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Improving Soil Fertility and Farm Productivity under Intensive Crop-Dairy Smallholdings: Experiences from Farmer Field Schools in the Highlands of Kiambu District, Central Kenya

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Abstract: A study to improve soil fertility and farm productivity under intensive crop-dairy smallholder farming systems was carried out in Kiambu District, central Kenya highlands in the period 2003-2005 using farmer field school approach. The objectives of the study were to diagnose farming system constraints and assess the contribution of livestock to soil nutrient balances, design and test potential interventions for improving soil fertility and fodder availability and to distil methodological learning experiences in using Farmer Field School (FFS) approach. Literature reviews, baseline studies, soil sampling and analysis and nutrient monitoring tool were used to diagnose production constraints. Based on farmer-extension-researchers' identified constraints, an FFS curriculum was formulated and implemented for farmer learning and capacity building and the following experiment jointly designed to address declining soil fertility and fodder-livestock productivity: T_1: Conventional Tillage (CT) + *Bana* Napier variety (B) + Farmyard manure (FYM, 10 t ha^{-1}) + Triple super phosphate (TSP, 50 kg ha^{-1}); T_2: *Tumbukiza* tillage (TT) + B + 64.7 t ha^{-1} FYM + 50 kg ha^{-1} TSP; T_3: CT + *KaKamega* 1 Napier variety (KK1) + 10t ha^{-1} FYM + 50 kg ha^{-1} TSP and T_4: TT + KK1 + 64.7 t ha^{-1} FYM + 50 kg ha^{-1} TSP. Treatment, T_1 was farmers' practice while T_2-T_4 were new practices. The treatments were replicated twice using a pair-wise design and data collected, bi-weekly over three agricultural seasons, using Agroecosystem Analysis (AESA) framework. Results showed that imported livestock feeds (concentrates, fodder and crop residues) were the major determinant of soil nutrient balances in the study site. The tested new practice, T_4 was agro-economically superior with positive partial soil P balance, high Napier dry matter yields and high gross margins and return to labour implying that it can be used to improve soil fertility and to bridge fodder gaps under intensive smallholder crop-dairy systems studied.

Key words: Soil fertility % farmer field schools % crop-dairy farming systems % Kenya

INTRODUCTION

Soil fertility management and food production in many parts of sub-humid and cool highland areas takes place in mixed crop-livestock farming systems. In these areas, as in the larger parts of sub-Saharan Africa [SSA], farming systems are intensifying with crops and livestock becoming increasingly integrated as human population increases and land becomes a more important constraint [1]. Studies carried out in highland areas have shown that soil fertility is on the decline as evidenced by documentations on farmers technical knowledge [soils, incidence of weeds etc.], soil analytical indicators and soil nutrient balance studies despite the prescription of a diversity of technical solutions and investment of time and resources by various institutions[2]. Declining soil fertility is closely linked to productivity and has been identified as one of the root causes of declining per capita food production [3].

Smallholder crop-dairy systems can potentially play a key role in soil fertility management and in maintaining ecological balance. Livestock plays crucial role in

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recycling of waste products and residues from cropping or agro-industries while manure from livestock is also used for crop production [4]. Manure use and improved feeding have often been suggested as methods of improving soil fertility in crop-livestock systems [5].

Improved livestock feeding through adequate and high quality fodder is expected to translate into increased manure production, manure quality as well as milk production [6]. Fodder is also important in contributing to soil fertility management when feed remains are incorporated into the soil and when planted along the contour to control soil erosion [7]. However, the main constraints associated with fodder under smallholder dairy systems include inadequate supply [leading to low dry matter intake in animals] and improper agronomic practices resulting in low yields [8].

Addressing the above constraints requires combining researchers, farmers and extension workers knowledge in a process of participatory technology development and learning to improve productivity, a situation met under FFS approach. Farmer field schools banks on farmers' experiences, intelligence and empowers them to be better learners based on informed analysis of their agro-ecology.

This study explores options for improving soil fertility and farm productivity under smallholder crop-dairy farming systems in the highland areas of Kiambu District, Kenya using FFS approach. The objectives of the study were:

- To diagnose farming system [soil-crop-livestock] constraints;
- To assess the contribution of livestock to nutrient cycles, flows and balances;
- To design and test interventions and technologies for improving soil fertility and crop-dairy system productivity;
- To distil methodological learning experiences in using farmer field school [FFS] approach.

MATERIALS AND METHODS

General approach: Farmer Field School [FFS] approach, which is a participatory research and extension methodology, was adopted in the study. Farmer Field School is a group of farmers who meet regularly to study about the how and why of a given technology. It is based on the premise that participating farmers can test various technological options available, during which they are able to decide the best alternatives for their particular circumstances according to their agro-ecological settings, farm size, available capital and access to markets [9]. Key attributes of FFS include [a] its recognition that farmers are adult learners whose training is enhanced by using non-formal adult education methods; [b] that the training covers the entire crop or livestock production cycle to enable farmers fully understand all components of the technology; [c] its focus on group training of about 25 to 30 people to bring individual experience and strengths into the FFS and to provide individuals with group support in trying new things; [d] enabling participants to focus more on basic processes [basic sciences] through field observations, analysis, discussions and presentations and [e] testing and validation of technologies using Participatory Technology Development [PTD] approach [10]. These characteristics of FFS and how they differ from conventional group approaches are further elaborated in Table 1.

The study site: The study was carried out in the highland areas of Kiambu District, Kenya [Latitude 0°75' and 1°20' South of the equator and Longitudes 36°54' and 36°85' East]. Kiambu has a total area of 1324 km^2 with a population density of 562 persons per square kilometre [11]. The altitude range for the study site is 1200-2550 metres above sea level while annual mean temperature ranges from 13.5 to 21.9°C. The annual rainfall in the district ranges from 600 to 2000 mm with an average of 1200 mm in the highland areas. The rainfall is bi-modal and falls in two seasons: March to May [long rains] and October-December [short rains]. The high altitude areas also receive drizzles in July-August, which allows for growing of horticultural crops.

Due to high population pressure, farm sizes in Kiambu District are small averaging 0.8 hectares [per household] among smallholder farmers who account for 99% of farm holdings and practice farming in 88% of the cultivated land. In the face of decreasing land sizes, dairy production has become an important enterprise in the district. The common dairy cattle breeds kept are Friesian, Ayrshire, Guernsey, Jersey and their crosses, which are stocked at a rate of 4-6 Tropical Livestock Units [TLUs] per hectare. The dairy animals are confined in stalls and fed by cut-and-carry system, also referred to as zero-grazing. Napier grass [*Pennisetum purpureum*] is the most important fodder in the production system. Although the dairy cattle kept are capable of producing more than 10 litres of milk per day, the actual values reported from farms are low due to inadequate year round supply of forage [especially Napier, which is the main livestock feed], poor

Table 1: General comparison of FFS and other group approaches

FFS approach	Conventional group approach
Farmer driven; use of participatory tools	Top-down; uses few participatory tools and more top-down approaches.
Recognises farmers' ideas (farmers' expertise) and indigenous technical knowledge (ITK) as well as modern scientific knowledge.	Farmers ITK not well integrated in research-extension approach.
FFS members in collaboration with facilitators (extension workers and researchers) design areas of learning and experimentation based on diagnosed farmers needs (Covers production, post production as well as socio-economic and life priority needs)	Promotion of technical packages and adoption of individual technologies/innovations
Farmers learn through self discovery in field based comparative studies/experiments (participatory technology development) designed in participatory processes in collaboration with facilitators to address identified farmers needs.	Learning mainly through promotional lectures, demonstrations etc.
Group learning and experimentation (participatory technology development) follows the (production) cycle of the theme of study; with emphasis on principles and learning by doing thereby empowering farmers to implement management decisions in their own fields; regular meetings are held to enhance learning.	Learning centred on packages and may not necessarily follow a production cycle of the theme of study.
Group dynamics, team building exercises, communication skills and building of local institutional structures for group/community demand driven actions emphasised; allows the emergence of local institutional structures that foster science-farmer expertise linkages and enhanced local dynamics.	Group dynamic issues addressed, but with weak emphasis on the building of sustainable local institutions; Institutional structures are based on science-to-practice continuum that allow for uninterrupted flow of technology from science to farmers.
Learning materials are learner generated; field based learning through participatory agroecological analysis; emphasis on managing the farm as an agro-ecosystem to enhance its self-regulation.	Learning materials mainly from the "teacher"; learning may not necessarily take place in the field and there is emphasis on technologies for controlling target variables
Decisions arrived through facilitation, consensus building and a non-hierarchical decision making processes among the learners and trainers/facilitators/researchers.	Decisions mainly through instructions from the "teacher"/extension worker
Experimentation and learning principles based on non-formal/ non-directive (adult) education principles to foster learning.	Learning based on transfer of knowledge/technology transfer principles through lectures, demonstrations etc.
Fosters the emergence of farmer local organisations/ that empowers farmers and creates a favourable environment for farmers-networking, mobilisation of local financial resources, group marketing and accessibility to production inputs.	Characterised, in some cases, by public/governmental institutional structures that support public/governmental finance for research and development, extension services and subsidy on input use without adequate strategies for sustainability of local institutions.

Source: Adapted from FAO and IIRR [12]; Röling [13]

quality of forages and challenges of animal genetics and diseases [14]. Other livestock kept in the district include poultry, pigs, sheep, goats, rabbits and bees.

An important feature of the system is that milk is a major cash earner and livestock manure is used to fertilize food and cash crops which include maize, Irish potatoes, vegetables, coffee bananas and fodder crops. The land is intensively cultivated and is cropped 1.4-1.7 times per year [15].

Farmer field school processes, approaches, methodologies and tools adopted:

Formation of farmer field schools and building of local institutional structures: The study was carried out in two farmer field schools [Kibichoi FFS and Ngaita FFS] in Kiambu District. The FFS were formed following community meetings held separately in two study sites [Kibichoi and Ngaita villages]. Volunteer farmers representing the community in each of the study sites formed the FFS with a learning focus on integrated nutrient management. Through facilitation and discussions, learning norms were jointly formulated with the FFS participants and a learning contract drawn, separately for each FFS. Using similar consensus building procedures, FFS meeting sites, frequency of meetings and study fields were decided upon. The FFS participants were trained in leadership and team building and later formulated their own by-laws [constitutions] and registered with relevant government bodies as recognised entities.

Diagnosis of production constraints and opportunities: Soil fertility and general farming system constraints were diagnosed in a four step procedure involving literature review, baseline survey, soil sampling and nutrient monitoring survey. Literature review was conducted by the FFS facilitators [researchers and extension workers] to get a perspective of soil fertility management constraints and general agricultural production in the study site. Baseline survey conducted through one-time recall semi-structured interviews identified farm production resources, ownership of productive assets, farming practices, broader livelihood strategies, current farming system opportunities, farmer's indicators of soil fertility and current constraints in soil fertility management. All the members of FFS were interviewed during the baseline survey.

Soil sampling and analysis, in each participating farm and FFS central learning plot, was carried out for texture, pH, organic carbon, total nitrogen, exractable and total phosphorus and exchangeable potassium. For FFS central learning plots analysis was also carried out for the following: Ca, Mg, Cu, Fe, Zn and Na. Soil textural analysis was done using a hydrometer method [16]. Soil pH was determined at a soil: water suspension ratio of 1: 2.5 [v/v soil-water suspension] using a conventional glass electrode meter. Organic carbon was determined by concentrated sulphuric acid-potassium dichromate oxidation followed by colorimetric methods [17]. Total N and P were determined by wet digestion using hydrogen peroxide, selenium-lithium sulphate and concentrated sulphuric acid followed by colorimetric methods [18]. Extractable P was determined using Mehlich I method with dilute sulphuric acid and hydrochloric acid as extractants [19]. Exchangeable cation [K^+] was extracted with ammonium acetate [1M NH_4OAc] and amounts determined using flame photometry [16, 20].

Nutrient monitoring [NUTMON] model, as described by Vlaming *et al*. [21], was used to diagnose the status of nutrient flows and balances as well as farm economic performance in the studied crop-livestock system. The model comprises a set of questionnaires [inventory and monitoring questionnaires] that captures the dynamics of farm management and computer software that analyses nutrient flows, nutrient balances and farm socio-economics. The inventory and monitoring questionnaires were administered through a one-time recall household interview at the beginning of the agricultural season and at the end of the season respectively and data collected processed by NUTMON software and further analysed using Special Programme for Social Scientists [SPSS] from SPSS Inc.

Farm characteristics of the FFS members' are presented in Table 2. The cultivated land areas are less than 1 hectare while livestock stocking rate is 5-6 TLUs/hectare. Soils in the study sites are well drained, deep to extremely deep, dusky red to dark reddish brown, friable clay in places with humic acid topsoil (Humic Nitisols) [22].

Participatory planning, farmer field school curriculum building and farmer feedback sessions: The results of farming system diagnosis were summarized into a list of constraints and opportunities and discussed with FFS members. Soil sampling (pH, total N, extractable P, exchangeable K, organic C) and nutrient monitoring results were presented as bar charts and analysed with farmers in a group process where each farmer was given his/her own results (Fig. 1). The constraints emerging from soil analyses were correlated to general soil management and farming system constraints in the study site and to the findings of the baseline survey and literature review. From discussions arising from diagnostic activities, a list of constraints was compiled and further stratified in a group process with farmers into potential thematic constraints and opportunities that could be experimented with in FFS setting, themes for demonstrations and learning themes [subject/topics] to be included in the FFS curriculum.

Further to the list of constraints from diagnostic activities, additional knowledge gap analysis was carried out with FFS participants. This involved plenary discussions and brainstorming sessions on farm management practices and socio-economic issues that FFS participants would like to learn about during the FFS process. The emerging issues from additional knowledge gap analysis were also delineated and added onto the above mentioned list of topics to be experimented with, themes for demonstrations and learning themes [subject/topics]. The result was a list of *experimental topics/themes* and integrated curriculum topics [technical, social and economic issues] or special topics for discussions and demonstrations during the running of the FFS activities.

Decision support and FFS tools and techniques adopted: The key decision support tools used in the FFS activities include participatory technology development [PTD]/experimentation, Agro-ecosystem analysis [AESA] and special topics. Other FFS techniques adopted were

Table 2: Farm characteristics of FFS members (mean values; standard deviation in parenthesis)

Characteristic	Kibichoi FFS (n = 30)	Ngaita FFS (n = 16)
Land		
Land cultivated (ha)	0.8 (0.5)	0.5 (0.4)
Average slope (%)	13.9 (7.2)	14.7 (8.5)
Labour		
Household size (persons)	6.3 (2.4)	5.8 (2.0)
Consumer units (aeu)[1]	4.2 (2.0)	4.2 (1.6)
Labour units (aeu)	3.4 (1.4)	2.3 (1.4)
Market		
Distance to the market (km)	6.1 (1.0)	5.3 (0.4)
Market orientation (% of produce sold)	52.0	46.0
Education		
Non educated (%)	3.3	6.3
Primary education (%)	43.3	0.0
Post primary vocational (%)	10.0	31.3
Secondary education (%)	36.7	50.0
Post secondary vocational (%)	6.7	12.5
Capital		
TLU[2]	4.0 (5.1)	2.9 (3.9)
Value of livestock (US$)[3]	1004.1 (1317.0)	274.1 (266.1)
Value of land (US$)	7978.4 (4592.2)	3322.3 (2591.4)
Value of equipment (US $)	83.5 (68.2)	50.8 (31.5)
Economic wellbeing[4]		
Net farm income (US $/farm/half year)	154.3 (500.6)	10.0 (394.9)
Off-farm income (US$/farm/half year)	241.4 (352.8)	107.7 (228.3)
Family earnings (US$/farm/half year)	395.8 (569.3)	117.7 (456.6)
Households below poverty line (%)[5]	80.0	67.0
Ratios		
Land: Labour (ha aeu^{-1})	0.3 (0.3)	0.6 (1.1)
Land: Consumer (ha aeu^{-1})	0.2 (0.2)	0.1 (0.1)
Consumer: Labour (aeu aeu^{-1})	1.3 (0.3)	4.1 (7.0)

[1]aeu: Adult equivalent units, [2]TLU: Tropical Livestock Units (Taken as 250 kg live weight of an animal), [3]1 US$: 75 Kenya Shillings, [4]Economic performance analysed using NUTMON model, [5]Poverty line: 1 US $ per person per day

host teams, group dynamics/team building and field days/study tours. These are briefly described below:

Participatory technology development [PTD]/ experimentation: Participatory Technology Development [PTD] is a purposeful and systematic way of using participatory methods and approaches to create a learning and experimentation process in which relevant technologies that fits farmers' socio-economic circumstances and address farmers observed constraints are generated or tested through comparative experiments with the aim of improving farm productivity and incomes as well as protecting production resources.

Farmers' experimental design workshops were held in the two study sites separately with FFS members to design experiments for improving soil fertility and crop-livestock productivity based on priority constraints identified during the diagnostic stage of the study. During the workshop, topical issues proposed for experimentation by FFS members were enlisted and discussed alongside those proposed by facilitators [researchers and extension workers], Fig. 2. From this list, priority topical issues/themes/problems for experimentation were selected in plenary using the following farmer-facilitator/researcher jointly formulated criteria: Issues/themes of interest to all farmers that address priority problem cited by majority of the FFS members; topical issues/themes that address a crop-livestock management problem; topical issues/themes with a potential to generate observable impact within one calendar year; topical issues/themes that allow easy data collection and making of observations; themes that fit

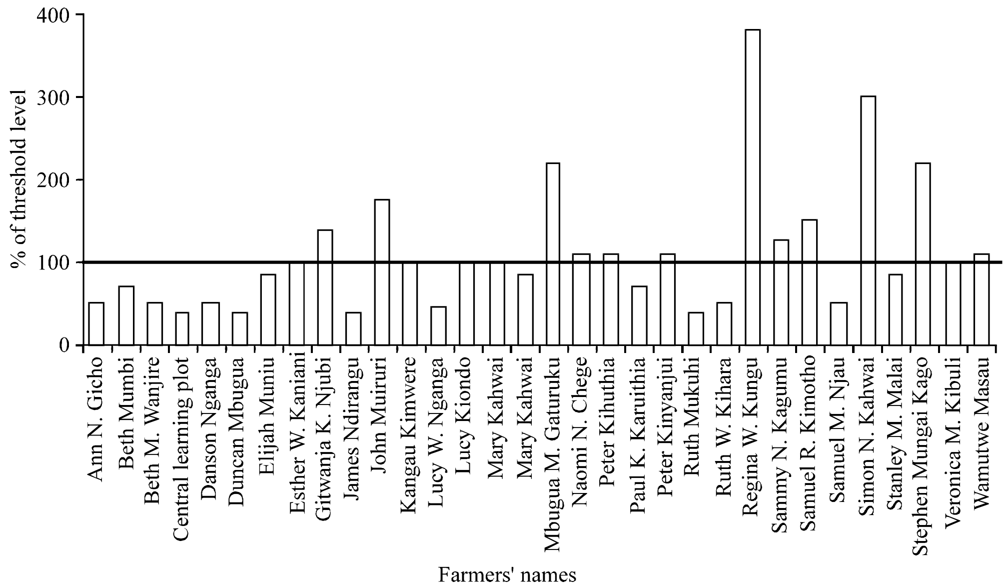

Fig. 1: Extractable phosphorus results in Kibichoi FFS Values expressed as a percentage of the soil critical value identified as agronomically adequate [23]

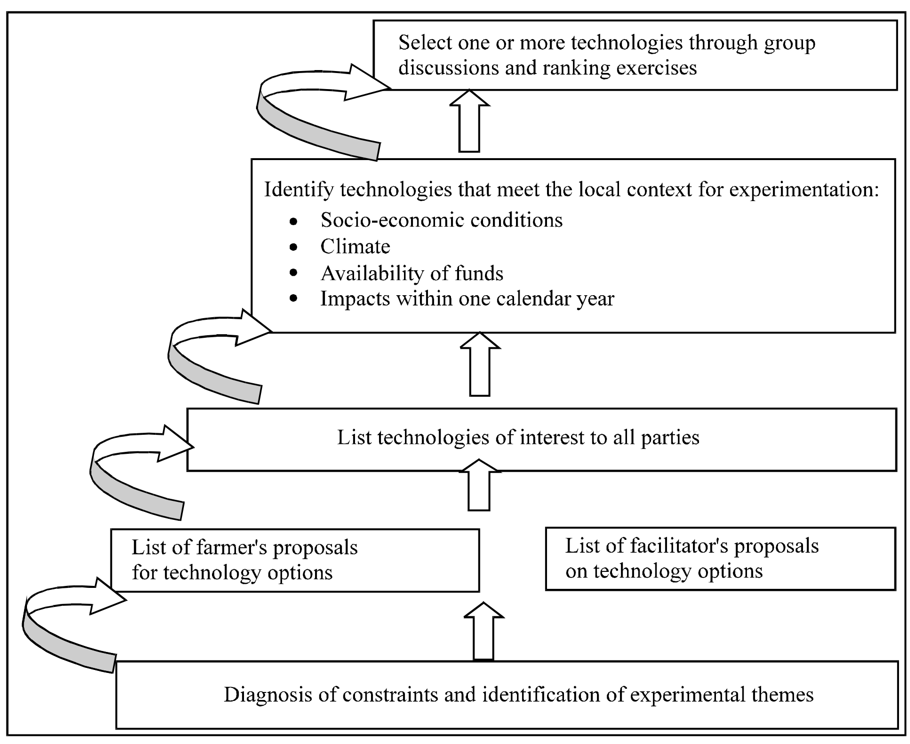

Fig. 2: Process adopted for choosing technologies for experimentation

within seasonal management practices [climatic factors]; and experimental themes that require low input costs to implement.

The technologies/experimental themes that met the above criteria were then prioritized through group discussions and ranking with FFS participants resulting in the choice of one priority technology for experimentation in FFS central learning plot and other technologies for implementation in individual FFS member's fields. Treatments, indicators for monitoring the

Box 1: Summary of main roles played by farmers in the PTD experiments

- Identification and prioritisation of topics/themes for experimentation where one theme was jointly chosen by farmers and facilitators through consensus building based on identified criteria.
- Participatory experimental design: setting up trial objectives, choice of test crop, treatments, plot sizes, plot lay-outs etc.
- Proposed indicators for monitoring and evaluating the experiments.
- Provided land (central learning plot) for setting up the trials; participated in the lay out of the trials.
- Provided non cash inputs required for implementing and managing the experiments (manure, labour etc.).
- Collected data and monitored the trials every FFS meeting day using Agro-ecosystem analysis framework; discussed the progress of trials and performance of different treatments every FFS meeting day.
- Evaluated performance of treatments using matrix scoring and ranking and qualitative assessments at the end of the trial period.
- Introduced the surrounding community members to the experiments and explained the performance of various treatments.
- After harvest, the farmers took the new Napier variety for planting in their own farms.
- Farmers gained from the insight emerging from laboratory analysis of manure and Napier crude protein contents and their implications.

Table 3: Treatments on improving soil-fodder-livestock productivity, Kibichoi FFS

Treatment	Description
T_1	Conventional tillage+*Bana* Napier variety+FYM (10 t ha^{-1})+Triple super phosphate, TSP (50 kg ha^{-1}) [1,2]
T_2	*Tumbukiza* tillage+*Bana* Napier variety+FYM (64.7 t ha^{-1})+TSP (50 kg ha^{-1})
T_3	Conventional tillage+*Kakamega 1* Napier variety+FYM (10 t ha^{-1})+TSP (50 kg ha^{-1})
T_4	*Tumbukiza* tillage+*Kakamega 1* Napier variety+FYM (64.7 t ha^{-1})+TSP (50 kg ha^{-1})

[1]Triple super phosphate (TSP) formulation: 46-0-0, [2]FYM = Farmyard manure

experiments and frequency of data collection were jointly formulated and discussed in each study site with FFS participants. The roles played by FFS participants in the experimental process is summarised in Box 1. In this paper one case study of a joint designed experiment implemented in FFS central learning plot to improve soil fertility and crop-livestock productivity in Kibichoi FFS is presented.

The objective of the trial was to determine the potentials of *Tumbukiza* tillage and fertilisation practices in improving Napier grass [*Pennisetum purpureum*] yields [dairy fodder] and in improving soil fertility. *Tumbukiza* is a Kiswahili word for “placing in a hole”. Two Napier varieties [*Bana* and *Kakamega 1*] were tested in two tillage systems [*Tumbukiza* and conventional tillage] using a pair-wise design over a period of three agricultural seasons, Table 3. Growing *Bana* variety of Napier grass under shallowly dug holes [conventional tillage, 15-20 cm deep] is the normal farmers practice in the study site [T_1]. Average nutrient contents of manure used in the trial plots were: 1.03% N, 0.32% P and 2.76% K.

Farmer field school participants and facilitators [extension workers and researchers] proposed indicators for monitoring the trials were inventoried in plenary discussions and used in data collection process. Farmer field school participants’ proposed criteria for monitoring the trials included plant height, colour of leaves, Napier yields, soil colour, incidence of pests and diseases, soil moisture retention and weed density. Facilitators' criteria included monitoring of inputs [labour, fertilizers and related costs] in addition to crop development parameters [stand count, plant height, crop vigour, weed infestation, pest and disease incidence, nutrient deficiencies and number of dried leaves] and Napier yields.

Agro-ecosystem analysis: Agro-ecosystem Analysis [AESA] is the establishment [study] of the interactions between a crop/livestock and other biotic and abiotic factors co-existing in the field through regular observations with the aim of improving decision making; and optimising ecological processes and productivity. Agro-ecosystem analysis was used as a tool by FFS members [farmers] for monitoring the trials, collecting data and making observations for improved decision making.

An agro-ecosystem analysis chart [chart with monitoring indicators] was used to collect data in bi-weekly FFS meeting sessions. Agroecosystem analysis involved FFS participants, in four sub-groups, making observations on the interaction between crops, soils and other biotic and a biotic factors co-existing in the experimental plots and recording the relevant data in AESA chart. The data collected and observations were analysed in sub-groups and presented to the plenary for further critique and decision making each FFS meeting day. Each sub-group presented their own field observations in plenary and defended their findings with agro-ecological arguments. This acted as the basis for consensus building on the performance of the various treatments and actions [management decisions] required in addressing emerging issues from the experimental plots.

At harvesting, Napier grass was cut at 1 metre high and at a stubble height of 5 cm from ground level and yields per plot recorded in the AESA chart. The quality of Napier harvested was determined through laboratory analysis for N, P, K, Ca, Mg, Fe, Cu, Mn, Zn, crude protein and moisture content. After harvest, weighing of the harvest and taking of samples for laboratory analysis, the FFS members took the new Napier variety [Kakamega 1] for planting in their individual farms.

Special topics, group dynamics, other FFS techniques used and regular running of FFS sessions: The FFS were run using farmer-facilitator-researcher developed curriculum in bi-weekly meeting sessions. The FFS curriculum formed the basis for season-long farmer learning and experimentation aimed at addressing the identified constraints. Based on FFS learning norms [time for reporting and ending FFS sessions each meeting day etc.] and FFS curriculum topics, an FFS schedule [time table] was formulated jointly with farmers to guide the learning process. Activities during these sessions included Agro-ecosystem analysis [AESA], special topics, group dynamics and team building and planning for next meeting's activities. These were conducted under the guidance of a facilitator using adult learning principles [non-formal education approaches].

The major elements of a typical FFS bi-weekly schedule were: prayer and roll call; introduction of the day's programme; agro-ecosystem analysis [field observations]; processing field observation in small groups; presentation of AESA observations in plenary by each sub-group]; carrying out a group dynamic activity; special curriculum topic or exercise/ demonstration for the day; recap of the day's schedule, activities and learning points; planning for the next FFS meeting; announcements; and final roll call and closing prayer. The FFS members were divided into four sub-groups to foster learning and active participation of every participant. The four FFS sub-groups conducted AESA in the experimental plots each meeting day and participated in all learning activities. However, for the purposes of logistics, each sub-group was allocated 'a day' to act as a host team and to conduct a group dynamic activity. The latter are team building exercises meant to develop the participants into a closer knit team, establish a learning climate that is enjoyable as well as fruitful, help participants experience and identify such aspects of team work as mutual support, the importance of individual roles to a team's success and behaviour that can build or hinder teamwork. Training in group dynamics also included, among others, communication skills, problem solving, leadership and discussion methods. Leadership training and facilitation of dialogical communication in farmer group trainings are elements which have shown high potential for improving cooperation, sharing of knowledge and participation of all gender and age groups in extension and rural development [24].

To foster learning, the FFS activities also included study tours to other farmer field schools, farmers and research and extension organisations. Also field days were conducted for neighbouring communities and other FFS to learn from FFS activities and technologies being tested.

Participatory evaluation:

Evaluation of the PTD experiments: The PTD experiments were monitored on an on-going basis [by FFS members] during each FFS meeting day. However, at the end of the trials, a participatory evaluation [quantitative and qualitative] was conducted to draw farmers' opinions, preferences, criticisms and suggestions about the technologies tested. Farmer field school participants' evaluation of the trials was done in four sub-groups using matrix scoring and ranking, based on 20 scores per criterion defined for evaluation. Scores were assigned by farmers according to perceived performance of the treatment with regards to a given criterion, with high scores assigned to treatments with higher performance. Qualitative evaluation of the trials was done in plenary by FFS participants highlighting the observed advantages and disadvantages of technologies tested on the basis of their performance. Agronomic data, data collected using AESA sheets and semi-quantitative data of matrix scoring and ranking were further processed and analysed using Excel [from Microsoft Cooperation] and Statistical Programme for Social Scientists [SPSS Inc.] at the end of the learning and experimentation period.

Evaluation of the FFS process and its outcomes: Evaluation of FFS process and its outcomes was conducted six months after graduation of FFS participants [after the end of active learning period]. The evaluation explored answers to the following questions:

- Has FFS improved knowledge and skills of farmers?
- Is experimentation skills gained by FFS members useful? Has the FFS members benefited from experimentation processes in FFS?
- Is the participation of farmers in FFS contributing to adoption of new technologies?
- Is the participation of farmers in FFS contributing to the start of new commercial enterprises and to increased household and group incomes?
- Does the knowledge and technologies from FFS processes disseminate to the rest of the community members?

Responses to the above questions were sought by comparing farmer's situations before and after joining FFS [longitudinal comparison] as well as direct comparison between FFS and non-FFS members [latitudinal comparison]. The evaluation was done using a semi-structured questionnaire administered to individual FFS members in their own farms and doing the same with non-FFS members. The latter was a control group. A purposive sampling of non-FFS members [a sample of 30% of total FFS members] was done to ensure that their production resources [land size and livestock numbers] were comparable with that of FFS members. Half of the non-FFS members were selected from the same Village as FFS members while the other half were drawn from the neighbouring village.

Local institutional development and post-FFS activities: Integrated in the FFS methodology were the institutional development of the FFS group and the sustainability of the FFS activities. Besides training in leadership and team building and facilitating the group to formulate their own by-laws [constitution] and register as legal entities, the approach adopted also included facilitating the FFS members to initiate group commercial activities and value adding activities. These included bulking new Napier variety [*Kakamega 1*] tested in this experiment for sale, growing seed amaranth for sale and small scale processing and packaging of milk products for sale [yoghurt, fermented milk etc]. The FFS members also prioritised the operation of agro-vet shop to sell farm inputs to their members and the surrounding community, at cheaper prices, and mobilisation of local funds [through merry-go-round and other sources]. These processes are on-going. The process of institutional development and strengthening was also done through creating vertical linkages between this [Kibichoi] FFS and other FFS, NGOs and Government departments in the same district.

RESULTS AND DISCUSSION

Diagnosed soil fertility and farming system constraints
Farmer's perceptions on soil fertility status: Declining soil fertility and high costs of inorganic fertilisers were mentioned as priority problems by farmers in Kibichoi and Ngaita FFS respectively (Table 4).

Farmers cited different indicators to show that soil fertility is on the decline. The ranking of these indicators according to number of farmers mentioning them in Kibichoi FFS was in the following order: declining crop yields, changes in soil colour, stunted crops and high incidence of weeds/pests. For Ngaita FFS, the indicators were in the following order: declining crop yields, changes in soil colour, stunted crops/weeds/pests and diseases and loss of topsoil through soil erosion. Similar studies carried out in the highlands of Kenya have also demonstrated that most smallholder farmers are aware of the problem of soil fertility and they use different indicators [e.g. crop yields and indicator plants] to identify that soil fertility is on the decline [25].

Soil-crop-livestock interactions and constraints: Crop residues were preferentially used as a livestock feed and for incorporation into the soil in that order (Table 4). Although cattle manure is important for fertilizing crops only about 30 and 20% of farmers in Kibichoi FFS and Ngaita FFS, respectively, reported getting adequate manure to meet their fertilization requirements in a

Table 4: Prioritised constraints based on number of farmers mentioning a particular constraint

	Kibichoi	Ngaita
Food crop constraints		
High costs of inputs (inorganic fertilisers)	4	1
Labour	3	6
Declining soil fertility	1	4
Unreliable rainfall	5	5
Pests and diseases	2	2
Seed quality	6	3
Soil fertility management		
Use of crop residues		
Livestock feed	1	1
For fuel	3	3
Incorporated into soil	2	2
Sold to neighbours	3	2
Constraints to soil and water conservation practices		
High labour demand	1	1
Inadequate farm tools	2	2
Takes away productive land	3	3

Table 5: Selected soil chemical properties for Ngaita and Kibichoi FFS member's farms, Kiambu District

	Total N %	Organic C (%)	Extractable P (mg kg^{-1})	Exchangeable K (cmol kg^{-1})	Soil pH
Ngaita FFS (n = 30)	0.26	1.86	15.17	1.10	4.7
Kibichoi FFS(n = 30)	0.24	1.65	22.32	1.34	5.2

single cropping season. Manure handling and storage methods in the study sites were poor in the study site with 80 and 33% of farmers in Kibichoi and Ngaita FFS, respectively, storing manure in the open sun or uncovered. About 50% of the study sample was keeping dairy cattle in zero-grazing housing units with concrete floor while 43 and 38% of the farmers had slurry drains in Kibichoi and Ngaita FFS respectively. Zero-grazing units with concrete floor, which are not well paved and housing units with fixed or no solid floor predisposes manure to nutrient losses through leaching and volatilisation. Other studies carried out in Central Kenya have shown that livestock housing, floor type and roofing type influences manure P and Ca contents. Zero-grazing units with concrete floor that have dairy cattle whose feeding regimes include feed supplements produce high quality manure [26].

The basal diet of the dairy cows was based on Napier grass [*Pennisetum purpureum*] while other on-farm produced livestock feeds were *Kikuyu* grass, banana pseudo stems and cereal crop residues. Besides forages, all farms reported using feed supplements [mainly dairy meal] for dairy cows in lactation. Concentrate feeding has been established to improve manure P content [26]. However, the rate of feeding dairy meal was a low flat rate of 2-4 kg per day and not according to lactation stage or milk yields per cow. Similar studies have also confirmed that smallholder dairy farmers in Kenya highlands generally give dairy cows a low constant amount of dairy concentrate of 2 kg throughout lactation period [27].

Chemical soil fertility: The soils collected from farmer's fields (Table 5) and in the central learning plots (Table 6) had moderate levels of N, organic C, K, Ca, Mg, Cu, Fe and Zn while P levels were low according to agronomic threshold values defined by Mehlich [19, 22]. The soil pH was strongly acid [Kibichoi] to extremely acid [Ngaita]. Values of pH less than 5.5 may lead to aluminium [Al] toxicity, unavailability of P [due to fixation] and other soil micronutrients such as molybdenum [Mo] as well as reduced biological activity [28]. At low pH, the availability of Ca and Mg may also be affected.

Nutrient balances and the contribution of livestock to nutrient flows: Partial NPK nutrient balances and total P

Table 6: Topsoil characteristics (0-20 cm) of the study central learning plots

Parameter	Kibichoi FFS	Ngaita FFS
Soil pH-H_2O	4.80	4.10
Exchangeable acidity (cmol kg^{-1})	0.20	0.70
Total Nitrogen %	0.39	0.37
Organic carbon %	1.69	1.51
Extracable Phosphorous (mg kg^{-1})	14.00	10.00
Exchangeable Potassium (cmol kg^{-1})	1.14	0.48
Calcium (cmol kg^{-1})	8.40	3.80
Magnesium (cmol kg^{-1})	2.65	1.90
Manganese (cmol kg^{-1})	1.44	1.36
Copper (mg kg^{-1})	0.98	1.46
Iron (mg kg^{-1})	20.90	27.50
Zinc (mg kg^{-1})	20.20	20.60
Sodium (cmol kg^{-1})	0.78	0.39
Ca: Mg	3.20	2.00
K: Mg	0.40	0.30
Mg: K	2.30	4.00

balances were relatively positive while total N balances were negative (Table 7). The negative N balances were mainly due to losses through leaching, gaseous losses and erosion and through export of crop and livestock products outside the farm. The positive P balance observed in the study was attributed to P imports through concentrates and phosphorus fertilisers.

Presence of livestock in the study system was a major determinant of nutrient flows and balances. The correlation between total N balance [kg ha^{-1}] and number of livestock [tropical livestock units] in the farming system was positive and significant [Kibichoi, r = 0.419, $p<0.05$; Ngaita r = 0.587]. With higher importation of mineral fertilisers and inorganic livestock feeds [concentrates], Kibichoi farms experienced less N mining and had positive K balances than Ngaita farms with low nutrient imports. Mineral fertilisers and inorganic feeds [concentrates] accounted for 64% of total N flows into Kibichoi farms (Table 7).

Livestock was also a positive determinant of internal nutrient recycling within the studied farming system. In Kibichoi FFS, the N flows were in the following order of decreasing magnitude: from livestock [SPU] to redistribution units [RU]; from RU to Crops [PPUs]; and from PPUs to SPUs (Table 8). For Ngaita, a similar trend was observed. SPU-RU and RU-PPU flows represented manure being moved from livestock to nutrient

Table 7: Average nutrient stocks, flows, balances (kg ha^{-1} half year) and farm economic performance

Nutrient flows and balances	Nitrogen		Phosphorus		Potassium	
	Kibichoi FFS	Ngaita FFS	Kibichoi FFS	Ngaita FFS	Kibichoi FFS	Ngaita FFS
IN 1 Mineral fertiliser+inorganic feeds	64.2 (70.6)	41.2 (65.0)	26.6 (25.0)	18.0 (24.9)	24.2 (26.1)	13.3 (23.3)
IN 2a Organic fertilisers+feeds	25.2 (42.6)	18.8 (28.3)	19.8 (35.6)	7.1 (11.5)	33.6 (60.1)	20.8 (40.3)
IN 2b Grazing animals	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
In 3 Atmospheric deposition	8.0 (0.0)	3.4 (0.0)	1.3 (0.0)	0.6 (0.0)	5.2 (0.0)	2.2 (0.0)
In 4 Biological N fixation	3.6 (2.2)	3.1 (3.4)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
OUT 1 Crop products+animal products	-19.1 (20.9)	-15.7 (16.5)	-2.3 (2.2)	-3.0 (3.3)	-8.9 (9.8)	-10.6 (11.9)
OUT 2a Crop residues	-2.3 (6.9)	-7.6 (14.0)	-2.4 (8.2)	-9.1 (20.3)	-4.1 (12.3)	-15.1 (32.4)
OUT 2b Animal manure	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
OUT 3 Leaching	-33.7 (21.6)	-37.0 (20.0)	0.0 (0.0)	0.0 (0.0)	-1.0 (0.8)	-0.8 (0.6)
OUT 4 Gaseous losses	-20.8 (12.7)	-22.8 (11.9)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
OUT 5 Erosion	-18.5 (14.8)	-21.7 (24.9)	-3.8 (3.3)	-4.4 (4.8)	-30.5 (29.3)	-36.3 (51.0)
OUT 6 Human excreta	-9.1 (6.5)	-11.8 (8.9)	-2.5 (1.8)	-3.2 (2.4)	-1.7 (1.2)	-2.4 (2.5)
Partial balance	58.8 (83.1)	24.9 (70.6)	39.3 (47.6)	9.8 (32.0)	43.1 (71.6)	6.1 (53.5)
Total balance	-2.6 (61.1)	-50.0 (81.2)	36.7 (48.8)	5.9 (34.5)	16.9 (80.5)	-28.2 (87.5)
Soil nutrient stock	7268.0 (811)	8006.0 (717)	1978.0 (570)	2229.0 (286)	16068.0 (5777)	14569.0 (8420)

Table 8: Matrix of N-flows (kg ha^{-1}) for Kibichoi FFS, Kiambu District[1]

Source	Destination					
	Ext	HH	Sto	PPU	SPU	RU
Kibichoi FFS						
Ext		0.0 (0.0)	0.0 (0.0)	27.3 (36.0)	61.9 (72.6)	0.2 (1.0)
HH	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.3 (2.4)	2.6 (2.6)	10.5 (7.4)
Sto	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
PPU	14.6 (21.3)	7.6 (8.6)	0.0 (0.0)	2.6 (8.0)	23.7 (20.0)	0.0 (0.0)
SPU	6.5 (8.5)	5.2 (8.8)	0.0 (0.0)	3.2 (4.1)	0.2 (0.6)	67.7 (69.3)
RU	0.3 (1.3)	0.0 (0.0)	0.0 (0.0)	50.6 (79.7)	0.0 (0.0)	0.0 (0.0)

[1]Ext, External environment; HH, Household; Sto, stock; PPU, Primary production units (crops); SPU, Secondary production units (livestock); RU, Redistribution units

concentration points, RUs, [manure heaps, pits] and manure being moved from RUs to crops, respectively. The flow from PPU to SPU was fodder for livestock.

Interventions tested for improving soil fertility and crop-dairy productivity:

Agro-economic performance of Napier grass: Agro-economic performance of Napier grass is illustrated by results from Kibichoi FFS. The dry matter [DM] yields of Napier ranged from 8.9 to 17.3 t ha^{-1} for three cuts, but with *Kakamega* 1 Napier variety attaining higher yields than *Bana* variety under equivalent tillage practices. Reported on-farm dry matter yields from different regions of Kenya average about 16 tonnes/ha/year [4 to 29 DM yields ha^{-1}] [29] with little or no fertilizer, while according to Schreuder *et al*. [30] Napier yields from research stations vary between 10-40 tonnes DM/ha/year [even higher] depending on soil fertility, climate and management factors. For a given Napier variety, DM yields were higher under *Tumbukiza* than under conventional tillage practices (Table 9). Similarly, for a given tillage practice, DM yields of *Kakamega* 1 was higher than that of *Bana* grass variety.

The gross margins, return to labour and benefit cost ratio [>2] were all positive for the technologies studied, implying that they were economically viable (Table 9). However, *Kakamega* 1 grown under conventional and *Tumbukiza* tillage practices outperformed *Bana* Napier variety grown under equivalent tillage practices in all major economic indicators. In a comparative study of growing Napier under *Tumbukiza* and conventional tillage practice in North Rift Valley of Kenya, Muyekho and Mose [31] corroborated that the use of these two tillage

Table 9: Agro-economic performance of three cuts of Napier grass grown under different tillage systems in Kibichoi FFS[1]

	Napier (*Bana* variety)		Napier (*Kakamega* 1 variety)	
	Conventional tillage	*Tumbukiza* tillage	Conventional tillage	*Tumbukiza* tillage
Dry matter yields (t ha^{-1})	8.90 (2927.7)	13.70 (3556.9)	13.30 (220.5)	17.30 (326.2)
Gross margins (US $ ha^{-1})[2]	1220.70 (507.3)	1,117.50 (677.4)	1,561.00 (176.4)	1,726.70 (341.1)
Return to labour (US $/day)[2]	16.10 (6.5)	14.20 (8.1)	19.70 (2.4)	21.50 (4.3)
Benefit/Cost ratio	5.30 (1.8)	2.00 (0.6)	6.40 (0.6)	2.50 (0.3)
N-partial balance (kg ha^{-1})	-173.70 (71.4)	-63.30 (94.9)	-260.20 (19.6)	-156.20 (47.1)
P-partial balance (kg ha^{-1})	5.10 (6.8)	53.60 (11.8)	-3.60 (4.2)	44.10 (3.5)
K-partial balance (kg ha^{-1})	-254.90 (124.4)	55.80 (186.7)	-378.20 (116.9)	-41.70 (6.2)
Crude protein (%)	14.50	13.20	14.20	14.10

[1]Napier can be cut every 6-8 weeks (6-8 cuts/annum) in Kenya depending on fertilizer application, rainfall amount and distribution [32]

[2]US $ = Ksh 75 at time of study

Table 10: Feeding value of Napier grass tested in the trials, Kibichoi FFS

	Napier (*Bana* variety)		Napier (*Kakamega* 1 variety)		Critical values	
	Conventional tillage	*Tumbukiza* tillage	Conventional tillage	*Tumbukiza* tillage	a	b
CP (%)	14.50	13.2	14.2	14.1	*	*
Ca%	0.18 (0.07)	0.16 (0.05)	0.21 (0.10)	0.18 (0.03)	0.43-0.77	0.30
P%	0.17 (0.05)	0.18 (0.05)	0.20 (0.06)	0.21 (0.04)	0.28-0.49	0.25
K%	3.90 (0.47)	4.07 (0.49)	3.76 (0.77)	3.86 (0.38)	0.90-1.50	0.07
Mg%	0.26 (0.03)	0.24 (0.05)	0.31 (0.06)	0.33 (0.05)	0.20-0.25	0.20
Fe (mg kg^{-1})	1113.00 (773.52)	1103.00 (809.73)	1028.50 (202.97)	1182.00 (303.75)	50.00	30.00
Cu (mg kg^{-1})	10.10 (5.14)	11.31 (6.09)	12.68 (9.74)	34.10 (21.57)	10.00	10.00
Mn (mg kg^{-1})	76.75 (47.36)	67.45 (31.05)	71.15 (9.28)	74.05 (11.35)	40.00	35.00
Zn (mg kg^{-1})	39.97 (7.13)	39.28 (6.85)	57.78 (0.67)	64.25 (10.75)	40-60.00	30.00

[a]Recommended requirements for dairy cattle [33], [b]Critical levels for ruminants [34]

practices results in positive economic benefits, but with Napier grown under *Tumbukiza* outperforming the same variety of Napier grown under conventional tillage in net present value, benefit cost ratio and return to labour.

Partial N and K balances for the *Bana* and *Kakamega* 1 Napier varieties grown under conventional and *Tumbukiza* tillage practices were largely negative (Table 9). This is explained by large N and K removals through Napier harvests, which was not balanced by N and K inputs. However, partial phosphorus balances were positive [except for *Kakamega 1* + conventional tillage] due to phosphorus inflows from manure and triple super phosphate fertiliser and comparatively low phosphorus outputs/removals.

Crude Protein (CP), Ca and P content of Napier were used as measures of the feeding value of Napier. The average CP content of *Kakamega* 1 and *Bana* Napier variety were not significantly different and ranged from 13.2 to 14.5% across tillage practices (Table 10). A review of Napier CP content by Schreuder *et al.* [30] indicate that the CP values lie between 5-9% while studies carried out in Rift Valley of Kenya have reported Napier CP in the range 11.5% to 16.3% [6]. CP of Napier is influenced by soil fertility, climatic factors, cutting age/frequency and genotype.

Napier analysis for mineral composition revealed that both *Kakamega* 1 and *Bana* varieties had low Ca and P for dairy lactating cows (Table 10). The concentrations of K, Mg, Fe, Cu, Mn and Zn in Napier were moderate to high. Inadequate availability of Ca and P may lead to deficiency diseases. Therefore, dairy cattle should be given balanced mineral-mixtures even when fed on Napier grass.

Farmers' evaluation: Farmers' evaluation showed that growing *Kakamega* 1 Napier variety on *Tumbukiza* was the most preferred technology (Table 11). This technology had few incidences of pests and low quantities of dead leaf materials. It also had better leaf colour, plant health, comparatively high moisture

Table 11: Farmers' evaluation of tested practices in Kibichoi FFS, Kiambu, Kenya[1]

	Treatment (Sum)			
Criterion	Conventional tillage + *Bana* variety	*Tumbukiza* + *Bana* variety	Conventional tillage + *Kakamega 1* variety	*Tumbukiza* + *Kakamega 1* variety
Incidence of pests	26	20	17	17
Leaf colour	11	18	23	28
Plant health	14	19	19	28
Soil moisture retention	12	20	19	29
Incidence of weeds	16	21	20	23
Vigour (plant height)	11	18	21	30
Quantity of dead leaf materials	25	28	12	15
Labour demand	15	25	15	25
Yields	13	28	16	23
Choice of technologies	11	20	11	38
Total	154	217	173	256

[1]Each figure is a sum of scores allocated by 4 sub-groups per criterion

Table 12: Farmers perceptions on the advantages and disadvantages of studied practices (Kibichoi FFS)

	Kakamega 1 Napier variety	*Bana* Napier variety
Advantages	Fast growth	Thick stems/watery-makes cows satisfied quickly
	Few disease incidence	Easy to cut
	High number of tillers	Cuttings locally available
	Not hairy	
	Appealing green colour	
	Grows tall	
	High yields	
	High frequency of cutting per unit time	
Disadvantages	Small thin stems	High disease incidence
	Hard sturdy stems	More hairy-cause allergy
	Liked by moles	Grows slowly
	Thin leaves	Dries up fast (less life span)
	Cuttings not easily available	Liked by moles
	Requires more labour to cut	Has few leaves
	Small frogs climb on it (not hairy)	Low frequency of cutting per unit time
	Tumbukiza	Conventional tillage
Advantages	Stores more moisture for long period	Easy to weed
	Fast Napier growth	Less labour
	High yields	Easy to harvest
	Economises space	
	Promotes high tillering	
	Few weed incidences	
Disadvantages	Requires high labour input to prepare holes	Needs large piece of land to give required yields
	Needs a lot of manure input	Less yields
	Weeds emerge in open spaces between holes	Does not store moisture for long period

retention and higher yields. This was further confirmed by farmers' perceptions on the advantages and disadvantages of each tillage practice and Napier variety (Table 12).

The criterion "choice of technology" was used to gauge farmers' choice of a technology that they would be able to practice in their individual farms among the tested technologies. Priority choices of farmers were in

Table 13: Technologies reported to address soil fertility decline (% of farm households mentioning a particular technology) by FFS and non-FFS participants in Kibichoi

	Technologies known	
Technologies	FFS (n=19)	Non-FFS (n=9)
Fertilizers (%)	68.0	89.0
Manure (%)	74.0	78.0
Terraces/grass strips (%)	48.0	11.0
Tithonia (%)	11.0	-
Compost (%)	47.0	-
Crop residues (%)	11.0	-
Crop rotation (%)	11.0	11.0
Double digging (%)	37.0	11.0
Green manure (%)	5.0	-
Mulching (%)	5.0	11.0
Lime (%)	11.0	33.0
Average number of technologies per farm	3.4	2.6
Number of different technologies	15.0	8.0

the order: *Kakamega* 1 grown on *Tumbukiza* >*Bana* grown on *Tumbukiza* >*Kakamega* 1 or *Bana* grown on conventional tillage practices. The high scores received by *Kakamega* 1 grown on *Tumbukiza* tillage practices was in agreement with quantitative analysis that rated the same technology to be of high agro-economic performance.

FFS process evaluation and methodological lessons learned: The evaluation showed that FFS process improved knowledge and skills of farmers. They were able to cite many diverse technologies for addressing soil fertility decline than their non-FFS counterparts receiving conventional extension messages (Table 13). Fertilizers, manure and terraces were the most frequently mentioned technologies both by FFS and non-FFS members while compost, *tithonia* green manuring, double digging, Agro-forestry and crop residues were typically mentioned by FFS members.

The participation of farmers in FFS experimentation and in AESA leads to a majority of them experimenting in their own farms with technologies learned from FFS or using the acquired skills to experiment on new topical issues of interest. The evaluation showed that FFS members conducted more and diverse on-farm experiments [about 95-100% of farm households] than their non-FFS members [35-65% of farm households] (Table 14). Some of the tested technologies on the central plot such as *Tumbukiza* Napier [Kakamega 1 variety] were also tested on individual plots by approximately 33% of the FFS members (Tables 12 and 14). The findings further demonstrate that the knowledge and understanding gained through FFS process and experimentation strengthens farmers' confidence in searching for their own solutions. This may

Table 14: Farm households conducting on-farm experiments before and after the active FFS learning period (% of farm households conducting experiments mentioned by type of experiment)

	Before FFS period		After FFS period	
Type of experiments	FFS (n = 19)*	Non-FFS (n = 9)	FFS (n = 19)*	Non-FFS (n = 9)
Farm households experimenting (%)	89.0	89.0	95.0	33.0
Inorganic fertilizers (%)	6.0	14.0	0.0	0.0
Manure (%)	0.0	29.0	6.0	0.0
Terraces (%)	0.0	0.0	0.0	0.0
Crop varieties (%)	100.0	100.0	67.0	67.0
Compost (%)	6.0	14.0	6.0	0.0
Planting method (%)	24.0	0.0	11.0	0.0
Double digging (%)	6.0	14.0	33.0	0.0
Manure-inorganic fertilizers (%)	0.0	0.0	0.0	0.0
Wood ash for insect pest control (%)	0.0	14.0	0.0	0.0
Inorganic fertilizers (+ridging) (%)	0.0	0.0	28.0	0.0
Tithonia green manuring (%)	0.0	0.0	17.0	0.0
Rhizobium inoculation (%)	0.0	0.0	0.0	0.0
Tumbukiza Napier (%)	0.0	0.0	33.0	0.0
Vegetables/spices (%)	0.0	0.0	26.0	67.0
Average number of experiments per farm	1.7	1.6	2.1	1.3
Number of different experiments	9.0	6.0	10.0	4.0

*Kibichoi FFS participants

Table 15: Adoption of new soil fertility management practices by Kibichoi FFS members over the last three-year FFS period compared to non FFS members over the same period

Soil fertility management practices	Kibichoi	
	FFS (n = 19)	Non FFS (n = 9)
Rhizobium (%)	11.0	-
Manure (%)	63.0	56.0
Fertilizer (%)	68.0	44.0
Tithonia (%)	53.0	-
Manure-Fertilizer (%)	-	11.0
Mulching (%)	11.0	11.0
Ridges (%)	-	-
Terraces (%)	32.0	11.0
Compost (%)	42.0	22.0
Double digging (%)	68.0	11.0
Tumbukiza Napier (%)	11.0	-
Crop rotation (%)	5.0	-
Different types of practices	12.0	9.0
Average number of practices per farm[1]	3.7	1.9

[1]Maximum of 4 practices per farm were recorded

eventually increase their ability to choose options and to develop solutions appropriate for their specific ecological, economic & socio-cultural conditions and circumstances.

The evaluation also showed that farmer's participation in FFS process and experimentation stimulates the adoption of new technologies. Farmers who had participated in the FFS process adopting more "new technologies" than their non-FFS counterparts over a three year period (Table 15). Other management methods adopted by FFS members include improved livestock feeding technologies [adopted by 58% of FFS members] and record keeping [adopted by 37% of FFS members], which were not reported among non-FFS members.

Assessment of the impacts of the FFS process in stimulating the start of new commercial activities by individual farm households indicated that there was no significant difference between FFS and non-FFS over the last three year period in which FFS activities were carried out (Table 16). All individual farm households studied engaged in new commercial activities, with dairy cattle, vegetables [kales], goats and poultry being the most important new commercial activities among FFS and non-FFS members. However, in terms of group approach to commercial activities, a difference was observed. FFS members organized themselves into a group marketing entity that adds value to milk [small scale milk processing into yoghurt and other milk products] and sells milk products as a group thereby reducing operational costs.

Table 16: New commercial activities by Kibichoi FFS members over the last three-year FFS period compared to non FFS members over the same period (% of farm households mentioned by type of commercial activity)

Commercial activities	Kibichoi	
	FFS (n = 13)[1]	non-FFS (n = 9)
Farms with new activities (%)	100.0	100.0
Maize and/or beans (%)	15.0	11.0
Livestock (poultry/goats) (%)	31.0	44.0
Dairy cattle (%)	46.0	44.0
Vegetables (kale, melon, tomatoes) (%)	77.0	55.0
Bananas (%)	23.0	11.0
Different types of activities	14.0	10.0
Average number of activities per farm	2.3	1.9

[1]Activities recorded with a lower number of respondents; Kibichoi FFS

Table 17: Percentage distribution of non-FFS households receiving information from Kibichoi FFS members

Technology	Non-FFS members
Farm households receiving info from FFS	66
Tithonia	-
Goat management	11
Seed quality	-
Fertilizer	-
Manure	-
Composting	11
Vegetables	33
Livestock management	22
Planting methods	11
Napier	33

Farmers participating in FFS share their knowledge and technologies that they have learnt from FFS with the rest of the community members. This study showed that about 66% of non-FFS members [from same village and neighbouring village to FFS site] received technical information from FFS members (Table 17). However, FFS activities were more known by non-FFS farmers in the same village where FFS was situated than in neighbouring villages.

Farmer field schools were first developed in Asia on integrated pest management [IPM] with learning period that span one cropping cycle [season]. However, experiences from this study showed the necessity of adapting this approach when dealing with soil fertility-crop-livestock interactions. There was need to stretch the learning period over several seasons for farmers to appraise the full range of costs and benefits associated with soil fertility technologies. Changes in productivity due to implementation of soil-crop-livestock technologies

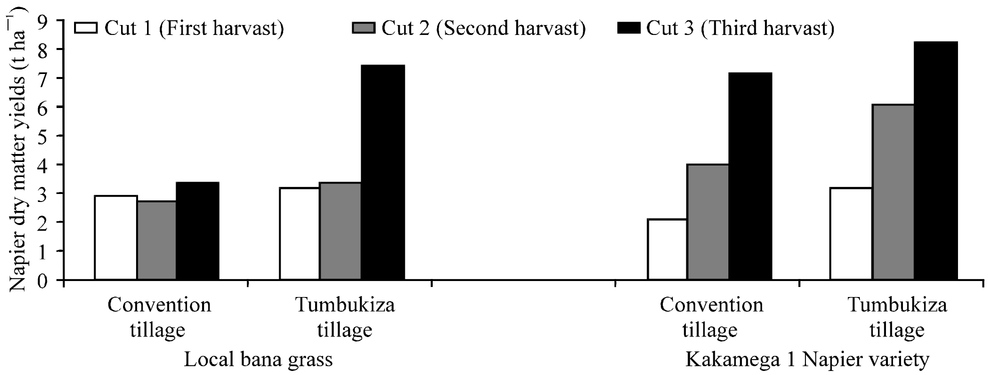

Fig. 3: Trends in the performance of Napier dry matter yields (tones/ha) over the learning and experimentation period (mean of two replications), Kibichoi FFS

take long to be observed compared with those of IPM and Napier yields increased after the first season of establishment (Fig. 3).

Most FFS processes implemented in East Africa have focused on documenting processes and qualitative data without much attention paid to quantitative data that is often collected by farmers in the AESA sheet [e.g. yields, plant height, labour time etc.]. A holistic documentation [combing both qualitative and quantitative data] is a necessity if FFS processes were to continue impacting positively on farmers, extension and policy stakeholders. This study has shown that, with attention paid to documentation processes, it is possible to demonstrate the impacts of FFS quantitatively as well as qualitatively.

Farmer field schools methodology is based on implementing experiments/demonstrations in group central learning plot. However, the use of the latter was not found feasible with dairy animals, which represent a higher investment with a slow return than crops. Farmers perceive direct experiments involving dairy animals to be risky especially when they result in loss of productivity, but consider fodder production/manure experiments less risky. Thus, in crop-dairy systems, improvement of soil fertility may target the nutrient cycling processes along soil-crop-livestock interactions without necessarily experimenting directly with farmer-owned dairy animals [e.g. experiments on manure and fodder or improving concentrate P feeding to improve manure-P content].

CONCLUSIONS

A productive soil resource base and improved crop-livestock interaction are required to support optimal and sustainable food production if the rising demands for food and fibre are to be met. The study has shown that through farmer field schools, researchers and extension workers can come to a common understanding with smallholder farmers on soil fertility and crop-dairy production constraints and design and test local solutions for improving productivity. Major constraints identified included general decline in soil fertility including low soil phosphorus, poor manure management, inadequate fodder and manure, low dairy productivity and high costs of farm inputs. Solving these constraints requires system based approaches that holistically address soil-crop/fodder-livestock interactions within a framework of farmer-science knowledge linkages and learning processes.

In intensive crop-dairy systems, livestock is an important determinant of soil nutrient balances. It can be concluded from the study that nutrient imports in the form of livestock feeds [concentrates, fodder and crop residues] and manure management dictates NPK balances and thus interventions for improving soil fertility in crop-dairy system should integrate strategies for improved livestock feeding as well.

The use of *Tumbukiza* tillage practice to plant *Kakamega* 1 was agro-economically superior to the use of farmers' conventional practices. It attained high dry matter yields, gross margins, return to labour and benefit cost ratio implying that the technology [*Tumbukiza*+ *Kakamega* 1] has a high potential to bridge fodder gaps under smallholder dairy farming in the Kenyan highlands. These findings were congruent with farmers' qualitative evaluation. However, *Tumbukiza* is associated with high labour input for establishment. To maximize on returns to labour, there is need to explore ways of intercropping Napier with dual value crops for improving fodder availability and soil fertility e.g. beans or leguminous fodder crops such as *Desmodium* spp.

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