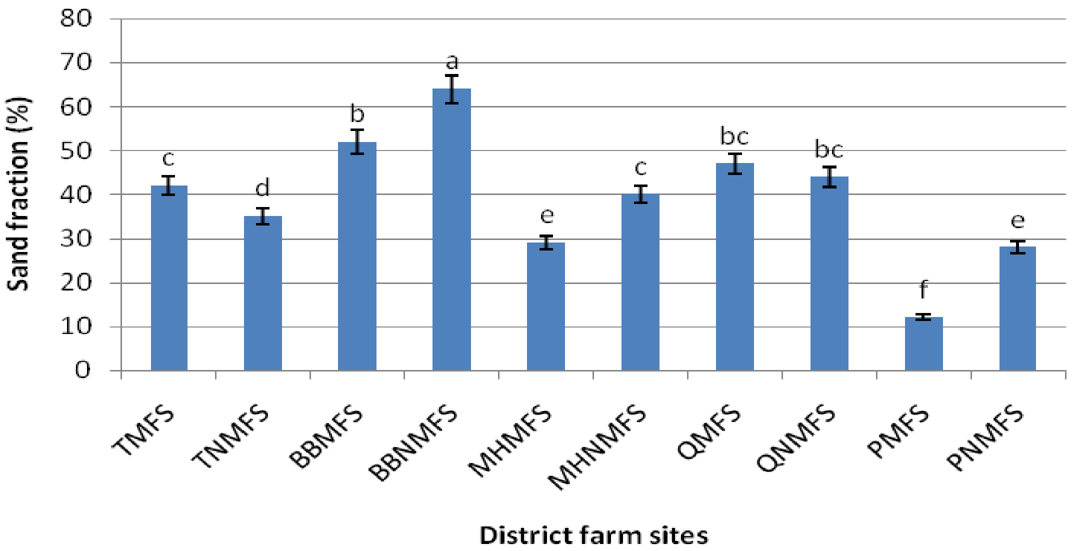

Figure 7. Sand fraction. Means with the same letter are not significantly different at Duncan's Multiple Range Test and grouping ($P< 0.05$).

and those with org C > 1.5% (that is, TMFS, TNMFS, BBMFS, MHMFS, QMFS and PMFS). These sites had significantly different levels of organic carbon (Figure 8).

Available phosphorus (P)

The available P was generally low and the farms could be grouped into two classes based on available P content: Those with available P of >10 mg/kg (that is, BBMFS, MHMFS and QMFS) and the others had < 5 mg/kg of P (that is, TMFS, TNMFS, BBNMFS, MHNMFS, QNMFS, PMFS and PNMFS) (Figure 9). These sites had significantly different levels of available phosphorus (P).

Lime rate

Results showed that the farms can be grouped into two categories based on their lime requirements. These are sites with lime rate > 1500 kg/ha (that is, TNMFS, BBMFS, BBNMFS, MHNMFS, QNMFS and PNMFS) and

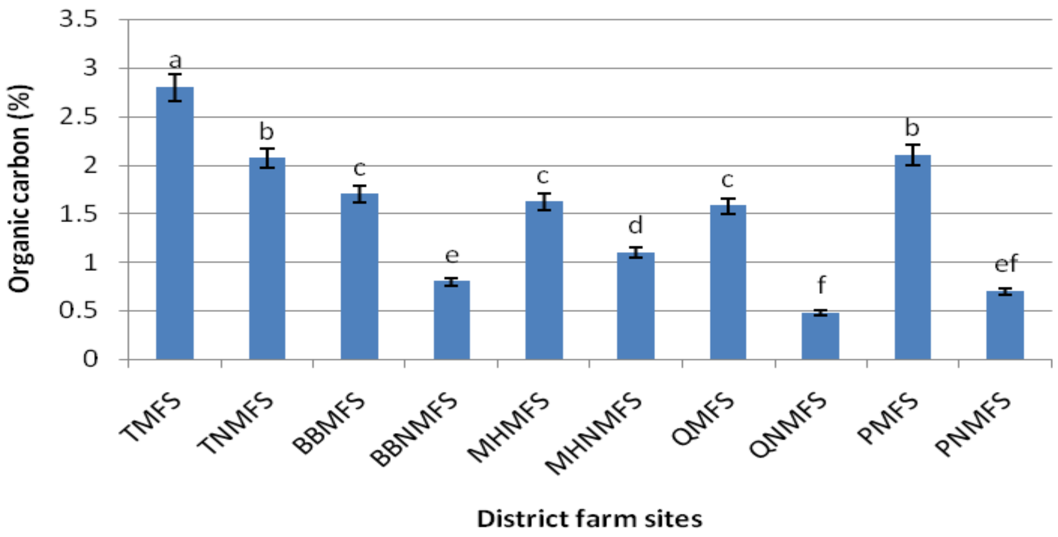

Figure 8. Organic carbon contents of soils practicing different farming systems. Means with the same letter are not significantly different at Duncan's Multiple Range Test and grouping (P< 0.05).

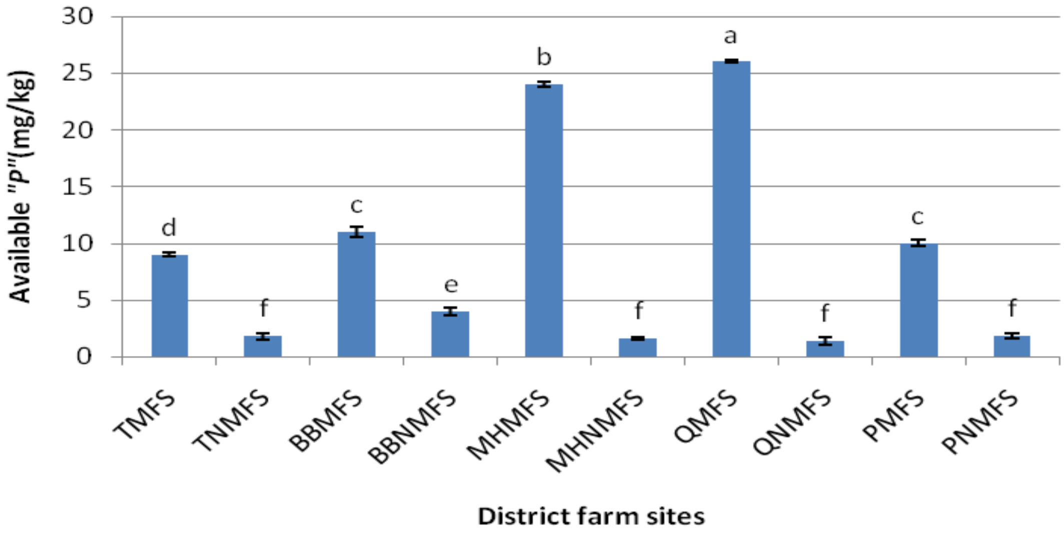

Figure 9. Available Phosphorus (*P*) in soils of Machobane and Non- Machobane Farming practicing fields. Means with the same letter are not significantly different at Duncan's Multiple Range Test and grouping (*P*< 0.05).

those with lime rates < 10 000 kg/ha (that is, TNMFS, BBMFS, BBNMFS, and PNMFS) (Figure 10).

DISCUSSION

In this study, soil samples brought from MFS practicing plots exhibited higher number of soil fertility indicator microorganisms that include *Bacillus* and non-symbiotic Nitrogen Fixing (NFB) bacteria compared to the NMFS practicing farms (Figures 2 and 3). An increase in the number of these microorganisms has also been shown to have an overall ameliorative effect on the soil pH and texture (Figure 4) (Colin, 2000; Cummings, 2005). Besides fixing nitrogen, the role of *Bacillus* spp. in increasing soil aggregation by producing gum (Paul and Clark, 1996), as plant growth promoting rhizobacter (PGPR) by the production of phytohormones, as antibiotics and iron chelating siderophores has been indicated by several other workers (Joo et al., 2004; Nguyen et al., 2012; Gopalakrishnan et al., 2013).

Bacillus spp. are also known for their migration to the

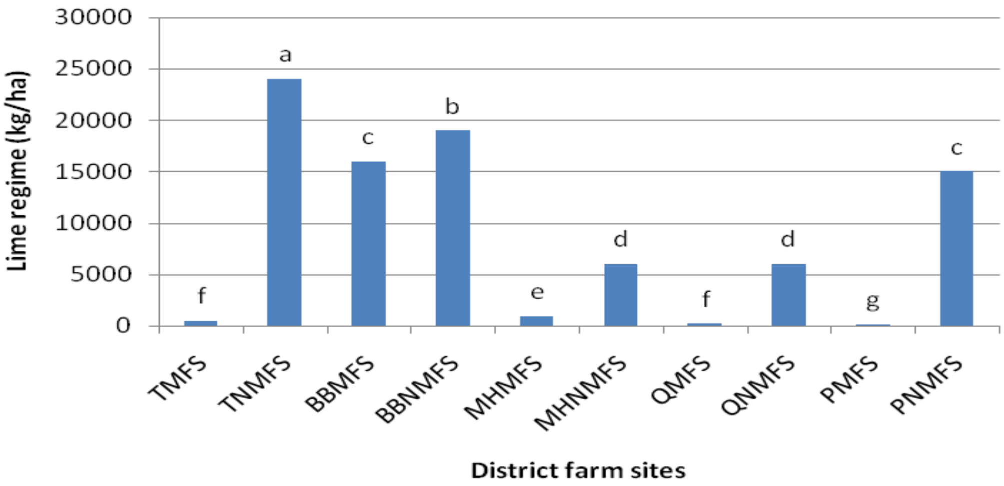

Figure 10. Lime Regime (Kg/ha) in different soils practicing Machobane and Non-Machobane Farming Systems. Means with the same letter are not significantly different at Duncan's Multiple Range Test and grouping (*P*< 0.05).

aerial parts of the plant for the mediation of disease suppression activity (Gnanamanickan, 2003). The presence of other group of bacteria such as Streptomyces spp. (data not presented) is known to provide additional mechanical support to the soil which would help in water retention capacity and drainage for efficient soil aeration (Samac et al., 2003).

In this study, it has so been shown that better availability of humus (as measured in terms of organic carbon) in the MFS soils resulted in an increase in pH of the soil to slightly acidic to neutrality by increasing the nitrogen fixing activity of NFB and *Bacillus* spp. with an increase in number. As reported by Dick et al. (2000), the cycling of organic matter is slower in acidic soils, which reduces the availability of the major elements: nitrogen, phosphrous and sulfur. As most of soil *Bacillus* spp. are endospore producing bacteria, they are tolerant to low pH, heat, desiccation and ultra–violet radiation so are able to survive for longer period of time in the acidic soils of Lesotho.

The percentage of sand fraction was found to be lower in almost 80% of the MFS farming practicing soils (Figure 7), implying their high content of clay (Figure 5) and organic carbon (Figure 8), unlike the non-Machobane Farming Systems practicing soils. It has been reported that soil organic carbon content varies with changes in climate, soil and crop management; being higher in places with larger average annual precipitation, lower mean annual temperature, and higher clay content (Nichols, 1984; Burke and Cole, 1995). The MFS, which involves increased soil and crop management practice, has conserved high level of organic matter, as determined by levels of organic carbon, showing relative resilience to climate change.

Phosphorus is an essential nutrient for plant growth and crop yield, however a large portion is immobilized because of intrinsic characteristics of soils such as pH that affects the availability of nutrients and the activity of enzymes, altering the equilibrium of the soil solid phase (Dick et al., 2000). Soil microorganisms play a key role on phosphate solubilization with the release of low molecular weight organic acids (Sundara and Hari, 2002) and production of extracellular enzymes as phosphatases. Phosphatases are a group of enzymes that catalyze hydrolysis of esters and anhydrides of phosphoric acid. Its activity depends on extracellular enzymes, which can be free in the soil water phase or stabilized in the humic fraction or clay soil content (Sundara and Hari, 2002; Turner and Haygarth, 2005). Higher levels of phosphorus determined in farms practicing the MFS can be attributed to a balance of conditions such as soil microorganisms, pH and humic matter that help increase crop productivity.

Under extended study of the farming practices with 400 questionnaires, in the four agro-ecological zones (100 for each), more than 66% of the household respondents of which, 51% male and 49% female were found practicing the MFS (Table 1). However, greater proportion of female respondents (56%) was found not to practice the MFS at all. In terms of yield, the focus group noticed resemblance between the MFS and conservation farming practices. However, the application of MFS to large scale farming system require more work and lots of input such as animal dung, ash and a special planter, which implied the need for technology support for scaling up the MFS. The majority of farmers consider the MFS to be a good farming practice because of variety of crops that it accommodates, nutrient availability and maintenance of soil moisture with sustainable crop harvesting cycles throughout the year (Robertson, 1994).

In general, participants from all areas visited have noticed climate is changing. Their new experience in early frost, an eminent shift in planting season, which has now excluded certain crops like peas and beans in the mountain areas, decreasing of yield because of poorly developing buds, pest infestation, drought, flooding and hail storms justify their arguments. On the other hand, in the mountain and the foothill villages, farmers who practice the MFS noticed that it is less affected by climate change due to its sustenance of soil fertility via steady release of nutrients and conservation of moisture content to the crop made its resilience to climate change noticeable.

Conclusion

The MFS has been shown to be the best indigenous farming practice due to its ability to maintain diversity of *Bacillus* spp., the non-symbiotic NFB, nutrient availability, soil moisture with sustainable crop harvesting cycles throughout the year. Its resilience to climate change is evident from the quantitative microbial and physicochemical data as well as noticed by practicing farmers. Hence, it could be regarded as a good farming practice for family food security. Distribution and diversity of *Bacillus* spp., the non-symbiotic NFB and physicochemical parameters including soil texture, pH, organic carbon, and available phosphorus can be used as soil quality parameters indicative of the resilience of the MFS for climate change.

Conflict of Interest

There is no conflict of interest regarding the publication of this paper.

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