Journal Brief

INTEGRATED SOIL FERTILITY MANAGEMENT PROSPECTS FOR SOIL PRODUCTIVITY AND FOOD SECURITY IN MACHAKOS COUNTY

S. W. Wamalwa[1#], B. Danga[1] and K. Kwena[2]

[1] Kenyatta University, Department of agricultural Resources and Management, P. O. Box 43844-00100, Nairobi, [2]Kenya Agricultural and Livestock Research Organization, P.O. Box 340 – 90100, Machakos

ABSTRACT

Integrated soil fertility management is the most cost-effective and time-efficient method of restoring soil fertility and increasing per capita yields on Sub-Saharan African smallholder farms. However, low acceptance has resulted from a lack of knowledge about the prospects of these strategies prior to promoting them. In 2016, the Mwania watershed in Machakos, eastern Kenya, was surveyed to fill this void. About 174 household heads were chosen using the "farmer-led adoption approach and a pretested structured questionnaire to obtain primary data on their household gender, education level, food security, cultivated land size, soil fertility practices, and constraints to determine the potential use of integrated soil fertility management practises at the watershed level. Data were analysed using the Statistical Package for Social Sciences Version 22 computer program for descriptive attributes. Relationships between dependent and independent variables were determined using the tobit regression model. According to the findings, 85% of households are headed by men, with over 82% being post-primary graduates, who are the main decision makers. The majority (83%) cultivate 2 ha and 57% acknowledged food insecurity, with 89.1%, 73.1%, and 45.1% blaming it on climate variability, limited soil moisture, and a lack of input access, respectively. Low fertility scored 40% at medium level with labour at 40% in low cluster constraints, could be because of high unemployment rates. Animal manure and chemical fertiliser use were reported at 95.5% and 76.6%, respectively, although they were using them separately, probably due to high cost, increased labour requirements, and accessibility problems resulting in continuous low yields. Therefore, huge prospects of integrated soil fertility management practices' use exist in the Kenyan semi-arid, especially when promoted at community level.

Keywords: Adoption,potential, integrated soil fertility management requirements, tobit model, community level.

INTRODUCTION

Globally, agricultural growth in 21st century is constrained with new and complex challenges emerging from global warming and climate variability (Unganai and Murwira, 2010; Kwena *et al*., 2018). The situation is worse in semi-arid areas such as lower eastern Kenya, where annual rainfall is between 500 and 800 mm, with a coefficient of variation of 45% (Jaetzold *et al*., 2006), and the agricultural growing season lasts between 60 and 120 days. Temperatures range from 20 to 35°C, while daily pan evaporation rates range from 4 to 9 mm. These areas have annual moisture deficits of more than 50% and are the most vulnerable to land degradation (Itabari *et al*., 2011; Karuma *et al*., 2014; Kathuli and Itabari, 2015; Jaetzold *et al*., 2006). Cereals and legume yields seldom exceeds one tonne and 0.5 t/ha, respectively against more than 1.9 t and 0.5 t/ha obtained from surrounding Kenya Agricultural and Livestock Research Organization (KALRO) stations (Kwena *et al*., 2017). According to Kenya National Bureau of Statistics (KNBS) (2019), Kenya's population residing in the country's eastern dry regions was 8%. It is crucial to note that the population of these regions is steadily increasing, with the majority migrating from overpopulated highlands to arid regions, thereby aggravating widespread poverty, a recurrent need for emergency food supply and an increasing dependence on food imports. Kenya imports on average 7.5 million bags of maize yearly (Faostat., 2021), to meet domestic demand, and expected climate change would exacerbate the problem (Unganai and Murwira, 2010). This ever-increasing demand for food, despite limited land resources, necessitates the development of new, more

[#]Corresponding author: wanjala2002@gmail.com

environmentally friendly food production methods, and one such approach is Integrated Soil Fertility Management (ISFM)

ISFM is a systematic, conscious, participatory, and broad knowledge intensive holistic approach to soil fertility research. To maximise production potential, the approach advocates for careful management of soil fertility aspects. It entails the development of nutrient management technologies to ensure an adequate supply of organic and inorganic inputs (Vanlauwe and Zingore, 2011; Mugwe *et al*., 2019). These technologies are widely used elsewhere to quickly and cheaply reverse declining soil fertility and obtain desired crop yield (Saginga and Woomer, 2009). But their professional use hasn't been well transferred to Kenyan semi-arid fields, and some of these technologies are too expensive and time-consuming for poor small-scale farmers to fully implement and reap the optimum benefits ISFM envisaged (Mugwe *et al*., 2009; Saginga and Woomer, 2009; Mutuku *et al*, 2017). These factors not only influence ISFM adoption, but also largely contributing to distorted agronomic knowledge at scale (Mugwe *et al.*, 2009; Mutuku *et al.*, 2017). Farmers, for example, are quick to adopt new crop varieties while consistently ignoring recommendations for improved soil and water management practises, resulting in marginal yield increases from improved germplasm rather than the full benefits envisaged in the ISFM framework. The majority of farmers, for example, do not use right inorganic fertiliser type, rates and timing (Ariga, *et al.*, 2008; Itabari *et al.*, 2013; Kwena *et al*., 2017). Therefore, ISFM concept necessitates a minimum level of education from participating farmers in order to grasp principles drawn from a variety of disciplines, particularly fertiliser use, which remains an entry point (Vanlauwe and Zingore, 2011; Mutuku *et al.*, 2017). However, the use of animal manure alone is limited in terms of collection, processing and application, necessitating huge family labor force which sometimes is not readily available (Itabari *et al*., 2013; Mutuku *et al*, 2017).

Instead of the silver bullet collections that have been used in the past, ISFM is a compass that shows land managers the best sustainable system of restoring soil fertility for improved rural livelihoods (Sanginga and Woomer, 2009). It becomes reasonable before scaling up a basket of ISFM recommendations that education level, labour demand, and cultivated land size must be well articulated (Mugwe *et al*., 2019; Mutuku *et al*., 2017). As a result, the study sought to ascertain the likelihood of employing the ISFM strategy to reverse declining soil fertility and boost crop yields. This study is significant for both farmers and researchers because it intents to identifies workable ISFM options and research that can be scaled up quickly and cheaply rather than traditional blanket ISFM recommendations, which most farmers avoid.

MATERIALS AND METHODS

Description of the Study area

The Mwania watershed covers 899.9 ha and is located at 10 33º to 10 34º E and 370 5º to 370 29º S in semiarid Machakos County, Kenya, . The study was superimposed on the ongoing project, "Integrated Management of Water for Productivity and Livelihood Security in Eastern and Central Africa under Variable and Changing Climatic Conditions." It operated in lower eastern Kenya's Machakos county in LM_4 (lower mid-land marginal cotton zone) and LM_5 (lower mid-land livestock millet zone).

The watershed is located in agro-ecological zone (AEZ) IV, defined as semiarid areas with limited potential for rain-fed agriculture (Jaetzold *et al.* 2006). The watershed receives 711 mm of annual rainfall, averaging between 250 and 400 mm per season, with a significant inter-seasonal coefficient variation (%) of 48 to 50 (Jaetzold *et al.* 2006). Farmers in the study area believe that short rains are more reliable for crop production than long rains, possibly due to their more even distribution (Okwach and Simiyu, 1999). Given that the majority of rivers in the study area are seasonal, they cannot provide adequate water when it is most needed. Groundwater resources are also scarce, and the water produced in many areas is saline (Jaetzold *et al*., 2006). The seasonal high and low temperatures are 25°C and 13.1°C, respectively, with July and September being the coldest and hottest months. Evapotranspiration rates are generally high, reaching 8.2 mm/day in February and September (Jaetzold *et al*., 2006), with February and September being the hottest months of the year (Jaetzold *et al*., 2006). As a result, the study site accurately represents the prevailing semiarid climatic conditions in Machakos County.

The Mwania watershed has prominent biophysical characteristics such as undulating topography with high slope variations ranging from 2-20% (Jaetzold *et al.*, 2006), resulting in frequent water runoff with little rain. The vast majority (98.8%) protect their land from loss of top fertile soil by erecting terraces and trash lines of legume and cereal stovers along the slope contour to prevent runoff and sheet erosion in the following cropping season (Kwena *et al*., 2017).

The Mwania watershed's soils are primarily Acrisol and Cambisol (World reference base for soil resources (WRB), 2006). The dominant soils are derived from granite parent material and are predominantly dusky, dark reddish-brown to dark red and dark brown in colour (WRB, 2006). Nitrogen (N) is still the most scarce essential nutrient in soil productivity in the study site (Kwena *et al*., 2017). Average soil pH (5.2) was slightly acidic but falls within established soil pH of 5.0-8.0 for growing both legumes such as pigeon pea and cereals such as maize and sorghum (Itabari *et al*., 2011; Okalebo *et al.,* 2002; Kwena *et al*., 2017). Average soil organic matter (SOM) is also low across farming landscapes, ranging from 0.6 to 1.25%. Similarly, nitrogen (N) levels are low, with less than 0.1% estimated (Okalebo *et al.,* 2002; Kwena *et al*., 2017). However, the average soil phosphorus (P) level across smallholder farms is 0.084 Cmol/kg, which is sufficient to feed a healthy maize crop without external replenishment (Okalebo *et al*., 2002). In general, the study area's soils' holding ability is low (CEC 24 cmol/ kg), with low levels of bases, namely calcium 4.0%, magnesium (Mg) 6.1%, and potassium (K) 0.8% (Kwena *et al*., 2017), with frequent shallow hardpans (Jaetzold *et al.* 2006).

The study design

Household heads were chosen using the "Primary and Secondary Participatory Agricultural Technology Evaluations (PPATEs/SPATEs)" extension methodology, also known as the "farmer-led adoption approach" (Mutuku *et al*., 2017).

The farmer-led adoption model anticipates the use of technology and techniques that promote the development of resilient farming systems, as well as how such adoptions can be scaled up in similar agro-ecological zones. Technology is a complex idea with the intention of solving a specific problem in farm fields that is always imposed on farmers without regard for farmers' perception, whereas technique refers to the art of doing or implementing the complex idea (Parvan, 2011). As a result, the model makes use of both vertical and horizontal scaling up. Household heads influence the decision, selection, and eventual use of farming technologies at the farm level (Njarui *et al*., 2012). As a result, understanding the demography of household heads is essential during evaluation studies. A household is a group of people who live, cook, and eat together, and a household head is the person who bears household risks, makes economic decisions, and assigns duties to other household members (Atuhaire *et al*., 2014).

Sample size calculation

Magnani's formula was used to calculate the number of household heads for the survey ((Magnani, 1999).

$$n= \frac{t^2 \times p(1-p)}{m^2}$$

Where;

n= sample size required

t= confidence level at 95 % (1.96) standard value

p= estimated ISFM practices in the study area =13.1% (Ogada *et al.*, 2014)

m= margin of error of 5 % (0.05 standard value).

Thus the sample size n= $1.96^2 \times 0.13(1-0.13)/0.05^2$ = 173.79 household heads.

Based on the above formula, the sample size was calculated to be 173.79 corrected to nearest whole number of 174.

Choosing the household head sample size for the ISFM technologies survey

Household demographic characteristics help to understand farming household heads because they influence farming decisions, agricultural technology selection, and adoption (Njarui *et al*. 2012; Atuhaire *et a*l. 2014). A household head is the person in the household who makes the overall social and economic decisions, assigns responsibilities, allocates resources, and bears all of the household's challenges and threats; additionally, a household is defined as a group of people who live, cook, and eat together (Atuhaire *et al*. 2014).

Household head sampling

The multi-stage sampling approach was used to collect the relevant information from 174 household heads (HHDs) out off 409 in the Mwania watershed. This was accomplished through stratified, substitution, and random sampling (Geta *et al*., 2013). The first step was to delineate the watershed using Google Maps and the ArcGIS version 10.5 computer programme, followed by ground truthing using the Global Positioning System (GPS) to locate households across the watershed. The next step was to find active farmer groups that met regularly and grew crops in the Mwania watershed that had been drawn. Based on the list of household heads obtained from each group, random sampling was performed, and any missing or unwilling respondent in the group was replaced with the next name. The GPS, a tool for precisepositioning, was used to geo-reference selected homes.

The data collection exercise used qualitative and quantitative techniques. Questionnaires were administered to selected households in mid-March and ended after 3 weeks. Data on socio-demography, biophysical, and economic attributes were captured. The questionnaire was pre-tested by administering it at various locations outside of the Mwania watershed prior to the actual survey to assess its effectiveness in terms of time, cost, and ability to meet the study's objectives. Before the study began, the necessary changes in vocabulary, units, wording, and order were made. Secondary data used to describe the study area came from KALRO Katumani, Kenya Meteorological Department, and Machakos County extension offices. The yield data collected was dated back four seasons, but most farmers remembered the short rains (SR) of October to December 2014 and 2015. During the study, dependent and independent variables were considered. ISFM adoption was the dependent variable, while the independent variables were land tenure systems, education, labour, gender, age, crop yield, benefits of ISFM, access to input, awareness and farm size. In this case, the degree of ISFM adoption was a continuous dependent variable as summarised in Table I. The different levels of ISFM technologies practised by smallholder farmers in the watershed are referred to as the degree of adoption.

Data Analysis

Descriptive statistics, paired sample t-test, multinomial logistic regression were obtained using IBM SPSS analytical software version 22.

RESULTS AND DISCUSSION

The results on social characteristics, household constraints, biophysical and the associations are shown in figures and tables below.

It was hypothesised that social demographic characteristics such as gender and education, of the household head influenced the potential use of ISFM practises.

Household heads' sociodemographics

Household heads are persons in charge of household economy and major decision makers. Watershed had over 85 % male headed households, hence gender of respondents had an ($P \leq 0.024$) influence on ISFM practise adoption. According to Mutuku *et al.* (2017), men, who are not preoccupied with household chores nor little time to socialise, share farm hours with housekeeping, are readily available to attend informational meetings and with more financial muscles compared to most women

TABLE I - SUMMARY OF INDEPENDENDENT AND DEPENDENT VARIABLES ANALYZED USING TOBIT REGRESSION MODEL

Variable code	Variable	Operational definition of the variables
Inswh	Insitu-water harvesting strucrures	a dummy variable with1 shows evidence of Insitu water harvesting structures and 0 indicates otherwise
Landtenre	Land tenure	a dummy variable with1 shows evidence of Insitu water harvesting structures and 0 indicates otherwise
Inorgfertuse	Use of inorganic fertilizer	a dummy variable with1 shows evidence of Insitu water harvesting structures and 0 indicates otherwise
Orgfert use	Use of manure	a dummy variable with1 shows evidence of Insitu water harvesting structures and 0 indicates otherwise
Labor	Labor	a dummy variable with1 shows evidence of Insitu water harvesting structures and 0 indicates otherwise
Landcult.	Land cultivated	Categorical value
EduclvlHHH	Education level of household head	Ordinal value
GenderHHH	Gender of household head	Nominal variable

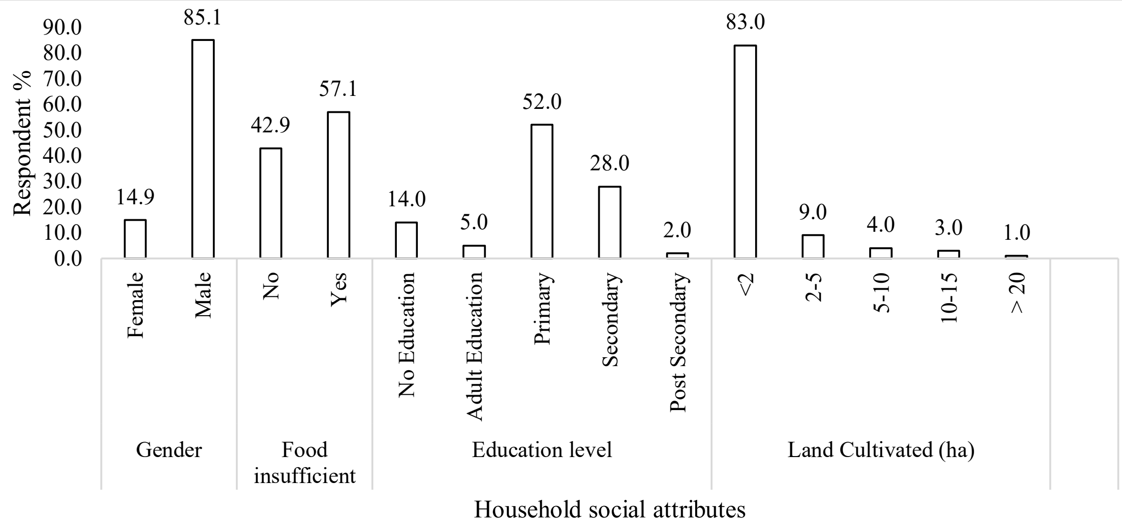

Figure 1: A summary of household social attributes of mwania watershed

(Sanginga and Woomer, 2009; Vanlauwe and Zingore, 2011). Equally, 57% of respondents agree that they are food insecure at household level.

The study also revealed that the majority (52%) of household heads in Mwania watershed had a primary level of education (Figure 1), followed by secondary level of education at 28%. There was a positive and significant regression relationship (P=0.026) between education level and prospects of using ISFM practises, with more than 80 % of household heads being post-primary graduates offering huge potential of adopting ISFM practices (Figure 1). The results of the logistic regression model indicated (Table II) that education had a significant impact on the potential adoption of ISFM practises. This could be due to the ease of grasping the ISFM concepts, considering it involves a multidisciplinary approach (Sanginga and Woomer, 2009). The findings of the study agree with the results of studies elsewhere, which noted that education provides farmers with better access to information besides grasping new farming concepts faster (Vanlauwe and Zingore, 2011; Vanlauwe *et al*., 2015; Mutuku *et al*., B, 2017; Mugwe *et al*., 2019).

Soil fertility improving practices namely chemical fertilizers, animal manure and tied ridging were used by 79%, 81% and 75% of farmers, respectively (Figure 3). This was most likely due to rigorous campaign program by an ongoing world bank project on "Integrated Management of Water for Productivity and Livelihood Security in Eastern and Central Africa under Variable and Changing Climatic Conditions" that raised awareness significantly ($P \leq 0.002$) (Table II), with a coefficient of 0.7866. The vast majority (83%) grew crops on less than two hectares, and cereal and legume yields rarely exceeded one tonne per hectare. Climate variability, lack of input access, low soil fertility, and low water availability were mentioned as likely causes of declining crop yields in the study area by the 89%, 44%, 39%, and 73% of the respondents, respectively. The lack of household labour recorded 52.6% (Figure 2). It could be because youth have relocated to town in search of work (Mutuku *et al.*, 2017). This show a huge potential of ISFM use as it has ability to mitigate climate change effect, control pest and diseases and suitable for farmers who own land since it takes time for ISFM to manifest fully (Sanginga and Woomer, 2009).

However, 95.5%, 76.6% and 75.4% of respondents use animal manure, chemical fertiliser and tied ridging, respectively (Figure 3).

The seemingly low use of chemical fertiliser and tied ridging could be due to the high cost, lack of access, and the perception that chemical fertiliser inhibits plant growth at early establishment, particularly during periods of low soil moisture (Okwach and Simiyu,

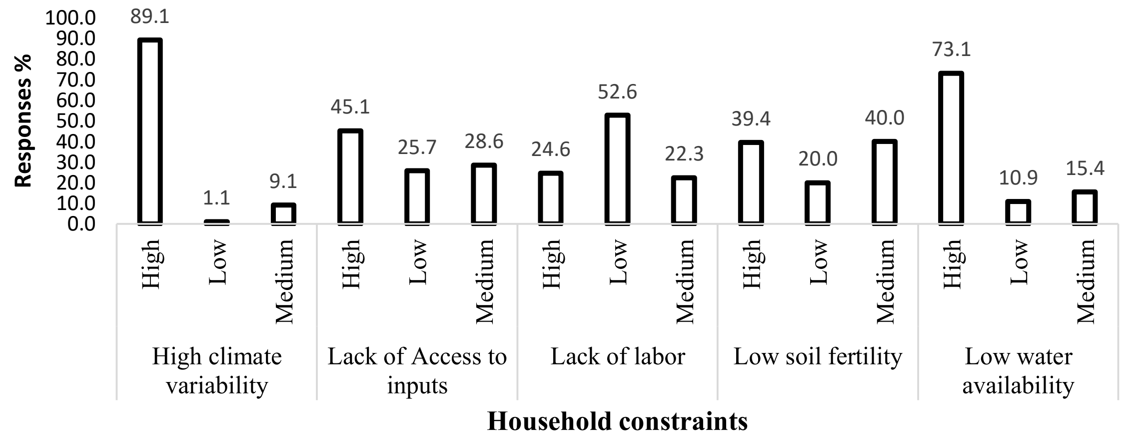

Figure 2: Responses on likely causes of declining crop yields in the study area

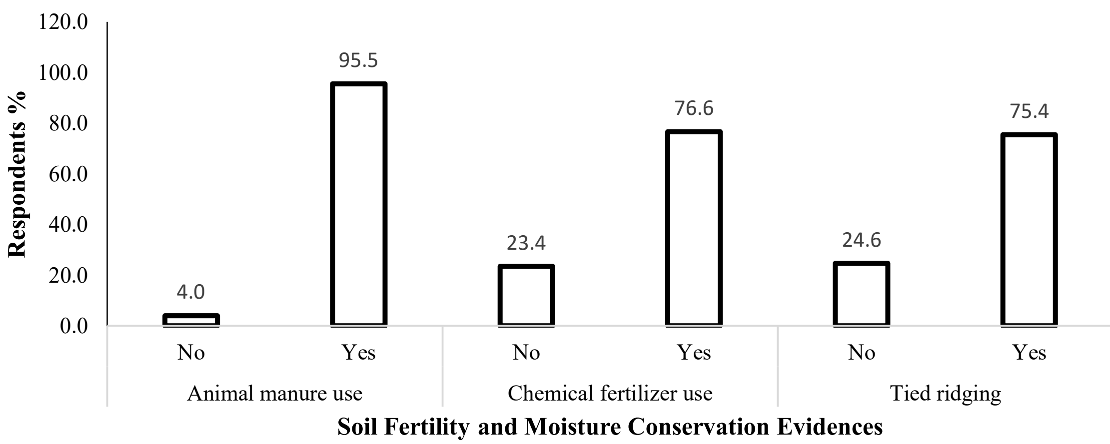

Figure 3: Common soil and water management practices used in the watershed

1999; Itabari *et al*., 2013) and mixed outcomes under tied ridging based on rainfall perfomance (Kathuli and Itabari, 2015). Combining animal manure, particularly compost and chemical fertilisers, was reported to be used, though composting was a new practise and farmers were unwilling to take the risk of practising it separately, which is why it was not included in Figure 3.

TABLE II- COEFFICIENTS OF STUDY VARIABLES AND ADOPTION OF ISFM PRACTICES USING LOGISTIC REGRESSION MODEL

Variable	Co-efficient	P value
Education	0.3535	0.026
Gender	0.1948	0.024
Labour intensive	-0.0392	0.032
Awareness	0.7866	0.002

The findings in Table II are consistent with several other studies that found that the key prospects of ISFM use are labour availability because the strategy is labour intensive, suitability for small-holder farms with limited mechanisation options, required education level because the approach is multidisciplinary, and that continuous low yields remain the best culprit for ISFM use on low resource-endowed farmers (Mugwe *et al.,* 2019; Mutuku *et al*., 2017; Atuhaire *et al*., 2014; Geta *et al.,* 2013; Mugwe *et al.,* 2009; Sanginga and Woomer, 2009).

CONCLUSION/ RECOMMENDATIONS

According to the survey findings, the potential for ISFM in semi-arid areas is enormous because the majority of farmers acknowledge climate change as among the main causes of declining soil fertility and, consequently, crop yields productivity. The integrated soil fertility practises can quickly and cheaply mitigate the ravaging effects of climate change, restore soil fertility, and sustainably improve crop yields. However, household differences in adoption of soil fertility improvement practices, especially separate use of animal manure and chemical fertilizer, attributed to household economic and social diversity, may be a significant barrier to ISFM use. To get the most out of social capital, the study suggests that ISFM strategies be aimed at the community and not at household level.

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