NATURAL RESOURCES SYSTEMS PROGRAMME

FINAL TECHNICAL REPORT[1]

R8115 ANNEX A

Improvement of Soil Fertility Management Practices in Rainwater Harvesting Systems

SOIL-WATER MANAGEMENT RESEARCH GROUP

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ABBREVIATIONS AND ACRONYMS

ASDS	Agricultural Sector Development Strategy
ASDP	Agricultural Sector Development Programme
CEC	Cation Exchange Capacity
CFC	Common Fund for Commodities
CPR	Common Pool Resources
DADP	District Agricultural Development Programme
DALDO	District Agricultural and Livestock Development Officer
FAO	Food and Agriculture Organization
FEG	Farmer Extension Group
FRG	Farmer Research Group
FYM	Farmyard manure
GIS	Geographic Information System
GPS	Global Positioning System
INM	Integrated Nutrient Management
ISFM	Integrated Soil Fertility Management
LISF	Local Indicators of Soil Fertility
LISQ	Local Indicators of Soil Quality
M&E	Monitoring and Evaluation
MIFIPRO	Mixed Farming Improvement Programme
NARS	National Agricultural Research Systems
NGO	Non Governmental Organization
NRSP	Natural Resources Systems Programme
PADEP	Participatory Agricultural Development and Empowerment Project
PRSP	Poverty Reduction Strategy Paper
PT	PARCHED THIRST
RWH	Rainwater Harvesting
SAIPRO	Same Agricultural Improvement Programme
SPSS	Statistical Package for Social Sciences
SQMS	Soil Quality Monitoring System
SUA	Sokoine University of Agriculture
SWMRG	Soil-Water Management Research Group
TALP	Tanzania Agriculture and Livestock Policy
TISQ	Technical Indicators for Soil Quality
TIIP	Traditional Irrigation Improvement Programme
WPLL	Western Pare Lowlands
UNIDO	United Nations Industrial Development Organization
URT	United Republic of Tanzania
VECO	A Belgium Supported project

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1. INTRODUCTION

Low soil fertility is one of the main constraints to plant growth and crop production in many parts of semi-arid sub-Saharan Africa. Low crop production has been attributed to inherently low availability of plant nutrients, nutrient imbalances and inadequate soil moisture for plant growth. The low soil fertility status in the semi-arid areas has been aggravated by improper and inappropriate soil conservation and management practices. Past and current soil management practices have tended to enhance the physical, chemical and biological degradation of the soils, resulting into reduced soil productivity. Furthermore, the intensification and diversification of the cropping systems and practices in areas where rainwater-harvesting (RWH) technologies are being practiced has compounded the decline in soil fertility. The decline in soil fertility, therefore, has been caused by the increased withdrawal of plant nutrients from the soil without replenishment consequent to increased plant growth. To raise and sustain soil fertility and productivity in such areas, appropriate and holistic soil fertility management practices have to be developed and adopted by farmers. The soil fertility management strategies so developed must take into account the wealth status of the farmers, gender issues, land tenure and the availability and costs of farm inputs such as fertilizers and manures.

The introduction and adoption of RWH technologies in some of the semi-arid areas of Tanzania, has significantly reduced the soil moisture constraint to plant growth. However, introduction and adoption of RWH technologies were not concurrently followed by the development of appropriate soil fertility management practices so as to arrest soil fertility decline. A significant amount of research on soils fertility management has been conducted in the semi-arid areas of Tanzania over the years (Annex B11). In addition, a good amount of relevant indigenous knowledge has been documented (Barrios *et al*., 2000a). However, the adoption of recommended soil fertility management strategies has been limited (Kimani *et al*., 2003). Reasons for the limited adoption of the strategies include the fact that most of the research work did not address the peculiar characteristics of farmers and land resources. Further, previous interventions did not consider in depth the magnitude of perception and comprehension of soils and soil fertility management aspects by the farming communities in the target area (Barrios *et al*., 2000b). Adoption of any innovation requires that views of the stakeholders in this case, the poor smallholder farmers, be given due consideration. In addition, stakeholders should be actively and fully involved in the design and development of such technologies and strategies.

In the semi-arid areas where RWH systems are being practiced, inappropriate information and knowledge transaction methods have also contributed to the slow rate of adoption of the research findings (Senkondo *et al*., 1999). Adoption of innovations requires that service providers be highly knowledgeable with all the concepts and aspects of the innovation. To increase the adoption of various soil fertility management technologies, stakeholders such as farmers, researchers, extension staff and input providers have to be involved in the design and development of the technologies. Further, researchers and extension staff have to be adequately knowledgeable on suitable communication methods that would facilitate the adoption of the various improved soil and plant nutrient management practices.

1.1 Objective of the study

The main objective of Project R8115 was to develop and promote improved strategies for integrated management of soil and plant nutrients under rainwater harvesting system that would benefit the smallholder (poor) farmers in semi-arid areas. The specific objectives of project R8115 were to:

(i) Define the current status of soil fertility and management strategies under rainwater harvesting systems,
(ii) Identify, verify and promote sustainable strategies for soil and plants nutrients management in rainwater harvesting systems, which take into account circumstances of different categories of farmers,
(iii) Increase the capacity of stakeholders, that is government and non-governmental organisations and private services providers, who are active in extension, to plan and provide extension services and advice on strategies for integrated nutrient management, that address the needs of the poor rural farming communities,
(iv) Identify, develop and promote mechanisms for transacting information and knowledge to support farmers' crop production decisions under RWH conditions.

1.2 Rationale

This project was designed to explore soil and plant nutrient management strategies based on the Integrated Nutrient Management (INM) approach. This approach involves the understanding and manipulation of inputs, outputs and internal flows of nutrients. Components of inputs include inorganic and organic fertilisers, nitrogen fixation, deposition, sedimentation, and exploitation from the sub-soil. Outputs include, nutrients withdrawal from soils by plants, leaching, erosion and losses to the atmosphere. Despite long term recognition that INM is an important strategy for improving soil fertility, there is a serious limitation in its use due to inadequate research on the performance of its several components under farmer conditions. Most previous research has focussed on individual aspects such as combining organic and inorganic sources of nutrients (Nandwa and Bekunda, 1998). Other components such as the use of agro-forestry to exploit nutrients from the sub-soil have also been widely investigated (Snapp *et al*., 1998). What is still missing is integration. However, it has been observed that farmers who practice RWH in the semi-arid areas of Tanzania are managing soil-water and nutrients availability through a judicious selection and mixing of crops. Crops that demand high levels of nutrients are grown in parts of the field known to have the required fertility. The farmers are implementing their own form of "precision farming" (Hatibu, 1999; Kajiru *et al*., 1998; FURP, 1987; CABI, 1994). Despite these efforts, crop yields are low and on the decline. Therefore, an understanding of current strategies used by farmers is the most viable starting point for introducing INM for fertility diagnosis, characterisation and improvement under RWH systems.

2. LITERATURE REVIEW

2.1 Soil Fertility

Soil fertility is defined as the ability or capacity of the soil to supply the essential plant nutrient elements in quantities, forms, proportions and at the appropriate time in the growth cycle of the plants for optimum plant growth. Ingram (1990) broadly defined soil fertility as the capacity of a soil to support plant growth and this capacity is determined by the physical, chemical and biological properties of the soil. Soil fertility is, therefore, measured in terms of the amounts or quantities of the available forms of the plant nutrients in the soil at any given time (Tisdale *et al*., 1993; Brady and Weil, 1996). The available and availability of plant nutrients in soils is controlled by various soil processes and factors. The processes that influence soil fertility include weathering and decomposition of rocks and minerals in the soil, decomposition of inherent soil organic matter, soil acidification and alkalinization, ion exchange, leaching and nutrient transformations in soils. The soil factors or properties include soil moisture, soil structure and texture, soil temperature, soil accretion, mineralogical composition of the soils, soil organic matter contents, ion exchange capacities and soil reaction (soil pH)

Soil fertility is closely linked to soil productivity, which is the capacity of the soil to support plant growth as determined by soil, plant, climatic and management factors (Nandwa, 2003). Soil productivity is measured in terms of crop yields per unit area of land. Soil productivity strictly relates the inherent and intrinsic soil qualities to the productive potential of the soil (Nandwa, 2003; Tisdale *et al*; 1993).

Perspectives of soil fertility include the recognition that (a) the capacity to manage soil fertility is dependent on the understanding of the bio-chemical processes that regulate nutrient fluxes in the soil as influenced by soil physical processes and (b) effective soil fertility management is achieved through the integration of the contributory soil processes with other factors that regulate the ecosystem dynamics (Seward and Woomer, 1992).

Soil fertility in most cultivated soils is on the decline hence reduced abilities to supply adequate or sufficient quantities of the essential nutrient elements to the plants (Nandwa, 2003). Soil fertility decline and hence reduced soil productivity is a subject of major concern in Africa as it contributes to hunger (famine), food insecurity and farm or household incomes (Nandwa, 2003). The decline in soil fertility caused by soil degradation processes and activities is manifested in (a) the appearance of wide distribution of soils deficient in plant nutrients in areas which were highly productive, ascertained by low crop yields, and soil analytical data, (b) appearance and prominence of plant species which perform well on soils with low fertility (c) changes in soil colour, texture and structure associated with low soil fertility (like poor water and nutrient retention) and (d) widespread nutrient imbalances (like toxicities and deficiencies) (Batiano *et al*., 1998; Nandwa and Bekunda, 1998; Nandwa *et al*., 1999; Tisdale *et al*, 1993) Soil degradation is caused by improper soil fertility management practices that don't take into account appropriate soil management and conservation practices that ignores the dynamics of the elements in soils (e.g gains and losses of plant nutrients) (Nandwa. 2003). The challenge of overcoming soil fertility decline, hence soil productivity is compounded by the fact that soil fertility status is highly dynamic, complex and heterogeneous phenomenon.

2.2 Soil Fertility Management

Soil fertility management encompasses all the attributes, aspects and activities that maintain, enhance and sustain the ability and capacity of the soil to supply adequate quantities of nutrient elements for optimal plant growth. Soil fertility management in semi-arid areas is mainly constrained by inadequate moisture and lack of replenishment of the nutrients lost from the soil through uptake by plants, leaching, volatilization and soil erosion processes (Nyathi *et al*; 2003). Soil fertility management strategies, therefore, have to focus on addition of nutrients to the soil from external sources, namely fertilizers and manures (Tisdale *et al*; 1993; Brady and Weil, 1996). The aforementioned can be achieved through integrated soil fertility management (ISFM). Integrated soil fertility management is the adoption of a systematic, conscious participatory and broad knowledge intensive holistic approach to research on soil fertility that embraces the full range of driving factors and consequences such as biological, physical, chemical, social, economic and political aspects of soil fertility degradation (Kimani *et al*; 2003).

ISFM approach to soil fertility management advocates for optimal soil productivity through incorporation of a wide range of adoptable soil management principles, practices, and options for productive and sustainable agro-ecosystems (Kimani *et al*., 2003). ISFM entails the development of nutrient management technologies that combine the use of organic and inorganic soil amendments or inputs that conform to the farmer's production goals and circumstances (Kimani *et al*., 2003; Sanchez et al; 1997). This approach also integrates the roles of soil and water conservation nutrient adding and saving practices and integrating the different research methods and knowledge systems (Kimani *et al*., 2003). The major emphasis in ISFM is on understanding and seeking to manage processes that contribute to changes in soil productivity hence the livelihoods of the farming communities. ISFM embraces the full range of multiple purpose options and driving factors and consequences all focused towards increased and sustained soil productivity. Among the successes of integrated soil fertility management based on multiple purpose options is the development and adoption of various soil fertility management strategies based on soil types (conditions), the peculiar characteristics of the farming communities, policy issues and land tenure (ownership) and availability and costs of the soil amendments and the crops to be grown. To address the aforementioned strategies, Tropical Soil Biology and Fertility (TSBF) research focused on empowerment of farmers, which aims to strengthen farmers status by facilitating access to knowledge and decision making through evaluation of management options for ISFM, facilitating pathways of knowledge interchange and improving policies for sustainable soil management (Onduru *et al*., 1998; Kimani *et al*., 2003). On farm research on ISFM, therefore, involves the need to understand the basis for decision making by farmers and the extent to which the decisions integrate the aspects and concepts of indigenous and scientific knowledge of soil fertility as modified by the socio-economic constraints.

The development of participatory learning and action research (PLAR) for ISFM is one of the recent attempts to assist farmers to improve their existing soil fertility management strategies through the integration of local and scientific knowledge on soil fertility and productivity (Baltissen *et al*., 2002; Kimathi *et al*., 2003). This can be achieved through (a) self-diagnosing and analyzing of current soil fertility management strategies and practices (b) planning, experimenting and evaluating alternative soil fertility management practices that are practical, appropriate and able to exploit available resources and diversity and (c) developing and designing effective and efficient farmer organizations that would ensure the sustainability of the developed strategies (Defoer *et al.*, 2000, Kimani *et al.,* 2003).

2.3 Local Indicators of Soil Fertility

In the management of soil fertility, local indicators of soil fertility (LISF) have been developed by farmers and tested for many years. On the scientific front, researchers have also developed a set of Scientific Indicators for Soil Fertility (SISF). Farmers and other stakeholders cannot easily grasp the scientific jargon used by researchers when referring to these technical indicators. Researchers are in a better position to understand the LISF developed by farmers and even match them with or find their equivalent in the SISF. Integrating the two and coming up with nomenclature common to all stakeholders is a major step towards developing technological options in soil management that can be taken up by farmers. So, knowledge of the local indicators of soil fertility is essential in bridging the gap between the different stakeholders, researchers and all other specialists learning from farmers and farmers learning from researchers and specialists.

LISF is based on visual observations of soils properties mainly physical such as soil colour, soil depth ease of cultivation and relating plant and soil animals and animal activity to certain soil conditions. Table 1 gives a summary of the LISF commonly used by farmers in Kwalei village, Lushoto, Tanzania.

Table 1: Local Indicators of Soil Fertility Used by Farmers in Kwalei, Lushoto Tanzania

Good soil	**Poor soil**
Well drained soil	Poorly drained/water logged soils
Workable soil /easy to cultivate (tifutifu)	Stoniness / rock outcrop
Deep soil	Shallow soils
Virgin soil	Cracking soils/vertisols
Valley bottom soils (Alluvial)	Salty soils
Black/Dark soils (High OM content)	Clayey soils/sticky soils
Water retaining	Difficult to cultivate /hard pan
Smell of rotting materials	Excessive run-off/gullies/erosion
Sedimentary rock (Parent material)	Red/brownish soils on steep slopes
	Murram soils

Source: **(Barrios *et al.,* 2000a).**

From Table 1, both good and bad soils have a combination of attributes. Soil fertility is, therefore, made up of the combinations of the physical, chemical and biological factors and functions of the soil (Doran and Parkin, 1994; Doran and Safley, 1997; Beare *et al*., 1997). A soil with negative attributes is regarded as bad and vice versa. Apart from physical and chemical properties, particular plant species are associated with soil fertility. A list of local plants associated with soil fertility is explained in details in Annex B1. For example *Amaranthus* and *Commelina difusa*, are indicative of fertile soils while *Bracken ferns*, *Striga* and *Digitaria sp*., are indicative of poor soils. Bracken ferns are also indicative of low pH soils. The presence of many diverse weeds and the ability of a soil to support many different types of crops are indicative of fertile soils. The colour of crops growing on a given soil gives an indication of the soil fertility. Local indicators may give a general indication of soil fertility but they do not give values that can be used as basis for determining the rate of application especially of inorganic fertilisers.

2.4 Scientific soil fertility indicators

Scientific soil fertility assessment is based on analysis of soil and plant samples for the contents of plant nutrients. Cut-off points have been established with regard to adequacy and deficiency of nutrients. Tables 2, 3 and 4, for example, show pH classification, rating of organic matter and its main constituents and guidelines for interpretation of available soil P determined by Olsen method (Landon, 1991). Whenever soil analysis is undertaken, the results should be checked against standard rates in order to establish soil fertility status and come up with suitable rates of application of soil amendments for increased and sustained soil productivity.

Table 2: pH Classification

pH	Class	Interpretation
>8.5	Very High	Alkali soils
7 – 8.5	High	Possibly some nutrient deficiency
5.5 – 7.0	Medium	Optimal range for many crops but too acid for some at lower level
<5.5	Low	Acid soils. Probable nutrient deficiency and toxicity problems

Source: Landon, (1991)

Table 3: Rating of Organic Matter and its Main Constituents

Class	Total OM %	Total OC%	Total N%	C/N Ration
Very high	>6	>3.5	>0.3	>25
High	4.3 – 6	2.51 – 3.5	0.226 – 0.3	16 – 25
Medium	2.1 – 4.2	1.26 – 2.5	0.126 – 0.225	11 – 15
Low	1 – 2	0.6 – 1.25	0.050 – 0.125	8 – 10
Very low	<1	<0.6	<0.050	<8

Source: Landon, (1991)

Table 4: Guidelines for Interpretation of Available Soil P Determined by Olsen Method

Characteristic crop demand	Examples	Indicative available P values (ppm)		
		Deficient	Questionable	Adequate
Low P	Cereals, soyabean, maize	<4	5 – 7	>8
Moderate P	Cotton, Tomatoes	<7	8 – 13	>14
High P	Onions, potatoes, celery	<11	12 - 20	>21

Source: Landon, (1991)

2.5 Soil Fertility Management Approaches

The fundamental biophysical cause of declining food production under smallholder farming systems is soil fertility depletion. For example during the last 30 years, the depletion has been estimated at an average of 660 kg N ha^{-1}, 75 kg P, ha-1 and 450 kg K ha^{-1} from about 200 million ha of cultivated land in 37 African countries (Sanchez *et al*., 1997). To reverse or reduce the aforementioned soil fertility depletion, appropriate and sustainable soil fertility management strategies have to be developed and promoted for adoption by the farming communities. The possible approaches would entail (a) intensification (b) extensification and (c) diversification and cash cropping (Nandwa, 2003).

2.5.1 Intensification

Intensification entails increasing agricultural production through increased yields per unit area of land and or of individual crops through increased use of production inputs, notably plant nutrients and improving nutrient use efficiency (Nandwa, 2003). For most food crops, unfavourable crop/fertilizer price ratios and financial constraints are the two key factors responsible for the low fertilizer use in many countries in sub-Saharan Africa (SSA). Most food crops are continuously grown with little or no replenishment of nutrients removed through crop harvests and other nutrient losses (like through erosion and leaching) resulting into depletion of the nutrients in the soil below the critical levels. Intensification of the cropping systems calls for recapitalization and replacement fertilization approaches (Buresh *et a* 1997). The recapitalization fertilization seeks to replenish the nutrients removed/lost from soils after several years of cropping as a means of restoring agricultural productivity and prosperity in smallholder farming communities. Under this approach large quantities of fertilizers and/or manures are to be applied, which is one of the drawbacks of this approach with respect to the poor smallholder farming communities.

The replacement fertilization approach embraces the repeated and continuous replenishment of the nutrients withdrawn from soils. The replenishment nutrient applications may be blanket or specific fertilizer recommendations. Under this approach, the amounts of fertilizers (nutrients) or manures required or to be applied are reasonably low hence more easily adoptable by the poor smallholder farming communities. The replacement fertilizer recommendations are based on specific soils, crops, climatic conditions and the anticipated crop production levels.

Increased use of fertilizers and manures either through recapitalization or replacement fertilization should be accompanied with increasing or improvement of the nutrient use efficiency of the nutrients added to the soils. Nutrient use efficiency can be improved by adoption of integrated nutrient management (INM) (Nandwa, 2003). Many studies conducted by TSFB have demonstrated high nutrient recoveries when organic and inorganic soil amendments are applied together (TSBF, 1985; 1989). INM is currently perceived as the judicious manipulation of all nutrient inputs, nutrient outputs and nutrient internal flows (Smalling *et a.,* 1996), thus recognizes the fact that nutrients enter and leave managed ecosystems in different capacities. In most soil fertility replenishment initiatives, promotion of high nutrient use efficiency is achieved through various cropping options, like intercropping, crop rotation and agro-forestry.

2.5.2 Extensification

Another approach to increase food production is by extensification that is increasing the acreage of cultivated land. Extensification system is common in areas with ample land and where labour is available. The potential success of this approach lies primarily on two options namely (a) focus on newly opened land that ensures establishment of balanced nutrient systems and (b) reclamation of wastelands through biological management of the system that ensure recapitalization (Nandwa, 2003). It has been reported that the extensification approaches that maintain sustainable productivity of crops and forest products are those in which the length of the arable phase is adjusted to fit nutrient stock replenishment (Nandwa and Bekunda, 1998).

2.5.3 Diversification and Cash Cropping

Agricultural production can be increased by increasing the number of crops, both food and cash crops, or cropping cycles sown/ grown on a particular piece of land. In cases where economic activities allow, farmers may devote their farmland to cash crops and use the revenue generated from the sale of the crops to purchase food from elsewhere and also invest in measures aimed at combating nutrient depletion (Nandwa, 2003). Increasing the number of cropping cycles entails optimization of the use of no-renewable inputs and technologies such as shifting from single annual cropping to double or triple cropping system whereby the agro-economic benefits of the latter outweighs the former (Nandwa, 2003; Hamilton, 1997). This can be achieved through introduction of crop varieties that are tolerant or resistant to abiotic and biotic factors limiting production of commonly grown crops. The main driving force in agricultural diversification and cash cropping is the attainment of complete self-sufficiency at farm level by growing all types of crops. However, most farming systems are becoming less diversified as the traditional crop and soil fertility management practices are gradually disappearing; and farming communities are becoming less diverse with respect to farm products and diets (Nandwa 2003) because of the commercialization of the agricultural sector.

2.6 Soil Fertility Management Strategies

Soil fertility management in semi-arid areas is mainly constrained by inadequate soil moisture and lack of resources for purchases of inputs (fertilizers). The problems of inadequate soil moisture are compounded by nutrient losses through plant uptake, leaching and erosion, and thus exacerbate the problem of soil fertility decline (Nyathi *et al*., 2003). Soil fertility management has to, therefore, focus on supplying inputs from external sources. To overcome the problem of soil fertility depletion, farmers have adopted various soil fertility management strategies. The most common soil fertility management strategies in semi-arid areas include intercropping, crop rotation, fallowing, growing of cover crops, agro-forestry, conservation tillage practices and use of organic and inorganic soil amendments. All these are aimed at maintaining and sustaining soil fertility by reducing or eliminating soil fertility degradation.

2.7 Nutrient Management

Nutrient management is one of the holistic approaches to the management of soils for increased crop yields. Nutrient management aims to achieve four broad interrelated goals, namely (a) cost effective production of high quality crops (b) efficient use and conservation of nutrient resources (c) maintenance and enhancement of soil quality and (d) protection of the environment beyond the soils, that is avoiding environment pollution (Brady and Weil, 1996; Tisdale *et al*., 1993; Muller-Sarmaann and Kotschi, 1994). The key concepts to the goal of nutrient management include renewal or re-use of the nutrient sources and nutrient budgeting that reflects a balance between systems inputs and outputs.

Nutrient management calls for the manipulation of the physical, chemical and biological processes in the soil in an attempt to reduce nutrient losses from soils and further increase the nutrient use efficiency by the target crops. Under INM, nutrient replenishment involves judicious use of fertilizers and manures and minimization of nutrient losses from soils (Brady and Weil, 1996, Nandwa, 2003; Nyathi *et al.,* 2003; Bationo *et al.,* 2003). In semi-arid areas under RWH, nutrient management is paramount as mismanagement of the nutrients may result into nutrient imbalances and development of saline and sodic soils (Mashali; 1997; Nyathi *et al*., 2003). Salinity and sodicity affect the soil chemical properties making them unfit for conventional crop production (Nabhan, 1997).

2.8 Developments in Soil Fertility Management

A review of the state of the art of the agronomic research in soil fertility management indicated that on-station research has developed considerable amounts of promising results but very few of these technologies have reached the smallholder farmer (Bationo *et al.,* 2003). The on-station developed technologies are rarely built on indigenous practices, local socio-economic realities of the smallholder farmers and farmers' priorities and perceptions (Bationo *et al.,* 2003; Nyathi *et al.,* 2003 Nandwa, 2003). The development of soil fertility management strategies, hence their adoption by farmers and other stakeholders should involve farmers, extension agents, NGOs, policy makers and researchers at the design, implementation and evaluation stages. There is need, therefore, for the developed technologies to be tested under farmers' conditions to allow scientists to observe the transfer of technologies to the farmers' field and determine the associated management practices to be adopted by farmers in order to ensure good economic returns (Bationo *et al.,* 2003).

Provision of choices/alternatives to farmers and empowering them to make decisions that would change the way to manage the available resource is very import and central in the adoption of ISFM technologies (Murwira, 2003). ISFM thus emphasizes context specific and adoptive responses that are tailed to meet the farmers' circumstances, constraints and opportunities.

2.9 Technological Delivery Methods and Media

An information delivery pathway is a channel through which research output reaches the end users (Norrish *et al*., 2001). There is a wide range of information communication methods that are currently being used by various extension and research organizations. Some of the commonly used methods to transact information on soil fertility management include: farm visits, demonstration plots, leaflets, radio, seminars and workshops (Adam, 1982; Matata *et al.,* 2001). Experience shows that some of the information exchange methods are more effective than others. This is largely controlled by a number of factors such as the wealth status, age, extent of involvement of the end users (participatory extension methods) and cultural factors (Wickama and Mowo, 2001). Therefore, a thorough knowledge about target group characteristics has profound effect in the selection of information transaction methods.

Adoption of better soil fertility management practices and indeed any other innovations require effective communication between the different stakeholders. In addition, farmers' experience should be integrated with technical–scientific knowledge because there are many management practices that farmers know and experiment with. A suitable communication approach should be developed for transacting information on soil fertility management giving due consideration to the nature of the messages to be transacted.

3. METHODS

3.1 Description of the Study Area

The research project was implemented in two districts, Maswa in Shinyanga Region and WPLL in Kilimanjaro Region. Both sites are located in the semi-arid areas of Tanzania and represent two contrasting farming systems (Figures 1 and 2).

In Maswa District, the study was conducted in the Ndala River catchment (Figure 1). In this catchment three villages were selected namely: Isulilo, Njiapanda and Bukangilija representing upper, middle and lower parts of the catchment, respectively. The catchment is situated between 2^{o} 45’ and 3^{o} 15’South and 33^{o} 0’ and 34^{o} 7’ East and has an altitude ranging from 1200 to 1300 meters above mean sea level. The rainfall ranges between 600 to 900 mm per annum with bimodal distribution the short rains starts in octaber and ends in December while the long rains starts in March and ends in June. The land use pattern is linked to the recurrent topo-sequence of soils known as Sukumaland catena (Milne, 1947).

In WPLL, the Makanya River Catchment was selected for the study (Figure 2). The catchment is located between 4^{0} 8′ and 4^{0} 25′ South, and 37^{0} 45′ and 37^{0} 54′ East. The area is located on the western slopes of South Pare Mountains on the leeward side at an elevation of between 600 m and 2462 m above mean sea level. Three villages, all practicing intensive RWH were selected namely; Tae, Mwembe and Makanya, representing three toposequence classes; the upper, mid and lowlands, respectively. The rainfall pattern in this area is bimodal, with mean annual rainfall of approximately 400 – 600 mm. The short rains (Vuli) start in November and extend to January. The long rains (Masika) start in March and extend to May. The mountains profoundly affect the climate of the area.

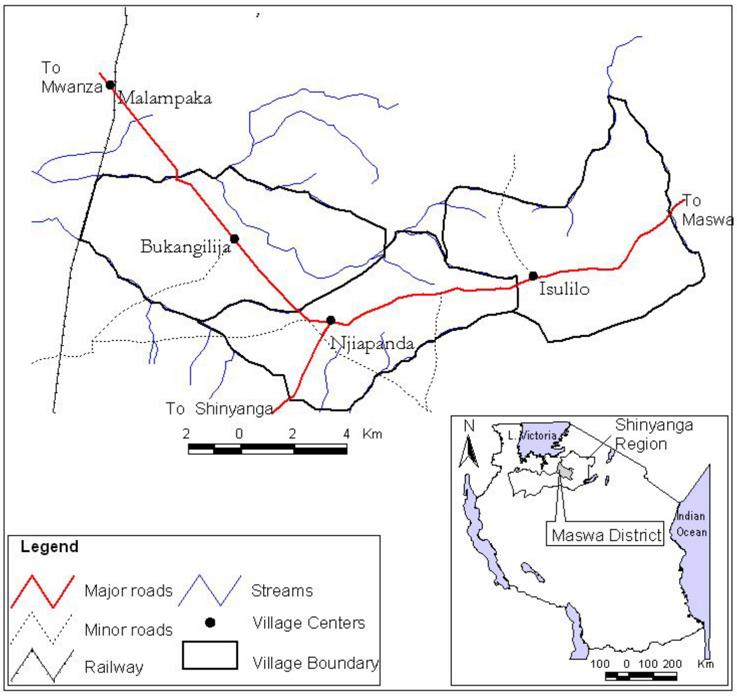


Figure 1: Ndala River Catchment (in Maswa District) Showing the Location of Bukangilija, Njiapanda, and Isulilo Villages

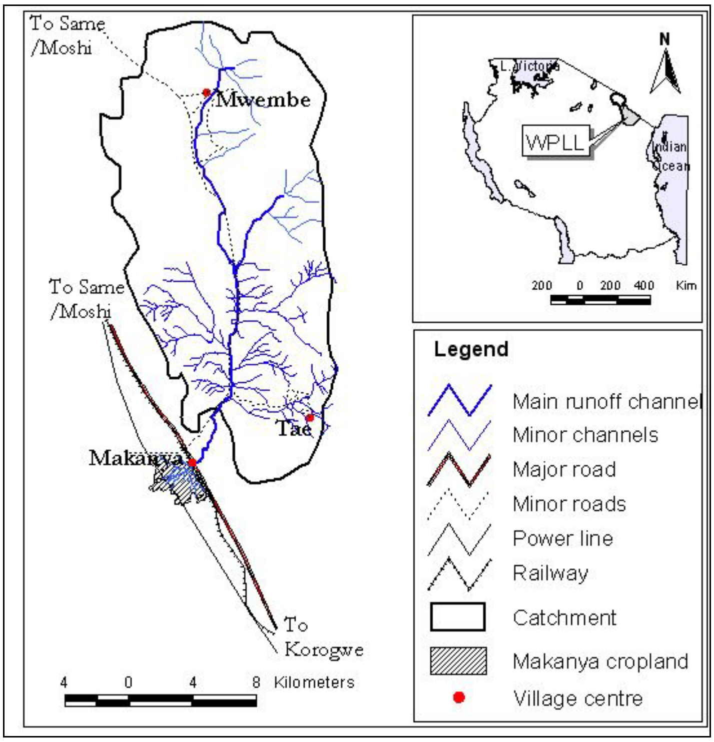


Figure 2: Makanya Catchment (in WPLL) Showing the Location of Makanya, Mwembe, and Tae Villages

3.2 Determination of Soil Fertility Status

3.2.1 Soil fertility status using local indicators

Identification of local indicators of soil fertility in the study catchments was conducted using participatory tools/means namely, focus group discussions, key informants' discussions, transect walks, participant observations and participatory mapping.

(i) Identification and selection of farmers

For both Makanya and Ndala River catchments, village leaders in collaboration with extension staff identified and selected farmers from their villages who participated in the study. The agreed criteria for selecting farmers included gender; age, wealth status; positions of their farms on the landscape (catchments), type of enterprises, types of crops cultivated and the type of RWH techniques used. The research team, the village leaders and extension staff carried out categorisation of farmers jointly. Based on the above criteria, 45 farmers were selected in WPLL, and 50 farmers in Maswa district. The detailed methods are presented in Annex B-1, section 2.1.

(ii) Identification of soil fertility indicators

Identification of the local indicators of soil fertility was conducted through interviews and discussions with the selected farmers and extension staff for each village. Some limited fieldwork was undertaken to verify some of the information and data gathered during the discussions and interviews. The soils were broadly categorized into two groups as perceived by farmers; that is; fertile (good) soils and infertile (poor) soils. Criteria such as amount and frequency of receiving runoff, proximity to water sources, distances from the households to the water sources and fields, vegetation type/species and crop yields were used to define cropland suitability classes (Annex B-1, section 3.1.1 to 3.2.2).

(iii) Participatory mapping

Participatory mapping was conducted in each of the target village as described below (also see Annex B-6, section 2.2.1).

- Initial meeting was conducted in each village to introduce the project.
- Separate focus group discussions involving farmers and livestock keepers were then conducted to provide informants with the skills to map key Common Pool Resources (CPR) identified by the communities themselves.
- Training sessions and focus group discussions were used.

Each informant was then asked to draw sketch maps depicting ones own community and classify the CPR into three suitability classes, i.e. Class I = fertile, Class II = medium fertile, and Class III = infertile. Local perceptions, for example, local indicators for soil fertility (LISF) and criteria such as amount and frequency of receiving runoff were used to define cropland suitability classes in addition to other indicators such as distance from water source, presence of a water source and vegetation type. By using the LISF, for example, the research team was actually asking farmers to pool their knowledge on soil fertility and offer practical and realistic assessment of the fertility of their soils.

3.2.2 Scientific soil fertility evaluation

(i) Soil sampling and analysis

The scientific soil fertility evaluation involved limited soil sampling and analysis as detailed in Annex B-9, section 2.1 to 2.3. Soil sampling was based on identified soil fertility classes during the processes of participatory mapping. In each soil class, composite soil samples were taken at 0-30 cm depth. From the composite soil samples soil parameters were analysed that included pH, organic carbon, total nitrogen, available phosphorus, CEC, particle size distribution and micronutrient (Zn and Cu). The pH of the composite soil samples were measured electrometrically in 1:2.5 soil: water suspensions (McLean, 1982). Organic carbon content was determined by the wet digestion method of Walkley and Black (Nelson and Sommers, 1982) and total nitrogen by the semi-micro Kjeldahl method (Okalebo *el al*., 1993). The available phosphorus content was determined by the Olsen's and Bray-1 methods (Shio-Kuo, 1996; Landon, 1991). Cation exchange capacities of the soils were determined by the neutral ammonium acetate (CH_3COONH_4) saturation method (Rhoades, 1982). The particle size distributions were determined by the hydrometer method (Gee and Bauder, 1986). Copper and Zinc contents in the soils were extracted by DTPA and measured by atomic absorption spectrophotometer (Lindsay and Novel, 1978). The exchangeable bases in the ammonium acetate filtrates collected above were measured by atomic absorption spectrophotometer (Rhoades, 1982). The analytical data generated was compared with farmers' perception.

(ii) Spatial patterns of soil fertility parameters

Geostatistics was used to describe and map spatial patterns of soil based on the nutrient analysed. Based on soil properties and GPS coordinates, soil fertility spatial pattern maps were then generated using ArcView GIS software and geostatistical analyst extension.

3.3 Development of Soil Fertility Management Options

(i) Identification of soil fertility management options

The identification of soil fertility management options suitable under different RWH systems was made based on the local and technical indicators of soil fertility. For each of the soil fertility category, small groups of farmers were constituted based on wealth, age and gender. The groups were facilitated and assisted by researchers and extension staff to design the best soil fertility management strategies. Possible soil fertility management practices appropriate in their respective areas were ranked specifying criteria used.

(ii) Demonstrations of suitable soil fertility management options

Based on the above, three farmers from Bukangilija, three from Njiapanda and two from Isulilo were selected and requested to avail 0.5 ha each of their farms for demonstrating some of the management options proposed in rice production. The demonstration plots included different integrated soil fertility management (ISFM) options as follows:

i. Option 1: Urea (40kgN/ha)
ii. Option 2: Urea (20kgN/ha), TSP (15 kg P/ha) and FYM (3.5 ton/ha)
iii. Option 3: A control without any soil fertility amendment.
iv. Option 4: TSP (30kgP/ha)
v. Option 5: FYM (7tons/ha)

Agronomic practices such as planting time, water management, and weeding; and pest control were adhered to during the growing cycle of the rice crop. Yield data collected include plant height, number of tillers per hill, dry matter and content of N, P, K in plant material using standard methods (see also Annex B-12, section 2.0 for more details).

3.4 The Role of Macro-catchments-RWH on Soil Fertility Status

Studies carried out in Makanya River catchment are used as a case study to describe the role of macro-catchment-RWH on soil fertility variability along the toposequence. In the Makanya catchment, Tae village is located upstream, Mwembe village in the midstream and Makanya village downstream. A participatory reconnaissance survey was carried out in the three villages for areas representing crop fields in each of the perceived land suitability class (refer section 3.2.1 (iii)). Soil samples were collected from selected crop fields for laboratory analysis in order to establish the current soil fertility status of the study areas. Runoff samples were also collected at different points on the toposequence from the main gullies. The following chemical properties were determined: soil pH, total nitrogen in soils, exchangeable Na and K, and electrical conductivity using standard methods. Detailed description is presented Annex B-15 an MSc Dissertation.

3.5 Capacity and Performance of Farmer Support Agencies

Information and data on alternative sources of information, capacity and performance of farmer upport agencies were obtained from discussions with farmers, extension staff, NGOs, researchers and input suppliers using a checklist. Participatory workshops were used to identify needs for capacity building, communication products for the current extension service providers and alternative providers of information to farmers. Detailed description is presented Annex B-11

3.5.1 Awareness raising

Two workshops were conducted to raise awareness of District Councillors and districts leaders (63 in Maswa and 40 in WPLL) on aspects of soil fertility management and participatory mapping results. These workshops also involved Members of Parliament, NGOs and Private Service Providers. The aim of these workshops was to create awareness of the benefits of RWH for crop production and need to support farmers in aspects related to ISFM. Consultation meetings with policy makers and planners from Maswa, Mwanga and Same districts were held as part of wider consultation on up-take on knowledge sharing products.

A one-day workshop was also conducted at the Ministry of Agriculture and Food Security (MAFS) headquarters. Directors and Assistant Directors (from the Department of Research and Development, Irrigation and Technical Services, Special Research Programme) responsible for natural resource management, research, policy and planning participated. The aim of the workshop was to create awareness on the RWH potential, constraints and the need for supporting farmers in the process of scaling up. Detailed description is presented Annex B-8.

3.5.2 Training of extension staff on local and scientific indicators for soil fertility

Two days training of village extension staff (12 in Maswa and 11 in WPLL target areas) was conducted. In collaboration with district officers, trainees were identified from the target villages. Training on LISF emphasized active participation of participants through participatory mapping and soil sampling. The following materials were used: soil sampling kit and tools; Munsell Colour Charts; Field soil test kit; GPS equipment and Laptop computers. The manual on procedures and methods for participatory assessment of soil fertility status and development of soil fertility management strategies (Annex B-2) was also used.

3.6 Sources and Delivery Mechanisms on Soil Fertility Management Information

Surveys were carried out to collect information on sources and delivery mechanisms of soil fertility management from farmers, researchers and extension staff. Sixty smallholder farmers selected from the study areas were interviewed. Both structured and semi-structured questionnaires were used. The primary data were coded and analysed using SPSS (Annex B-14 an MSc. Dissertation)

3.7 Baseline survey and monitoring and evaluation

Baseline survey to monitor extent of change of farmers' strategies for managing soils and plant nutrient and use of different sources of information was carried out in the target villages. The survey involved 204 households in Maswa and 100 households in WPLL. The data was analyzed and formed the basis of comparison during the monitoring and evaluation exercise (Annex B-4 and B-5).

4. RESULTS AND DISCUSSIONS

4.1 Soil Fertility Status

Good or fertile soils refer to those soils with very few or minimum limitations with respect to crop production. Good soils have the desired combinations of physical, chemical and biological attributes or aspects of soil fertility and productivity. Such soils require minimum or insignificant amounts of soil amendments for optimal soil productivity. The detailed research findings are presented in the following section.

4.1.1 Results of soil fertility based on local indicators

Farmers in both catchments revealed different local indicators of soil fertility as shown in Table 5. The black or dark colours of soils as indicators of good (fertile) soils are reflections of the high amounts of organic matter contents in the soils. Similarly, black or dark colours of the soils are associated with high availability of plant nutrients, high capacities to retain nutrients in exchangeable forms, high moisture retention and storage and source of energy and carbon to soil micro-organisms. This is in agreement with available literature (Brady and Weil, 1996; Lavelle, 1988; Stevenson, 1982; Oades, 1984; Lal, 1986; Hue *et al*., 1986), which is summarised in Annex B-1.

Table 5: Local Indicator of Soil Fertility

Fertility Category	Study site	
	WPLL	**Maswa District**
Good (fertile) soil	**Soil colour**: Black deep soils **Soil structure**: visible cracks **Soil texture:** high clay content **Water retention capacity**: low frequency of watering/irrigation; **Plant growth vigour**: vigorous growth of specific plants like wild sisal **Crop yield:** Good crop performance, like maize, millet etc without the use of fertilizers, manures and crop residues **Indicator plants**: presence/vigorous growth of a certain plants or weeds like *Solunum indicum* (*Ndulele*), Cyperus sp (*ndago*), *Cynodon sp.* (*sangari*), presence of green vegetation during dry season;	**Soil colour**: Black soils; deep soils **Soil structure**: presence of friable soils **Soil texture:** high clay content **Water retention capacity**: high moisture content and retention capacity; **Plant growth vigour**: dense plant population with a variety of plant species; vigorous growth of the vegetation **Crop yield**: high crop yields without the use of fertilizers and manure. Continuous cultivation without decline in crop yields **Indicator plants**: presence of specific plants like *“mashibili”* and *“samangombe”*, *“malaba”* on ant hills;
Poor (infertile) soil	**Soil colour:** Red or light sandy soils; **Soil structure:** compacted soils; **Soil texture**: sandy soils: presence of very coarse sands, gravel and stones on the surface. **Water retention capacity:** soils which dry up fast after rains or irrigation; **Plant growth vigour:** poor vegetation even where water is not limiting; **Crop yield:** poor crop performance even with application of fertilizer or manure; **Indicator plants:** presence of specific plants like baobab trees and *Cyperus sp. (ndago), “igulangoji, jangare, mbigiri, (minyaa)”that are mostly weeds*; **Salinity**: presence of white spots or patches on the soil surfaces; presence of salts	**Soil colour:** light colour and red soils **Soil structure:** presence of rocks and stones **Soil texture**: Sandy soils **Water retention capacity:** soils which dry fast **Plant growth vigour:** presence or growth of drought resistant trees; low and sparse plant population; **Crop yield:** low crop yields and **Indicator plants:** presence of specific plants (weeds) like *Cyperus spp (ndase), “magunguli”, “hodi”, “”, Cyperus spp.(ndago), Striga spp (kiduha), Mlenda (makonda)* **Soil depth**: shallow soils

The presence and vigorous growth of specific plants as shown in Table 5 is a manifestation of the soils ability to supply sufficient nutrients and water for such plants that have high demands for plant nutrients and water (heavy feeders). Such soils are dominant on the bottom (plains) of the toposequences, but may occur at the top summit and middle of the catchments on locations or positions where the slopes are not prohibitive and in depressions. Development of visible cracks on the soils during the dry season is an indication of the high content of the 2:1 expanding lattice clay minerals like montimorillonite and vermiculite. These soils are locally known as '*mbuga'* in Maswa and '*ngamba'* in WPLL. Such soils are most suitable for rice (paddy) cultivation because of their ability to store water.

Red and light coloured soils usually contain high amounts of Fe and Al in the parent material and have undergone extensive weathering. Red soils are called '*mthau mnkhundu*' in WPLL, while in Maswa they are known as '*ikingu'*. Such soils have low soil moisture and nutrient retention capacities, low organic matter contents, acidic soil reactions and low percent base saturation. Based on LISF such soils are categorized as bad soils. Scientifically, such soils are also regarded as infertile because of the negative attributes. Because of the low nutrient and water retention capacities of such soils coupled with strong acid soil reactions, the soils can only support plants with low nutrient and water demands (for example sorghum in Maswa) and can tolerate acid soil conditions. In the two catchments, areas with red and light coloured soils are mostly reserved for grazing or under forest.

Poor crop growth, scanty and stunted natural vegetation is an indication of inadequate supply of plant nutrients and water by the soil to plants. It could be argued that poor and stunted growth of plants is a manifestation of the poor and improper balance of the physical, chemical and biological attributes of soil fertility, soil moisture and the low plant nutrient contents being the most important. The nutrients might be in the soils but in forms not available to plants either due to low moisture contents in the soils or the nutrients are strongly fixed or retained by the soil components hence not exchangeable or the nutrients have been converted into insoluble compounds through various transformations in the soils. Further, such soils may fail to support plant growth because they are naturally poor or deficient in the essential nutrients elements due to the low contents of the elements in the parent materials of the soils coupled with low soil organic matter contents. The low contents of the plant nutrients in such soils could also be due to extensive weathering coupled with significant losses of plant nutrients through the processes of leaching, plant uptake, volatilization and soil erosion.

The sandy soils are dominated by quartz, which is an inert soil component with no surface charges thus very limited capacity to retain water and plant nutrients. Soils with low water retention in semi-arid areas can lead to rapid loss of the limited water resource from erratic and inadequate rainfall. Presence of salts or white patches or spots on the surface of soils is an indication of the presence of sodic, sodic-saline or saline soils. These soils are mostly found at the bottom of the landscape where drainage is often poor. The inability of these soils to support crop growth other than weeds is one of the criteria that farmers use to categorize such soils as bad or of low fertility status.

From this discussion it can be inferred that there is convergence from both project study areas with regard to local indicators, which are almost similar. For example, black soils are perceived as fertile with high moisture retention capacity and vigorous plant growth both in Maswa and Same districts. Attributes identified under LISF, have sound scientific explanation. Fertile soils for example, refer to those with very few or minimum limitations with respect to crop production as identified under LISF.

More details on issues presented in section are found in Annex B-6.

4.1.2 Cropland suitability based on local perceptions

Based on the farmers' local indicators of soil fertility (LISF), cropland suitability classes based on local perceptions were developed in both Maswa and WPLL. In both sites, farmers classified the cropland into three suitability classes (I, II and III). Class 'I' being highly suitable/ fertile and class III being the least (marginally) suitable/ fertile for crop production. In WPLL class III constitutes the highest proportion of the available cropland and class I the least proportion (Figures 3, 4 and 5). While class III constitutes 58%, %54% and 55% of the available cropland in Makanya, Mwembe and Tae villages, respectively. Class I constitutes only 14%, 7% and 9% of the available cropland in the same villages. As discussed earlier, the categorization of land suitability was based on a combination of local indicators for soil fertility evaluation. Proximity to a water source is the most important factor on the classification. In most cases, land close to a water source was categorised as Class I and vice versa.

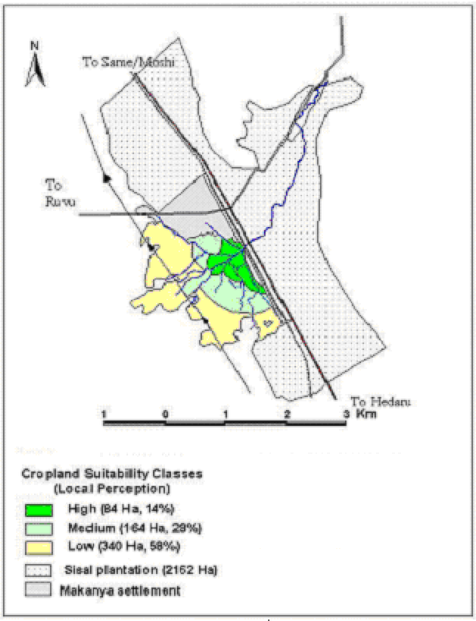


Figure 3: Distribution and Extent of Coverage of Cropland Suitability/ Fertility Classes Based on Farmers' Perception in Makanya village

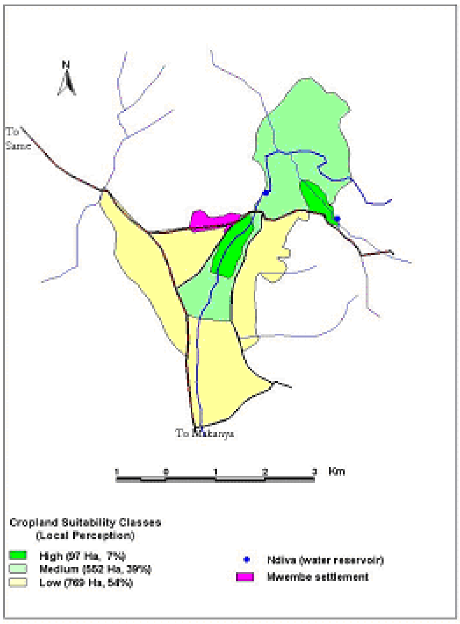


Figure 4: Distribution and Extent of Coverage of Copland Suitability/ Fertility Classes Based on Farmers' Perception in Mwembe Village

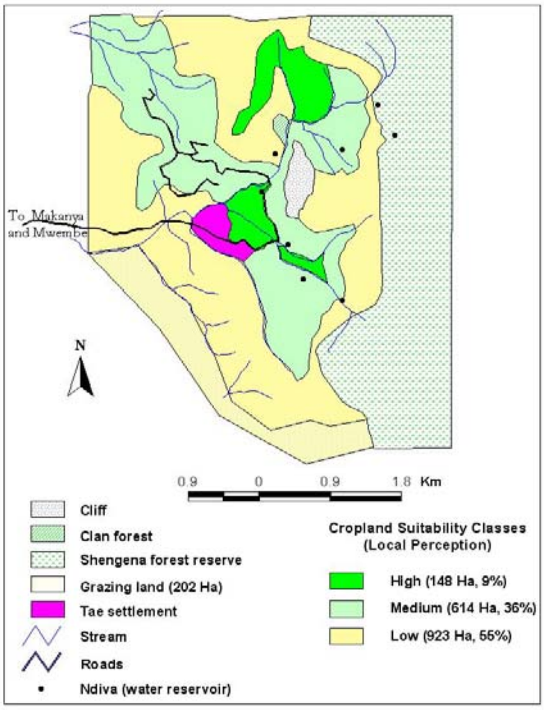
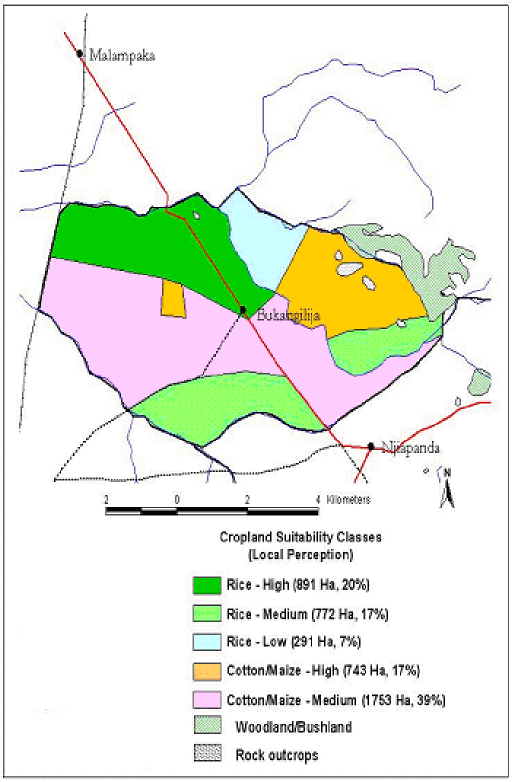


Figure 5: Distribution and Extent of Coverage of Cropland Suitability/ Fertility Classes Based on Farmers' Perception in Tae Village

In the Ndala River catchment in Maswa district (Figures 6, 7, and 8), the cropland can broadly be categorised into land for rice production and land for maize and cotton. Rice production is considered to be the main economic activity. Cropland for cotton/maize constitutes the highest proportion of the available cropland. It constitutes 56%, 88% and 77% of the available cropland in Bukangilija, Njiapanda and Isulilo, respectively. Highly suitable class (Class I) forms the highest proportion of the available cropland for rice production. There are no class III cropland for cotton/maize in Bukangilija and no class III cropland for rice in Isulilo village.



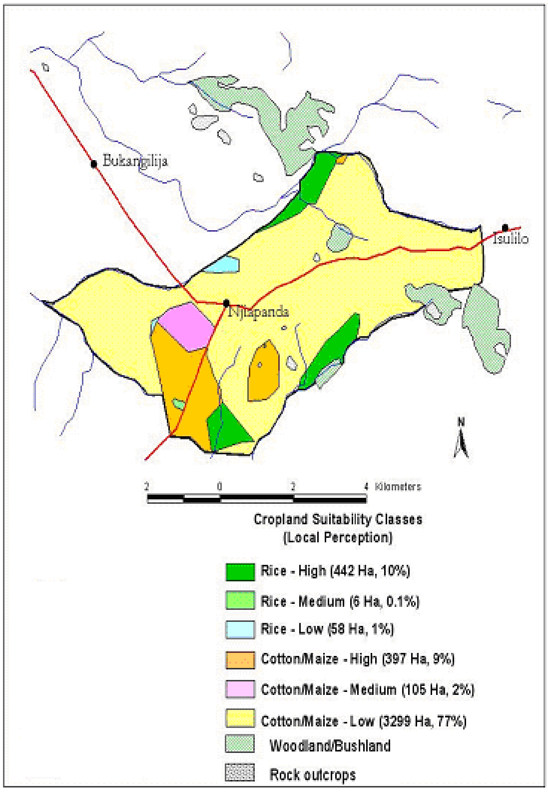


Figure 6: Cropland Suitability/ Fertility Classes for Bukangilija village

Figure 7: Cropland Suitability/ Fertility Classes for Njiapanda Village

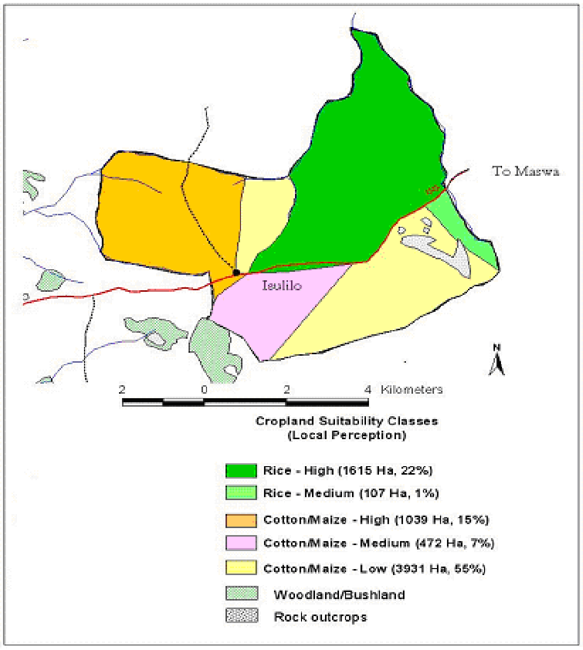


Figure 8: Cropland Suitability/ Fertility Classes for Isulilo Village

4.1.2 Scientific indicators of soil fertility and crop suitability

The results on physical and chemical analysis from limited soil sampling are presented in Annex B9 and discussed in this section. The discussion focuses at the contents of nutrients and adequeacy for crop production. The adequacy is based on combined evaluation of individual plant nutrients requirements.

The soils from various sites within the villages had previously been categorized as fertile or infertile/ poor for crop production using local indicators of soil fertility (Table 6and Table 7). Various soil attributes were analysed based on the recommended standard procedures for soil fertility evaluation. The soil analytical data were interpreted based on established critical values of the attributes and accordingly the soils were categorised as of high, medium or low fertility status. From the soil analytical data, 32 out of the 36 and all the soil samples from WPLL and Maswa district were categorized as of low fertility and medium fertility status, respectively. The major soil fertility attributes which variably contributed to the low and medium fertility status include low total nitrogen, low organic matter, low plant available phosphorus, alkaline soil reaction and low plant available Zu and Cu. The soil fertility status categorization by farmers based on local indicators was not in conformity with the technical state of the art indicators of soil fertility. The majority of the soil samples analysed were of low soil fertility status. There were no significant differences in nutrient content between soils perceived as good (fertile) and those regarded as poor (infertile) (Table 6). The local indicators of soil fertility are qualitative while the technical indicators are quantitative and correlated to plant growth and nutrition. Categorization of soils based on local indicators of soil fertility by farmers, soil moisture (availability of water) was the guiding and sole criterion as well as comparison of the performance of the crops in the neighbourhood. However in soil fertility categorization both the local and technical indicators of soil fertility have to be given due and appropriate proportional consideration. For sustainable and optimal crop production, the soil must be accorded the appropriate soils fertility management practices.

Table 6. Local Soil Fertility Perception viz a viz Soil Analytical Results and Scientific Evaluation in Makanya River Catchment Western Pare Lowlands

Soil identity	Village	Local Fertility Perception	Soil Analytical Results				Scientific Fertility Evaluation
			OC%	TN%	P(mg/kg)	pH	
E. Mnyuku 1	Makanya	Bad soil	2.21	0.2	38.5	7.99	medium
Alfani Kalewa – 2	Makanya	Bad soil	1.17	0.14	52.9	8.04	low
Mwajabu Lusandi 1	Makanya	Bad soil	1.44	0.14	40.2	8.04	low
Asha Sailo 2	Makanya	Bad soil	1.24	0.13	51.2	7.8	low
Saidi Simba 1	Makanya	Bad soil	1.26	0.12	46	8.13	low
Eliasini Bakari 3	Makanya	Bad soil	0.9	0.11	55.1	7.91	low
James Linazi 2	Makanya	Bad soil	0.55	0.06	68.7	6.63	low
Raheli Kisaka 3	Makanya	Bad soil	0.47	0.05	52.1	7.65	low
Elisante Nikombolo 3	Makanya	Bad soil	0.83	0.01	20.2	8.19	low
Mean			**1.12**	**0.11**	**47.21**	**7.82**	
Standard deviation			**0.50**	**0.05**	**12.70**	**0.45**	
Alfani Kalewa – 2	Makanya	Good soil	1.46	0.15	48.6	8.15	low
Saidi Simba 1	Makanya	Good soil	2.43	0.22	39.4	7.86	medium
James Linazi 2	Makanya	Good soil	1.54	0.14	77.1	7.58	low
Mwajabu Lusandi 1	Makanya	Good soil	2.21	0.09	41.3	7.95	low
Elisante Nikombolo 3	Makanya	Good soil	1.17	0.13	35.3	7.78	low
Eliasini Bakari 3	Makanya	Good soil	1.04	0.12	57.5	7.88	low
E. Mnyuku 1	Makanya	Good soil	1.5	0.17	37.3	8.09	low
Raheli Kisaka 3	Makanya	Good soil	1.13	0.12	123	8.34	low
Asha Sailo 2	Makanya	Good soil	1.48	0.19	37.8	8.11	low
Mean			**1.55**	**0.15**	**55.26**	**7.97**	
Standard deviation			**0.45**	**0.04**	**27.05**	**0.21**	
Coef of Var Makanya (good Vs bad soil)			**0.04**	**0.00**	**24.19**	**-0.03**	
tTest (at 5% level)			**NS**	**NS**	**NS**	**NS**	
Mohamedi Mzingazi 1	Mwembe	Bad soil	3.93	0.28	53.5	7.56	medium
Ramadhan Saidi 3	Mwembe	Bad soil	0.81	0.06	62	7.48	low
Madina Adam 3	Mwembe	Bad soil	1.3	0.08	62	7.23	low
Juma A. Mrutu 2	Mwembe	Bad soil	0.2	0.03	12.2	7.96	low
Hemed Dimon 1	Mwembe	Bad soil	1.46	0.14	64	8.21	low
Mean			**1.54**	**0.12**	**50.74**	**7.69**	
Standard deviation			**1.42**	**0.10**	**21.92**	**0.39**	
Mohamedi Mzingazi 1	Mwembe	Good soil	2.83	0.02	41.9	8.11	low
Ramadhan Saidi 3	Mwembe	Good soil	0.89	0.16	49	7.38	low
Madina Adam 3	Mwembe	Good soil	2	0.18	72.2	7.29	low
Juma A Mrutu 2	Mwembe	Good soil	0.83	0.15	61.6	8.33	low
Hemed Dimon 1	Mwembe	Good soil	1.71	0.16	63	8.31	low
Mean			**1.65**	**0.13**	**57.54**	**7.88**	
Standard deviation			**0.83**	**0.06**	**12.03**	**0.51**	
Coef. of Var. Mwembe (good Vs bad soil)			**0.88**	**0.00**	**-11.67**	**0.14**	
tTest			**NS**	**NS**	**NS**	**NS**	

Table 7: Local Soil Fertility Perception viz a viz Soil Analytical Results and Scientific Evaluation in Ndala Catchment Maswa District.

Soil identity	Village	Local soil fertility perception	% OC	% TN	Ext .P BR-1 mg/kg	Soil pH. (1:2.5) H_20	Scientific Fertility Evaluation
Bukangilija M_1	Bukangilija	high for rice	0.82	0.06	5.73	7.55	**low**
Bukangilija M_2	Bukangilija	medium for rice	0.38	0.03	5.24	7.03	**low**
Bukangilija M_3	Bukangilija	low for rice	0.52	0.04	4.39	8.92	**low**
	Mean		**0.57**	**0.04**	**5.12**	**7.83**	
	Std Dev.		**0.22**	**0.02**	**0.68**	**0.98**	
Bukangilija P_1	Bukangilija	high for cotton	0.4	0.03	32.1	8.15	**low**
Bukangilija P_2	Bukangilija	medium for cotton	0.38	0.02	4.63	6.98	**low**
	Mean		**0.39**	**0.03**	**18.37**	**7.57**	
	Std Dev.		**0.01**	**0.01**	**19.42**	**0.83**	
	COVAR Bukangilija (cotton Vs rice soils)		**0.00**	**0.00**	**5.84**	**-0.55**	
Isulilo M_1	Isulilo	high for rice	0.63	0.04	3.9	8.75	**low**
Isulilo M_2	Isulilo	medium for rice	0.61	0.05	6.83	7.73	**low**
	Mean		**0.62**	**0.05**	**5.37**	**8.24**	
	Std Dev.		**0.01**	**0.01**	**2.07**	**0.72**	
Isulilo P_1	Isulilo	high for cotton	0.82	0.06	11.47	7.15	**low**
Isulilo P_2	Isulilo	medium for cotton	0.9	0.08	35.88	6.86	**low**
Isulilo P_3	Isulilo	low for cotton	0.54	0.06	23.06	6.84	**low**
	Mean		**0.75**	**0.07**	**23.47**	**6.95**	
	Std Dev.		**0.19**	**0.01**	**12.21**	**0.17**	
	COVAR Isulilo (cotton Vs rice soils)		**0.00**	**0.00**	**-9.39**	**0.01**	
Njia Panda M_1	Njia Panda	high for rice	0.63	0.04	6.95	8.68	**low**
Njia Panda M_2	Njia Panda	medium for rice	0.46	0.03	5.49	7.92	**low**
Njia Panda M_3	Njia Panda	low for rice	0.63	0.05	6.95	8.03	**low**
	Mean		**0.57**	**0.04**	**6.46**	**8.21**	
	Std Dev.		**0.10**	**0.01**	**0.84**	**0.41**	
Njia Panda P_1	Njia Panda	high for cotton	0.25	0.04	5.73	6.71	**low**
Njia Panda P_2	Njia Panda	medium for cotton	0.92	0.08	9.64	6.65	**low**
Njia Panda P_3	Njia Panda	low for cotton	0.46	0.03	5.73	6.25	**low**
	Mean		**0.54**	**0.05**	**7.03**	**6.54**	
	Std Dev.		**0.34**	**0.03**	**2.26**	**0.25**	
	COVAR Njia Panda (cotton Vs rice soils)		**-0.02**	**0.00**	**-1.27**	**0.03**	

Key:
P=Soils suitable for cultivation of cotton and maize (1=high, 2= medium, 3= low suitability)
M=Soils suitable for cultivation of rice (1=high, 2= medium, 3= low suitability)

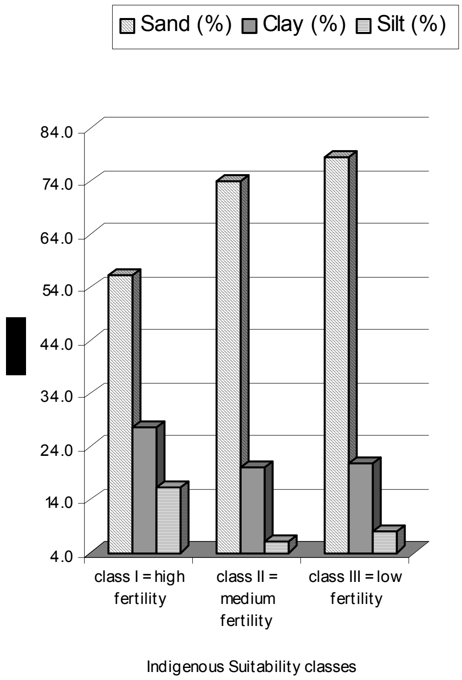


Figure 9: Soil Particle Size Distribution in the Indigenous Suitability/ Fertility Classes for Makanya Village

(iii) Chemical characteristics

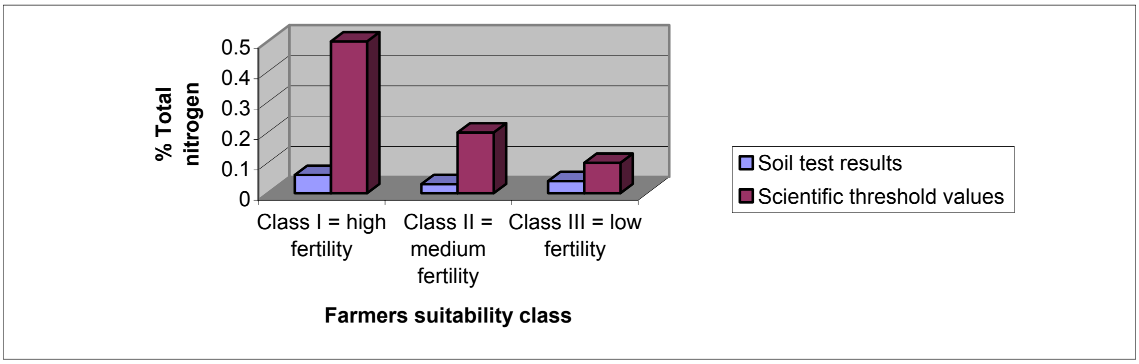
(a) Soil pH

In Ndala River catchment the soils' pH values ranged from 6.3 to 8.9 with a mean pH of 7.5. The optimum soil pH for rice production ranges from 5.5 to 6.5 under dry conditions (non irrigated rice production system) and 5.5 to 7.2 under flooded conditions (Landon, 1991; De Datta, 1981;). Further, it has been reported that cultivation of rice is even possible in soils with pH of up to 9.0. Based on soil pH, the soils along the Ndala River catchment are suitable for rice cultivation. On the other hand, Makanya catchment soils' pH ranged from 7.2 to 8.3, which is high and may lead to some nutrient deficiencies for a number of crops (Landon, 1991).

(b) Total nitrogen

Total nitrogen in the three classes of cropland suitability based on LISF ranged from 0.03 to 0.06 in Ndala River catchment. These values are rated as very low (Landon, 1991). The soils are therefore deficient in nitrogen even in soils perceived by farmers as fertile. In order to achieve high yield in rice production, nitrogen in the form of fertilizers, manure and crop residues should be applied to the soil to arrest N deficiency in the soils. In Makanya River catchment, the percentage total nitrogen ranged from 0.01 to 0.3. Out of 35 sampled sites only five locations had medium N content (average of 0.28%) and the rest had very low values (average of 0.11%). Generally N content is very low and thus application of N containing soil amendments is necessary to increase yield (Table 3 and Figure 10.).

Figure 10: Measured and Critical Threshold Total Soil N in Farmers' Suitability Classes in Bukangilija Village



(c)Organic carbon

The organic carbon content in the Ndala River catchment soils, ranged from 0.4% to 0.8%. These values are rated as very low (Table 3, Landon, 1991). The low percentage organic carbon content translates to low organic matter content in the soils. Organic matter in soils influence physical, chemical and biological properties of soils. Such properties include soil structure, water retention, nutrient contents and retention and microbiological activities. In Makanya catchment organic carbon content ranged from 0.5% to. 3.9%. These values vary from low to very low (Table 3 and Landon, 1991). The low organic carbon correlates with the low total nitrogen content observed in these soils, which calls for application of N containing soil amendments.

(d) Phosphorus

In Ndala River catchment, the plant available phosphorus (Olsen's P) content in the soils ranged from 14.2 to 17.2 mg P kg^{-1} soil (Fig. 11). These plant available phosphorus values are rated as medium (Landon, 1991). Rice being a low P-demanding crop, the observed plant available phosphorus values would satisfy the phosphate demand by the rice crop, hence no dramatic response to phosphate application to these soils as inorganic or organic soil amendments would be expected in the short run. In Makanya River catchment the Bray-1 P ranged from 20% to 77%, which is rated as medium to high. The only problem may be high pH levels that may reduce its availability (Landon, 1991).

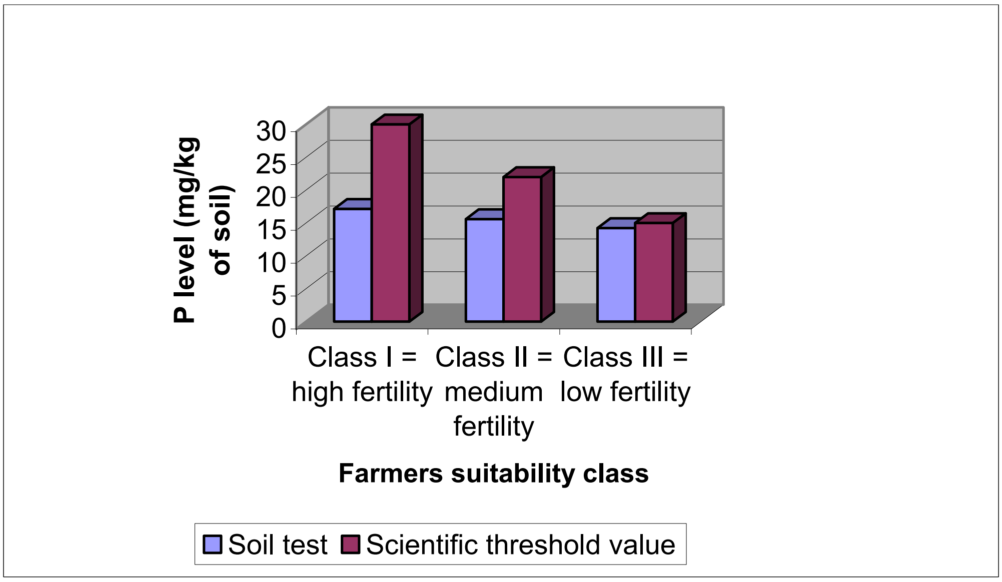


Figure 11: Measured and Critical P Threshold Contents in Farmers' Suitability Classes in Bukangilija Village

Potassium

The exchangeable K in soils in the Ndala River catchment ranged from 0.11 to 0.36 cmol$_{(+)}$ kg^{-1} of soil (Fig. 12) and these values are rated as very low (Landon, 1991). Similarly, in Makanya River catchment exchangable K values were very low (0.6 to 3.0 cmol$_{(+)}$ kg^{-1} of soil. Corrective measures through application of different soil amendments are, therefore, necessary.

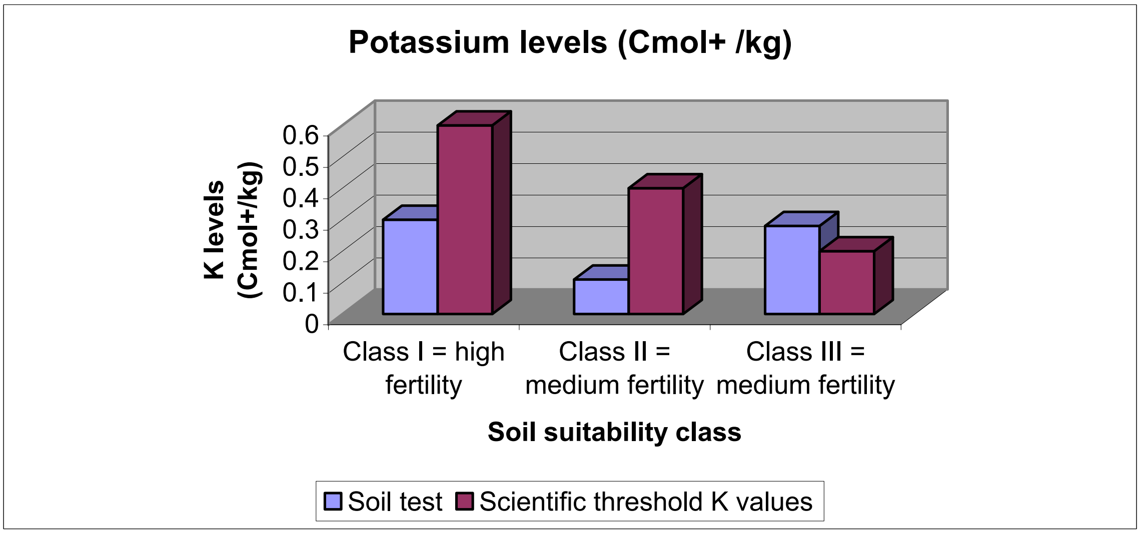


Figure 12: Measured and Critical K Levels in Farmers' Soil Suitability Classes in Bukangilija Village

From the above results, it was observed that with the exception of P, nitrogen and potassium are very low even in soils perceived by farmers as fertile. Although soil suitability classification by farmers is based on LISF, availability of water tends to bias their final classification. The scientific soil fertility evaluation on the other hand is based on physical and chemical parameters such as available P, percent total nitrogen and exchangeable K.

LISF can qualitatively discriminate between fertile and infertile soils, but is unable to quantify them. However, LISF can be used to guide the sampling exercise for nutrient quantification. It is recommended, therefore, to test for the major plant nutrients so as to guide soil fertility amendment recommendations for sustainable crop production.

4.2 Role of Macro-catchment RWH Systems on Soil Fertility Status

The role of macro-catchment RWH systems on soil fertility status presented hereunder is based on a study carried out in the Makanya River catchment. The study focused on the chemical analysis of runoff water along the toposequence and this was supplemented with the analysis of soil nutrients.

The mean pH value in runoff water (Figure 13) shows some variations along the toposequence. Generally, the pH values indicated that the water was alkaline (pH > 7.8) and increased from downstream to upstream with the exception of the pH of the runoff at mid-slope during the long rainy season (*masika)*. Water pH variations were portrayed at each sampling station in terms of temporal variation. For the Tae (upper zone) and Makanya (lower zone) stations, the pH decreased from *vuli* to *masika* season. The temporal variation of the pH could be related to the temporal distribution of the rainy seasons. The *vuli* season normally starts after a very long dry period (four to five months). This makes the area lose vegetation and thus when the *vuli* rains start, soluble salts erode with the soils. As a result, runoff contains high sediments with high concentrations of soluble salts and exchangeable bases and hence high pH level. However, the pH trends of the runoff obtained in the current study call for further investigation to as certain the results/trends

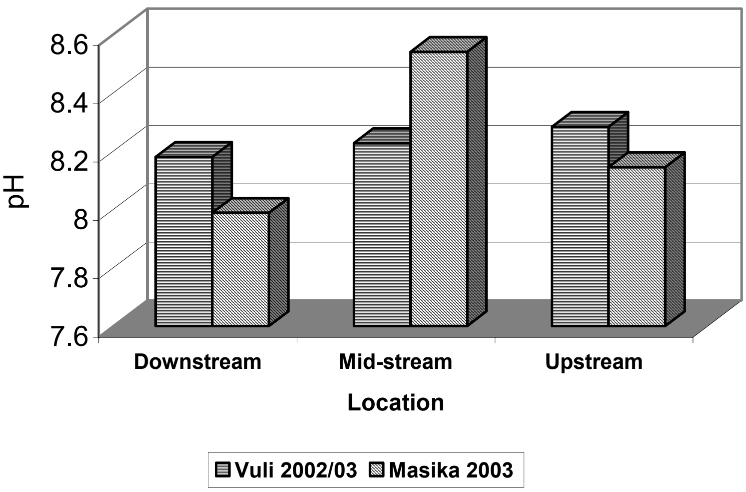


Figure 13: Variation of pH in Runoff Water Along the Toposequence in the Makanya River Catchment

The variation of K in runoff water along the toposequence is shown in Figure 14. The concentration of K is relatively low upstream compared to mid and downstream. Similar trends were observed for other bases (Ca, Mg and Na) in the runoff water (see Annex B-15 MSc. Dissertation). The variations in the basic cations concentrations in the runoff between *vuli* and *masika* could probably be accounted for by the temporal variation. The temporal variability could also be explained by different factors such as changes in vegetation cover and EC during the rainy season.

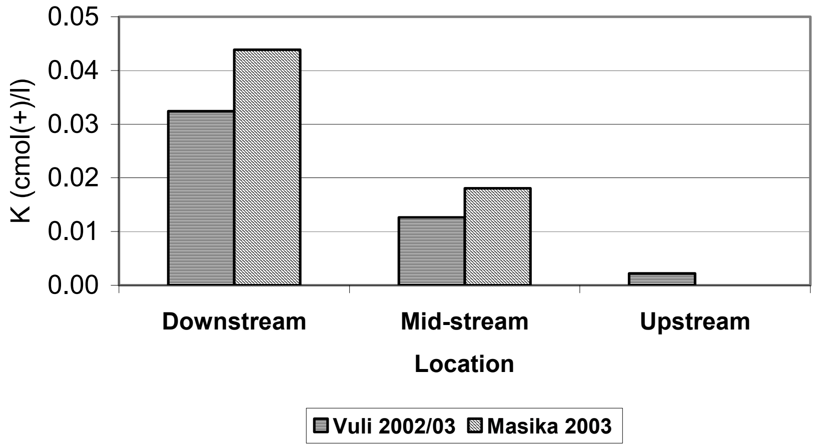


Figure 14: Variability of the Amounts of K in Runoff water Along the Makanya River Catchment

Therefore, Figure 14, show that there is movement and concentration of nutrients in the runoff water from upstream to downstream. These nutrients accumulate and enrich the lowlands through the runoff water. Hatibu and Mahoo (1999) reported similar observations in the tropical semi-arid areas of Tanzania where high value crops like vegetables are grown in the lowlands where runoff collects.

Total nitrogen along the toposequence was > 0.2 % in the upstream, < 0.2% in the mid zone and between 0.2 – 0.5 % in the valley bottoms. Downstream, the total N was relatively high (0.5 – 1.0 %). The reasons for the lowlands to contain high total N is possibly due to organic matter contained in the harvested runoff water. A similar trend was observed for exchangeable K. In the lower zones exchangeable K values were relatively high and uniform.

The increase in nutrient content in runoff water from upstream to downstream areas demonstrates the role of macro catchment RWH in contributing nutrient to croplands located downstream. The question is on the adequacy of this process to meet the plant nutrients requirement and whether it is sustainable, which is a question for further research. The effect of macro catchment RWH on soil fertility at farm level is discussed in detail in a MSc. Dissertation (Annex B-15).

4.3 Strategies for Soil Fertility Management in the Study Area

This section presents results of soil fertility management (SFM) options developed for different categories of farmers using participatory action research methods. The first three sub-sections (**4.3.1 to 4.3.3**) present the results on the baseline status of SFM, SFM options and KSPs on SFM. The impact is looked at by comparing baseline and the current status and the results are presented in sub-section **4.3.4**.

4.3.1 Farmers' Soil Fertility Management Practices

The use of inorganic fertilizers in the Ndala and Makanya River catchments is very low. For example, the quantity of inorganic fertilisers sold between 2001 and 2003 in Maswa and Malampaka townships ranged from 1 to 5 tonnes per year (**Annex B-11**). Little amounts of inorganic fertilizers in the form of Urea and CAN are used mainly in vegetable and rice production. Indigenous soil fertility enhancement strategies practiced by farmers, in the Ndala River catchment, include ridging, intercropping, minimum tillage, use of crop residues, application of manures, crop rotation, fallowing, use of ashes from crop residues and deep tillage. More detailed discussion is presented in Annex B – 7.

In Makanya River catchment, it was observed that only 3 percent of the households use different forms of inorganic fertilizers (Table 8). Other soil fertility management practices include the use of crop residues (86%), intercropping (76%), application of farmyard manure (76%) and application of mulch (72%). Agro-forestry practices (66%) were found to be most applicable in Mwembe and Tae villages, most probably due to high rainfall compared to Makanya village. Bush fallowing (40%) appeared to be the most favoured practice in Makanya village compared to Mwembe and Tae villages. The most used fallowing period was one year or less. This is practiced more in the lower zone of the catchment, possibly due to rapid depletion of plant nutrients and also availability of agricultural land in Makanya village compared to the mountainous areas (Tae and Mwembe).

Table 8: Soil Fertility Management Practices in the Makanya River Catchment

Fertility management practice	Makanya (n = 54)		Mwembe (n =47)		Tae (n = 43)		Makanya Catchment (n = 144)	
	Frequency	Percent of n	Frequency	Percent of n	Frequency	Percent of n	Frequency	Percent of n
Application of inorganic fertilisers	1	2	0	0	3	7	4	3
Application of farmyard manure	26	48	41	87	42	98	109	76
Agro-forestry practices	6	11	47	100	42	98	95	66
Application of mulch	14	26	46	98	43	100	103	72
Intercropping	23	43	46	98	41	95	110	76
Use of crop residues	35	65	47	100	42	98	124	86
Bush fallowing	34	63	5	11	18	42	57	40
Others	6	11	46	98	12	28	64	50

As perceived by farmers in both catchments, constraints leading to low use of inorganic fertilisers include:

a) **Cost**: It was pointed out that inorganic fertilizers are expensive and consequently most of the farmers are using them in highly paying crops such as vegetables.
b) **Availability**: Sometimes, inorganic fertilizers are not available when required.
c) **Fear of dependence on external inputs**: Some farmers claimed that use of inorganic fertilizers for a long time creates dependence on them, and without using them yields are extremely low.
d) **Inadequate moisture**: It was also claimed that the fertilized crops are highly affected by drought compared to unfertilized crops or crops fertilized using organic fertilisers.
e) **Low value crops**: Non-assurance of getting higher returns due to growing of low value crops

The aforementioned strategies of soil fertility management have for a long time sustained the productivity of soils. However, under the current intensive cropping systems and scarcity of arable land, a more sustainable approach based on integrated soil fertility management strategies has to be developed. This should be based on the local and improved soil fertility management strategies that advocate use of organic and inorganic fertilizers, and other soil amendments. Farmers can easily and profitably adopt soil amendment practices for enhanced and sustainable crop production if these are developed using participatory approaches.

4.3.2 Soil fertility management options

The farming rural communities are comprised of different categories of farmers with regard to resource endowment, biophysical locations of their fields, age and gender. For successful soil fertility management, a basket of soil fertility management options that are holistic and integrative, site specific and responsive to peculiarities of each farmer were developed. Through participatory processes, which involved farmers, extension staff and researchers, a basket of locally based options for soil fertility management suitable for the different wealth categories of farmers, type of enterprise, runoff availability, soil type and RWH system were developed. These include:

a) Use of organic manure
b) Use of appropriate tillage operations
c) Combined application of organic and inorganic nutrient sources
d) Intercropping with nitrogen fixing leguminous plants to exploit biological nitrogen fixation
e) Use of indigenous herbaceous species known to have fertilizing effect on soils such as *Vernonia subligera* and *Tithonia diversifolia*
f) Rotation and use of improved fallow involving leguminous species
g) Mulching to minimize evaporation losses and maintain suitable soil temperature and structure hence to reduce surface run-off and soil erosion
h) Choice of crop to match the prevailing local conditions including use of crops sharing different niches, as this will ensure better nutrient exploitation

Tables 8 and 9 present some of the developed soil fertility management options for maize-beans cropping systems for *mthau mnkhundu* (red soil) and *Ngamba* (black soils) soil type in WPLL and rice-based cropping systems for *itogolo, ibambasi* and *mbuga* soils types. Options provided in WPLL are subject to availability of runoff, whereas in Maswa, availability of water is a must for rice cultivation. More soil fertility management options for other cropping systems under different RWH conditions are presented in a booklet (Annex B-13).

Table 9: ISFM Options for Maize-beans Cropping system and M*thau mnkhundu* Soil Type in WPLL

Locations and soil types	RWH system	Runoff availability	Farmer category	ISFM options
UPPER SLOPE, MTHAU MNKHUNDU (Red`soils = Oxisol)	Insitu	Adequate	Poor	Crop residues, green manure (weeds), intercropping, crop rotation
			Rich	FYM, crop residues, green manure (weeds), intercropping, crop rotation
		Inadequate	Poor	Crop residues, green manure (weeds), intercropping, crop rotation
			Rich	FYM, crop residues, green manure (weeds), intercropping, crop rotation
	Sheet flow diversion	Adequate	Poor	Crop residues, green manure (weeds), intercropping, crop rotation
			Rich	Crop residues, green manure (weeds), intercropping, crop rotation
		Inadequate	Poor	FYM, crop residues, green manure (weeds), intercropping, crop rotation
			Rich	FYM, crop residues, green manure (weeds), intercropping, crop rotation

LOWER SLOPE NGAMBA (Black soils= Vertisol)	Runoff diversion	Adequate	Poor	FYM, Rotation, intercropping, minimize sand deposition
		Inadequate	Rich	FYM, Rotation, intercropping

Table 10: ISFM Options for Rice-based Cropping System and I*togoro-ibambasi* and M*buga* Soil Types in Maswa

Location	RWH system	Soil type (local)	Farmer category	ISFM options
UPPER SLOPES	Insitu	Itogoro-Ibambasi	Poor	FYM, crop residues (burn and spread ashes)
			Rich	FYM, inorganic fertilizer
	Sheet flow diversion	Itogoro-Ibambasi	Poor	FYM, crop residues (burn and spread ashes)
			Rich	FYM, inorganic fertilizer
LOWER SLOPES	Insitu	Mbuga	Poor	FYM, crop residues (burn and spread ashes)
			Rich	FYM, rotation, intercropping, green manure, inorganic fertilizer
	Sheet flow diversion	Mbuga	Poor	FYM, crop residues (burn and spread ashes)
			Rich	FYM, relay cropping, intercropping, green manure, inorganic fertilizer

Yield response results from the demonstration plots in Maswa indicated that application of Urea, FYM and Urea-TSP-FYM increased rice grain yields, compared to those of farmers practice (Appendix 12 Tables 2 and 3). The current rice production in Maswa district and in particular at Bukangilija village ranges from 700 to 1000 kg/ha and the expected yields under appropriate soil fertility management under rainwater harvesting ranged between 5000 – 7000 kg/ha (SWMRG, 2002). The observed yields in the demonstration plots under farmer's practices (no addition of soil amendments) 2,353 kg/ha (mean over two seasons) are significantly ($P>0.001$) higher than the control and base line yields (700 – 1000 kg/ha). The increase is attributed to the efficient use of the harvested rainwater, planting at the appropriate time and control of weeds.

The response of rice in terms of grain yields, N, % P and % K contents, plant heights and tillering to Urea, TSP, farmyard manure and a combination of urea-TSP-FYM applied on demonstration plots confirmed the inherent deficiency of N in the soils as earlier revealed by soil analysis (Appendix 12 Tables 2 and 3). The poor response of rice to the applied P as TSP compared to the other plots concurred with the inherent adequate phosphorus levels for plant growth in the soils (Tables 11 and 12). The superior effect (average yield of 3662 kg/ha) of Urea-TSP-FYM applications against the control (average yield of 2353 kg/ha) is a reflection of the positive effect of INM on soil fertility and uptake of plant nutrients due to nutrient balance in the soils and improvement in the physical, chemical and biological properties of the soils. Therefore, the higher yields are realized when there is efficient use of runoff water and adoption of INM.

Table 11: Response of rice to N, P and FYM Application (2002/2003) season at Bukangilija, Njiapanda and Isulilo Villages, Maswa, District, Tanzania

Levels	Treatment	Yield (kg/ha)	Plant height (cm)	Number of tillers/hill	Dry matter (kg/ha
1	Urea (40 kg N/ha)	3020 b	74.65 a	7.12 ab	5493
2	1Urea + FYM + TSP	3642 a	73.85 a	8.85a	6027
3	TSP (30 kg P/ha)	2345 c	68.5 b	6.45 b	5553
4	FYM (7 ton/ha)	2580 bc	71.65 ab	6.97 ab	5095
5	None (farmers Practice)	2345 c	62.15 c	6.57 b	5812
	CV%	12.05	4.34	18.26	12.94
	LSD	517.42	4.69	2.024	1115.5
	F Test	***	***	***	Ns

* Figures in the same column followed by the same letters are not significantly different at P>0.05

Table 12: Response of Rice to N, P and FYM Application/Treatments (2003/2004) Season at Bukangilija, Njiapanda and Isulilo villages, Maswa, district, Tanzania

Levels	Treatment	Yield (kg/ha)	Plant height (cm)	Number of tillers/hill	Dry matter (kg/ha
1	Urea (40 kg N/ha)	3184 b	1061a	9.86 b	5502.6
2	1Urea + FYM + TSP	3681 a	105.0 a	11.0 a	5820.0
3	TSP (30 kg P/ha)	2688 c	99.26 c	8.69 c	6009.7
4	FYM (7 ton/ha)	2885 c	102.2 b	8.7 c	5512.5
5	None (farmers Practice)	2361 d	94.9 d	8.3 c	5589.5
	CV%	10.89	2.49	12.28	11.42
	LSD	265.225	6.407	1.31	534.5
	F Test	***	***	***	ns

* Figures in the same column followed by the same letters are not significantly different at $P \geq 0.05$

Combined use of inorganic and organic sources of plant nutrients has proved to be the most appropriate soil fertility management strategy in semi-arid-areas under RWH-system as it takes into account the wealth status of the smallholder farmers in the acquisition of the plant nutrient-sources. "Soil Fertility Management Options" in detail are presented in booklet, which appear as Annex B-13.

4.3.3 Communication products on fertility management strategies

This study revealed that few knowledge-sharing products (KSPs) contained information on soil fertility management. For example, in Maswa District of the 35 KSPs distributed only 11% contained some information on SFM. In WPLL, 23% of the KSP contained information on SFM. More details on KSPs distributed by different stakeholders in the two study areas are contained in Annex B-4. Consultations with different stakeholders identified areas on which the following KSPs and information transaction mechanisms were developed:

i) Planning guides on soil fertility management options.
ii) Posters on soil fertility and cropland suitability maps produced using local and scientific indicators for soil fertility management. These were distributed in the target villages.
iii) Demonstration plots showing best practices on ISFM specifically using FYM for soil

amendment was carried out in Bukangilija village in Maswa district. Practical demonstration was highly demanded by district and village leaders during the workshops.

iv) Leaflets and brochures produced include:
   a. Soil Fertility Management Strategies for rice and maize in RWH systems (leaflet)
   b. Preparation of Good Quality Manure (leaflet)
   c. Soil Fertility Management Strategies for Rice and Maize under RWH (brochure).

4.3.4 Changes in the extent of use of organic and inorganic soil amendments

The extent of use of organic and inorganic soil amendments in crop production for the period 2002 to 2004 was monitored and the results are shown in Table 13. The results showed an increasing trend on the use of organic soil amendment in Bukangilija (24 %), Makanya (6%) and Njiapanda (10 %) villages. The increase may be attributed to the training provided to farmers and other stakeholders on the importance and usefulness of organic soil amendments in enhancing and sustaining soil fertility and productivity. This could also be attributed to training given to the farmers in the preparation of compost using local materials and leftovers from the households and farmyard manure (Annex B-5).

The results also show that there was increased use of inorganic fertilisers by 13 %, 31% and 5% in Makanya, Mwembe and Tae villages, respectively. The increase is attributed to the increase in the number of farmers producing high value crops like tomatoes and cabbage because of the favourable market infrastructure available in the area.

Non-use of inorganic fertilizers in Bukangilija and Njiapanda villages is attributed to unfavourable fertilizer in crop price ratios given the poor market infrastructure (poor roads to major markets) and limited opportunities for the production of high value crops like in WPLL.

Table 13: Extent of Use (%) of Organic and Inorganic Soil Amendments in the Study Villages in Maswa and WPLL

Soil amendments	**Baseline (2002)**	**After 2 yrs (2004)**	**Change**		**Baseline (2002)**	**After 2 yrs (2004)**	**Change**
	Maswa				**WPLL**		
Lower slope	*Bukangilija*				*Makanya*		
FYM	9	33	+24		12	18	+6
Compost	0	5	+5		5	37	+32
Inorganic fertilizer	0	0	0		2	15	+13
None	91	62	-29		81	30	-51
Total	100	100			100	100	
Mid slope	*Njia Panda*				*Mwembe*		
FYM	27	37	+10		47	22	-25
Compost	0	14	+14		47	33	-14
Inorganic fertilizer	0	0	0		3	34	+31
None	73	50	-23		3	11	+8
Total	100	100			100	100	
Upper slope	*Isulilo*				*Tae*		
FYM	73	42	-31		58	28	-30
Compost	0	14	+14		27	32	+5
Inorganic fertilizer	0	2	+2		15	24	+9
None	27	42	+15		0	16	+16
Total	100	100			100	100	

Presence of farmers not using any soil amendments could be attributed to the common belief that harvested runoff water contains organic matter and dissolved nutrients. Given the fact that the quantity of FYM available in the study areas is limited, combined use of organic soil amendments and inorganic fertilizers should be encouraged to optimise agricultural production. Detailed data is provided in Appendices 1 and 2, and.

4.4 Capacity and Performance of Farmer Support Agencies

4.4.1 Support agents in the catchments

There are various farmers support agents who are involved in the dissemination of agricultural technologies in the target catchments. The main support agents identified include:

- Extension service providers under the District Agricultural and Livestock Development (DALDO) offices.
- **National Agricultural Research Systems (NARS**): Main actors are the Zonal Agricultural Research and Development Institutes. In Maswa, the Ukiriguru Research Institute based in Mwanza has the mandate to provide technological information to clients in the Lake Victoria zone. The WPLL lies within the mandate of the Selian Agricultural Research Institute (SARI), which also provides technological information to clients in the Northern zone.
- **NGO**: Catholic Relief Services (CRS) is partly providing soil fertility management technological messages through promotion of chickpea production in the Ndala River catchment. In WPLL, NGOs involved include the Mixed Farming Improvement Programme (MIFIPRO); Same Agricultural Improvement Programme (SAIPRO); Traditional Irrigation Improvement Programme (TIP) and VECO, a Belgium Supported organization.
- **Agricultural input stockists**: These provide agricultural inputs such as inorganic fertilizers and limited advise on type, rates and application methods. These stockists have input shops around Maswa and Malampaka towns in Maswa; and Same, Makanya, Hedaru and Mwanga towns in WPLL.

4.4.2 Performance of farmer support agencies

(i) ***District Agricultural and Livestock Development Offices***

The District Agricultural and Livestock Development Offices are responsible for disseminating all crop and livestock production technologies in the districts through extension agents in the villages. The main source of technologies is from NARS such as Ukiriguru Agricultural Research Institute and Selian Agricultural Research Institute; Universities such as Sokoine University of Agriculture and NGOs interested in promoting Integrated Nutrient Management (INM) in the districts. The district team has experts in livestock and crop production, most of them are diploma and certificate holders and few are graduates. These have expertise in specialised fields like crop production, irrigation, land-use planning, horticulture, animal health, home economics and nutrition and animal production. The districts do not have sufficient number of experts to allocate in all villages to cover all major disciplines. For example a village extension officer who is specialised in animal health is expected to offer advise in all aspects related to agriculture. The advice may fall short in terms of details needed by farmers. In addition, most of the village extension workers are not well facilitated in terms of transport to cover large distances, extension kits and up-dated knowledge sharing products. They, thus fail to meet expectations of their clients (ie.farmers).

(ii) ***Zonal Agricultural Research and Development Institutes (ZARDI)***

The Zonal Agricultural Research and Development Institutes in the two target areas conduct research on soil fertility management. Past research work in the target areas is presented in Annex B-10. The institutes have adequate expertise in crop and livestock production aspects as all researchers are University graduates. The Ukiriguru Agricultural Research Institute is conducting research in many villages in Maswa District. Bukangilija village for example, has been used as a testing site for disseminating different technologies. The Institute has formed Farmer Research Groups (FRG) that participate in all on-farm trials. Farmers from nearby villages including Isulilo and Njiapanda learn from these FRG. The Agricultural Research Institutes have teams of experts dealing with Integrated Soil Fertility Management (ISFM). The zones also offer ISFM technologies through production of different types of extension products such as leaflets, posters and training manuals for district extension staff.

In Makanya River catchment, researchers from SARI have also been conducting both inorganic and organic fertiliser trials for various crops in farmers' fields. For both ARIs, messages on ISFM are very few and in most cases they are not addressing the challenges of fertility management in RWH systems in semi-arid areas. In these areas emphasis has been on drought resistant crops like sorghum and cassava, crops that have not received priority in fertility management. The challenge is that with access to RWH technologies, farmers have shifted to producing high value crops. Research in the ARIs has not kept pace with the emerging information demands in RWH production systems including ISFM.

(iii) ***Non-Governmental Organisations***

There are a number of NGOs working in the target areas on agricultural related activities. Catholic Relief Services (CRS), for example, is one of them and it promotes the production of grain legumes such as chickpeas and pigeon peas in Maswa district. The organization also deals with the marketing of the produced legume crops. In collaboration with district extension staff, CRS tests and provides improved seeds of chickpea in the district. The promotion of leguminous crops improves soil fertility through nitrogen fixation.

In WPLL, NGOs providing extension services in soil fertility management aspects include MIFIPRO; SAIPRO; TIIP and VECO. Their activities include promotion of use of organic and inorganic fertilizers; agroforestry and soil and water conservation activities. VECO is also involved in desalinisation interventions in Makanya area through promotion of soil fertility management practices. Most of the NGOs carry out their activities in few villages and have limited funds and personnel.

(iv) ***Agricultural input stockists***

In Maswa, most farmers in the Ndala catchment areas, that is, Isulilo, Njiapanda and Bukangilija villages, obtain their soil fertility related inputs from either Malampaka or Maswa townships. There are five stockists who are selling different agricultural inputs, and it was observed that district extension staff owns most of these shops. However, sales persons, who mostly are their relatives, have limited agricultural knowledge in general and INM in particular. It was also observed that when fertilizer stock is exhausted it takes about two weeks to replenish as most fertilizers are purchased from Shinyanga or Mwanza towns more than 150 km away and on a rough road. Occasionally, when the shop owners are present in the shop, they do give advice on fertilizer use including rate of application for various crops, time and method of application. The main types of fertilisers stocked included Urea and CAN.

Input stockists in WPLL are situated in Same, Hedaru and Makanya townships. Like in Maswa, most of these stockists are district extension staff. The most common types of fertilisers sold in WPLL are Urea and SA. With regards to proximity to source of fertilisers, WPLL has all weather roads to Moshi and Arusha, but the amount stocked is very little due to limited use.

From these observations it can conclude that farmer support agencies are facing a number of constraints. The ARIs have limited funds that cannot support longterm research in INM and messages developed are few and rarely focused on RWH systems. Extension officers are few, not adequately trained in INM and not well facilitated to provide required services to farmers who are scattered over large areas. The input stockists stock very small amounts due to limited demand, lack of capital and most of the sales persons cannot offer advice due to lack of knowledge on fertiliser use. This explains the low use of soil amendments in the target areas, thus posing a challenge to future intervention on ISFM. Appendix 11, gives detailed account of input stockists, what they sell and amounts sold and stocked.

4.4.3 Capacity development of support agencies

Different mechanisms to develop capacity of support agencies for disseminating information to support farmers in making decisions on use of soil fertility amendments were used. Awareness creation seminars and workshops were conducted for policy makers at district and national level. These were envisaged to influence policy and planning process that are pro-poor so that they provide required support to knowledge dissemination and utilisation in order to increase use of ISFM for increasing productivity. The research team facilitated training of extension service providers at village levels to create a common understanding of the concepts of INM including use of local indicators. The outcome of the seminars and workshops were positive as the participants benefited theorically and practically on various aspects of ISFM and INM.

(i). Creating awareness to policy and planners at district level

It was observed that most of the district leaders were not aware of several policies and legal frameworks that guide the implementation of ISFM and NRM strategies in general. This ignorance made them fail to link policies in the district development plans and programmes that would spearhead sustainable management of land resources through use of improved technologies (Annex B8).

After the awareness workshops, policy makers, while appreciating the knowledge they received on RWH systems and ISFM, required more understanding of national policies and strategies related to agriculture, environment, water, land, forestry and relevant legislations and regulations. Another area which training was required is on making and implementing plans using suitable decision aid. To meet this demand there is an opportunity for utilizing the PARCHED-THIRST Model as well as GIS approaches linking them to indigenous knowledge on soil fertility management. Linkages to good markets (*smart farming*), to improve profitability of RWH for agriculture and thus among other things attract youths to RWH based agriculture, has been identified as a key area that need to be addressed.

(ii). Training of extension staff on local and technical indicators of soil fertility

Extension officers from Maswa district and WPLL were trained on the use of local and technical indicators of soil fertility, soil analysis and soil fertility management. Upon completion of training on SISF, course participants were facilitated to identify and prioritise local indicators of soil fertility and integration of scientific and local indicators of soil fertility

in devising integrated soil management strategies. Finally the soil 'fair' was used to give practical orientation to ISFM. Details are presented in Annex B-3.
Based on the outcome and observations made during the training workshops and seminars it was concluded that, a combined training of both farmers and extension staff should be conducted in the future. This would enable the farmers, extension staff and other stakeholders to share their knowledge and experience in soil fertility management, hence designing appropriate soil fertility management strategies through participatory approaches. It was also realised and concluded that farmers and extension staff understanding of indigenous knowledge and expertise in soil fertility management for various enterprises on the farm, was essential in designing and development of appropriate and sustainable soil fertility management strategies.

4.5 Information Sources and Delivery Mechanisms on SFM

4.5.1 Sources of information on soil fertility management and their delivery mechanisms

From the interviews and discussions with farmers it was found out that the major sources of information on soil fertility management are extension officers, researchers and innovative farmers (Annex B-11 and Annex B-14). Indigenous knowledge on soil fertility management formed a good basis for the development of modern, state of the art soil fertility management options. Old farmers constituted potential sources of indigenous information on soil fertility and productivity.

Research institutions have mandate to generate and provide information on soil fertility management options while the role of extension service providers is to disseminate information from the research institutions to beneficiaries, mostly farmers. However, it was noted that researchers and communication intermediaries, such as NGOs and primary school teachers, lack the necessary tools, coordination and facilities for efficient communication of the information. The existing communication methods and media for the dissemination of soil fertility management strategies in the study areas include farm visits by extension staff and researchers, demonstrations plots and meetings (farmer groups or village meetings); study tours, written materials such as booklets, posters and leaflets (Figure 16).

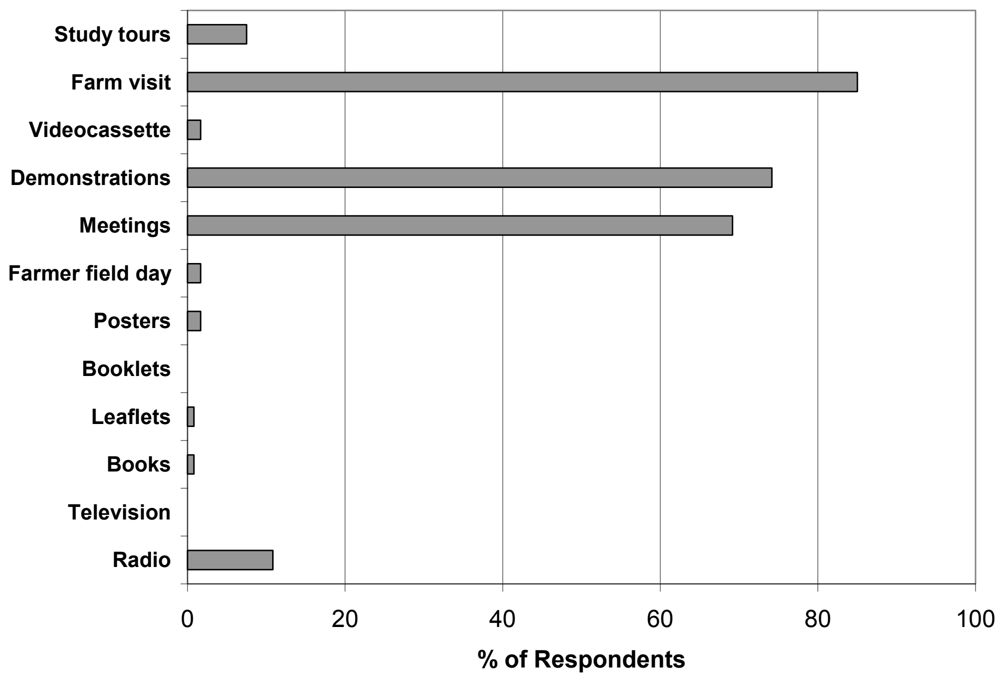


Figure 15: Existing Communication Methods in the Study Areas

Assessment of different methods used to transact information on agricultural aspects showed that farm visits, demonstration plots and meetings were rated as the most common, appropriate and effective communication methods in the transaction of information and research findings to smallholder farmers (Figure 17). These communication methods were perceived as more interactive and responsive to the immediate needs and aspirations of the smallholder farmers. Low preference of written materials like books, leaflets, booklets and posters as communication methods may be attributed to their low availability and inability of majority of the smallholder farmers to read and write.

Radio was rated low by farmers as a media compared to other media because it is a one-way communication methods. Moreover, farmers claimed that they did not know the exact airtime for agricultural programmes. In addition, farmers admitted that currently there are many broadcasting stations that have music programmes that attract many people especially the youths. Agricultural shows and campaigns were reported to be very expensive to conduct and have turned out to be more of social occasions than opportunities for learning.

Study tours and farmer field days as communication methods are not used frequently because of the cost implications in organization and implementation. Very limited popularity of television and videos as communication media is due to the fact that very few smallholder farmers can afford a television set and videocassettes. Moreover, electricity has not reached all rural areas.

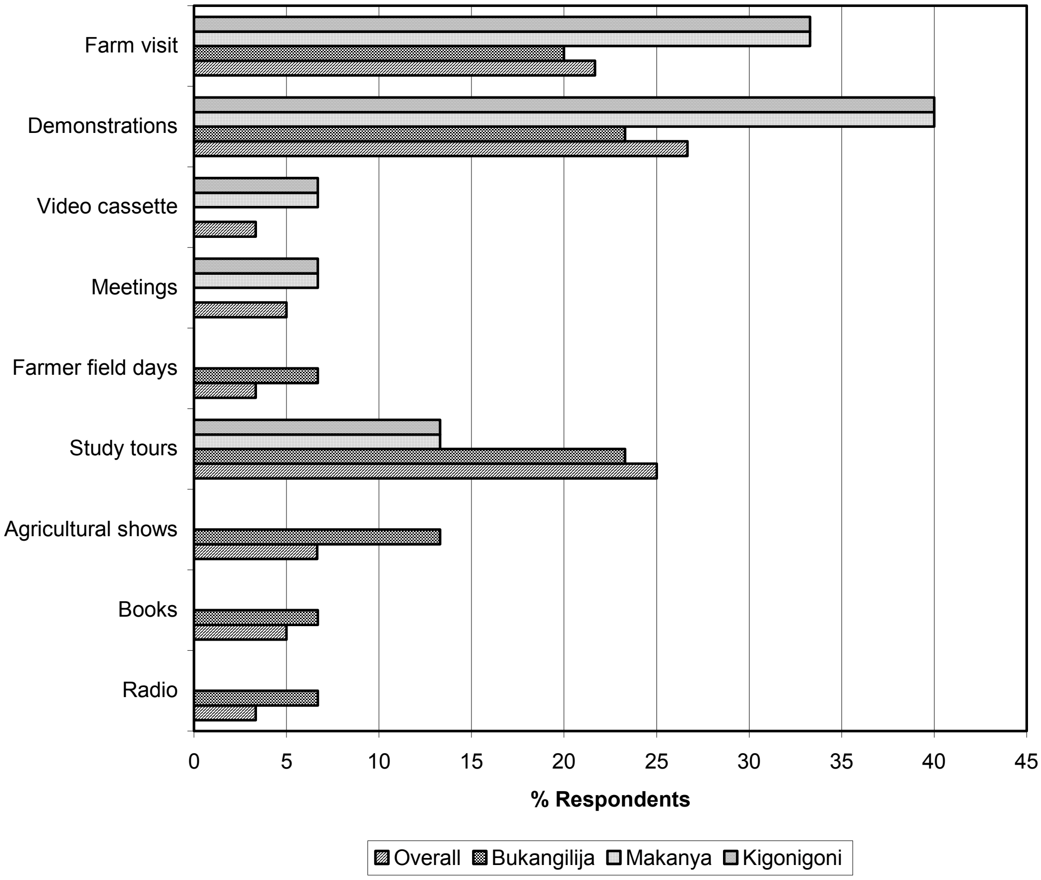


Figure 16: Effective Communication Methods as Mdentified by Farmers in Study Villages

Farmers also evaluated the level of clarity of messages presented by various methods. The communication methods not understood by the farmers and reasons are presented in Figure19. It was argued that some of the information is not relevant to the stakeholders, especially the farmers. It was further noted, through discussions that videos, meetings, farmer field days could be significantly effective if accompanied or combined with other information delivery mechanisms such as written materials with illustrations so as to enhance comprehension and interpretation by the farmers. Figure 19 gives an example of reasons for limited use and poor understanding of messages disseminated through radio programmes.

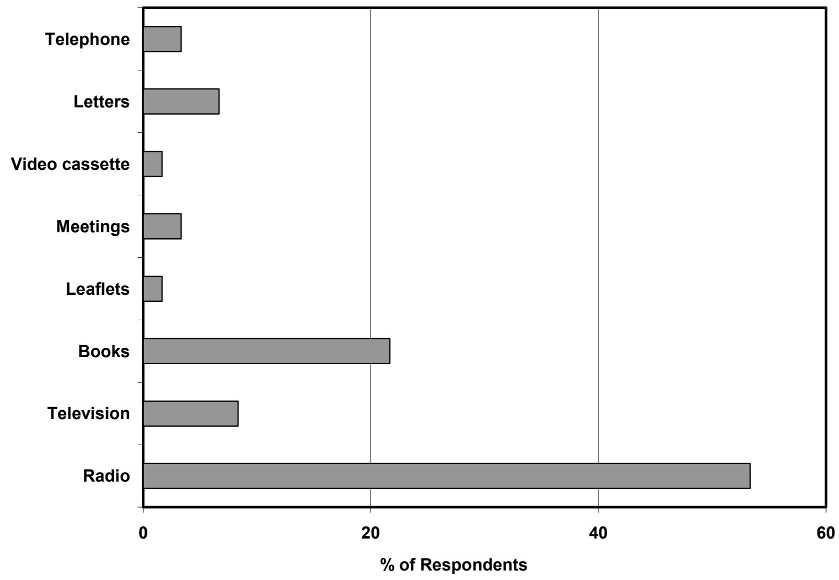


Figure 17: Communication Methods ranked by Farmers as less effective when used to Disseminate Information.

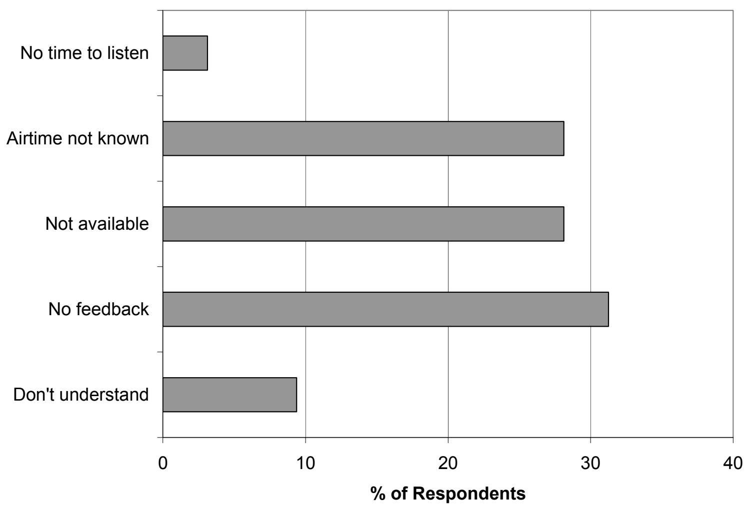


Figure 18: Reasons for Low Preference of Radio as a Communication Media

In summary, the current communication methods identified as effective are not fully exploited and not delivering required information on soil fertility management. Reasons include inadequate packaging of messages appropriate and specific to different areas; inadequate number of extension staff in the villages; inadequate communication skills and under funding of communication activities. It is therefore recommended that the government and private service providers, who are key players in agricultural development, should invest more in improving communication approaches to ensure that research findings reach the targeted users to enhance impact.

4.5.2 Changes on the extent of use of different sources of information for INM in crop production

Sources of information on INM for farmers include: farmer-to-farmer, family member, radio, agricultural show, institutions, newspapers, researchers and extension staff (Table 12). The baseline survey results showed that there is limited use of these sources other than farmer to farmer and extension staff in almost all villages studied. The above is attributed to lack of awareness and limited understanding by farmers on sources of INM information. After two years of the project interventions, a positive contribution of the institutions such as NGOs and input suppliers, newspapers, researchers and family members was observed (Table 12).

Table 14: Change on the Extent of use (%) of Different Sources of Information for INM in the Target Villages

Source of information	Baseline (2002)	After 2 yrs (2004)	Change	Baseline (2002)	After 2 yrs (2004)	Change
	Maswa			WPLL		
Lower slope	*Bukangilija*			*Makanya*		
Farmer to farmer	66	23	-43	29	22	-7
Radio	0	11	+11	0	0	0
Agricultural Show	0	0	0	7	0	-7
Institutions	0	11	+11	2	9	7
Newspapers	0	3	+3	-	-	-
Researchers	5	7	+2	2	21	+19
Extension staff	30	17	-3	0	22	+22
Family Member	0	29	+29	-	26	+26
None	-	-	-	60	-	-
Total	100	100		100	100	
Mid slope	*Njia Panda*			*Mwembe*		
Farmer to farmer	80	32	-48	47	6	-41
Radio	6	2	-4	0	5	+5
Agricultural Show	3	0	-3	6	0	-6
Institutions	0	11	+11	22	29	7
Newspapers	6	2	-4	0	7	+7
Researchers	0	4	+4	14	26	+12
Extension staff	6	23	+17	0	27	+27
Family Member	-	26	+26	1	-	-
None	-	-	-	11	-	-
Total	100	100		100	100	
Upper slope	*Isulilo*			*Tae*		
Farmer to farmer	39	38	-1	4	8	+4
Radio	5	4	-1	4	3	-1
Agricultural Show	0	4	+4	0	0	0
Institutions	3	13	+10	4	18	+14
Newspapers	0	1	+1	-	-	-
Researchers	0	2	+2	0	18	+18
Extension staff	49	20	-29	80	36	-44
Family Member	-	23	+23	0	17	+17
None	-	-	-	60	0	-
Total	100	100		100	100	

This was due to awareness raising activities and training conducted by SWMRG, research institutions, local government institutions and NGOs on the importance of the afore-mentioned sources of INM information. The interventions were through seminars, workshops and provision of booklets, manuals, leaflets and posters. Meanwhile, the use of radio is very low due to inadequate and inappropriate radio programs on INM and other reasons explained in the Monitoring and Evaluation Report (Annex B-5).

5. CONCLUSIONS AND RECOMMENDATIONS

Most of the land identified by farmers as fertile using proxy indicators was found to have low nutrient content levels. Therefore, categorization of soil quality based on farmer's knowledge should be applied cautiously. It is recommended that indigenous classification of soil fertility should be backed with scientific input to validate and quantify the extent of soil fertility status.

For optimal and sustainable crop production, appropriate soil fertility management packages have to be developed and adopted in the whole catchment area. The soil fertility attributes combined with spatial pattern distribution are useful in designing soil fertility management practices. However, the designing has to be carried out using participatory processes. Understanding of indigenous knowledge and expertise in soil fertility management by farmers and extension staff for various enterprises on the farm is essential in designing and development of appropriate and sustainable soil fertility management strategies.

Nutrient load in runoff water increased from upstream to downstream areas. This supports the enrichment claims by downstream farmers who do not apply soil fertility amendments. This is unlikely to continue for a long time because the fertile topsoils, which are the source of these nutrients, are severely eroded and degraded. For sustainability, use of manure and other soil amendments should, therefore, be encouraged.

Farmer support agencies are facing a number of constraints. Extension staff are few, not adequately trained in INM and not well facilitated to provide required services to farmers who are scattered over large areas. The ARIs have limited funds to support longterm research in INM. The messages developed are few and rarely focused on RWH systems.The input stockists stock very small amounts of inputs due to limited demand, lack of capital and most of the sales persons cannot offer advice due to lack of knowledge on fertiliser use. This explains the low use of soil amendments in target areas, thus posing a challenge to future interventions on ISFM. Continued training and reliable funding of research and extension activities is crucial in order to succeed in promoting INM.

Farm visits to farmers groups by the researchers and extension staff and on-farm demonstration of the various soil fertility management practices came out as the most effective methods in transacting and disseminating information. These are common methods but they are not fully exploited because there are very few extension officers in the villages, and some villages do not have any. To cover the whole village or more than one village transport is required which is not available to many village extension staff.

It is, therefore, recommended that the government and private service providers, who are key players in agricultural development, should invest more in improving communication approaches to ensure that research findings reach the targeted users.

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7. APPENDICES

Appendix 1: Response of Rice to N, P and FYM Application (2002/2003) Season at Bukangilija, Njiapanda and Isulilo Villages, Maswa, District, Tanzania

	Treatment	**Yield (kg/ha)**	**Plant height (cm)**	**Number of tillers/hill**	**Dry matter (kg/ha)**	**Percentage N**	**Percentage P**	**Percentage K**
1	Urea (40 kg N/ha)	3020 b	74.65 a	7.12 ab	5493	2.255 d	0.037 c	0.73 a
2	[1]Urea+FYM+TSP	3642 a	73.85 a	8.85 a	6027	3.455 b	0.09 a	0.53 ab
3	TSP (30kg P/ha)	2345 c	68.5 b	6.45 b	5553	2.54 c	0.04 c	0.59 ab
4	FYM (7 ton/ha)	2580 bc	71.65 ab	6.97 ab	5095	4.117 a	0.065 b	0.45 b
5	None (Farmers practice)	2345 c	62.15 c	6.57 b	5812	1.83 e	0.03 c	0.442 b
	CV %	12.05	4.34	18.26	12.94	4.72	23	24
	LSD	517.42	4.69	2.024	1115.5	0.207	0.019	0.211
	F Test	***	***	***	ns	***	***	***

Appendix 2: Response of Rice to N, P and Fym Application/Treatments (2003/2004) Season at Bukangilija, Njiapanda and Isulilo Villages, Maswa, District, Tanzania

	Treatment	**Yield (kg/ha)**	**Plant height (cm)**	**Number of tillers/hill**	**Dry matter (kg/ha)**	**Percentage N**	**Percentage P**	**Percentage K**
1	Urea (40 kg N/ha)	3184 b	106.1 a	9.86 b	5502.6	2364 d	0.035 d	0.449 c
2	[1]Urea+FYM+TSP	3681 a	105.0 a	11.0 a	5820.0	3.583 b	0.095 a	0.791 a
3	TSP (30kg P/ha)	2688 c	99.26 c	8.69 c	6009.7	2.596 c	0.04 c	0.462 c
4	FYM (7 ton/ha)	2885 c	102.2 b	8.7 c	5512.5	4.037 a	0.06 b	0.635 b
5	None (Farmers practice)	2361 d	94.9 d	8.3 c	5589.5	1.892 e	0.032 e	0.422 d
	CV %	10.89	2.49	12.28	11.42	5.82	23	4.81
	LSD	265.225	6.407	1.31	534.5	0.137	0.002	0.026
	F Test	***	***	***	ns	***	***	***