1.0 Introduction

Soil degradation and nutrient depletion due to continuous cultivation, removal or burning of crop residues, loss of nutrients through soil erosion, overgrazing between cropping seasons and inadequate use of inorganic fertilisers are the major causes of declining food production per capita in smallholder farms in western Kenya (Stoorvogel et al., 1993). Nutrient balance studies carried out in western Kenya have shown that N and P balances were negative (Smaling et al., 1993). On average 22 kg N, 2.5 kg P, and 15 kg K/ha are lost annually and losses can be as high as 112 kg N, 3 kg P, and 70 kg K/ha in the intensely cultivated highlands of western Kenya (Van den Bosch et al., 1998). These losses are much higher than the estimated inorganic fertiliser use in Africa of 5 to 10 kg/yr (Heisey and Mwangi, 1996), emphasising the need for soil fertility replenishment. Phosphorus limitations could partly be attributed to low native P and P-fixation by aluminium and iron oxides in the predominantly acid soils of western Kenya, in addition to mining of P from the soil that is estimated at 1.5-13 kg/ha/yr from smallholder mixed farms (Smaling et al., 1993). Nitrogen and P limit crop production while soil carbon does so through limitation of the biological activity in the soil. Although judicious application of inorganic fertilisers is recognized as the most effective amendments for overcoming soil fertility decline or alleviating nutrient deficiencies, their high cost, inaccessibility, and generalized recommendations resulting in low, erratic and unprofitable crop responses limit their use, particularly on smallholder farms in eastern Africa (Nandwa and Bekunda, 1998).

However, the soil fertility problem is not uniform both at regional and farm scales. Thus, the strategy of tackling this constraint requires a robust approach. The Soil Management Project (SMP) was initiated in 1994 to address this constraint with the financial and technical support from the Rockefeller Foundation. The project is implemented at the two centres of Kenya Agricultural Research Institute (KARI), of Kitale and Kisii with the goal of increasing crop and livestock production through the use of sustainable and low-cost soil management technologies. The initial objectives of the project were to, 1) appraise causes of declining soil fertility in smallholder farms, 2) develop together with farmers low cost technologies for addressing the problem and 3) disseminate those technologies found to be feasible and sustainable to smallholder farmers in the regional research mandate areas. Farmer participatory research approach using PRA techniques was adopted to ensure that farmers participated actively in the process of technology development from problem diagnosis, research implementation and technology transfer. The project was initially implemented in four sites each at Kitale and Kisii mandate regions. Because of using the PRA technique to initiate the project, some constraints identified by farmers were beyond the mandate of the research.
team. While farmers participated actively in problem diagnosis their participation in subsequent stages of technology development was less active. As a result, two more sites were initiated to train research teams on FPR methods of involving farmers in all stages of technology development and transfer.

The preliminary results of the project activities were presented in the first scientific conference of the SMP and LRN project held in March 1997 where over 60 papers were presented (Mureithi et al., 2000a). At the end of the first phase of the project, a second scientific conference was held in June 2000 where seventy seven papers which highlighted the results attained in phase one, identified promising technologies and provided useful insights for the way forward of the project were presented (Mureithi et al., 2002). The low-cost sustainable technologies developed during phase 1 of the SMP (1994 and 2000) were: 1) organic manure (FYM and compost) management and its use alone or in combination with inorganic fertilisers for crop production, 2) suitable crop varieties for diversification in the Kisii and Kitale mandate regions, 3) alternate food grain legumes, 4) relay cropping green manure legumes into the common maize-bean intercropping systems, 5) improved production, management and utilisation of pastures and fodders, 6) use of plant extracts (local technical knowledge) to control pests on maize and vegetables, 7) quality seed production on smallholder farms and 8), low cost soil conservation methods.

The ethnic diversity in both the Kitale and Kisii mandate districts expresses itself in various farming systems, which offer the socio-cultural acceptance of certain technologies. Because of the complex and diverse biophysical and socio-economic conditions in western Kenya, sustainable land use is likely to be achieved by classifying variability in the landscapes types of different AEZs or farms and selectively utilizing them appropriately for crop and livestock production. Adoption studies carried out at the end of phase one (Mose et al., 2003; Odendo et al., 2003, Gor et al., 2003; Wanyama et al., 2003) showed that dissemination, diffusion and adoption of the developed technologies by non-participating farmers and outside the sites where they were developed were low. Although technology development was to continue in phase two (2001-2005) to address gaps that were identified in phase 1, the initial focus in this phase was to scale up the technologies to more farming communities within the region in order to enhance food security and alleviate poverty among smallholder farmers. Farmer Participatory Research and Farmer Field School (FFS) approaches were used in the scaling up process. These approaches involve the participation of farmers, extensionists and non-governmental organisations (NGOs) in technology evaluation and dissemination to enhance adoption. In the FPR approach, farmers led by Farmer Research Committees (FRC) evaluate the technologies with backstopping support from researchers and extensionists. Unlike the FPR approach, which had been used in phase 1 in developing the
technologies, the FFS approach was new in the project. Therefore researchers (12), extension officers (6) and farmers (6) in the project underwent a training of trainers (TOT) course on the FFS methodology in 2001 to become resource persons for training other stakeholders. In addition to FFS, part of the scaling up and dissemination process was through the preparation and dissemination of extension messages using leaflets and brochures.

In line with the initial objectives of the SMP, some of the developed technologies were scaled up in the areas where they were developed and efforts were made to extend them to other areas. However, others needed participatory modifications or refinement based on previous experiences before they could be extended to new areas. The specific objectives of this synthesis were to: 1) highlight the most promising results since 1994 when the project started so as to avoid duplication of previous research in other new sites, 2) identify research gaps and 3) provide useful insights or suggest the way forward for the project.
2.0 Centre research mandate regions

2.1 Introduction

Soil Management Project (SMP) is implemented in western Kenya in the regional research mandate areas of two KARI centers, namely Kitale and Kisii. The areas cover the greater part of western Kenya which stretches on the western part of the rift valley from North Rift of north western Kenya to south western Kenya around the shores of Lake Victoria. Although the agro-ecology of this region is diverse, it encompasses a greater proportion of the high agricultural potential sub-humid and humid highlands that are the most densely populated in Kenya. Farming systems in the area vary and have developed in response to prevailing soil and climatic conditions and socioeconomic and ethnological preferences. Crop-livestock mixed farming system where intercropping of maize and common bean is closely integrated with dairy production is the most common system in the sub-humid and humid highland areas. Extensive grazing with limited growing of suitable food crops dominate in the less potential transitional zones. The region has features conducive to smallholder on-farm research and development. The population density ranges from 250 to 1200 persons/km². More than 90% of non-urban center households are agricultural and about two thirds own cattle. The household land sizes vary from as low as 0.02 acres in the densely populated highlands to as high as 100 acres in low potentials areas. Most of the land is under freehold land tenure system, but majority of the farmers have not acquired title deeds for it. Several PRAs and farm characterisation studies conducted the in region indicate that about 54% of land is used for growing food crops (e.g. maize, beans, sorghums/millets, vegetables), 15% for cash crops (e.g. tea, coffee, sugarcane, crops for sale) and 23% for pasture. The mean household size is 6 persons and majority of the households (over 80%) are male headed. Females perform more than half of the household activities. About 50% of household heads are educated to primary school level. The percentage of those with higher level of education is greater in households with livestock. Over 70% of agricultural households have income of less than KSh 5,000 per month, translating to income per capita of less than KSh 28/day (US $ 0.36/day). The income from dairy activities is higher than that from all other farm enterprises, except in districts like Nyamira where income from cash crops (mainly tea) is higher. There is severe food insecurity because majority of households have no food (particularly maize that is the staple food) for three to eight months in a year. Only about 5% households have piped water and electricity is connected to only about 2% of the households. The mean distance from households to roads passable by vehicles all year round is about 3 km and can be as high as 30 km. The average distance from households to the nearest market or trading centre is 1.8 km. The poor infrastructure and long distances to urban centres limit access to markets and availability of other essential services.
2.2 KARI-Kitale

The KARI-Kitale adaptive research mandate area covers five districts, namely Trans-Nzoia, Uasin Gishu, Keiyo, Marakwet and West Pokot (Fig. 1) occupying a total of 171,840 km². The region comprises a diverse agro-ecology in which all major AEZs in Kenya (except coastal lowland) are represented. Out of 27 zones found in the region, ten of them account for more than 80% of agricultural land. These are LH₃ (19.4% of total agricultural land), UM₄ (10.4%), LM₅ (16.5%), UM₄₋₅ (7.9%), LH₂ (5.4%), UH₁ (4.2%), UH₂ (4.1%), LH₄ (3.5%), L₆ (8.3%) and UM₅ (2.6%). The AEZs of UH, LH, and UM represent the high and medium potential areas where most of arable agricultural activities are practiced. Elevations vary from about 900 m in Kerio Valley to more than 2700 m above sea level in the Elgeyo Escarpment of Keiyo and Marakwet districts, and to more than 3000 m asl in the Cherengani Hills in West Pokot District (Jaetzold and Schmidt, 1983). Rainfall increases with altitude from less than 200 mm in the inner lowland of Marakwet district to 2700 mm per year in the upper highlands. The rainfall pattern in most agricultural AEZs is unimodal, which normally starts in March/April and continues up to October/November with peaks in May and August. There is a prolonged dry spell from the end of November to early March when scarcity of livestock feed is most severe. The region is characterized by a variety of soils due to its diversity in parent rocks, topography, climate and vegetation. The major soils are humic Ferralsols in Trans-Nzoia, humic Cambisols in West Pokot, ferralic Cambisols and ferralic-chromic Acrisols in Uasin Gishu and chromic Luvisols and humic Nitisols in Keiyo-Marakwet according to FAO-UNESCO (1974) classification (Mwangi et al., 1997).

The five major ethnic groups that inhabit the region are the Luhya, Nandi, Keiyo, Marakwet, and Pokot. However, with time other ethnic groups such as the Kikuyu and Kisii are rapidly increasing in number. A recent participatory monitoring and evaluation (PME) survey conducted in the region showed that the average household size is 7 persons. The average household size of agricultural land ranges from 4 acres in Uasin Gishu to 8.4 acres in West Pokot District. More than 90% of the households own land, but only 27% have acquired title deeds. This suggests that access to credit from commercial banks is limited because title deeds are the only security farmers can have. The major crops in terms of numbers of farmers growing them are; maize, beans, Irish potatoes, vegetables (kales, cabbages and indigenous leafy vegetables), millet, pyrethrum, sweet potatoes, cassava, wheat and sorghum. Dairy cattle are the most important livestock in the high potential districts of Uasin Gishu and Trans-Nzoia. Beef cattle, sheep and goats are more important in the dry districts of West Pokot, Keiyo and Marakwet (Nyambati, 1997).
Soil fertility improvement technologies for western Kenya

Fig. 1. Map of the KARI-Kitale Research Mandate Districts and SMP sites

Fig. 1. Map of the KARI-Kitale Research Mandate Districts and SMP sites
A photo of Kitale region
2.3 KARI-Kisii

The KARI-Kisii adaptive research mandate area covers 14 districts of Kisii Central, Nyamira, Kericho, Bomet, Buret, Transmara, Migori, Kuria, Homa Bay, Kisumu, Suba, Gucha, Rachuonyo and Nyando (Fig. 2) that occupy about 11,000 km\(^2\). Although up to 17 different AEZs are found in the mandate region, six of them account for 78% of the total agricultural land. These are LM\(_3\) (18.3%), LM\(_2\) (17.6%), LH\(_1\) (15.1%), UM\(_1\) (11.9%), LH\(_2\) (8.1%) and LM\(_4\) (7.1%) (Jaetzold and Schmidt, 1983). The higher rainfall AEZs (LH\(_{1-2}\) and UM\(_1\)) are characterized by two distinct long and short rain seasons. The long rains start in mid-February and the second in September with three distinct peaks in April, August and November. The mean annual rainfall ranges from 400 to 2100 mm in the long rains, and 350 to 700 mm in the short rains in the high rainfall AEZ of LH\(_{1-2}\) and UM\(_1\). In the lower rainfall AEZs (UM\(_{2-4}\) and LM\(_{1-5}\)), the long rains range from 380 - 1000 mm and 50 - 700 mm in the short rains (Njue et al., 1997).

The region has diversity of soil types varying in their genesis, fertility and workability. The major soil types are the relatively fertile, well-drained Nitisols occurring in upper middle-level uplands and in the volcanic footridges. Planosols, Vertisols, Solonetz and Gleysols are found in the bottomlands, floodplains and erosional plains. The fertile Phaeozems are the third largest group mainly found on the footslopes and lower level uplands of the Kisii District (Njue et al., 1997). Soil erosion is severe in most farms due to steep undulating hills with erodible soils.

Six major ethnic groups inhabit the diverse agro-ecological zones. These are Abagusii, Luos, Maasai, Abasuba, Kuria and Kipsigis. The region is characterized by high population density ranging from 215 persons/km\(^2\) in Homa Bay to 800 persons/km\(^2\) in Kisii District. The household family size is 6 – 8 persons. Labour is mainly provided by the household members. Men are the decision makers in most households. The average household farm sizes vary from 1 acre in the highlands to 5 acres in the low potential lowlands such as in Ranchuonyo District, but can be as low as 0.03 and as high as 50 acres. In the cooler highland areas, the production system can be described as tea, maize and pyrethrum production zone and in the lower more warmer areas as coffee and maize zones. The main food crops grown are maize, beans, finger millet, sweet potatoes, bananas and vegetables. Cash crops are tea, coffee, pyrethrum, sugarcane and horticultural crops such as tomatoes, onions and cabbages. The main livestock kept are both improved and indigenous breeds of cattle, sheep, goats and chicken. The maize-bean, sorghum and millet and banana – based systems are the most common cropping practices and are closely integrated with dairy production in the cool high rainfall highlands. The main livestock production system is open grazing, but about 15% of livestock farmers keep dairy cattle under zero grazing where the main feeds are maize stover, banana
pseudostems, Napier grass, and sweet potato vines. Agriculture is the major source of food and income. Because of small acreages and low yields of crops and livestock, there is food shortage 5 to 8 months in a year resulting to severe malnutrition in some areas. The communication network from the major centers in the region to other parts of the country is fairly good with two major tarmac roads, namely the Homa Bay – Kisii – Nairobi and Migori – Kisii – Kisumu roads that open the region to outside markets. Transport infrastructure in most rural areas is very poor with only few all weather roads. The rest are ungraded roads that are impassable during the rain season. This makes access to markets very difficult and compels farmers to sell their produce at low prices.
Fig. 2. Map of the KARI–Kisii Research Mandate Districts and SMP sites
3.0 Study site characteristics

In the KARI-Kitale mandate area, the selected sites were Matunda, Anin, Cheptuya, Chobosta and Weonia spanning across four AEZs and representing about 23% of the total agricultural area under KARI-Kitale mandate area (Fig. 1 and Table 1, 2). Matunda and Weonia are in Kiminini Division of Trans-Nzoia District in the upper midland (UM4) at an altitude of about 1800m asl with mean annual rainfall of 900-1200 mm and represents 42% of the total agricultural land (Table 2). Both villages are located within the sunflower – maize zone and are inhabited by the Luhya ethnic group. The average farm size is two acres and the major crops are maize-bean intercrop, vegetables, sorghums and finger millets.

Anin sub-location is in Central Division of Keiyo District along the UM3-4 AEZ with an altitude range of 1500-2000m and represents 11% of total agricultural land. The area receives unimodal rainfall with an annual mean of 800-1200 mm. It lies in a sunflower, maize and coffee zone and is inhabited by the livestock keeping Keiyo sub-ethnic group of the Kalenjins. Farm size ranges from 0.4 to 6 acres and the main food crops are maize-bean intercrop, finger millets, sorghums, sweet potatoes and horticultural crops. Cheptuya village is in Kapenguria Division of West Pokot District and is inhabited by the Pokot ethnic group. It lies along the transitional zone of upper midland (UM4,5) with a hot and dry climate in most months of the year receiving mean annual rainfall of 800-1000 mm. The zone represents 17% of the total agricultural land within the district. The area is hilly with slopes of up to 80% that are prone to severe soil erosion. The farmers keep predominantly livestock under extensive grazing systems, but they also grow food crops mainly maize and beans. Chobosta village is in Soy Division of Uasin Gishu District in LH4 at an altitude of about 2000m asl receiving mean annual rainfall of 900-1000 mm. It represents 15% of agricultural land in the district. It is located within the cattle, sheep and barley zone inhabited by the Nandi and Keiyo sub-ethnic groups of the Kalenjins.

In the KARI-Kisii mandate area, the selected sites were Nyamonyo, Otondo, Kamingusa, Bogetario and Nyatieko (Fig. 2 and Table 1, 3) (Mbugua et al., 2000). Nyamonyo Village is in Ogembo Division of Gucha District in the upper midland (UM1) at an altitude of about 1200 - 1700m asl. Bogetorio Village is located in Rigoma Division of Nyamira District in LH1 at an average altitude of about 1850 - 2200m asl. The area has a bimodal rainfall pattern with annual mean rainfall of 1800 mm. Both Nyamonyo and Bogetario are located within the tea/dairy zone and the main crops include tea, maize, common bean (Phaeolus vulgaris), bananas, finger millet, horticultural crops (fruits and vegetables), except for wheat and pyrethrum which are grown only in the cooler highlands of Bogetario. Nyatieko Village is in Mosocho Division on the western side of Manga ridge of Kisii Central District in UM1 at an altitude of about 1600m asl in a coffee/banana zone with annual bimodal rainfall of 1500 – 2000 mm. The first rains are from February with a peak in April and second
Table 1. Characteristics of soil management project study sites in western Kenya

<table>
<thead>
<tr>
<th>Site</th>
<th>District</th>
<th>AEZ</th>
<th>Elevation (masl)</th>
<th>Rainfall (mm)</th>
<th>Soil type</th>
<th>Ethnic group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matunda</td>
<td>Trans-Nzoia</td>
<td>UM₄</td>
<td>1800</td>
<td>900-1200</td>
<td>Humic Ferralsols (sandy loams)</td>
<td>Luhya</td>
</tr>
<tr>
<td>Cheptuya</td>
<td>West Pokot</td>
<td>UM₄,₅</td>
<td>1500-1800</td>
<td>860-950</td>
<td>Cambisols (shallow to deep sandy loams)</td>
<td>Pokot</td>
</tr>
<tr>
<td>Chobosta</td>
<td>Uasin Gishu</td>
<td>LH₄</td>
<td>2000</td>
<td>900-1000</td>
<td>Orthic Ferralsols (red loams with rocky outcrops)</td>
<td>Nandi, Keiyo</td>
</tr>
<tr>
<td>Anin</td>
<td>Keiyo</td>
<td>UM₃,₄</td>
<td>1000-1700</td>
<td>900-1200</td>
<td>Humic Nitisol (Red soils with rocky outcrops)</td>
<td>Keiyo</td>
</tr>
<tr>
<td>Weonia</td>
<td>Trans-Nzoia</td>
<td>UM₄</td>
<td>1800</td>
<td>900-1200</td>
<td>Humic Ferralsols</td>
<td>Luhya</td>
</tr>
</tbody>
</table>

KISII

<table>
<thead>
<tr>
<th>District</th>
<th>AEZ</th>
<th>% of mandate region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nyamonyo</td>
<td>UM₁</td>
<td>1200-1700 1500-1800</td>
</tr>
<tr>
<td>Kamingusa</td>
<td>LM₃</td>
<td>900-1200 750</td>
</tr>
<tr>
<td>Nyatieko</td>
<td>UM₁</td>
<td>1500-1900 1700-1900</td>
</tr>
<tr>
<td>Bogetaorio</td>
<td>LH₁</td>
<td>1900-2200 1400-2100</td>
</tr>
<tr>
<td>Otondo</td>
<td>UM₂,₃</td>
<td>1450-1700 1400-1600</td>
</tr>
</tbody>
</table>

Table 2. Coverage of SMP sites within the KARI-Kitale mandate agricultural land area

Table 3. Coverage of SMP sites within the KARI-Kisii¹ mandate agricultural land area

¹Excluding Transmara District from the KARI-Kisii mandate region

Season in September with a peak in October. The Abagusii ethnic group inhabits Nyamonyo, Bogetaorio and Nyatieko villages. The land tenure is individual ownership with title deeds. Average farm size is 0.2 – 2 ha. Nyamonyo and Nyatieko represents 12% of the total agricultural land area in the KARI-Kisii mandate region and Bogetaorio represents 15%. Kamingusa Village is in Kendu Bay Division of Homa Bay District and lies in the lower midland (LM3) zone along the shores of Lake Victoria at an altitude of 900-1200m representing 18% of the land area in the region. The soils are variable, ranging from Cambisols on top of the hills, to Vertisols on the lower parts towards the lake. The average rainfall is 750 mm falling in bimodal pattern with long rains starting in February to July and short rain from August to October which is erratic. The major crops grown during the long rains include cotton (Gossypium girsutum), maize, common beans, sorghum, sweet potatoes, groundnuts and local and exotic vegetables. Sweet potatoes and cassava (Manihot esculenta) are grown during the short rains. Otundo Village is in Kabondo Division of Rachuonyo District and is located in the transitional coffee agro-ecological zone upper midland (UM2-3) at an altitude of 1450-1700m asl and is characterized by bimodal rainfall, with average annual rainfall of 1400 – 1600 mm. It represents 0.8% of the mandate region. Otundo Village has predominantly Nitisol soils. Both Otundo and Kamingusa are inhabited by the Luo ethnic community.

Farmers in the study sites are fairly homogenous in socio-economic characteristics and could easily be grouped into broad recommendation domains such as, 1) farmers with low income but with adequate labour and materials for compost making, 2) crop-livestock mixed farmers who own at least 1-2 heads of cattle and have FYM available on their farms and 3) farmers who have cash crops or other source of income that can afford to use inorganic fertilisers.
4.0 Farmer participatory research (FPR) methodology

To ensure greater involvement of farmers and other stakeholders in technology evaluation and dissemination, the FPR approach was adopted. Participatory approaches can empower farmers to overcome the socio-economic constraints at the farm level that limit the adoption of technologies (Noordin et al., 2001). The main features of FPR include problem diagnosis, respect for the capability of people to produce and analyse knowledge, the commitment by researchers to involve the community and the recognition that research is an educational process for researchers and the community (Farrington and Martin, 1988). The aim of FPR is to empower the community to use their own indigenous technical knowledge and capacity to learn, adapt and do better. The approach starts with an analysis by clients, placing greater emphasis on the farmers’ own capacity to solve their own problems using participatory methods and tools. The FPR focuses on groups of farmers (i.e. farmer research groups and expert panels) instead of individual farmers during the implementation of research and dissemination activities so as to enhance sharing of ideas leading to greater impacts and adoption of technologies. Participatory Rural Appraisal (PRA) techniques and tools were used to 1) understand the main characteristics and farming systems of the communities in project sites, 2) diagnose and prioritise crop and livestock production constraints and 3) identify and prioritise opportunities and potential solutions to address those constraints using problem and cause analysis techniques. The farmers were also actively involved in testing and evaluating the identified interventions.

The project adopted a multi-institution and multi-disciplinary approach because declining soil fertility is affected by different components of the farming system. Apart from involving other stakeholders such as the MOALD and local NGOs, the project involved researchers from different disciplines. Four sites were selected within KARI-Kitale and four within KARI-Kisii mandate areas. As recognized by Nabasa et al., (1995), the PRA approach was useful in involving farmers during initial exploration stages of the project when it was vital to learn as much as possible about the farmers’ production system. The approach enhanced information flow and linkage between stakeholders (farmers, government extension officers, research scientists and NGOs) and encouraged a holistic review of constraints to productivity. Efforts were made to involve farmers in the management, monitoring and evaluation of the trials. Scoring and ranking using farmers own criteria were used to evaluate treatments.

The holistic approach taken during PRAs raised issues that were beyond the mandate of the SMP research team. These included infrastructure such as roads, water, health care, schools and markets. Efforts were made to link the communities with agencies, which could assist them. The interest and
involvement of farmers in the research process tended to diminish after the diagnostic stage. Regular contact between the research team and the farming communities was difficult to sustain because of limited resources, especially human and time (Mbugua et al., 2000). To enhance farmer interest and involvement during the implementation stage, there was need to retrain researchers on FPR techniques that could actively involve farmers in all stages of technology development and to empower them to have greater influence on priorities and decisions in the research process. With support from the CIAT FPR project, known as participatory research in agro-ecosystems management (PRIAM), initiatives were made to develop and refine FPR methods (Mureithi et al., 2000b). This included retraining scientists on FPR and initiation of FPR research activities in two new sites to test their understanding of the FPR concepts. The new sites were Weonia (Trans-Nzoia District) in Kitale and Nyatieko (Kisii Central District) in Kisii mandate region. In these new trial sites Farmer Research Committees (FRCs) were formed to 1) visit farmers regularly to monitor progress of the trials, 2) hold regular meetings with research teams to discuss progress of the trials and 3) convene regular farmers meetings to discuss other developmental issues. The active participation of farmers in these new sites confirmed that farmer involvement is a critical ingredient for innovative, relevant and effective agricultural research and technology development and dissemination in agreement with Noordin et al., (2001).

The FPR training also enhanced farmers’ understanding on different aspects of experimentation (choice of treatments, value of controls, site selection, plot size, replication, management of the trial and measurements). This helped demystify agricultural research for farmers. The retraining also improved the skills of the research teams in applying PRA tools and was an eye-opener for researchers to see how empowering farmers can generate sustainable farmer commitment. All possible modifications were done to the other on-going SMP activities to accommodate greater farmer participation.
5.0 Technology options

5.1 Nutrient Sources

The main sources of plant nutrients in Kenya are inorganic and organic fertilisers. The limited supply or inaccessibility of both inorganic and organic nutrient sources is a major determinant of soil fertility improvement strategies used by farmers. Therefore, proper management of organic resources and use of appropriate type of inorganic fertilisers is a prerequisite for improved soil productivity.

5.1.1 Inorganic fertilisers

Inorganic fertilisers are mainly from mineral ores and contain high levels of nutrient elements that are readily soluble and available to plants. Inorganic fertilisers available on the Kenyan market are of two types, namely straight and compound. Straight fertilisers contain one nutrient whereas compound ones contain two or more nutrients. Fertiliser grade is represented as %N, %P (P₂O₅), and %K (K₂O). The most common used straight and compound fertilisers in Kenya are shown in Table 4. The Fertiliser Use Research Project of Kenya developed recommended inorganic fertiliser rates for regions in Kenya including western Kenya (Muriuki and Qureshi, 2001).

Use of inorganic fertilisers is limited because they are expensive relative to incomes of the majority of financially constrained smallholder farmers. Other factors contributing to low mineral fertiliser usage by smallholder farmers include 1) inefficient distribution systems resulting to long distances to stockists and retailers, 2) lack of appropriate fertiliser packages for smallholder farmers, 3) widespread subsistence farming among smallholders leading to low purchasing power and 4) lack of awareness and benefits to be realized from fertiliser applications. In some instances, even when the government imports fertilisers, they are distributed and sold by middlemen stockists and retailers at unnecessarily higher prices because of market liberalisation. When stockists repackage the fertilisers in small packages, there are possibilities of fertiliser adulteration and deterioration and increased costs due to extra labour and inaccurate weights.

5.1.2 Farmyard and compost manures

Cattle manure is an integral component of soil fertility management in many areas of the tropics and its importance as a source of nutrients for crop production is widely recognized (Bationo and Mokwunye, 1991; Powell and Williams, 1995). PRA surveys conducted in western Kenya showed that farmers


Table 4. The most commonly used straight and compound inorganic fertilisers in Kenya

<table>
<thead>
<tr>
<th>Fertiliser name</th>
<th>Element (S) supplied</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Straight fertilisers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium sulphate (SA)</td>
<td>Nitrogen</td>
<td>21% N (NH₄), 24% S</td>
</tr>
<tr>
<td>Calcium ammonium nitrate (CAN)</td>
<td>Nitrogen</td>
<td>26% N (NH₄⁺, NO₃⁻), 15% S</td>
</tr>
<tr>
<td>Urea</td>
<td>Nitrogen</td>
<td>45-46% N (NH₄)</td>
</tr>
<tr>
<td>Single Super Phosphate (SSP)</td>
<td>Phosphorous, Sulphur</td>
<td>21% P₂O₅ (water soluble), 9% S</td>
</tr>
<tr>
<td>Triple Super Phosphate (TSP)</td>
<td>Phosphorous</td>
<td>43-46% P₂O₅ (water soluble)</td>
</tr>
<tr>
<td>Phosphate rock (quality depends on the source)</td>
<td>Phosphorous</td>
<td>30% P₂O₅ (citrate soluble)</td>
</tr>
<tr>
<td>Muriate of Potash (MOP)</td>
<td>Potassium</td>
<td>60% K₂O</td>
</tr>
<tr>
<td>Sulphate of Potash</td>
<td>Potassium, Sulphur</td>
<td>50% K₂O, 17% S</td>
</tr>
<tr>
<td>Lime (calcium carbonate)</td>
<td>Calcium</td>
<td>56% CaO</td>
</tr>
<tr>
<td>Magnesium carbonate</td>
<td>Magnesium</td>
<td>63-94% MgO</td>
</tr>
<tr>
<td><strong>Compound fertilisers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Di-ammonium phosphate (DAP)</td>
<td>Nitrogen, Phosphorous</td>
<td>18% N (NH₄), 46% P₂O₅ (water soluble)</td>
</tr>
<tr>
<td>Mono-ammonium phosphate (MAP)</td>
<td>Nitrogen, Phosphorous</td>
<td>11% N (NH₄), 52% P₂O₅ (water soluble)</td>
</tr>
<tr>
<td>20:20:0</td>
<td>Nitrogen, Phosphorous</td>
<td>20% N (NH₄), 20% P₂O₅ (citrate soluble)</td>
</tr>
<tr>
<td>20:0:10</td>
<td>Nitrogen, Potassium</td>
<td>20% N (NH₄), 10% K₂O</td>
</tr>
<tr>
<td>23:23:0</td>
<td>Nitrogen, Phosphorous, Potassium</td>
<td>23% N (NH₄), 23% P₂O₅</td>
</tr>
</tbody>
</table>

1 Source: Muriuki and Qureshi, 2001

rely on organic manures as low cost and easily available alternatives to inorganic fertilisers (KARI-Kitale, 1995; KARI-KISII, 1994). The quantity and quality of manures available on smallholder farms are the major factors limiting its contribution. The use of FYM requires that farmers own livestock as the market for it is thin because of inadequate amounts available and partly because of inadequate knowledge on its benefits (Mose et al., 2003). One dairy cow produces 4 kg DM (Nyambati, 2002) that is equivalent to 1.5 t DM/yr. A farmer who has only two heads of cattle could have about 2 t/yr of cattle manure if collected and stored well to ensure 70% recovery, which is low compared to the recommended rate of 10 t/ha. Improving the diets of cattle by supplementation using legume herbage has the potential to provide an additional 208 kg cattle manure DM/yr that could supply 5 kg N, 0.6 kg P, 0.53 kg K, 1.4 kg Mg, and 5.5 kg Ca/yr (13 kg of nutrients/yr) (Nyambati and Sollenberger, 2003).
Composting is a low-cost processing method for improving the handling and quality of organic residues/wastes through biological decomposition. Compost can be made from a wide range of organic materials including plant residues (such as maize stover, bean straw, grass trash, tree/hedge cuttings, banana pseudostems), animal manures and kitchen wastes. Composting reduces the bulkiness and enhances the release of nutrients contained in organic materials and wastes. The material used, degree of decomposition and storage method used influence the availability of plant nutrients from compost. Application of compost is known to improve the physical, chemical and biological properties of soils. The option of using compost was selected by researchers in SMP because most smallholder farmers own none or 1-2 cattle, which cannot produce adequate amount of FYM required for crop production, whereas the materials used for composting are available in most farms and do not involve cash. However, composting is labour intensive and where labour is limiting, inadequate amounts are prepared. An adoption survey conducted in the region (Mose et al., 2003) showed that farmers modified compost preparation, and FYM/compost storage and their rates of application to save on the extra labour required.

Nutrient analysis of the manures (Table 5) show that 5 t/ha cattle manure can supply approximately 58 kg N, 11 kg P, 39 kg K, 44 kg Ca and 13 kg Mg/ha, but this potential particularly for N, K, Ca and Mg varies across farms. Crop responses to decomposed or non-decomposed manure application may be due to increases in soil pH, N, P, cations such as Ca and Mg or to physical effects of additional soil organic matter on water infiltration and retention. However, the responses to cattle manure application are highly variable due to differences in the chemical composition of the manures and the rates and frequency of manure application. The chemical composition of cattle manures differs because of variation in animal diet and manure storage. Poor storage conditions may result in ammonia losses through volatilisation and leaching of nitrate. A survey in Cheptuya Village of West Pokot District to determine how livestock and manure management practices (stocking rate, feeding, collection, composting and storage) affect the quality of the manure for crop production indicated that collecting boma manure and just heaping it on the soil surface resulted in very low quality manure (Wanjekeche et al., 1999). The organic C ranged between 3.9 and 5.6 g/kg, while phosphorus ranged between 0.02 and 3.1 g/kg, which were lower than that from smallholder farms in Kipsaina in Trans-Nzoia District (Nyambati, 2002) (Table 5). Nitrogen concentration followed similar ranges as those of organic C. The difference in organic C and N between the sites could be due to differences in cattle diets, methods of collection and storage, degree of decomposition, and handling conditions of the manures. Phosphorus, organic C and N concentrations did not fluctuate much between farms, but there is a wide variation in the concentrations of K, Ca, and Mg of the manures.
Table 5. Nutrient concentration of organic manures in farmers fields in western Kenya

<table>
<thead>
<tr>
<th>Organic nutrient source</th>
<th>Site</th>
<th>pH 2.5:1H₂O</th>
<th>N</th>
<th>P</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FYM</td>
<td>Kipsaina¹</td>
<td>-</td>
<td>11.6 (6.2-13.8)</td>
<td>2.2 (1.2-2.9)</td>
<td>8.8 (4.7-11.5)</td>
<td>2.6 (0.94-4.0)</td>
<td>7.8 (6.9-14.2)</td>
<td>116 (62-138)</td>
</tr>
<tr>
<td>FYM</td>
<td>Cheptuya²</td>
<td>8.5 (8.0-8.9)</td>
<td>4.3 (3.9-5.6)</td>
<td>1.7 (0.02-3.1)</td>
<td>10.9 (0.2-20.8)</td>
<td>1.0 (0.3-1.5)</td>
<td>5.9 (0.04-10.3)</td>
<td>42.5 (39-56)</td>
</tr>
<tr>
<td>Compost</td>
<td>Bogetario³</td>
<td>7.4 (7.2-7.6)</td>
<td>-</td>
<td>0.053 (0.033-0.075)</td>
<td>9.0 (9.0-9.0)</td>
<td>0.6 (0.24-0.97)</td>
<td>5.5 (4.5-6.1)</td>
<td>59 (58-61)</td>
</tr>
<tr>
<td>Green manure⁴</td>
<td>Kipsaina¹</td>
<td>-</td>
<td>22.1 (31-40)</td>
<td>2.2</td>
<td>15.9</td>
<td>5.3</td>
<td>11.0</td>
<td>-</td>
</tr>
<tr>
<td>Titthonia transfer</td>
<td>Matunda, Kakamega</td>
<td>-</td>
<td>35 (31-40)</td>
<td>3.7 (2.4-5.6)</td>
<td>18</td>
<td>4</td>
<td>41 (27-48)</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: ¹ Nyambati (2002); ² Wanjikeche et al., (1999); ³ Okoko and Makworo (2003a); ⁴ From Mucuna and Lablab; ⁵ Other quality parameters are Lignin = 120 g/kg, total extractable polyphenol (TEP) = 16 g/kg (Jama et al., 2000), the analysis was done by ICRAF, Maseno.
The review presented above show clearly that with proper management farmyard manure could have positive impact on the nutrient dynamics of low-input farming systems. With this in mind, training workshops were held to expose farmers to recommended management practices of composting and FYM handling in an effort to standardize the quality of the manures used.

5.1.3 Green manures

In recent years, there has been a resurgence of interest from the scientific community in leguminous green manure/cover crops in many parts of the tropics where the use of commercial inorganic N fertilisers is not economically feasible. They are used not only as a cheap source of biologically fixed N, but also for improving soil physical and biological properties, protection of soil against erosion, build up and maintenance of soil organic matter, and suppression of weeds as well as reducing the labour required for the following crop. In addition, they conserve water when used as cover crop mulch, have no application cost and can partly be a source of high quality feed.

Research on green manure in western Kenya started with initial screening trials in 1995 to find best bet species in terms of outstanding characteristics (i.e. nodulation, DM and groundcover), optimum planting dates, potential uses/niches for the best performing species and adaptability in different regions (Kirungu et al., 2000; Maobe et al., 2000). Kirungu et al., (2000) screened a total of 33 species and results showed that most species exhibited effective nodulation with sunnhemp (Crotolaria juncea, C. ochroleuca), mucuna, Vicia spp and soybean having the most effective nodulation (> 26 nodules/plant). For soil fertility improvement in rotations or as improved fallows, long-lived annuals and perennials such as mucuna, jackbean (Canavalia ensiformis), lablab, green leaf desmodium (Desmodium intortum), stylo (Stylosanthes guianensis) that can accumulate significant DM in 4-6 months were recommended. Those that were recommended for use as food legumes included soybean, field peas (Pisum sativum ssp arvence) and lablab. The short-lived (3-6 months) annuals such as vetches, field peas and sunnhemp that can produce large amounts of DM in 2-3 months were recommended for in-season and quick rotation green manures. Species that can survive the 3-4 month dry season in northwestern Kenya include mucuna, lablab, jackbean, sunnhemp and lupins (Lupinus luteus).

Maobe et al., (2000) evaluated 42 herbaceous legumes in south-west Kenya for emergence, vigor and ground cover, nodulation, N-fixation, pest and disease incidence and DM. Planting and harvesting dates corresponded to the niches for incorporation of the species into the farming systems. Emergence and early vigor of most species ranged from good to excellent and groundcover at 2 to 3 months after planting was in the range of 60% or over. Species differed in nodulation (number and size) and N-fixation activity and in DM yield. DM yield was
influenced by planting date and period of persistence. Based on DM and multiple usages the five best species were lablab, sunhemp, mucuna, lana vetch (*Vicia darycarpa*), and Trapper peas(*Pisumsativum*).

In north-western Kenya, relay cropped green manures could yield up to 2.3 t DM ha\(^{-1}\) with a potential of providing 65 kg N, 6 kg P, 28 kg K, 48 kg Ca and 14 kg Mg/ha (Nyambati, 2002), suggesting that if higher biomass can be attained, their potential of contributing nutrients is greater than from cattle manure or compost when their quality is not limiting. When green manures were grown as short season fallows in rotation with maize, the biomass yields were higher, ranging from 2.6 - 5.4 t/ha (Ojiem *et al*., 2003) contributing 75 - 148 kg N/ha. Another potential source of nutrients, particularly P, that has been used in western Kenya is tithonia (Jama *et al*., 2000; Table 5). Tithonia is a shrub that grows wild in western Kenya and the use of 2 t/ha can supply about 70 kg N, 7.4 kg P, 82 kg K, 36 kg Ca and 8 kg Mg/ha. The lignin and total extractable polyphenol concentrations of 120 and 16 g/kg respectively, are below the critical ranges that significantly reduce decomposition. Although when green manure legumes grown as relay intercrops have a lower N yield potential than in rotations, the land and labour use may be more efficient and the system is flexible around farmer needs. The challenge is how to integrate these legume green manures into the current production systems.

5.2 Crop and fodder responses to organic and inorganic sources of nutrients

Research on the effect of FYM and compost as alternatives or supplements to inorganic fertilisers on crops formed the backbone of the SMP activities in phase one. The application of FYM or compost alone or in combination with inorganic fertilisers on important crops in the region, namely maize, kales, cabbages, indigenous vegetables, finger millets, sorghums and Napier grass was evaluated across 10 sites from 1995 to 1999 with the aim of identifying low-cost sustainable options for improving and maintaining soil fertility.

5.2.1 Maize

*Farmyard and compost manures*

In northwestern Kenya, application of the recommended rates of compost (10 t/ha) FYM or and half the recommended inorganic fertiliser rate (30 kg P\(_2\)O\(_5\) + 30 kg N/ha) combined with half recommended rates of FYM or compost were evaluated on maize production against the recommended inorganic fertiliser rate, farmers practice and non-fertilized control (Kamidi *et al*., 1999; 2003; Kiiya *et al*., 2000; Onyango *et al*., 2003a). The treatments evaluated were: 1) 10 t/ha FYM, 2) 10 t/ha compost, 3) 60 kg P\(_2\)O\(_5\) + 60 kg/ha N 4) 5 t/ha FYM + 30 kg P\(_2\)O\(_5\) + 30 kg N/ha 5) 5 t/ha compost + 30 kg P\(_2\)O\(_5\) + 30 kg N/ha, 6) 30 kg P\(_2\)O\(_5\) + 30 kg N/ha, 7) farmers practice and 8) non-fertilised control. Across many sites,
the results show that when half the recommended rate of FYM or compost was combined with half the recommended rates of inorganic fertilisers, the maize grain yields were higher than the non-fertilised control and were comparable to the recommended rate of inorganic fertilisers (Table 6; Figure 3). The combined treatments increased maize grain yields by 68% over the non-fertiliser control. The inconsistent and sometimes low response when FYM and compost were applied alone could be attributed to the varying and sometimes low nutrient concentrations of the organic sources depending on how the FYM was collected and stored, and on what materials were used in making the compost. The low responses to FYM could also be attributed to immobilisation of nutrients. The results show that FYM or compost can substitute or supplement the inorganic fertilisers, which can also cause poor germination due to seed scorching in areas that receive erratic rainfall. Also the FYM and compost are potentially high in pH and organic C that are essential in soil fertility improvement and its maintenance.

Table 6. Mean maize grain yield (t/ha) across five years in five sites\(^1\) after application of various organic and inorganic fertiliser treatments in northwestern Kenya

<table>
<thead>
<tr>
<th>Fertiliser Treatments</th>
<th>Mean maize grain yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 kg P(_2)O(_5) + 60 kg Na/ha</td>
<td>7.2(^{\text{a}})</td>
</tr>
<tr>
<td>10 t/ha compost</td>
<td>6.9(^{\text{ab}})</td>
</tr>
<tr>
<td>5 t/ha compost + 30 kg P(_2)O(_5) + 30 kg N/ha</td>
<td>6.7(^{\text{ab}})</td>
</tr>
<tr>
<td>30 kg P(_2)O(_5) + 30 kg N/ha</td>
<td>6.2(^{\text{abc}})</td>
</tr>
<tr>
<td>5 t/ha FYM + 30 kg P(_2)O(_5) + 30 kg N/ha</td>
<td>5.7(^{\text{bc}})</td>
</tr>
<tr>
<td>10 t/ha FYM</td>
<td>5.3(^{\text{cd}})</td>
</tr>
<tr>
<td>Farmer practice(^2)</td>
<td>4.4(^{\text{de}})</td>
</tr>
<tr>
<td>Non – fertiliser control</td>
<td>3.7(^{\text{e}})</td>
</tr>
<tr>
<td>CV</td>
<td>14.6</td>
</tr>
<tr>
<td>P value</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

\(^{abcde}\) Means followed by different letter superscript within a column are significantly different (P < 0.05)

\(^1\) The sites were Matunda, Weonia, Cheptuya, Chobosta and Anin

\(^2\) Farmers used suboptimal fertiliser application rates and some used low quality FYM at suboptimal levels.
Maize grain yields from farmers’ practice treatment suggest that over time there was an increase from 2 t/ha to 4 t/ha. Evaluations by farmers in Matunda site using their own criteria showed that they recognized the effect of organic manure on other soil characteristics such as soil tilth apart from their effect on crop performance.

In southwest Kenya, six treatments that were modified from those in northwest Kenya to include higher rates of organic manures combined with lower rates of inorganic fertilisers were evaluated (Okoko and Makworo, 2003a; Nzabi et al., 2003). The treatments were: 10 t/ha compost/FYM, 10 t/ha compost/FYM + 15 kg P\textsubscript{2}O\textsubscript{5} + 15 kg N/ha, 10 t/ha compost/FYM + 30 kg P\textsubscript{2}O\textsubscript{5} + 30 kg N/ha, 60 kg P\textsubscript{2}O\textsubscript{5} + 60 kg N/ha, 50 kg P\textsubscript{2}O\textsubscript{5} + 70 kg N/ha and farmers practice. At Bogetaoario (Okoko and Makworo, 2003a), combining 10 t/ha compost with half (30 kg P\textsubscript{2}O\textsubscript{5} + 30 kg N/ha) or quarter (15 kg P\textsubscript{2}O\textsubscript{5} + 15 kg N/ha) recommended inorganic fertiliser resulted in mean yield increase from 3.9 under farmer practice and 3.8 t/ha under 10 t/ha FYM to 4.9 t/ha, which was similar to 4.7 t/ha when the recommended rate of inorganic fertiliser was used alone (Figure 4). However, yield increases over the seasons when compost was used could not be attributed to the residual effects since the inorganic fertiliser treatments also resulted in similar increases.

These results suggest that the amount of inorganic fertiliser combined with 10 t/ha compost could be reduced to a quarter of the recommended rate. Farmers preferred the combination and economic analysis showed that the benefit cost ratio was greater than 2, suggesting that farmers can make profit by using these technologies. At Nyamonyo and Nyatieko sites in southwest Kenya (Nzabi et al., 2003), either compost or FYM was used and treatments included a FURP recommendation of inorganic fertiliser (50 kg P\textsubscript{2}O\textsubscript{5} + 75 kg N/ha). The combined organic and the half or quarter inorganic treatments yielded similar maize grain (3.0 and 3.3 t/ha for quarter and half inorganic fertiliser treatments, respectively) as those when the recommended inorganic fertilisers were applied alone (3.4 and 3.6 t/ha for FURP and non-FURP, respectively) in agreement with Okoko and Makworo (2003a). Although economic analysis showed the organic/inorganic fertilisers had higher gross margins, it was argued if farmers have their own organic manures, the gross margin of the combinations could be higher than that of inorganic fertilisers alone.

Green manure legumes relay-intercropping
Intercropping of soil improving legume green manures with cereal crops is a promising, low-cost, ecological means of improving soil fertility. Research trials were conducted to introduce the green manures into the cropping systems and determine their soil improvement potential.
Fig. 3. Changes in maize grain yields (t/ha) in five sites after application of various organic and inorganic fertiliser treatments
Evaluation of the potential for green manure [Mucuna, lana vetch (*Vicia dasycarpa*), trapper pea (*Pisumsativum*) and desmodium] use in the production of small grain cereals (finger millet or wheat) showed that the presence of the legume as an intercrop with finger millet did not depress straw yield, but lana vetch significantly increased the straw yield (3.9 t/ha) than the monocrop control (2.4 t/ha) (Maobe *et al.*, 1999). The intercrop legumes also did not depress the grain yield except under the lana vetch where the yield was lower (1.4 t/ha) than the monocrop control (1.8 t/ha) probably because of competition for soil moisture and other nutrients apart from N. When the legumes were grown in wheat intercrops, the wheat grain and legume DM yields followed similar trend as in finger millet. At the time of harvesting finger millet, the persistence of the legumes were in the order of mucuna > lana vetch > trapper pea > silverleaf desmodium, suggesting that velvetbean and lana vetch could be used for producing green manure for millet/wheat rotation cropping systems. However, the use of these organic residues alone may not be sufficient to overcome both N and P deficiencies. The integration of small amounts of inorganic P and green manure legumes offers a strategy to meet both N and P requirements of crops (Jama *et al.*, 1997).
The potential of relay green manures as alternatives to dry season natural weed fallow for sustaining soil productivity in the maize – bean intercrop system was tested in the sub-humid highlands of western Kenya. Combined use of green manure [mucuna, soyabeans, lablab, sunhemp and cowpeas (*Vigna unguiculata*)] and half the recommended rate of inorganic fertilisers significantly increased maize grain (6 to 7 t/ha) compared to the farmers’ practice control (4.8 t/ha) (Kamidi *et al*., 1999; 2003). This response was similar to when compost/FYM was used in combination with half the recommended rate of inorganic fertilisers (7 t/ha) (Kiiya *et al*., 2000). Farmer evaluations based on their own criteria [biomass yield (Table 7), drought tolerance, ease of incorporation, weed control, and maize response], ranked the green manures in the following order: mucuna > crotalaria > soyabean > lablab > cowpeas. However, the results on the combined use of green manure and inorganic fertilisers are non-conclusive because the time of planting the green manures varied, and the application of inorganic fertilisers was not consistent across the years of evaluation.

Nyambati *et al* (2002) evaluated mucuna and lablab as relay intercrops for both soil fertility improvement and as supplementary feed for livestock when either whole or part of the biomass was incorporated, compared to cattle manure, inorganic N, and natural weed fallow. Defoliation of the top canopy of legumes was included as a treatment to mimic controlled grazing. On farmers’ fields, undefoliated mucuna yielded more biomass (2.3 t/ha, mean of two seasons) than undefoliated lablab (0.8 t/ha). Nitrogen contribution ranged from 6 kg/ha in defoliated lablab to 65 kg/ha in undefoliated mucuna treatment. Above ground fraction of both undefoliated mucuna and undefoliated lablab contributed the highest amount of N (88 and 80%, respectively) compared to roots, which contributed 7.8 and 8.4%, respectively. Relative to the controls, undefoliated mucuna, defoliated mucuna, and undefoliated lablab resulted in 52, 34, and 14% increase in subsequent maize grain yield compared to the natural fallow where no N was applied. Defoliation at 10 cm above ground provided an average of 1 and 1.8 t/ha of mucuna and lablab fodder, respectively, that was of high CP (130 and 111 g/kg, respectively) and digestibility (617 and 693 g/kg, respectively). These yields were 52 and 76% of the above-ground herbage, respectively, suggesting that the upper canopy herbage had potential as dry-season protein supplement, but this practice significantly reduced the quantity of nutrients that were returned to the soil. However, defoliation of top-canopy biomass resulted in the incorporation of intermediate quality (low N and P, high lignin) residues extending the period of nutrient availability to succeeding maize, resulting in increased efficiency of N recovery due to reduced losses.

Relay-cropping green manures (sunnhemp, mucuna and lablab) into maize after harvesting various food legumes (common bean, soyabean, groundnuts and cowpeas), Onyango *et al*. (2003b) showed that the green manures produced low
dry matter yields ranging from 0.4 to 2.8 t/ha (Table 7). The incorporation of the legume biomass resulted in significant grain yield increases of subsequent maize compared to non-fertiliser control. After one year of residue application, the mean maize grain yield under green manure treatments (7.8 t/ha) was 44% greater than the non-fertiliser control, and was comparable to the recommended fertiliser treatments (8.5 t/ha). The maize grain after two years of residue application followed a similar trend in which green manure residue treatments resulted in a mean of 7.0 t/ha, that was 30% higher than the non-fertilized control. This may suggest that residual effect of applied legume biomass is minimal. Grain yields of subsequent maize after lablab, mucuna and sunnhemp residue applications were 8.1, 6.2 and 6.1 t/ha, respectively, compared to 7.3 t/ha for recommended inorganic fertiliser. Grain yields of common bean, soyabean and groundnuts were 225, 241 and 90 kg ha⁻¹, respectively, showing that soybeans could be a suitable alternative to common bean in the maize intercrop. Green manures grown in rotation during the short season at Kakamega had the potential of producing higher residue biomass ranging from 2.6-5.4 t/ha contributing 75-148 kg N/ha resulting in 1.5 t/ha maize increases (Ojiem et al., 2003). The combination of green manure with inorganic N at a rate of 15-30 kg N/ha increased yields further by 2.5 t/ha, while the combination of FYM and 30 kg N/ha increased maize grain yield by 1 t/ha, suggesting that the integration of green manure or FYM with reduced inorganic sources of N has the potential to increase maize grain yields.

Table 7. Mean dry matter yields of aboveground biomass of green manures relay – cropped in the maize - common bean intercrop system in northwestern Kenya

<table>
<thead>
<tr>
<th>Species</th>
<th>DM (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucuna (Mucuna pruriens)</td>
<td>1.6</td>
</tr>
<tr>
<td>Lablab (Lablab purpureus)</td>
<td>1.4</td>
</tr>
<tr>
<td>Sunnhemp (Crotolaria ochloreuca)</td>
<td>1.9</td>
</tr>
<tr>
<td>Cowpeas (Vigna unguiculata)</td>
<td>0.8</td>
</tr>
<tr>
<td>Soyabean (Glycine max)</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Tithonia biomass plus rock phosphorus (RP)

In addressing P deficiency constraint on Nitisol soils in Bogetario, Nyamonyo and Nyatike, Obaga et al (2003) evaluated 10 t/ha FYM in combination with 200 kg/ha Minjingu RP (a cheap and readily available source of P from Tanzania), combination of 1-2 t/ha tithonia (*Tithonia diversifolia*) biomass and 200 kg/ha. Minjingu RP, 1-2 t/ha tithonia biomass and 10 t/ha FYM as alternative P sources compared to the recommended inorganic fertiliser rate (60 kg P$_2$O$_5$ + 60 kg N/ha) and farmers’ practice. Combining either FYM at 10 t/ha or 1-2 t/ha tithonia biomass with 200 kg/ha Minjingu RP gave comparable maize yields to application of the recommended inorganic fertiliser rate of 60 kg P$_2$O$_5$ + 60 kg N/ha. Similar results were obtained in Uasin Gishu district at Chepkoilel [Rhodic Ferralsol soils with a pH (1:2.5 soil:water) of 5.01, organic carbon of 1.86%, total N = 0.2% and available P (Olsen) = 5.4 mg/Kg] where a combination of various rates of Minjingu RP and various levels of tithonia biomass showed that a combination of 200 kg/ha RP plus 2 t/ha tithonia was the most effective in increasing maize grain yields (Ndungu and Okalebo, 1999). A combination of 20 kg RP with 30 kg N/ha was the most effective for common bean because of increased grain yield by 67% (Njeri and Okalebo, 1999) on acid and low fertility soils. Although RP has long residual effect and slow release of P that sustains high crop yields (Nyambati, 1999), it can be insoluble in neutral soils, hence the need for addition of organic residues to partly solubilise it. In addition to releasing N and other nutrients after organic residue decomposition, the presence of P increased N uptake by maize. But these results were not conclusive because they were of one season only. The positive effects of combining RP might with organic sources of N showed that the application of organic materials may increase crop-available P either directly by the process of decomposition and release of P from the biomass or indirectly by the production of organic acids (products of decomposition) that chelate Fe or Al, reducing P fixation (Nziguheba *et al.*, 1998). Another possible option of increasing the solubility of RP is to blend it with soluble P fertilisers such as TSP (Ngoze *et al.*, 2003).

5.2.2 Vegetables

Both exotic (i.e. kales-*Brassica oleracea* Var. Acephalla and cabbages-*Brassica oleracea* Var. Capitata) and indigenous (i.e. Black nightshade-*Solanum nigrum*, Spider flower-*Gynandropsis gynandra*, cowpea-*Vigna unguiculata*, Mito-*Crotonalria brevidens*) vegetables are popular in many smallholder households. These vegetables are nutritious and rich in β-carotene, minerals such as iron and calcium and protein especially essential amino acids. They are also a source of constant cash for resource poor farmers. However, farmers realize low vegetable yields due to declining soil fertility. The effect of compost application at 10 t/ha was compared to inorganic fertiliser (200 kg DAP) or compost (10 t/ha) combined with reduced levels of DAP (50 kg DAP or 100 kg DAP), and a non-fertilised control on yields of black nightshade (Onyango, 2003). The yields from
the combined application of compost and inorganic fertiliser were not different from when 200 kg DAP was applied, but was higher than from compost alone or the unfertilised control. The yields ranged from 2 t/ha in the no fertiliser plots to 7 t/ha in the fertiliser combination plots. These positive effects of the fertiliser combination treatments were attributed to the readily available P, which could enhance root growth and establishment and the organic manure that could have prolonged the harvesting period resulting in higher yields.

Okoko and Makworo (2003b) evaluated a wider range of fertiliser treatments that included 20 t/ha FYM either alone or combined with 15 kg/ha P$_2$O$_5$ + 15 kg N/ha or 30 kg/ha P$_2$O$_5$ + 30 kg N/ha and farmer practice on two local vegetables. The yields obtained showed similar trend as that of Onyango (2003) where the combinations of organic and inorganic fertilisers yielded the same as inorganic fertiliser and higher than the control. The fresh leafy yields ranged from 0.61 t/ha (for control) to 9.16 t/ha (inorganic fertiliser) for spider flower and 2.6 t/ha (control) to 9.2 t/ha (inorganic fertiliser) for black nightshade. The rates of organic and inorganic fertilisers in the Onyango (2003) and Okoko and Makworo (2003b) trials were not uniform. The effects of more organic manures (compost, FYM, tithonia green manure) were evaluated alone or in combination with inorganic fertilisers on the yield of exotic vegetables (cabbages and kales) (Rono et al., 2003). The fertiliser treatments increased the yield of cabbages at Anin by 274% from 11.5 t/ha when no fertiliser was used to an average of 43 t/ha when 10 t/ha compost/FYM was used alone or 5 t/ha compost/FYM was combined with 30 kg P$_2$O$_5$ + 30 kg N/ha. Similar increases were observed for kales in Matunda where the yields increased by 134% from 23 t/ha when no fertiliser was used to 54 t/ha when either 25 t/ha tithonia transfer biomass or a combination of 5 t compost + 30 kg P$_2$O$_5$ + 30 kg N/ha was used.

5.2.3 Sorghums and Millets

Finger millet is a hardy low-input small grain cereal that is planted by many communities in western Kenya as an insurance against crop failure. Because of the popularity of maize, little research effort has been directed to finger millet improvement and as a result yields on farmers fields are low (0.5 to 0.9 t/ha) compared to a potential of 5.8 t/ha (M’Ragwa, 1986). A study was conducted in Chobosta in northwest Kenya over two seasons to evaluate the effectiveness of low levels of P, N, and compost/FYM (12 kg P$_2$O$_5$ + 12 kg Na/ha and 2.5 t/ha compost/FYM) and their combinations compared to recommended rates of inorganic fertiliser (25 kg P$_2$O$_5$ + 25 kg N/ha) and compost (5 t/ha) (Kute and Chirchir, 2003). The combination of low rates of organic and inorganic fertilisers increased grain yields by 82% from 1.8 t/ha in the no fertiliser control to 3.3 t/ha, which was comparable to when the recommended rates of inorganic fertiliser or organic manures were used alone (2.6 t/ha). Farmer evaluation using several criteria (vigor, size of fingers, tillering, disease and pest tolerance
and yield) showed more preference for the recommended inorganic fertiliser and the combination of lower rates of organic and inorganic fertilisers.

5.2.4 Fodders

Continuous grazing due to small scale acreages, low quality of natural pastures and agricultural by-products, and overstocking leads to high rates of soil erosion, which is a major contribution to the nutrient depletion and declining soil fertility. The introduction and evaluation of high quality forages including legumes for both soil fertility enhancement and livestock feed formed a major research component during the first phase of SMP. Several demonstrations and trials on improved forages were carried out in many sites (Ruto et al., 1999; Masinde et al., 2003; Muyekho et al., 2003) to enhance awareness and technical knowledge on how to establish and manage forages, reduce production costs by encouraging on-farm seed production, determine their productivity and persistence, and to assess the effect of using organic amendments either alone or in combination with inorganic fertilisers on varieties of high yielding fodder Napiers. Based on DM yields and persistence, farmers preferred Napier grass, Rhodes grass (*Chloris gayana*), desmodium, lucerne, Nandi setaria (*Setaria sphacelata*), lablab, and mucuna.

Organic manures (FYM or compost) when used alone (10 t/ha) or combined with inorganic fertilisers at half recommended rates (5 t/ha organic manure +30 kg P$_2$O$_5$/ha + 30 kg N/ha) on Napier grass, yielded similar DM as to the recommended inorganic fertilisers (60 kg P$_2$O$_5$ +60 kg N/ha) (Ruto et al., 1999; Masinde et al., 2003) which were higher than the non-fertiliser control showing that they were viable options. In northwestern Kenya, Napier grass DM from four cuts increased by 90% from 8.2 t/ha in the no fertiliser control to a mean of 15.6 t/ha when the combined organic and inorganic nutrient sources were used at half the recommended rates. Although an on-farm feeding trial conducted in Anin to assess the quality of introduced improved fodders showed that improved forages could sustain milk yields during the dry season (Ruto et al., 1999), the results were non-conclusive because the concept of on-farm livestock experimentation was new to the research team. When Napier grass intercropped with either silverleaf desmodium (*D. uncinatum*) or lablab was used as test crops (Mbugua et al., 1999; Masinde et al., 2003), the inorganic fertiliser and the combination of organic and inorganic fertilizers increased total DM yields (mean of 27.3 t/ha) in desmodium intercrop, whereas all the fertiliser treatments increased DM (mean of 23.3 t/ha) yields in the lablab intercrop compared to the unfertilised control (mean of 19.9 t/ha). The combination of organic and inorganic fertilisers increased Napier grass DM in both intercrops by 31% compared to the unfertilised control. The mean DM yields of desmodium and lablab under the intercrops were 0.89 and 0.20 t/ha, respectively, suggesting that desmodium was better adapted. Economic analysis indicated that both the
recommended rate of inorganic fertiliser and the combination of half rates gave the highest net benefits.

‘Tumbukiza (a Kiswahili word meaning placing in a hole) is a new method of planting Napier grass in well-manured holes that was started by farmers in western Kenya. The method ensures efficient use of nutrients with sustained high yields compared to the conventional method (Otieno et al., 1999). To enable researchers provide scientific guidance to farmers, research was conducted at KARI-Kitale and on farmers’ fields to determine the merits of the method and to develop an optimal agronomic package for its use (Wandera et al., 2000). Initial results during the establishment year showed that the conventional method produced more tillers and that ‘Tumbukiza’ did not show any superiority in terms of dry matter yields at the time of the first cut in the establishment year (Wandera et al., 2000). Further assessments (Muyekho et al., 1999; 2003) indicated that ‘Tumbukiza’ method of production is superior compared to conventional method in terms of dry matter yields and dry season persistence.

Evaluation of Tumbukiza compared to the conventional method using the recommended different fertiliser regimes [10 t/ha FYM, 2) 5 t/ha FYM, 3) 5 t/ha FYM + 30 kg/ha $P_2O_5$ at planting and 30 kg N/ha as annual top-dress, and 4) 60 kg/ha $P_2O_5$ at planting and 60 kg/ha N as annual top-dress] was done together with farmers during the scaling up process using the FPR and FFS approaches. Napier grass under “Tumbukiza” yielded greater DM (9.3 t/ha) compared to the conventional method (4.8 t/ha) (Table 8) confirming the results obtained during the technology development phase (Muyekho et al., 1999; 2003). Although the effect of fertilisation regime was not different across the two methods, the combination of half inorganic + half organic fertilisers and the recommended rate of FYM yielded on average 1.2 t/ha more DM than the recommended rate of inorganic fertiliser or half FYM. This suggests that the slowly released nutrients after organic manure application could be used more efficiently by the Napier grass. Napier grass grown under “Tumbukiza” method of production was taller than under the conventional method (Figure 5), indicating that growth was faster under “Tumbukiza” than the conventional method in agreement with Muyekho et al. (1999). Although the total cost for “Tumbukiza” as estimated together with the farmers was higher due to the additional cost of digging the holes, the gross margin net profit was similar to the conventional method (Muyekho and Mose, 2003). Farmers preferred “Tumbukiza” to the conventional method because it yielded higher herbage even during the dry season and had greener and healthier foliage with greater persistence. This could be attributed to efficient nutrient use, better water retention and less competition in the hole.
Soil fertility improvement technologies for western Kenya

Table 8. Napier grass DM yields (t/ha)\(^1\) under “Tumbukiza” and Conventional methods grown in various Farmer Field Schools at Kitale during the 2002-growing season

<table>
<thead>
<tr>
<th>Fertiliser Treatment</th>
<th>Conventional</th>
<th>Tumbukiza</th>
<th>Mean (^{a})</th>
<th>Farmer Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 t/ha FYM</td>
<td>5.3</td>
<td>9.9</td>
<td>7.6(^{a})</td>
<td>4</td>
</tr>
<tr>
<td>5 t/ha FYM</td>
<td>4.2</td>
<td>8.5</td>
<td>6.3(^{a})</td>
<td>1</td>
</tr>
<tr>
<td>60 kg P(_2)O(_5) + 60 kg N/ha</td>
<td>4.7</td>
<td>8.2</td>
<td>6.4(^{a})</td>
<td>3</td>
</tr>
<tr>
<td>5 t/ha FYM + 30 kg P(_2)O(_5) + 30 kg N/ha</td>
<td>5.0</td>
<td>10.3</td>
<td>7.7(^{a})</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>4.8(^{a})</td>
<td>9.3(^{b})</td>
<td>7.1</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Mean of two cuts measured during the FFS school season
\(^{ab}\) Means followed by different letter superscript within a column or row are significantly different (P < 0.05)

Fig. 5. Change in napier grass plant height under “Tumbukiza” and conventional methods of production during the 2001 growing season on farmers’ fields at Kitale
5.2.5 Effects of organic and inorganic nutrient sources on soil nutrient status

The continuous use of fertiliser alone on the poorly buffered Kaolinitic soils found in many areas of western Kenya, cannot sustain crop yield and maintain soil fertility in the long-term because of soil acidification, loss of soil organic matter, and soil compaction. Mwangi et al., (1997) showed that in more acid soils such as those in some parts of Uasin Gishu (pH 5.1 - 5.3), the continuous use of acidic fertilisers such as Di-ammonium phosphate (DAP) is not advisable and use of FYM and or lime is recommended. Limited attempts had been made to monitor soil nutrient changes after organic manure (FYM or compost) application in western Kenya. The alkaline pH of farmyard manure suggests that it could improve the pH of the moderately acid infertile soils of western Kenya if applied repeatedly over several seasons. The effects of various amendments such as liming, use of FYM alone or in combination with inorganic fertilisers and use of non-acidifying fertilisers on soil chemical properties were investigated on acid soils in UM4 (on Acrisols) and LH3 (on Ferralsols) in northwestern Kenya over five seasons (years) compared to the use of DAP and CAN, which were thought to be the cause of increasing acidity (Mwangi et al., 2003). The use of FYM in combination with non-acidifying inorganic fertilisers increased soil exchangeable Mg (10%) and K (26%) and organic carbon (11%), but increased soil pH more slowly (5%) than the use of lime (33%). Okoko et al., (2003) showed that continuous application of compost/FYM and their combination with inorganic fertilisers over seven seasons in Bogetario, southwest Kenya, increased plant nutrients P, K and Ca by 70, 120 and 170 %, respectively for 0 – 15 cm soil depth. The pH of the top-soil was increased from 5.1 to 6.5. Application of organic manures at Nyamonyo and Nyatieko in UM1 at an altitude of 1500-1700 m in the same region tended to decrease or had no effect on soil nutrient changes (Nzabi et al., 2003). Although there are records of some changes in soil nutrient status, they are inconclusive because they have not been evaluated over many sites for periods long enough to detect changes. The non-consistent changes in soil nutrient status after organic manure application despite their positive effects on yields, suggest that the amounts applied or their quality did not release sufficient nutrients to meet those demanded by the recipient crop.

5.3 Suitable crop varieties

5.3.1 Maize

Maize is the most important staple food crop for smallholder farmers in western Kenya. However, yields on farmers’ fields of 1.5 t/ha (national average) are low compared to research yields of 9 t/ha (KARI-Kisii, 1979). Low adoption of the recently released high yielding maize varieties by farmers is among the major constraints to maize production in the region. Although many improved maize varieties have been released for different climatic regions, farmers tend to prefer
H614, which always runs out of stock because of high demand. Maize varieties are affected by pests (e.g. weevils in the field and store), rotting in the field, lodging, and uneven distribution of rainfall depending on the climatic and soil conditions. Verification trials were conducted in different sites to expose farmers to currently available maize hybrids that could be grown in various agro-ecological zones in western Kenya (Onyango et al., 2000; Kiiya et al., 2003; Muyonga et al., 2003a). The results showed that many other varieties yielded as much or outyielded the commonly preferred H614. At Anin along the transitional UM₃₄ (Keiyo District) farmers can grow H625, H626 and H614 with a yield potential of 6.4, 6.1 and 5.4 t/ha, respectively. At Chobosta in the LH₄ (Uasin Gishu), farmers have a wider choice including most 600 series; H626, H625, H614D and H627 with a yield potential of 11.5, 10.9, 10.0 and 9.9 t/ha, respectively. In Cheptuya along the transitional UM₄₅ zone (West Pokot), farmers can grow H513 (6.5 t/ha) in addition to H614D (7.5 t/ha). At Nyatieko in UM₁ (Kisii Central District) with a bimodal rainfall pattern, late maturing hybrids (H627, H625 and H614) were most preferred by farmers during the long rains season because of their high positive gross margin and yield potential of 7.3, 6.7 and 6.2 t/ha, respectively (Muyonga et al., 2003a). During the short rains, medium maturing hybrids H513 and Pioneer with yield potential of 2.7 and 2.6 t/ha, respectively were preferred. In selecting the hybrids, farmers also considered other factors such as physical appearance of the grain, resistance to weevils (in the field and store), susceptibility to lodging and ear rot, grain density and sweetness when boiled/roasted.

5.3.2 Sorghum and Millets

Sorghum and finger millet are important cereals after maize and wheat in Kenya. They are hardy low input crops grown mainly for food in small acreages in a diversity of habitats in the region. The yields are low ranging from 0.5 to 0.9 t/ha because farmers/plant low yielding varieties and do not use proper agronomic practices. Several introduced varieties of sorghum and millets were evaluated in comparison with farmers’ local varieties to determine high yielding ones. In northwestern Kenya at Chobosta in LH₄, the most promising sorghum variety was E1291 with a yield potential of 4.6 t/ha but at Matunda in UM₁ both E1291 and Livoywa yielded as much as the local variety with a yield potential of 1.9 t ha⁻¹ (Kute et al., 2003a). Factors considered important by farmers when selecting the sorghum varieties were bird-damage, maturity period and colour. In both Chobosta and Matunda, the introduced finger millet varieties yielded as much as the farmers’ variety. The yield potentials were 3.5, 3.8, 4.0 and 3.8 t/ha for Gulu-E, P283, P224 and farmers’ variety, respectively in Chobosta whereas in Matunda the yield potential for all the varieties was 2.3 t ha⁻¹ showing that farmers have wide range to choose from (Kute et al., 2003b). Farmers preferred P283 and P224 because of their uniform maturity, better closing of fingers, good
taste in porridge and good malting quality. In south west Kenya at Nyatieko in UMI (Muyonga et al., 2003b) farmers preferred the finger millet varieties Ikhulule and Gulu-E that yielded 3.3 and 3.2 t/ha, respectively because they had good food quality, resisted lodging, were tolerant to finger millet blast [(Pyricularia grisea (cook) Saco] in addition to giving high yields.

5.3.3 Grain Legumes

The maize - common-bush-bean intercropping system is the major source of cash and food for smallholder farmers in northwestern Kenya. Low grain yields of the common bush bean caused by low soil fertility and susceptibility to pests and diseases is a major constraint to increased food security in the region. Bean fly damage and occurrence of bean root rot are the major common bean disease problems in western Kenya (Otsyula et al., 1998). In an attempt to address this problem, sixty-six genotypes were assessed for resistance to bean stem maggot combined with a number of cultural practices (Ogecha et al., 2003). Eleven bean genotypes tolerant to bean stem maggot and to some extent root rot were identified, with the most promising ones being Exl 55, Exl 52, MLAMA, and P13 with yield potentials of 941, 792, 730, and 592 kg/ha. Grain yields in this study were comparable to that of GLP2 control of 793 kg/ha. Also, several legumes [pigeon peas (Cajanus cajan), groundnuts (Arachis hypogaea), bambara nut (Voandzeia subterranean), soybean (Glycine max), cowpeas (Vigna unguiculata), chick pea (Cicer arietinum), garden pea (Pisum sativum), green grams (Vigna radiata), and lablab (Lablab purpureus)] were evaluated as alternative grain legumes (Mwangi and Wanjekeche, 2003; Wanjekeche et al., 2003; Onyango et al., 2003b) under intercropping with maize and as monocrop stands in Cheptuya, Matunda and Kipsaina sites. Most of the legumes nodulated well except chick peas and garden peas, and the nodulation were better under monocrop stands than under intercropping. Apart from cowpeas, the legumes were more resistant to pest and diseases than beans. Under the maize intercrop, the most promising legumes were soybeans, groundnuts and lablab that yielded 240-355, 90-240 and 60 kg/ha compared to common bean (350 kg/ha). Economic evaluation of two groundnut varieties (Red Valencia and Manipinta) as alternative cash crops for smallholders showed that the gross margin per hectare of groundnuts was higher than that of maize (Okumu, 2003). This was attributed to the fact that groundnuts are a low input crop but with high market value. Farmers preferred Manipinta because of its higher yields, tolerance to diseases and fewer weeding requirements despite the fact that Red Valencia was tastier and more marketable. Several pigeonpea varieties were tested for adaptability and acceptability as a protein food supplement in the cereals based diets in the low moisture AEZs (LM3 and LM4) of southwest Kenya. The most promising varieties were ICEAP 00040, ICPL 87091 and ICEAP 9145 with a grain yield potential of 548, 446 and 358 kg/ha. Based on vigor, pest tolerance, grain
appearance and taste, farmers preferred ICEAP 00068, ICEAP 00020 and ICPL 87091, which are medium, long and short maturing varieties, respectively (Okoko et al., 2003). However, these results of performance of the grain legumes were not consistent across years and sites and were therefore not conclusive. Previous research focus has been on evaluation of the legumes as monocrop stands and results are from only a few sites.

5.4 Integrated Pest Management

The incidence/occurrence of pests and diseases is one of the most commonly cited production constraints on smallholder farms in western Kenya. This is because the use of commercial insecticides and pesticides is limited due to their high costs. The most common pests are maize stalk borer (i.e. *Busseola fusca*; *Sesamia calamistis*), diamondback moth (*Plutella xylostella* (L.) (Lepidoptera: *Plutellidae*)), which is the most destructive pest of cabbage (*Brassica oleracea* var. *Capitata*) and other Crucifers, aphids (*Aphis craccivora*), bean stem maggot (*Ophiomyia* spp) and leaf rust (Anthracnose, caused by *Collectotrichum* spp). Plant extracts separated from neem (*Azadirachta indica*), hot pepper (*Capsicum* spp) and common bean haulm ash were evaluated as cheap and safe pesticides compared to commercial insecticide permethrin and a non-insecticide for maize stalk borer control (Maala et al., 2003) at Chobosta in northwestern Kenya. Neem and hot pepper reduced the damage caused by stem borer by 50 and 23%, respectively compared to permethrin, which reduced the damage by 52%, indicating that Neem and hot pepper were as effective as the commercial insecticide permethrin for maize stalk borer control and are potential low cost and safe alternative pest control measures for resource poor farmers. Integrated pest management (IPM) strategies for bean stem maggot were evaluated together with farmers at Nyamonyo and Otondo sites (Ogecha et al., 2003). Cultural practices and chemical control were evaluated. These were:

- seed dressing with diazinon at 2 ml/kg seed
- Murtano (Thiram + Lindane) seed dressing at 3 gm/kg seed
- 30 kg P₂O₅ + 30 kg N/ha + 5 t/ha FYM
- ridging or earthing up soil around the bean plant at first weeding
- mulch at first weeding, rotation with sweet potatoes and
- farmers practice of 5 t/ha FYM.

The combined application of FYM with inorganic fertilisers reduced bean stem maggot infestation by 56% with a yield advantage of 234 kg/ha (61% increase) compared to farmers practice. The positive effects from fertilisation are consistent with the observation of Otsyula et al., (1998) that low soil fertility in western Kenya increases the susceptibility of common bean to pests and diseases.
5.5 Soil conservation methods

Soil erosion is a major cause of soil nutrient depletion constraint to agricultural production in western Kenya (KARI Kisii – 1994; 1995; Odendo and Wasike, 1999). The traditional method of soil conservation that is widely advocated and used by farmers in western Kenya is the construction of bench terraces (Odendo and Wasike, 1999). However, it is very labour intensive, particularly in shallow and rocky soil types. Soil erosion control experiments were carried out to evaluate other less labour demanding soil erosion control methods. The methods tested included; grass strips [Makarikari grass (*Pannicum coloratum*), Vetiver grass (*Vetiveria zizaniodes*), maize stover trash lines, sweet potato (*Ipomoea batatus*) strip lines, stone lines, and stone lines + vetiver grass strips. Results from a combination of conservation structures (Fanya juu terrace; grass strips; trash lines) and types of forage grasses (Napier; panicum; makarikari; Rhodes) in Cheptuya, west Pokot, showed that farmers preferred conservation structures in the order of grass strips > trash lines > bench terraces (Khaemba *et al.*, 1999). The grasses were preferred in the order of Napier > Rhodes > panicum > makarikari, showing that farmers preferred less labour intensive biological conservation structures with grasses/fodders that can be utilised as livestock feed. In southwest Kenya at Nyamonyo, maize stover trash lines and sweet potato strips were recommended for short-term control while makarikari and vetiver grass strips provided the best option for long-term control (Nzabi *et al.*, 2000). Soil conservation structures reduced surface run-off on average by 40 %, ranging from 29 % under vetiver to 50 % under maize stovers on high rainfall (1867 mm) sites in UM1 with 12-25% slope. The soil eroded was reduced by 52 %, ranging from 26 % under vetiver and 50 % under maize stovers. Farmer ranking showed most preference for live forage (Makarikari and sweet potatoes) because they provided fodder for livestock and vetiver grass because it was used for thatching houses.
6.0 Scaling-up and dissemination of promising results

6.1 Introduction

Adoption studies carried out at the end of the first phase of the project indicated that the uptake of the technologies developed in the project beyond the participating farmers was low (Mose et al., 2003; Odendo et al., 2003, Gor et al., 2003; Wanyama et al., 2003). Phase two of the project was to focus more on the technology scaling up and dissemination to more farmers to ensure greater impact on household food security in the region. Scaling up of promising technologies is done using three approaches: 1) conventional shifting focal area group extension, which was supplemented by farmer leaflets and extension bulletins, demonstrations and backstopping by researchers/extensionists, 2) Farmer participatory research where farmer to farmer dissemination was facilitated by formation of farmer research committees and participatory research demonstrations and 3) Farmer field schools which empowers farmers to disseminate technologies to other farmers in their communities while the researchers played the role of backstopping to ensure the quality of the technologies was maintained.

6.2 Methodologies

Agricultural extension services in Kenya play a vital role in promoting technological and managerial innovations to increase land and labor productivity in resource-poor farms and rural areas. The impact of the conventional extension methods has been limited, mainly because it is not responsive to particular needs and constraints of smallholder farmers in addition to limited public sector budgets to support a large number of agricultural extension personnel adequately. Other reasons include inappropriateness of ‘contact farmer’ methods and inadequate feedback of farmers’ requirements into research agendas. FFS was started as a farmer-based effective approach of availing a wide rage of technology options that provided solutions to their production constraints. The FFS and FPR enhance the vital link between farmers, extension and research. The FFS approach also creates cohesiveness and togetherness among community members, thus accelerating and enhancing information exchange. Dissemination of information among group members and to other groups is active and can lead to significant multiplier effect in disseminating the technology on a wide scale since these approaches have the support of village groups. The schools help farmers to get acquainted with each other and to understand technical messages behind the results they see. Progress has been made in training researchers/extension personnel and farmers in FFS principles and concepts and its application in the scaling up and dissemination process of the developed soil management technologies. Although the FFS methodology is effective in empowering
farmers to disseminate and adopt technologies, the involvement of researchers has no comparative advantage because their main responsibility is to conduct research. There is need for rigorous evaluations and fine-tuning of the FFS approach to suit both smallholder farmers and researchers.

6.3 Coverage and Leadership

In the KARI-Kitale mandate region, the results are applicable to 23% of the agricultural land area, whereas in KARI-Kisii region the results are applicable to 46% of the agricultural land area. However, the AEZs covered in the Kitale mandate region (UM4, UM2–3, UM4–5, and LH4) are different from those covered in the Kisii region (LH1, UM1, UM2–3 and LM3), suggesting that technologies developed in one region could only be applicable in similar AEZs in the other region where farmers have similar socio-economic characteristics. In the KARI-Kitale mandate region, the major AEZs that were not covered include LH3 (19%), LM5 (16%), LH2 (5%), UH2 (4%) and UH1 (4%) with a potential to improve coverage by 48%. In KARI-Kisii region, the major zones that were not covered include LM2 (18%), LH2 (8%), LM4 (7%) and UM2 (5%) with a potential to increase coverage by 38%. Wide-scale scaling up and dissemination through demonstrations are required to increase coverage. Another option of increasing coverage is to place more leadership roles on farmers by facilitating FFS in the region to form local FFS farmer networks that will empower them to bring farmers close to government institutions and other service providers such as micro credit institutions and research and development organisations to source for knowledge and inputs from other stake-holders.
7.0 Critical knowledge gaps

This review has highlighted key research results that have been obtained during the past seven years of the SMP. The research focused on five principle areas namely: management and use of organic residues (FYM, compost, green manures), combined use of organic and inorganic fertilisers on various crops and fodders, evaluation of suitable crop and fodder varieties, integrated pest management and soil conservation methods. All research activities and technologies did not receive equal attention during that period; for example while the uses of FYM and compost had been evaluated since 1994/95, the evaluation of ‘Tumbukiza’ with farmers had been researched since 1997/98. Few other activities like soil conservation methods were evaluated in only a few sites, whereas others like evaluation of alternative grain legumes had not resulted in farmer acceptable yields. The importance of integrated nutrient management for long-term sustainability of low-input mixed farming systems was one area of research that was poorly understood. This is because nutrient cycling involves the uptake, utilisation, release and re-utilisation or loss of nutrients by various processes in a system and is affected by many factors including climatic, adaphic and socio-economic characteristics. In order to resolve location and farming system soil fertility constraints, efforts should be taken to equip farmers with skills to diagnose soil fertility problems and search for relevant solutions. The key research gaps identified in the review are presented in the following sections:

7.1 Integrated Nutrient Management Strategy

The integrated use of organic residues and inorganic fertilisers has been shown to be a useful alternative for increasing crop productivity in the region. However, many studies did not determine the quality of residues to quantify the amounts of nutrients added in relation to the measured yield responses. In most cases soil changes were not monitored to detect improvements in terms of physical, chemical and biological properties. The main limitation was due to poor maintenance and functioning of soil analysis laboratories in both centres. The integrated use of many soil fertility amendments was limited and was not matched to the variability in terms of soils, climate and socio-economic conditions. However, because some information on the quality of these organic resources is available, a predictive understanding can be developed to aid in the extrapolation of results from previous SMP sites for the design of sustainable INM strategies linked to production systems used by farmers in other sites.

7.2 Poor Performance of Alternative Grain Legumes

Research to identify suitable alternative food legumes for intercropping with maize and improving soil fertility has not been conclusively evaluated. The
yields of most of the grain legumes introduced as intercrops were low, suggesting that suitable varieties have not been identified. Past research focus has been on evaluation of these legumes mostly as rotational monocrop stands, despite the fact that farmers prefer intercropping grain legumes with maize.

7.3 Relay Cropping of Green Manures into the Cropping Systems

In areas where land is scarce such as in smallholder farms in western Kenya, the intercropping/relay cropping of green manures in cereals may be a feasible means of generating organic inputs. In such cases, management of green manures to minimise competition with maize while maximizing the residual benefit in yield is critical. Relay cropping green manures into the current maize-common bean cropping system at physiological maturity of the maize has potential to add N from N-fixation and root decay and decomposition of aboveground legume biomass. In the research reviewed here use of green manures alone when relay cropped in maize yielded low DM resulting in non-consistent effects on subsequent maize. The efficiency of transferring N from a legume green manure to the succeeding crop depends on synchronizing the N release from the legume residue with the demand of the recipient crop. This is particularly important in high rainfall climates with high potential for N leaching. The plant species and management practices have a great influence on the success of this synchronisation.

7.4 P deficient soils

Although participatory rural appraisal exercises conducted in the region indicated the existence of purple coloration and stunted growth of young maize leaves indicating P deficiency, little research was conducted to replenish P.

7.5 Integration of Crops and Livestock

Little emphasis was put in exploiting the benefits of crops/livestock interaction in soil fertility improvement and increasing household income/cash. Dairy cattle farming is one of the best avenues in which both soil-fertility improvement and increased productivity from livestock can be achieved on smallholder farms. These mixed farming systems involve complementary interactions between crops and livestock, such as using traction and manure for cropping, and feeding crop residues and other cropland forages to livestock. Cattle manure is an integral component of soil fertility management in many areas of western Kenya and its importance as a source of nutrients for crop production is widely recognised. The quantity and quality of manures available on smallholder farms are the major factors limiting its contribution, as they were the major reasons for modification or non-adoption of the use of FYM or compost. Too little attention was given to livestock management issues (i.e. feeding and disease control) that
could enhance the option of integrating livestock and cropping systems more closely to maximise the use of crop residues and producing more manure. Efforts should be made to enhance these complimentary interactions to strengthen the INM strategies.

7.6 Lack of High Quality Seed for Some Crops

The adoption studies showed that one of the reasons for non-adoption of certain technologies was lack of improved seeds. Smallholder farmers could not afford to buy certified seeds every season and some crops did not have organised seed production and marketing systems including indigenous vegetables, legume, sorghum and finger millet varieties. Little seed production work was conducted in phase one.

7.7 Integrated Pest Management

Plant extract - based insecticides are an important low-cost component of integrated pest management strategies for insect pests. To enhance the effectiveness and wider use of the methods that were evaluated, more research is required to determine optimal rates of applications when used alone or combined with the commercials synthetic pesticides. Infestation of maize by Striga [Striga hermonthica (Del.) Benth] weed is a serious constraint in some parts of the region and efforts to develop an integrated management strategy were not conclusive.
8.0 Way forward for the Soil Management Project

8.1 Research strategy

Since its inception in 1994, SMP has been in the forefront within KARI in strengthening the link between stakeholders and in empowering farmers through participatory technology development and dissemination. To enhance the quality of research, more efforts are required to link good science with farmer participatory research. Some demand-driven strategic or basic research is required on-station to strengthen adaptive research. For example, long term studies on the integrated use of organic manures and inorganic fertilisers are required to monitor soil fertility changes. Also the evaluation of several bean germplasm and other alternative grain legumes both as monocrops or in different intercropping patterns including their response to inoculation require comprehensive on-station studies linked to on-farm studies that will test only a few promising varieties. Another area where on-station research is required is the use of green manures as feed in addition to their soil fertility improvement potential. In particular the potential of Mucuna as feed for ruminants is great, but further work needs to be done to investigate the effect of feeding increasing levels to ruminants on milk yields and on the level of L-DOPA (3, 4-dihydroxyphenyl alanine) in milk and its safety for human consumption.

Another option of improving the quality of research and training capacity of scientists is the linking of academic training to the on-going research where senior scientists in the project work closely or form part of the supervisory committees of the students. This will also result in increased collaboration with local institutions such as Moi University, Maseno University and Egerton University, which will enhance the quality of research within the project.

8.2 Research teams and themes

The project adopted a multidisciplinary and multi-institutional approach to research and this has been one of the greatest strengths of SMP. The representation of various disciplines and institutions in teams should however be reorganised based on the capacity and level of involvement of members. Research issues that cut across many sites should be addressed in research themes that will be implemented across sites. This will enhance the implementation of activities across sites to improve the quality of data collected.

8.3 Study site locations

More than 50% of land area in both research regions is covered by less productive AEZs, mainly the lower midlands (LM) and its transitional zones. Despite the great proportion of low potential AEZs, most of the study sites were
located mainly in high potential AEZs. Yet the availability of FYM, for example, and the lack of suitable crop varieties could be more critical in these low potential transitional AEZs. Even in the high potential AEZs, the representation of all AEZs in different socio-cultural regions is not well balanced considering the fact that KARI has redefined the regional research mandate regions. A critical evaluation of the location and roles of SMP sites should be undertaken to include AEZs that the project can have greater impact in. For example in KARI – Kitale, the current AEZs covered by SMP represent only 23% of the mandate region and therefore the team should consider moving to LH3 and LM5 which represents 19.4 and 16.5%, respectively of agricultural land in the mandate area to increase their coverage to about 60%. In KARI – Kisii the team should move to LM2 and LH2, which represents 18 and 8%, respectively of agricultural land in the mandate area to increase their coverage from 48 to 74%. The roles of the new sites should be clearly defined (i.e. whether for new technology development, verification, scaling up and dissemination). The new sites should be chosen after ex-ante studies in collaboration with other stakeholders and should be demand driven and located in AEZs where greater coverage/impact is expected.

8.4 Holistic approach to targeted nutrient management strategies

Phase one of the SMP showed that a combination of inorganic and organic fertilisers resulted to acceptable yield increases of maize, vegetables (indigenous and exotic mainly kales and cabbages) and Napier grass. Other soil management technologies such as soil conservation structures were developed in some sites. However, most farmers integrate more than one strategy to maintain soil fertility, therefore significant and sustainable increases in productivity will require availing a basket of targeted INM options that utilise available nutrient resources under different farming conditions to optimise nutrient cycling and maximise nutrient use efficiency. The research focus has mostly been on the organic/inorganic fertiliser combinations; However, the research strategy should move to holistic combinations of many strategies that integrate many technological options on a farm-based scale in different farming systems and AEZs to minimise nutrient loss processes and optimise all aspects of nutrient cycling. Issues that deserve further attention are:

- Development of farmer diagnostic tools for soil fertility assessment. This should include indicators for different soils, soil characteristics, soil fertility gradients and quality of organic resources. The farmers’ indicators (i.e. plant species, colour of leaves, taste of plant etc.) will be strengthened by doing correlation analysis with soil and plant laboratory analysis.
- The diagnostic tools should be used to identify on-farm soil fertility gradients and their causes to increase the precision of targeting appropriate technologies.
Data (both socio-economic and technical) should be collected at appropriate spatial scale for targeting INM strategies. This information should include socio-economic issues influencing variability such as resource endowment, cultural beliefs and management of resources. Farmers knowledge should be used to delineate landscapes and farms into niches, which they would manage differently depending on the perceived benefits. Factors to be considered include location in relation to slope, fertility level, texture, water holding capacity and drainage, farming system and preferred time of cultivation, farming constraints and opportunities.

Because of huge variability in terms of soils, climate and socio-economic conditions, farmers should be grouped in well defined typologies, which will form ‘resource management domains’ for future on-farm experimentation and scaling up efforts.

Integration of multiple soil fertility technologies at farm level in site-specific ‘micro-scale’ farmer-managed experiments should be done to enable them to adapt and target the new practices to their local farm variability and resource endowments. Several soil fertility improvement technologies such as legume rotations, ground cover and green manures, farmyard manure and compost should be combined and adjusted to complement each other or combined with other options such soil conservation structures and conservation tillage to solve problems at a micro-scale and matched to AEZs and farmer socio-economic characteristics.

The materials for compost making should be grouped according to their availability in different farming systems and the expected quality and nutrient contribution potential predicted. In general, organic residues should be grouped according to the quality and determining how much of that residue will supply what amounts of nutrients and yield levels that are expected.

Research should be conducted to shed light on nutrient release from those organic residues in order to synchronise with the demand of the recipient crop. Little information is available on the synchrony of nutrient release and uptake by recipient crops in relation to the quality of residues (i.e. FYM, compost, green manures).

Some parts of east Africa have large quantities of phosphorus in phosphate rock (PR) deposits (Okalebo, 1999). The challenge is to transfer it to where it is needed and applied in cost effective ways in the highly weathered acid soils of western Kenya with available P below 5 mg kg\(^{-1}\).

The assessment of subsequent changes in the soil chemical (pH, N, P, K, % Organic Carbon), biological (micro- and macro – fauna) and soil physical characteristics after organic manure additions should be determined in relation to different adaphic and climatic factors.

More efforts should be made to continue researching on more innovative targeted combinations of several strategies for soil fertility improvement and
to link good science with farmer participatory research to understand the underlying biological/scientific processes of integrated soil fertility management practices tailored to suit local agro-ecological conditions and farmer resources.

- The information generated from the above outputs could be used to develop models that can be used to adapt the results in other similar sites.

8.5 Integration of green manures into the farming systems

The adoption of green manure legumes in western Kenya is generally low (Odendo et al., 2003). Adoption of green manures has been much more rapid when the legumes had other uses in addition to soil fertility improvement (Versteeg et al., 1998). To enhance the integration and adoption of green manure legumes into the farming systems, future research should focus on:

- Evaluating with farmers the potential of legumes to provide other uses such as food or feed.
- Although research has demonstrated the potential of green manures in improving soil fertility, knowledge on how best to integrate them in different soils and climatic conditions and farming systems is still limited. Options may include screening for more suitable species and their evaluation in combination with rock P, a cheaper source of P or inorganic fertilisers to increase the quantity of nutrients applied or the complimentary effects. Organic inputs from plant residues alone cannot provide sufficient P for crop growth due to low tissue concentrations, but they can increase P availability in P-fixing soils. This is because organic anions formed by decomposition of organic inputs can compete with phosphate anions for the same adsorption sites and thereby increasing P availability in soil. Thus the application of plant organic residues with rock phosphate is a potential strategy of increasing both N and P in P-fixing soils as those in western Kenya. Where possible legumes that accumulate P or that perform well in P-deficient soils should be evaluated.
- The efficiency of N uptake and recovery in relation to different times of residue application and onset of rains and planting should also be tested for different crops including the high value horticultural crops.

8.6 Alternative grain legumes

In recent years, yields of common beans have been declining due to increased incidences of pests and diseases partly due to increased stress factors such as low soil fertility. The focus of previous research to identify suitable grain legumes in the maize-bean system has been evaluating these legumes as monocrop stands and results lack scientific rigor because the work was done in few sites and not consistent over years. Only a limited number of legumes were
evaluated and their yields particularly under maize were very low. Future research should focus on screening more varieties particularly under intercropping with maize in many sites to identify high yielding ones and for seed bulking. Future studies should focus on:

- Evaluating wider range of species and bean varieties resistant to pests and diseases particularly bean stem maggot and root rot, especially in KARI–Kitale mandate area including their response to inoculations.
- Evaluating the most promising grain legumes as intercrops since the farmers traditionally intercrop maize and beans in western Kenya. The evaluation of the intercrops can also be combined with ITK evaluations.
- Combining cultural practices such as spatial arrangements and rotating beans with other alternative grain legumes or green manure to break the cycle of pest populations.

8.7 Integration of crops and livestock

The use of livestock manure and urine to fertilise the soil is an important linkage between livestock and soil fertility maintenance. The animals are also a source of income, which can be invested in crop production apart from providing food for the household. To enhance these positive interactions and nutrient cycling processes, future research should focus on:

- On-farm evaluation of herbaceous legumes such mucuna and lablab as supplements for dairy cows feeding on low quality feeds such as maize stover and Napier grass should be undertaken to evaluate the potential of these legumes in providing additional benefits (i.e. increased milk and quantity and quality of manure) to the smallholder farmers. This could be combined with relay cropping green manures in maize after harvesting the first bean crop and defoliating part of the biomass for feed and the manure from cattle returned to the defoliated plots. This option can also be combined with conservation structures of Napier grass strips that can be used as basal feed for livestock feed.
- Tumbukiza is one of the technologies whose uptake by farmers has had the most impact under the soil management project. Apart from the yield and persistence advantages, farmers learnt that “Tumbukiza” had wider spaces between the Napier grass stools where they could interplant with other crops with less competition. They intercropped Napier grass with sweet potatoes which is an important crop for food security in the region and which provides nutritious fodder that can be fed together with Napier grass. Future research should focus on intercropping with forage legumes.
- Feed strategies that ensure quality feeds are available throughout the year (i.e. feed production, conservation and use of legumes).
On-farm feed ration formulation to efficiently utilise the various crop residues (including those from legumes) and use of low cost disease control/treatment measures (i.e. ITK methods) to enhance the contribution of livestock due to increased milk and quantity and quality of manure.

8.8 Integrated Pest Management / Crop Management

The incidence of pests and diseases is a major production constraint in the region because the use of commercial agro-chemicals is limited due to their high cost. Few plant extract-based insecticides were found promising as part of low-cost component of integrated pest management strategies for insect pests. Infestation of maize by Striga weed is a serious constraint to maize production in some parts of KARI-Kisii mandate region. The Soil Management Project in collaboration with C-MAD initiated a research to integrate green manures legumes to the farming systems for Striga control. However, this research has not attained conclusive results. To enhance the effectiveness and wider use of these integrated pest management strategies, future research should focus on:

- Mapping and characterisation of pests and diseases of priority crops in different AEZs.
- Identify and evaluate a wider range of interventions, including locally available biopesticides in combination with commercial synthetic pyrethroid insecticides and cultural practices such as time and methods of planting, suitable crop varieties to control pests and diseases, which are a major production constraint in the region.
- Evaluate different levels of plant-based insecticide application to ascertain economical rates.
- Develop an integrated approach to Striga control including evaluation of maize varieties tolerant to Striga in combination with use of green manures, crop rotations and other multiple cropping strategies.

8.9 Soil Conservation

Soil erosion is one of the major contributors to the nutrient depletion problem and yet research on this topic was given less emphasis both during the technology development phase and during the scaling up and dissemination especially in the KARI-Kitale mandate region. Because of the widespread nature of the soil erosion in the region, future research should focus on:

- The use of soil conservation structures developed in phase one combined with other strategies such as conservation tillage and use of organic manures to minimize the nutrient depletion problem in areas that are prone to soil erosion in addition to controlling weeds and conserving moisture in low rainfall AEZs.
8.10 High Quality Seed for Some Crops

To increase adoption of certain technologies for crops that do not have organized seed production and marketing systems such as indigenous vegetables, some legume seeds, sorghum and finger millet varieties future research should focus on:

- Evaluation of management practices that can enhance seed production such as fertilisation, defoliation methods and time of harvesting.
- Training farmers on seed production techniques and bulking of seed of promising crop varieties and where possible farmers should be organized to produce certified seed.

8.11 Scaling up, Dissemination and Adoption and Impact Studies

Several soil-improving technologies were developed and were being scaled up and disseminated using participatory FPR and FFS approaches in addition to the conventional extension shifting focal area approach.

- To attain the potential coverage of 23% and 48% in the KARI – Kitale and KARI – Kisii mandate regions, respectively, wide-scale scaling up and dissemination through demonstrations is needed. However, others need participatory modifications or refinement based on the farming systems and previous experiences before they can be extended to new areas. Plans are underway to integrate the FFS approach with FPR to increase the capability of farmers in translating scientific knowledge to adoptable land management strategies for improving and sustaining soil fertility on smallholder farms.
- Adoption studies are required to determine adoption trends and sustainability of adopted technologies.
- Impact studies should be carried at the end of phase two to determine the impact at the farm level of SMP technologies on the livelihoods of the farming communities (i.e. food security and income generation) and to find out the reasons for non- adoption of some technologies to provide guidance for future modifications or refinements.

8.12 Other suggested research areas

The project should widen its focus to include other agricultural production constraints that are likely to assist farmers in their goals of enhancing food security and alleviating poverty. These include:

- Exploring ways for farmers to access to credit cheaply
- Conducting research to add value to products to enhance their marketing
Soil fertility improvement technologies for western Kenya

- Conducting marketing studies in order to promote sale of products arising from the use of SMP technologies
- Forming farmer research groups/networks to serve as centres through which agricultural information on production and markets availability can be passed on to farmers.
- Directing more efforts to increasing and sustaining the close collaboration with all stakeholders involved in agricultural development in the mandate regions of the SMP.
9.0 References


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