Effects of Integrated Soil Fertility Management Practices on Soil Micronutrients and Maize (*Zea Mays* L.) Yields in Semi-Arid, Kenya

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Abstract

Declining per capita crop yield in Sub-Saharan Africa is linked to widespread depletion of soil micronutrients due to non-conventional cropping systems that disregard optimal replenishment on smallholder farming systems. Use of Integrated Soil Fertility Management (ISFM) quickly and cheaply improves the levels of micronutrients needed for health crop production. However, assessments on micronutrients retention and effect on crop yields of soils in Arid and Semi-Arid Areas (ASALs) after ISFM adoption remains unknown at community level. The study was conducted in the Mwania watershed in Machakos County, Kenya between 2016 and 2018 to determine the effect of selected ISFM practices on soil micronutrients and maize yields at watershed level. About eighty-one farmers were randomly sampled; Nine ISFM farmers were superimposed on each of selected nine ISFM practices that were distributed uniformly across the watershed. Data was collected on soil micronutrients and maize yields. The aforementioned variables of interest were analysed using a one-way analysis of variance (ANOVA) in GENSTAT software version 15.1 computer program. Treatment means were separated using Duncan's Multiple Range test (DMRT) tests owing to the large number of treatments. The results showed maize yields increased after ISFM use compared to control regardless of cropping system. Combining 2 t/ha animal manure with 40 kg/ha of di-ammonium phosphate (DAP) fertilizer and tied ridging on either maize/pigeon pea or maize sole crop recorded highest 1.32 t compared to 1.38 t/ha of maize grain yields respectively compared to 0.88 t/ha (control) in short rains. During long rains, maize/pigeon pea intercrop alone was the highest at 1.577 t compared to 0.83 t/ha of maize grain yield from maize sole crop neither with fertilizer, animal manure nor tied ridging (control). It also significantly (≤ 0.05) increased soil iron (Fe) levels from 15.99 ppm (control) to 24.74 ppm. This was attributed to 0.14 % increases in soil pH (water) compared to control after speedy mineralization and dissipation of soil organic matter, which enhanced Fe solubilisation. Subsequently promoting rapid maize crop growth, avoiding adverse weather conditions ahead. Therefore, farmers in semi-arid areas could achieve desired maize yields with only 50% less than recommended fertilizer rates with ISFM practices that may reverse declining soil micronutrients and improve crop yields quickly and cheaply.

Keywords: ISFM, Soil fertility, Soil micronutrients, Maize and semiarid areas

INTRODUCTION

Soil nutrient depletion remains a biophysical cause of declining crop yields per area in semiarid areas of Sub Saharan-Africa (Sanchez, 2019). Notably, common major limiting nutrients like nitrogen (N) and phosphorous (P) are well understood and eliminated through routine use of commercially formulated fertilizer. Soil micronutrients such as Manganese (Mn), Copper (Cu), Iron (Fe) and Zinc (Zn) have shown to improve efficiency of applied N and P by crops on non-responsive soil (Njoroge *et al.* 2018). Highly leached, organic, highly alkaline, over-cropped and intensively cultivated soils associated with smallholder farming system, especially across Kenyan semi-arid tend not to respond optimally to NPK's applied due to unreliable soil moisture but mainly deficient (Mwende *et al.* 2019). Plant yield depends on the amount of most scarce nutrient, therefore to maintain plant growth all essential nutrients are necessary, including micronutrients, which are known for their important role in chlorophyll biosynthesis, participates in many enzymatic reactions and functions as electron carrier in photosynthesis and respiration reactions. The world population is expanding and so is the demand for quality food in view of curbing hunger and malnutrition, therefore sustainable production of quality food that preserves the environment and natural resource base are vital.

Maize is a staple food and source of income to many households in semiarid areas of sub-Saharan Africa, however, decline in per capita maize yields is widespread among smallholders' farms. For instance, widening gap of 175 % between maize yields averaged from smallholder farms and obtained from surrounding on station and commercial farms in Kenya has been reported in the past decade, contrary to the global trend (Payne, 2010; Kwena *et al.* 2017; Mwende *et al.* 2019). Studies have attributed the root cause of declining per capita maize yields to climate variability but mainly widespread soil-micronutrient depletions (Oldman *et al.*, 2017; Karaya, *et al*., 2012; Gachene, 2015; Sanchez, 2019). Soil with depleted nutrients is a poverty trap to many households in semi-arid regions because of widespread food insecurity and malnutrition resulting to a recurrent need for emergency food supply and increased dependency on food imports (Ngome *et al*., 2013; Karaya *et al*., 2012; Mucheru-Muna, *et al*., 2014; Itabari*et al*., 2011). On average, Kenya imports over 1.5 million bags of maize annually to meet its domestic demand (FAO, 2014). For instance, Nitrogen (N) and phosphorus (P) seriously limit crop yields (NAAIAP, 2014; Mwende *et al.* 2019), across the country and the situation is worse in semi-arid areas. For example, in Machakos County, soil levels for major nutrient such as N $< 0.1\%$ is lower than recommended 0.2 %, although P of 11 Cmol/kg and slightly acidic soil pH 5.2 (water) falls within recommended ranges for maize production, although extremely low soil organic matter (0.6 -1.25%) compromises resilience of semiarid soils to external shocks (Kisaka *et al*., 2016; Karuma *et al*., 2015; Itabari *et al*., 2013). Subsequently exposes over 12 million Kenyans who reside in this region to rampant malnutrition and abject poverty (KNBS 2018).

Mwende *et al.* (2019), recommended a basket of practices to be effective in reversing soil nutrient depletion and increasing crop yields in semiarid areas, however, widespread professional use by farmers is lacking. The reason cited is that majority of recommendations are too general and not only disregards the inherent soil variability, do not consider also diverse household adaptive power and the need for farm specific recommendations (Mugwe *et al.*2008; Kwena *et al.* 2017), such as once from integrated soil fertility management (ISFM) strategy. The ISFM system entails an integrated management of social, economic, political, physical and chemical soil properties. The approach not only takes into consideration inherent soil variability within the farming system, but also recognises household social and economic status as well as political aspects of land management. ISFM strategy advocates for the use of organic and inorganic nutrient sources at rates corresponding with the farmer’s socio-economic circumstances (Vanlauwe *et al.*, 2015). Besides, organic residues that improve soil holding capacities, maximizes utilization of external inorganic nutrients applied by improved germ-plasm (Mwende *et al.* 2019). Incorporating legumes also pulverises the soil, retrieving leached soil micronutrients on top soil surface for utilization by shallow rooted crops (Kwena *et al.* 2017). That way, ISFM remains a suitable option for poor farmers with limited choices towards improving soil fertility and crop yields (Vanlauwe *et al.*, 2015). However, ISFM use on household level remains a challenge due to intensive labor requirements and high initial cost (Mutuku *et al.* 2017). Many researchers have opted for landscape recommendations of ISFM practices, which gives choices to individual households to adopt practices that suit their household disposable income and desired yield goal. Although large area recommendations increased ISFM usages by smallholder farmers in Machakos and beyond (Kwena *et al.* 2018), concrete evidence on their effect on soil micronutrients and maize yields remains scarce. Consequently, affecting utilizations of this unique soil fertility improvement strategy at a very large scale to fight poverty and rampant food insecurity in Kenyan semiarid areas. Thus, the study to, (i) determine the effects of ISFM practices on soil micro nutrients (ii) Assess the effects of ISFM practices on maize yield at watershed level was conducted between 2016 and 2018.

MATERIALS AND METHODS

Study site description

Mwania watershed is located between 37^0 25’ to 37^0 29’ E and 1^0 55’ S to 1^0 58’ S, in Machakos County, Eastern Kenya as presented in Figure 1.

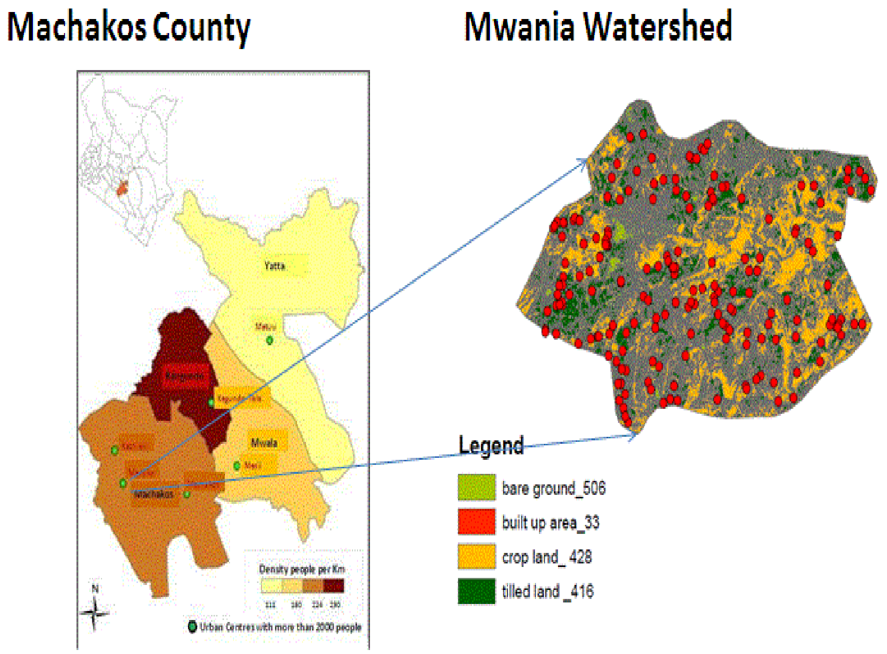

Figure 1: Location of Mwania watershed in Machakos County, with households earmarked in red dots (from survey 2016-unpublished)

Mwania watershed was picked as the study area because of receiving a basket of ISFM interventions suitable for semi-arid conditions in the past, its conspicuous agro-ecological and biophysical characteristics with undulating topography with slope variations of 2-20 %. Climate of Mwania watershed is cooler semi-arid climate, with highly erratic and unreliable bi-modal rainfall, with cropping patterns matching rainfall seasons, hence a representative of typical semi-arid. Planting is strictly done during rainfall onset and in case of any delay, a farmer could incur yield losses proportional with time delayed (Kwena *et al.* 2017). According to Jaetzold *et al.*, (2006), farmers perceive short rains (October-November) as more reliable than long rains (March-May). Mean annual temperature 20^{o} C, with lowest being $17\ ^{o}$ C and highest as $240\ ^{o}$ C annually, with February and September being hottest months. High evaporation rates (ETo), surpassing the amount of rainfall (r) apart from November. In a year mean evaporation rates range between 1820-1840 mm against evapotranspiration 1239 mm (Gicheru, 1996), hence yielding r/ETo of 0.57. The soils in study site are dominated by *Luvisols* (WRB, 2006; FAO/UNESCO., 1997), originating from granitic parent material, they are shallow, dusky, dark reddish brown to dark red and dark brown and dominated with quartz of sandy (WRB, 2006; FAO/UNESCO., 1997; Gicheru and Ita, 1987), with low soil organic matter < 2.41%, low in total N<0.15 %. However, soils in Mwania watershed are slightly acidic < pH 5.52, adequate levels of P > (30 ppm), K > (0.59 cmol/kg), Mg > (1.47 cmol/kg ppm) and Ca > 6.25 (cmol/kg) to nourish maize and pigeonpea without external replenishment (Kwena *et al.* 2017).

Field trials

Field trials were conducted for four seasons from the short rains of 2016 to the long rains of 2018. A total of 81 farms were selected for the study from across the entire watershed, based on the farmers' willingness to participate in the study (Figure 3). Majority of the farms were less than two hectares in size and most of them had been cultivating their fields continuously for over 10 years. Maize and pigeonpea were the main staple crops grown by farmers in Mwania watershed, either as sole crops or intercrop. Most of the farmers selected for this study either used inorganic fertilizers alone or combined inorganic fertilizers with manure to replenish soil nutrients. Majority of them also had constructed water harvesting structures such as tied ridges on their farms. A total of nine treatments were tested in this study and are summarized below in Table 1.

The ISFM practices were distributed uniformly across the watershed with coverage of 38.45 ha of cultivable land Figure 2, with varying farm sizes and treatments described in the Table 1. For every group, the researcher superimposed a single ISFM practice on 9 households spread randomly across the watershed. The farmers, however, asserted that recommended planting fertilizer triple super phosphate (TSP) was not available in the local markets; hence, they chose Di-ammonium phosphate (DAP), which is common in local markets as a source of both N and P. All farmers selected maize as the test crop because it is a staple food, responds well to external nutrients besides being a cash crop, and most farmers gave it priority when applying soil-improving inputs. A composite sample of cattle manure used in this study was analysed and chemical properties averaged and presented in Table 2.

Table 1: Summary of nine ISFM practices tested on 81 farms in Mwania watershed

Treatment[1]	Description
T_1	Maize sole crop + 0 kg ha^{-1} NP + 0 t ha^{-1} manure + No Tied ridging
T_2	Maize sole crop + 7.2 kg ha^{-1} N + 18.4 kg ha^{-1} P + No Tied ridging
T_3	Maize sole crop + 7.2 kg ha^{-1} N + 18.4 kg ha^{-1} P + Tied ridging
T_4	Maize sole crop + 7.2 kg ha^{-1} N + 18.4 kg ha^{-1} P + 2 t ha^{-1}Manure + No Tied ridging
T_5	Maize sole crop+ 7.2 kg ha^{-1} N + 18.4 kg ha^{-1} P + 2 t ha^{-1}Manure+ Tied ridging
T_6	Maize/ pigeon pea intercrop + 7.2 kg ha^{-1} N + 18.4 kg ha^{-1} P + NoTied ridging
T_7	Maize/ pigeon pea intercrop+ 7.2 kg ha^{-1} N + 18.4 kg ha^{-1} P + Tied ridging
T_8	Maize/ pigeon pea intercrop + 7.2 kg ha^{-1} N + 18.4 kg ha^{-1} P + 2 tha^{-1}Manure + No Tied ridging
T_9	Maize/ pigeon pea intercrop + tied ridges + 7.2 kg ha^{-1} N + 18.4 kgha^{-1} P + 2 t ha^{-1}Manure + Tied ridging

N= total nitrogen, P=P_2O_5

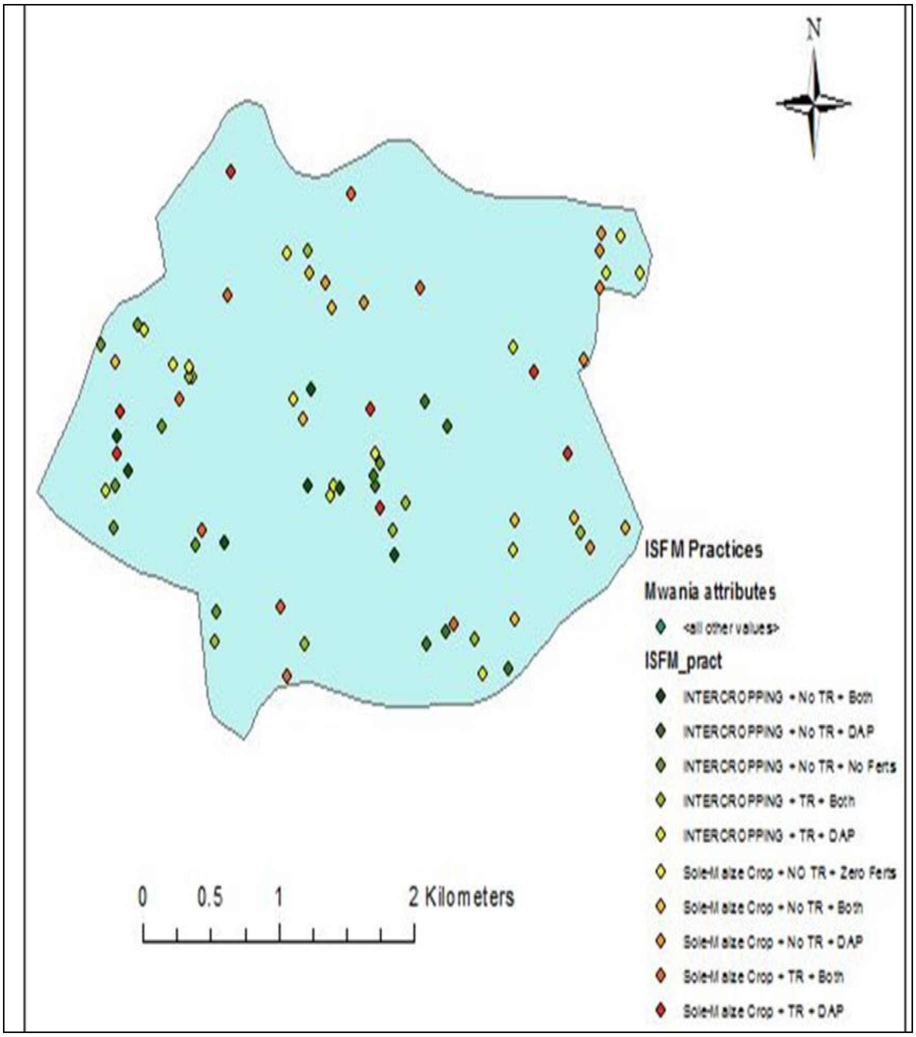

Figure 3: well distributed farms with respective ISFM practices across the Mwania watershed (survey 2016-unpublished)

Table 2: Chemical properties of manure used in the study

Parameters	Units	Level
pH		8.83
Ec (salts)	mS/cm	13.90
Dry matter	%	92.90
Carbon	%	19.20
Total Nitrogen	%	1.48
Phosphorus	%	1.60
Potassium	%	2.69
Calcium	%	4.99
Magnesium	%	0.73
Sulphur	%	0.37
Sodium	ppm	2300
Manganese	ppm	775
Iron	ppm	8380
Zinc	ppm	441
Copper	ppm	106
Boron	ppm	75.20
C:N		13

[1]*Average chemical properties of animal manure used during the study*

The early maturing improved maize local variety from KALRO-Katumani was the most popular maize grown at the study site, therefore the improved local variety was selected and planted using recommended spacing of 75 × 30 cm, with expected grain yields of about 2 tons ha^{-1} under researcher- managed trials (Kwena, 2018). The selected 9 farmers per ISFM practice across the study sites voluntarily tested the agreed practice and were ready to follow researcher instructions to achieve intended objectives. The farmers agreed that each farm hosting the trial will facilitate the researcher and other interested stakeholders to regularly visit the trial site and conveniently guide the farmers on appropriate standards of agronomic practices. Majority of farmers prepared their fields using ox-plough before onset of rainfall and followed by sowing during the first week of rainfall onset. For instance, during short rains (OND), sowing happened from mid to end of October, similarly during long rains (MAM) season sowing occurred mid-march up to the end with local variety purchased from KALRO-Katumani research station. At knee high, weeding was done to control weeds, while pest and disease control were well monitored, and for any incidence, it was recorded and considered during yield calculation.

Harvesting field trials

Fields were harvested when the entire maize stalks were completely dry at the end of every cropping season to avoid interference from farmers. The transect line and 25m^2 quadrant was used for maize yield sampling. The transect string was laid across the maize field and anchored on both ends. Areas avoided were end rows of the maize and areas affected by erosion or insect infestations. Sampling was done by walking along the line and looking straight down at the end and starting point for each transect string. The line was divided into stakes at an interval of between 50 m in a hectare. Maize crops inside the quadrant were harvested and necessary field measurement taken and a subsample of about 8 -10 stovers with cobs were reweight, harvested, chopped, and taken to the laboratory for further investigation. Cobs and stovers were air dried to constant weight, cobs shelled and weight measurements were taken on both stover and grains.to a constant weight and measurement taken. Yield measurements were computed at every end of cropping season and crop field measurements were used to compute total yield using formulas by (Bell, 1994).

Soil Sampling

At the end of 2018 long rains, soil samples were collected in a transect across each farm using 600cm^3 soil auger at a depth of 20cm. About 18 soil augers per ha were mixed thoroughly inside the bucket before being quartered to obtain a representative sample. A composite sample of 0.5Kg was scooped and taken to the laboratory, air dried till dusty, grounded using a mortar and a pestle, passed through 2mm sieve and analysed for pH and soil micronutrients.

Soil analysis

Analysis of micronutrients was carried out on soil samples collected at the end of the experiment in 2018. Copper, Zinc, Iron and Manganese were determined using a chelating ethylenediaminetetraacetic acid (EDTA) procedure described by (Marschner, 2011).

Data analysis

Soil and maize data were subjected to one way analysis of variance (ANOVA) using GENSTAT software version 15.1 (Payne *et al*, 2013). Means were separated using Duncan's Multiple Range test (DMRT), owing to many treatments involved.

RESULTS AND DISCUSSIONS

Effect of ISFM practices on soil micro-nutrients

Results of soil pH (water) and micro-nutrient levels after four cropping seasons are presented below in Table 3. Generally, ISFM had significant ($p \leq 0.05$) effect on Manganese (Mn), copper (Cu), and iron (Fe) irrespective of the cropping system. Farmers on maize-pigeon pea intercrop without tied ridging reported significantly highest soil levels of Mn (1.21 Cmolkg^{-1}), Cu (4.68ppm), Fe (87.67ppm) and Zn (7.47ppm) compared to control Mn (0.5939 Cmol kg^{-1}), Cu (1.163ppm), Fe (15.99ppm), Zn (5.507ppm).

Table 3: Mean comparison of soil trace elements after four seasons of the study

ISFM Practices	Soil pH and micronutrients levels[1]				
	Soil pH (H_2O)	Mn Cmol/kg	Cu (ppm)	Fe (ppm)	Zn (ppm)
Maize + NoTR + O kg /ha NP + 0 kg /ha AM	6.296b	0.5939 b	1.163 b	15.99 e	5.507a
Maize + NoTR + 7.2 kg ha^{-1} N + 18.4 Kg ha^{-1} P	6.486ab	0.8052 b	1.807 b	48.62 bcd	7.212a
Maize + TR + 7.2 kg ha^{-1}N + 18.4Kg ha^{-1} P	6.524ab	0.6929 b	1.185 b	51.84 bc	5.4a
Maize + NoTR + 7.2 kgha^{-1}N + 18.4Kgha^{-1}P +AM	6.618ab	0.7993 b	2.167 b	54.74 b	6.508a
Maize + TR + 7.2 kg ha^{-1}N+18.4kg ha^{-1}P + AM	7.017a	0.7294 b	0.685 b	24.97 de	7.031a
Maize/PP + No TR + 7.2 kg ha^{-1}N + 18.4 kg ha^{-1}P	6.712ab	0.5917 b	0.779 b	25.52 de	9.004a
Maize/PP + TR + 7.2 kg ha^{-1}N + 18.4 kg ha^{-1}P	6.392ab	0.6156 b	0.927 b	34.63 bcde	8.507a
Maize/ PP +NoTR +7.2 kg ha^{-1} N +18.4 kg ha^{-1}P+AM	7.049a	1.2082 a	4.681 a	87.67 a	7.472a
Maize/PP + TR +7.2 kg/ha^{-1}N+18.4 kgha^{-1}P+AM	6.305b	0.7327 b	0.847 b	24.74 cde	6.676a
Coefficient of variations (CV %)	9.4	39.30	91.30	62.30	59.50
$p \leq 0.05$	0.085^{ns}	0.001*	<0.001*	<0.001*	0.648^{ns}

[1]Avarage soil chemical properties (soil micronutrients), TR – tied ridging, NP – inorganic nitrogen and phosphorous, AM- animal manure. Data averaged from 9 farms per treatment, *Significant, ^{ns}not significant at $p \leq 0.05$, column means having common letters are not significantly different using DMRT test.

This was attributed to increases in soil pH (water) against 6.296 (control). According to Behera and Shukla, (2013), in India, soil micronutrients are pH dependent, thus at high pH (water) >6.8 crops may show deficiency symptoms of both nutrients since they precipitate out of soil solution and become unavailable for crop uptake. Results of this study agree with findings of Adeniyan and Ojeniyi, (2005) reported increases in soil nutrients in Nigeria after combining poultry manure and NPK 15-15-15, which the study attributed to rapid mineralization of soil organic matter from manure. Similarly, Kwena *et al.* (2017), reported increases in soil nutrients on top soil in Kenyan semi-arid after ploughing back 4 t/ha of pigeonpea residue for 8 continuous cropping seasons. The study attributed increases of soil nutrients to rapid mineralization of crop residues, beside pigeonpea ability in pulverizing and retrieving leached nutrients (Abunyewa and Karbo, 2005). Equally, Kapkiyai *et al.* (1999) and Verde *et al.* (2013) reported solubilization of soil micronutrients when optimal soil pH ($CaCl_2$) between 5.5-6.0 is achieved on soils of Kenyan highlands that subsequent solubilized soil nutrients such as trace elements which are pH dependent. Likewise, Ngetich *et al.* (2014) reported increases in clay and organic matter on tied ridges which translates to improved soil holding capacity of both soil micronutrients and scarce soil moisture (Mwende *et al.* 2019). From above discussion, ISFM with a basket of manure showed liming effect, inorganic fertilizer provided much needed N and tied ridging obstructed clay and less of sand soil around roots of growing crops. The study also reported increased Fe^{2+} in the soil which can be attributed to clay adsorption of retrieved Fe by tap rooted pigeonpea, overcoming Fe deficiencies which may obstruct important enzymatic reactions and biosynthesis of chlorophyll leading to general poor health of maize crop (Terry and Abadía, 1986).

Maize yields responses to ISFM options

Results of maize grain and stover yields obtained from various ISFM interventions after four cropping seasons are presented below in Table 4.

Table 4: Maize yield comparison on selected ISFM practices after four consecutive seasons

ISFM practices	Yields (t /ha)[1]			
	Short Rains (SR)		Long Rains (LR)	
	Grain	Stover	Grain	Stover
Maize + NoTR + 0kgha^{-1} NP + 0kgha^{-1}(2)- control	0.879	1.596	0.83	1.493
Maize + NoTR + 7.2 kgha^{-1}N + 18.4 Kgha^{-1} P (5)	1.21	1.967	1.296	1.93
Maize + TR + 7.2 kgha^{-1}N + 18.4 Kgha^{-1} P (9)	1.375	2.219	1.381	2.372
Maize + NoTR + 7.2 kgha^{-1}N + 18.4 Kgha^{-1}P +AM (4)	1.022	1.652	1.353	2.136
Maize + TR + 7.2 kg ha^{-1}N+18.4 kg ha^{-1}P + AM (3)	0.991	2.023	1.176	1.93
Maize/PP + No TR + 7.2 kg ha^{-1}N + 18.4 kg ha^{-1}P (1)	0.847	1.263	1.147	1.679
Maize/PP + TR + 7.2 kg ha^{-1}N + 18.4 kg ha^{-1}P (7)	1.283	1.906	1.473	2.259
Maize/ PP +NoTR +7.2 kg ha^{-1} N +18.4 kg ha^{-1}P+AM (6)	1.233	1.917	1.362	2.369
Maize/PP + TR +7.2 kg/ha^{-1}N+18.4 kgha^{-1}P+AM (8)	1.323	2.067	1.577	2.477
Grand mean	1.13	1.85	1.29	2.07
Coefficient of variations (CV %)	54.30	51.10	58.30	51.50
$p \leq 0.05$	0.495^{ns}	0.552^{ns}	0.643^{ns}	0.523^{ns}
Total Rainfall (mm)	317	317	882	882

[1]Averages of maize yields, TR – tied ridging, NP – inorganic nitrogen and phosphorous, AM-

Generally, ISFM practices had no significant < 0.05 effect on maize yield. Farmers who planted maize sole crop on tied ridging with combination of animal manure and inorganic fertilizer reported higher maize grains and stover 1.38t and 1.596 t/ha, followed by 1.32t and 2.067 t/ha from farmers who intercropped maize pigeonpea on tied ridging combined manure and inorganic fertilizer on tied ridging compared to 0.879 t/ha (control) in short rains. Similarly, during long rains, farmers who planted maize as sole crop with combination of manure and fertilizer obtained maize grain and stover 1.382 t and 2.372 t/ha, while farmers who intercropped maize and pigeon pea with combined manure and fertilizer on tied ridging recorded 1.577 t/ha of maize grain and 2.477 t/ha of maize stover yield compared to 0.83 t/ha of maize grain and 1.493 t/ha of stover yield reported on control. Insignificant increases compared to control in maize yield at the end of the study on farms that combined manure and inorganic fertilizer on tied ridging was attributed to adequate rains received both in short and long rains during the study period and low amounts of manure and fertilizer applied.

The study findings match those of Bationo *et al.* (1997), who reported an increase in maize yield from 0.885 t ha^{-1} in low input cropping system to 2.8 t ha^{-1} after ISFM adoption in Mali. Similarly, Agegnehu *et al.* (2014) in Ethiopian highland, reported increases by 151 % after applying 60 kg ha^{-1} N and 20 kg ha^{-1} P integrated with 50 % N source of equivalent manure on wheat. A similar trend was observed by Mwende *et al.* (2019) in semi-arid eastern Kenya, where the study reported 650 % maize yield increases after combining 5 t ha^{-1} manure and 20 kg ha^{-1} inorganic N fertilizer on tied ridging. Equally, the study findings agree with Wanderi *et al.* (2011) who reported 15 and 30 % maize grain and stover yield increases respectively, in Thika near Nairobi, under maize-pigeon pea long term experiment and other authors; Mapfumo and Mtambanengwe, (2004), Rao and Mathuva, (2000), Abunyewa and Karbo, (2005) and Kwena, (2018), attributed increases in maize yields to improved soil fertility. It is apparent from the study that maize yield semi-arid not only flourish with abundance of soil moisture but also micronutrients.

CONCLUSION AND RECOMMENDATIONS

It is apparent from this study that ISFM on a landscape level can reverse declining soil fertility and increase maize yield at only a half of current recommended rates. Therefore, maize- pigeon pea intercrop crop plus tied ridging with 2 t ha^{-1} of manure mixed with 40 kg ha^{-1} of DAP offers the better option since it gave the highest maize yield long-term. However, we recommend economic analysis of tested practices before being used for future validations and experimental planning, besides linking study results with poverty data using GIS technology which becomes appealing to policy makers instead of usual tables and charts for upscaling purposes.

ACKNOWLEDGEMENT

The authors would like to express their deepest gratitude to the Director General of the Kenya Agricultural and Livestock Research Organization through the World Bank-supported Improving Agricultural Water Productivity project for extending a grant to carry out this research work. Thanks to the Department of Agricultural Resource Management of Kenyatta University for technical support. We also thank the following KALRO staff: Reuben Ruto, Mr. Elias Thuranira and Stephen Muindi in Geographical Information Systems (GIS), biometrics and soil sampling respectively. We also thank farmers from Mwania watershed in Machakos County for participating in this research.

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