Chapter 24

Sustainable Intensification of Maize and Rice in Smallholder Farming Systems Under Climate Change in Tanzania

Ephraim J. Mtengeti, Frank Brentrup, Eva Mtengeti, Lars Olav Eik, and Ramadhani Chambuya

Abstract Maize and rice are major staple food crops in Tanzania and constitute 31 % and 13 %, respectively, of total food production. The current productivity of the two crops (1.6 t/ha and 2.3 t/ha, respectively) will not match with the increasing demand for food created by population growth unless there is an expansion of cultivated land or intensification measures are imparted to smallholder farmers, who produce nearly 90 % of each crop in the country. Expansion of cropped areas is limited by increased land-use pressure. Under smallholder farming the same land is continuously cultivated without proper input to replenish the removal of nutrients with crop harvesting, which leads to a decline in the subsequent crop yield. The situation is exacerbated by the effects of climate change. The smallholder farmers lack agro-inputs, information and extension services, and are faced with erratic rainfall. Therefore, a public-private partnership comprising two public universities and two multinational companies dealing with fertilizer and crop protection was initiated in December 2010, aiming at demonstrating sustainable intensification of maize and rice production in smallholder farmers' fields. Five farms for maize and four for rice crops in different villages and districts were selected, and their soils were sampled for physical and chemical analysis. Two treatments were imposed on each farm. The treatments were farmers' practice (control) and improved practice, which includes the proper use of fertilizer, crop protection inputs and recommended crop seed variety. Generally, the soils of most farms were acidic with low phosphorus, potassium, magnesium, sulphur, copper and zinc values. On average, maize

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E.J. Mtengeti (✉) • E. Mtengeti
Sokoine University of Agriculture, P.O. Box 3004, Morogoro, Tanzania
e-mail: emtengeti@yahoo.co.uk

F. Brentrup
Research Centre Hanninghof, YARA International, Duelmen, Germany

L.O. Eik
Department of International Environment and Development Studies/Noragric, Norwegian University of Life Sciences (NMBU), P.O. Box 5003, No-1432 Ås, Norway

R. Chambuya
SYNGENTA International AG, Schwarzwaldalle e 215, CH-4058 Basel, Switzerland

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and rice grain yield 14 % moisture content ranged from 2.5 to 5.4 t/ha in farmers' practice and 6.6–8.5 t/ha in improved practice. Maize and rice stover/straw biomass ranged from 5.33 to 15.4 t/ha for improved practice and 2.11–9.13 t/ha for farmers' practice. It can be concluded that improved agricultural practices, including plant nutrition, plant protection, improved seeds and conservation agriculture measures (e.g., crop residue recycling), enable sustainable intensification of smallholder crop production. Crop yields are improved, soil fertility is maintained, and family income is increased all at the same time. Therefore, public-private partnerships are needed to put this concept into practice and to make knowledge and technology available to smallholder farmers.

Keywords Fertilizer • Field days • Food crop • Nutrient removal • Public-private partnership

24.1 Introduction

24.1.1 *Importance of Maize and Rice in Tanzania*

Tanzania's economy is largely dependent on agriculture, which accounts for about 30 % of the GDP, provides 85 % of exports and employs about 80 % of the population. However, people active in the agricultural sector also represent the vast majority of the 12.5 million people living below the national poverty line (Ahmed et al. 2009). Maize and rice are the largest and most preferred food and cash crops in the country (RATES 2003; USDA 2012). Nearly 90 % of the production of these two cereal crops is done by small-scale farmers, with an average farm size ranging from 0.5 to 2 ha.

Maize crops are grown in nearly all agro-ecological zones of Tanzania. The primary maize-producing regions in the country include Arusha, Iringa, Manyara, Mbeya, Njombe, Rukwa and Ruvuma. Together, these seven regions have the capacity to supply at least 50 % of the national maize output, and the Iringa, Mbeya and Njombe regions in the southern highlands along the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) may account for a quarter of the national maize production, producing on average more than 700,000 tons each year (Rowahni et al. 2011). Planted areas with maize crops increased from 2,570,147 ha in 2005/06 to 3,050,714 ha in the 2009/10 agricultural year with an average yield between 1.3 and 1.6 t/ha (MAFC 2010). Maize constitutes 75 % of the cereals consumed and 31 % of the total food production in the country (WEMA 2010). In general, the consumption of maize averages approximately 74.5 kg/person/year (PASS 2012).

Tanzania is the second-largest rice producer in Eastern, Southern and Central Africa. Rice is produced in the alluvial lowlands and coastal plains, along bottom valleys of mountains, and in land depressions as well as along river-valley basins. The main producing regions include Mwanza, Morogoro, Mbeya, Shinyanga and Tabora. On the other hand, Mbeya, Morogoro and Mwanza account for >48 % of national production whereas the region with the highest yield of rice (Kilimanjaro with 3.6 tons/ha) represents less than 3 % of the national rice production (Rowahni et al. 2011). There are small irrigation farms averaging about 2–2.5 ha/farmer per irrigation scheme, and a few large-scale commercial rice irrigation schemes such as Madibira (3,000 ha), Kapunga (3,000 ha) and Mbarali (3,200 ha) in the Mbarali district (USAID/COMPETE 2010). Planted areas with rice increased from 702,000 ha in 2005/06 to 1,136,287 ha in the 2009/10 agricultural year while the yield increased from 1.5 to 2.3 t/ha within the same year (MAFC 2010). Rice accounts for 13 % of all cereals produced and is the second most important grain consumed, with per capita consumption of rice increasing from about 14.5 kg/person/year in 1999 to approximately 16.5 kg/person/year in 2010 (FAOSTAT 2012).

24.1.2 Sustainable Intensification of Maize and Rice in Tanzania

The cultivated areas of maize and rice and overall productivity by the year 2010 was three million ha at 1.5 t/ha and one million ha at 2.3 t/ha, respectively (MAFC 2010). This level of productivity could meet the demand of the two crops for 45 million people. It is expected, however, that the human population in the country will increase to 82 million by 2030 and reach 138 million by 2050. If it is assumed that there will be no diet changes and that it is projected that undernourishment will be reduced by half by 2030 and eliminated altogether by 2050 (based on the 2010 maize productivity), areas of maize cultivation should be expanded to approximately 6.38 million ha in 2030 and 12 million ha in 2050. If, however, maize productivity is increased to 5 t/ha, the required land will be 1.98 million ha in 2030 and 3.74 million ha in 2050.

Expansion of cropped areas is ultimately limited due to increased land-use pressure and is increasingly undesirable as it continues to degrade the environment under the current effects of climate change. The adverse impacts of climate change are already noticeable in the country, with frequent droughts, floods, and temperature increases, along with a dwindling supply of water (Rowahni et al. 2011). Total global greenhouse gas emissions are estimated at 49 billion t CO_2eq, and agriculture contributes 26 % (IPCC 2007). There are large emissions due to land-use changes in agriculture. It is therefore undesirable to continuously expand arable land and thus to improve productivity within the same areas through intensification of agro-input use (e.g., fertilizer, pesticide, herbicides and better crop variety seed), as well as following up with improved agronomic practices. Smallholder farmers would like to increase maize and rice crop productivity but their efforts are hindered by a wide range of constraints. These include: (i) inadequate use of inputs such as fertilizer, improved seeds and crop protection. Indeed, the 2002/03 National Sample Census of Agriculture report indicated that the reasons for the low use of inputs were high prices (45 % of the farmers), lack of purchasing power (10.5 %), and insufficient knowledge of the effects of inputs (7.9 %) and how to use them (7.8 %) (National Bureau of Statistics et al. 2006); (ii) inadequate access to information and extension services. Most farmers lack appropriate information about improved maize and rice varieties and agronomic practices due to the low levels of interaction with extension officers and other agricultural agents (WEMA 2010); (iii) erratic rainfall and frequent prolonged drought periods pose threats to maize and rice production (Rowahni et al. 2011).

24.1.3 Sustainable Intensification Strategy for Maize and Rice Production in Tanzania

Therefore the question is how to intensify agriculture on smallholder farms to provide more food for a growing population while conserving dwindling forests, wildlife and water. Opportunities for new and more sustainable agricultural investments and management choices that could also contribute to improved livelihoods and the reduction of poverty in rural communities are currently available through climate change mitigation and helping communities adapt to its impact. Opportunities for the increased use of inputs in Tanzania emanated from global food and inputs increases in 2008 that led the nation, with the assistance of the World Bank, to introduce the National Agricultural Inputs Voucher Scheme (NAIVS) (World Bank 2009). The NAIVS initially targeted the southern highlands regions, namely Iringa, Mbeya, Njombe, Ruvuma and Rukwa, which are seen as the “bread basket” of the country. The input vouchers included a 50 % subsidy to smallholder farmers for the prices of fertilizer and improved seeds estimated to be suitable for 0.5 ha of maize/rice crops. According to the World Bank (2009), a mixture of the fertilizers (32 kg N and 23.3 kg P_2O_5/ha) and improved seeds inputs were expected to raise the yields of maize and rice from 1.1 to 3.2 t/ha and 1.7–3.3 t/ha, respectively.

Faced with the aforementioned constraints of improving crop productivity and the increased demand for food by an increasing human population, intensification of agricultural production practices seems to be the proper way forward. Smallholder farmers therefore need a full amount of knowledge on how to improve maize/rice productivity (i.e., all inputs and how to use them appropriately). However, provision of discrete technological information on inputs and how to use them appropriately will not provide the sustainable profit margins necessary to motivate poor smallholder farmers to adopt new agricultural technologies (Foster and Rosenzweig 2010). Thus, an appropriate technological package to intensify crop production should strategically incorporate efficient agronomic practices such as soil and water management, weed and pest management, increased soil fertility exploitation and the use of improved crop seed varieties. These four agronomic practices, however, require skill and capital. A strong partnership between public technical advisory (both researchers and extensions) and agro-industries (both agro-input providers and agro-product processors) should therefore be the right vehicle to enhance crop productivity, especially of food crops, and thus reduce the vulnerability of rural communities, especially to the effects of climate change. Such partnerships, especially of the Public–Private Partnership (PPP) model, are currently being encouraged by the Tanzanian government under its "Kilimo Kwanza" (*agriculture first*) strategy, and essentially within the recently launched Southern Agricultural Growth Corridor of Tanzania (SAGCOT).

This paper presents the results of a 3-year implementation of the public–private partnership model constituted by Sokoine University of Agriculture (SUA), Norwegian University of Life Sciences (UMB), Yara (an international fertilizer company) and Syngenta (an international plant protection inputs company) regarding smallholder maize and rice farmers in the Njombe, Mvomero, Morogoro and Kilombero districts. The partnership was initiated in December 2010, aimed at conducting research and demonstrating how to achieve sustainable intensification of maize and rice production among smallholder farmers in Tanzania, and specifically to show how to use appropriate agricultural inputs for increasing crop productivity, producing more food without expansions of agricultural land, and improving smallholder farmers' household and income security.

24.2 Materials and Methods

24.2.1 *Description of the Study Area*

The study was conducted in the Morogoro, Mvomero and Kilombero districts in the eastern agricultural zone and in Njombe in the southern highlands zone (Table 24.1). Maize trials were established in the villages of Ibumila, Kichiwa, Welela and Matiganjola in the Njombe district and at the Sokoine University of Agriculture farm in the Morogoro Region. Typically, Njombe receives 1,200 mm of rainfall per year with a temperature range of 15–20 °C. The Sokoine University of Agriculture farm is located along the western part of the Uluguru Mountains and receives an average of 800 mm of rainfall per year with a temperature range of 20–33 °C. Rice trials were established in the Dihombo and Mkula villages, and the Dakawa Rice Research Institute farm. Dakawa and Dihombo are in the Mvomero district and Mkula is in the Kilombero district. The average annual rainfall in Dakawa, Dihombo and Mkula is 1,000 mm with a temperature range of 24–32 °C (Table 24.1).

24.2.2 *Reconnaissance Survey and Soil Sampling Before Planting*

Except for the two trials that were conducted at research stations (i.e., maize and rice plots at Sokoine University of Agriculture and Dakawa Rice Research Institute), all other demonstration plots were conducted within smallholder farmers' fields. A reconnaissance survey and soil sampling was conducted on each farm before planting in order to establish baseline data of the soil's

Table 24.1 Locations and crops involved in demonstration trials

Region	District	Villages	Crops	Trials	Altitude (masl)
Morogoro	Mvomero	Dihombo	Rice	1	370
		Dakawa	Rice	1	370
		DRRI[a]	Rice	1	366
	Kilombero	Mkula	Rice	1	290
	Morogoro	SUA#	Maize	1	550
Njombe	Njombe	Ibumila	Maize	1	1,820
		Kichiwa	Maize	1	1,798
		Welela	Maize	1	1,793
		Matiganjola	Maize	1	1,791

[a] Dakawa Rice Research Institute; # Sokoine University of Agriculture

physical and chemical properties and to recommend the use of fertilizers according to plant nutrient deficiencies. Historical background of the farms was requested from the owners and recorded before soil sampling. The information recorded included how long the farm had been used, what types of crops were planted, if farm was irrigated or not, and if there was any fertilizer or plant protection input use. A free survey was conducted to discover the boundary and size of each farm. Important features of the farm such as landform, soil color and soil texture were observed in order to draw sampling units. At each sampling unit 10–15 points were selected in zigzag fashion, and at each point a pit of 60 × 60 cm was made and two soil samples were collected (one each in two sampling depths of 0–20 and 20–40 cm). Soils were air-dried, sieved through a 2 mm sieve, packed and sent to the soil laboratory at Yara International, Research Centre Hanninghof, Germany.

24.2.3 *Treatments*

Two treatments were included in each crop trial. These were: (i) farmers' practice (FP) and (ii) Yara/SUA/Syngenta (YSS) improved practices. The improved agricultural practices of the YSS included: (a) appropriate use of fertilizer, (b) crop protection through appropriate use of herbicides and pesticides, and (c) use of recommended improved maize/rice seed varieties for the locality. Fertilizers and plant protection application regimes for YSS and FP in maize and rice crop trials are shown in Tables 24.2, 24.3, 24.4 and 24.5.

24.2.4 *Planting Patterns*

Maize crops were planted at the beginning of the long rainy season in early December in Njombe and in early March in Morogoro for three consecutive years. Planting spaces were 90 cm by 30 cm for long maturity varieties

Table 24.2 Fertilizer application regimes for Yara/SUA/Syngenta (YSS) and Farmers Practice (FP) in maize trials

		Kg/ha								
Practice	Period of application	Product	N	P_2O_5 (P)	K_2O	CaO	MgO	S	B	ZN
YSS	Planting	Yara Mila Cereal	81	35.1 (P)	17.5	0	0.7	10.5	0	1.1
	Top dressing (Knee height)	Yara Mila Cereal	46	20 (P)	10	0	0.4	6.0	0	0.6
	Top dressing (Tasseling)	Yara Mila Java	11	3.0 (1.32P)	5.9	0	0.1	1.5	0.1	0
	Spray (4–6 leaves)	Yara Vita Tracel^{TM} BZ	0.1	0.2	0.1	0	0.2	0.1	0.1	0.1
Total			**137.7**	**69.2 (29.86P)**	**33.6**	**1.3**	**18.1**	**1.8**	**1.8**	**1.8**
FP	Planting	DAP	4.5	11.5	0	0	0	0	0	0
	Top dressing 30 days old	Urea	23	0	0	0	0	0	0	0
Total			**27.5**	**11.5**	**0**	**0**	**0**	**0**	**0**	**0**

Table 24.3 Plant protection application regimes for maize crops using YSS and Farmers' practices

Activity	Inputs		Time of application
	Yara/Syngenta/SUA (YSS)	Farmers' Practice (FP)	
Seed treatment	A seed treatment containing difenoconazole/thiamethoxam/metalaxyl-M at 10 g/4 kg seed	No seed treatment	Seed preparation during planting
Pre-emergence herbicide application	An atrazine/S-metalachlor mixture at 1.2 l/acre	No application. But 1st weeding 3rd week after planting with use of hand hoe	Just after planting
Insecticide application	Spray of lambda-cyhalothrin formulation to control stalk borers at 160 ml/acre	Spray of lambda-cyhalothrin formulation to control stalk borers @160 ml/acre	If symptoms of attack occur
Herbicide application	A paraquat formulation at 600 ml/acre	2nd weeding with use of hand hoe	10th week after planting

(120–150 days) and 75 cm by 30 cm for medium maturity varieties (90–110 days) at Njombe and Morogoro, respectively. Rice is usually grown twice per year at Dihombo and Mkula in August and March and harvested in December and June, respectively; at the Dakawa site, rice is grown once per year and is planted in March and harvested in July. Planting spaces for rice were 20 cm by 20 cm.

24.2.5 Farmers' Field Days

Farmers' field days were conducted before every crop harvest when the crops were just mature enough but not yet dry enough to harvest. All farmers, village leaders and extension staff in the villages were invited to the farmers' field days. The aim of the farmers' field days was to show how effective the improved crop production practices were compared with the normal farmers' practice methods. Usually on the farmers' field days the contact farmer in the presence of the researchers would explain step-by-step how she/he used improved crop production practices. Farmers' field days were chosen as the most cost-effective method of training agricultural technology since the invited farmers or communities could see the performance of the crops under improved agronomic practices. They were also used to encourage invited farmers to adopt technologies that had been adopted by fellow farmers.

24.2.6 Harvesting the Crops

During harvesting periods each treatment was demarcated into three sub-plots. Two sampling units were then fitted in each of the three sub-plots making a total of

Table 24.4 Fertilizer application regimes for Yara/SUA/Syngenta (YSS) and Farmers' Practice (FP) in rice trials

Practice	Period of application	Kg/ha								
		Product	N	P_2O_5 (P)	K_2O	CaO	MgO	S	B	ZN
YSS	Seedbed	Yara Mila Cereal	3.4	1.5	0.7	0	0	0.4	0	0
YSS	Spray (4–6 leaves)	Yara Vita Tracel BZ	0.1	0.2	0.1	0	0.2	0.1	0.01	0.1
	Tillering/booting	Yara Mila Java	54.3	14.8	30	0	0.4	7.0	0.5	0
	Top dressing tillering/booting	Yara Liva Nitrabor	9.5	0	0	15	0	0	0	0
Total			102.3	31.5	39	15	0.9	12.1	1.0	0.6
FP	Planting	None	0	0	0	0	0	0	0	0
	Top dressing 12 days old	Urea	23[a]	0	0	0	0	0	0	0
Total			**23**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

[a] The rate for FP is tentative and may fluctuate depending on crop markets and/or readily available input subsidies

Table 24.5 Plant protection application regimes for rice in YSS and Farmers' practices

Activity	Input application YARA/SUA/SYNGENTA practice (YSS)	Farmers' Practice (FP)	Time of application
Seed treatment	A seed treatment containing difenoconazole/thiamethoxam/metalaxyl-M at 2.5 g/kg seed	No seed treatment	Seed preparation during planting
Herbicide application	A glyphosate formulation at 1 l/acre	No treatment	Clear weeds before cultivation
Herbicide application	A pyribenzoxim/pretilachlor mixture at 600 ml/acre	Hand weeding	2–3 weeks after transplanting
Insecticide application	A lambda-cyhalothrin/thiamethoxam mixture at 400 ml/acre	Application of Karate 5 EC @ 160 ml/acre	If symptoms of attack are noted
Fungicide application	A propiconazole/cyproconazole mixture at 200 ml/acre	No application of fungicide	If symptoms of attack are noted

six sampling units per treatment. Rice sampling units were just 1 m^2 while maize sampling units were lines 4 m long. The sampling units were placed in the middle of each sub-plot. After sampling, the farmers continued to harvest the rest of their crops. Two soil samples at 0–20 and 20–40 cm soil depth were collected in each crop sampling unit for physical and chemical analysis. In order to estimate nutrient removal, soils, crop grains and biomass samples were analyzed for Nitrogen, Phosphorus, Potassium and Sulphur. The parameters recorded for maize crops were: inter-row (between) and intra-row (within) spacing of the plants, number of plants per 4 m row (sampling unit), plant height, cob weight, cob length, grain yield (t/ha at 14 % MC), grain-specific weight (1,000 seed wt), stover biomass, (t DM/ha) and weed biomass/sampling areas. For the rice crops the parameters were: number of plants/m^2, number of tillers/m^2, tiller height, number of panicles/m^2, grain yield (t/ha at 14 % MC), grain-specific weight (1,000 seed wt), and weed biomass/m^2. However, in this article only grain and stover/straw biomass yield results will be discussed.

24.2.7 *Fertilizer Rate Adjustment in Subsequent Season*

After the first crop harvest in 2011 the fertilizer rates were adjusted for the next season depending on crop removal. In the 2012 season the fertilizer rate was increased by 20 % at Kichiwa to compensate for the high removal of fertilizer through crop harvesting, while at Ibumila the rate was reduced by 20 % because the applied fertilizer in the previous season (2011) had low removal.

24.2.8 Management of Crop Residue

After harvesting maize under farmers' practice, crop residues are fed to animals. In rice farms after threshing, rice straw is heaped in the fields and burnt to reduce bulk material that may interfere with cultivation in the next cropping season. Burning straw is also done to reduce or eradicate carriers of disease pathogens that may affect the next crop. At SUA and Dakawa, crop residues were incorporated in the soil after harvest.

24.2.9 Data Analysis

The crop harvest data was handled and analyzed using Excel and a *t*-test was used to check if the difference between improved (YSS) and farmers' (FP) practices was significant. The soil's fertility status was interpreted using a handbook for soil survey and agricultural land evaluation in the tropics and subtropics by Landon (1991).

24.3 Results and Discussion

24.3.1 Chemical Characteristics of Soils in the Study Sites

Results of chemical characteristics of soils in **the** study sites are summarized in Table 24.6. In all Njombe sites, the soils had very low pH (<4.4 pH $CaCl_2$), plant-available phosphorus (Bray 1 P) and mineralizable sulphur, while potassium, magnesium and micronutrients (boron, zinc and copper) were also at low levels (Landon 1991). Levels of total organic carbon and total nitrogen were also low (Landon 1991). These soils were depleted of plant nutrients and had a low capacity to hold nutrients. This was shown by very low soil pH and low organic carbon, a reddish color and a clayey texture. Soils in Njombe sites were therefore highly weathered, strongly acidic and inherently low-fertility sand clay and could benefit from the application of manure and incorporation of crop residue so as to improve soil structure and the recycling of plant nutrients (Bationo et al. 1998). Liming can also reduce exchangeable Al and Mn, which are likely to occur under waterlogging conditions in these soils. These soils require large amounts of fertilizer with major nutrients N, P and K plus moderate amounts of Ca, Mg, S and micronutrients in order to sustain high crop yields.

Soils at SUA were moderately acidic with very low plant-available P, low levels of S, Ca, Cu, B and Zn, and high levels of K and Mg (Table 24.6). Total N and organic carbon were at low levels (Landon 1991). The soil texture was clayey and reddish brown in color and could be rated as moderately fertile, but P-fertilization is crucial to maintaining a high crop yield.

Table 24.6 Selected chemical properties of soils in the study sites before experiments

Site	Soil depth (cm)	pH ($CaCl_2$)	Bray 1 P (mg/100 g)	K (mg/100 g)	Mg (mg/100 g)	Ca (mg/100 g)	N total (%)	N mineralized (kg/ha)	S mineralized (kg/ha)	Organic carbon (%)	Bo mg/kg	Zn mg/kg	Cu mg/kg
SUA	0–20	5.3	0.77	35.5	44.1	123.0	0.15	13.75	9.5	1.71	0.38	1.38	2.36
	20–40	5.2	0.54	25.8	43.1	120.79	0.13	10.78	9.37	1.49	0.32	0,98	2.45
Kichiwa	0–20	4.46	0.68	8.2	7.7	–	0.11	33.3	2.73	1.3	0.27	0.49	0.26
	20–40	4.33	0.33	6.4	6.5	–	0.07	29.1	3.05	0.92	0.18	0.13	0.13
1 bumila	0–20	4.14	0.64	6.4	2.05	–	0.08	31.6	4.7	1.0	0.14	0.33	0.24
	20–40	4.2	0.34	3.5	0.9	–	0.06	37.4	2.5	0.8	0.13	0.24	0.14
Welela	0–20	4.3	1.1	15.5	6.8	20.8	–	31.0	5.3	1.1	0.1	0.41	0.22
	20–40	4.4	0.3	13.0	6.0	16.5	–	16.5	5.1	0.8	0.1	0.01	0.12
Matiganjola	0–20	4.2	1.4	6.0	2.3	9.8	–	33.8	1.85	1.2	0.03	0.22	0.11
	20–40	4.3	0.6	4.8	2.0	9.5	–	15.0	2.33	0.8	0.03	0.01	0.09
Dakawa Research	0–20	5.3	1.3	13.4	50.5	164.6	–	20	26	1.4	0.18	0.8	4.2
	20–40	6.1	0.5	13.7	64.3	209.2	–	9	10	1.0	0.19	0.4	3.4
Dakawa	0–20	5.2	0.5	9.12	50	137.5	–	18	53	0.9	0.19	0.41	3.0
	20–40	7.1	0.3	5.7	65.2	164.77	–	9	40	0.2	0.32	0.13	2.1
Dihombo	0–20	7.67	1.19	3.54	27.28	–	–	20	6	1.75	0.2	1.36	3.24
	20–40	4.82	2.28	3.58	23.07	–	–	18	3	0.91	0.15	0.57	3.85
Mkula	0–20	4.4	0.28	3.30	49.84	98.5	0.21	28.85	38.6				
	20–40	4.8	0.51	2.57	52.74	91.64	0.11	8.9	14.9				

Soils at Dihombo and Mkula were slightly-to-moderately acidic with very low plant-available P and potassium. The soils of the two sites had moderate levels of mineralizable N and S and moderate levels of Mg and Ca. Generally, these soils can be rated as moderately fertile but need NPK fertilizers and good management of crop residue to sustain their production capacity.

Dakawa sites had moderately fertile soils. The top soils were slightly acidic while the sub-soils had pH ranging from neutral to slightly alkaline (Table 24.6). The higher acidity of top soils than sub-soils could possibly be due to (i) leaching of basic cations K, Ca and Mg because of frequent irrigation (sub-soils had higher levels of cations than top soils) and (ii) prolonged use of urea fertilizer, which has acidifying effects in soils. These soils had very low plant-available P and S and low levels of Zn while cations K, Mg and Ca were at sufficient levels.

Soils of rice fields were moderately fertile when compared to soils of maize fields in Njombe. Most soils in Njombe were found to have low levels of N, P and K, which could be associated with crop residue removal. Both maize and rice crop residues have high levels of N, P and K (Tables 24.14 and 24.16).

24.3.2 Maize Crop Performance

Total maize grain yields (t/ha at 14 % moisture content) including the rotten grain were persistently higher using YSS than FP treatment for all sites and years (Table 24.7). Higher grain yields under YSS than FP were explained by the quantity and quality of fertilizer used in YSS practice (Table 24.2). These fertilizers, composed of plant nutrients N, P, K, Ca, Mg, Cu and Zn, were applied according to the stage of plant development and plant demand. These gave balanced nutrients to the crop and maintained soils against degradation through the restoration of nutrients removed by crop harvest. The Ibumila village trial produced relatively lower amounts of grain in all treatments and years. In 2012 all sites except Ibumila produced nearly the same amount through YSS treatments, but in the following year Welela produced the highest amount of grain followed by Kichiwa. A higher yield of YSS than FP indicated that the soils were indeed poor in terms of available plant nutrients, and therefore farmers should know such important information and be trained on the

Table 24.7 Mean maize grain yield (t/ha) at 14 % moisture content

	2011		2012		2013	
Villages	YSS	FP	YSS	FP	YSS	FP
Ibumila	3.81^a	0.85^b	2.9^a	2.54^a	4.29^a	1.11^b
Kichiwa	7.13^a	4.19^b	6.28	NR	7.90	6.21
Matiganjola	NR	NR	6.72^a	2.53^b	5.57^a	2.29^b
SUA	NR	NR	6.16^a	3.38^b	5.89^a	4.80^b
Welela	NR	NR	6.07^a	1.80^b	9.28^a	3.16^b

Means of YSS and FP in the same village and year with different superscripts are significantly different at $P < 0.05$ according to *t*-test (two tails)

NR Not recorded

appropriate use of the required amounts of fertilizers in order to sustain their maize crop yields. The soils at the Ibumila site were strongly acidic, with low levels of plant nutrients and low cation-exchange capacity (CEC), which implied that the soil had low capacity to hold fertilizers. The situation in Ibumila could have been exacerbated by the release of exchangeable Mn (reduced from Mn^{4+} to Mn^{2+}) and the release of toxic Aluminium ions ($AlOH^{2+}$), processes that usually occur in strongly acidic soils under waterlogging conditions (Brady and Weil 2002), and which may have led to plant toxicity (Brady and Weil 2002) and thus less effectiveness of the fertilizer used, leading to low crop yields even under YSS treatment. The mean total yield of maize grain increased gradually with the years both in YSS and FP practices. This could be explained by the increased experience of farmers with the appropriate use of inputs. This was noted earlier in Zimbabwe as smallholder farmers gradually learn to adopt new farm practices (Mapiye et al. 2006).

Maize grain rotting was a major problem in most sites in the Njombe district, except in Welela village (Table 24.8). The village of Ibumila had the highest amount of grain rotting, especially in 2011 when the rotting reached 60 % of the produce in FP. However, in the following years rotting declined and by 2013 it was <10 % in Ibumila and just above 10 % in Kichiwa and Matiganjola. The cause of rotting could be due to maize variety and/or deficiency of certain plant nutrients that may have increased fungal attack in the maize grain; this needs further investigation.

After exclusion of the rotten grain, the grain yield showed a similar trend of higher yields in YSS than FP (Table 24.9). The yields under YSS in all sites and FP in some sites were higher than the national average of 1.5 ton/ha, implying that the cost of fertilizers was offset by the increased yield. If maize grain consumption in Tanzania is estimated at 74.5 kg/person/year (PASS 2012) then a family of six people will require about 0.5 t of maize grain per year. Therefore, the use of improved agronomic practices not only improves household food security but tremendously improves household income through sales of surplus grain, thus increasing the standard of life of the household. Regardless of village, mean grain production under both YSS and FP increased gradually from 2011 to 2013. The marketable maize grain of YSS increased by 112, 119 and 95 % over FP in 2011, 2012 and 2013, respectively. The overall mean of YSS for all 3 years is 5.4 t/ha, which could be produced by 3.6 ha using FP based on the mean national grain yield

Table 24.8 Rotten maize grain (% of the total grain yield)

	2011		2012		2013	
Villages	YSS	FP	YSS	FP	YSS	FP
Ibumila	26b	61a	29	29	0.1^{b}	4a
Kichiwa	14a	5b	26	NR	4^{b}	11a
Matiganjola	NR	NR	7^{b}	10^{a}	4^{b}	13a
SUA	NR	NR	0	0	0	0
Welela	NR	NR	0	0	0	0

Means of YSS and FP in the same village and year with different superscripts are significantly different at $P < 0.05$ according to t-test (two tails)

NR Not recorded

Table 24.9 Marketable maize grain (t/ha at 14 % MC), excluding rotten grain

Villages	2011		2012		2013	
	YSS	FP	YSS	FP	YSS	FP
Ibumila	2.83^a	0.41^b	2.06^a	1.8 ^{a}	4.25^a	1.06^b
Kichiwa	6.1^a	3.98^b	4.67	NR	7.55^a	5.54^b
Matiganjola	NR	NR	6.34^a	2.27^b	5.37^a	1.99^b
SUA	NR	NR	6.16^a	3.38^b	5.89^a	4.8^b
Welela	NR	NR	6.07^a	1.8^b	9.28^a	3.16^b

Means of YSS and FP in the same village and year with different superscripts are significantly different at $P < 0.05$ according to t-test (two tails)
NR Not recorded

Table 24.10 Maize stover (without grain) (t/ha)

Villages	2011		2012		2013	
	YSS	FP	YSS	FP	YSS	FP
Ibumila	7.3^a	2.7^b	7.3^a	7.1^a	5.33^a	2.11^b
Kichiwa	10.9^a	7.7^b	15.4	NR	9.62^a	9.13^a
Matiganjola	NR	NR	14.2^a	4.84^b	6.8^a	3.25^b
SUA	NR	NR	11.63^a	6.2^b	7.80^a	5.92^b
Welela	NR	NR	11.16^a	3.0^b	10.86^a	6.91^b

Means of YSS and FP in the same village and year with different superscripts are significantly different at $P < 0.05$ according to *t*-test (two tails)
NR Not recorded

of 1.5 t/ha. Thus, intensification of major staple food production can reduce the expansion of cultivatable areas and improve household food security.

Maize stover and cobs without grain are the most important grain yield components. The yields of these components were rather higher under YSS compared to FP in all trial sites (Table 24.10). The yields varied from 5.33 to 15.4 t/ha for YSS and 2.11–9.13 t/ha for FP. The variations could have been due to losses of over-dried maize leaves that might have been blown away by winds before harvest, or as a result of differences in seasonal, altitudinal and/or soil properties.

The results of the maize grain harvest index (HI) (i.e., the ratio of harvested grain to the total shoot dry matter yield) are summarized in Table 24.11. The HI values observed in this study in 2011 and 2012 at all sites were within the reported range of 0.4–0.6 by Linden et al. (2000). In 2013, the HI values were higher than those in preceding seasons. The higher the HI the better the yield.

24.3.3 Rice Crop Performance

Generally, regardless of season and site, the rice crop yields were higher under YSS than FP (Table 24.12). However, the difference between YSS and FP was not as high as for the maize crops. The small difference between YSS and FP in rice production

Table 24.11 Maize harvest index = grain/total biomass

Villages	2011		2012		2013	
	FP	YSS	FP	YSS	FP	YSS
Ibumila	0.52[a]	0.31[b]	0.40	0.36	0.80[a]	0.53[b]
Kichiwa	0.65[a]	0.54[b]	0.41	NR	0.82[a]	0.68[b]
Matiganjola	NR	NR	0.47	0.52	0.82[a]	0.71[b]
SUA	NR	NR	0.53	0.55	0.76	0.81
Welela	NR	NR	0.54	0.60	0.85[a]	0.46[b]

Means of YSS and FP in the same village and year with different superscripts are significantly different at $P < 0.05$ according to t-test
NR Not recorded

Table 24.12 Rice grain yield (t/ha) at 14 % moisture content

Villages	2011		2012		2012		2013	
	Long rains		Short rains		Long rains		Long rains	
	YSS	FP	YSS	FP	YSS	FP	YSS	FP
Dihombo	8.23[a]	7.76[a]	8.9[a]	8.87[a]	7.64[a]	6.14[a]	7.00[a]	6.68[a]
Mkula	8.18[a]	6.83[b]	5.3[a]	4.84[a]	6.95[a]	4.69[b]	8.31[a]	5.58[b]
Dakawa	NR	NR	NR	NR	NR	NR	10.77[a]	8.37[b]
DRRI	NR	NR	NR	NR	7.32[a]	5.33[b]	8.30[a]	7.73[a]

Means of YSS and FP in the same village, season and year with different superscripts are significantly different at $P < 0.05$ according to t-test (two tails)
NR Not recorded

could be due to the high paddy price it fetches: Tanzanian Shillings 800 per kg (0.51 US$) compared to maize at Tanzanian Shillings 500/=per kg (0.32 US$). The higher paddy price encouraged the farmers to apply fertilizers, thus lowering the difference between YSS and FP. Moreover, the rice sites were relatively naturally fertile compared to the maize sites (Table 24.6) and as a result showed little response to the fertilizers. The rice sites were located in lowlands and in flood plains with frequent flooding, therefore receiving fine fertile deposits from surrounding uplands; this explains the reason for high fertility in these sites. Both the YSS and FP mean grain yields were higher than the national mean rice production of 2.33 t/ha (MAFC 2010). The overall mean for YSS regardless of site and season was 7.8 t/ha, which would require 3.4 ha based on the national mean rice production. On average, the rice yield in Mkula was lower in both the short and long rainy seasons of 2012. This could be due to the incidence of plant diseases and pathogens; bacteria and fungi were noted in the area in 2012, but this was corrected in 2013.

The trend of rice straw yields (Table 24.13) followed that of grain yields. The highest straw yield was during the short rains of 2011 (16.27 t/ha) and the lowest was during the long rains of 2012 (6.63 t/ha). There was a rather small difference between YSS and FP in terms of rice straw yield.

Table 24.13 Rice straw biomass (t/ha) at 14 % moisture content

	2011		2012		2012		2013	
	Long rains		Short rains		Long rains		Long rains	
Villages	YSS	FP	YSS	FP	YSS	FP	YSS	FP
Dihombo	16.27^{a}	13.05^{b}	11.14^{a}	10.48^{a}	13.72^{a}	9.48^{b}	8.02^{a}	7.26^{a}
Mkula	15.78^{a}	11.92^{a}	11.20^{a}	11.01^{a}	7.30^{a}	6.63^{a}	15.4^{a}	8.92^{b}
Dakawa	NR	NR	NR	NR	NR	NR	12.3^{a}	9.79^{b}
DRRI	NR	NR	NR	NR	10.93^{a}	7.14^{b}	8.79^{a}	7.49^{a}

Means of YSS and FP in the same village, season and year with different superscripts are significantly different at $P < 0.05$ according to t-test (two tails)
NR Not recorded

24.3.4 Plant Nutrient Removal by Maize Grain and Stover

Nutrient balance did not account for the nutrient reserves in the soil and from roots after harvesting, but was based on the difference between nutrients applied and nutrients removed by shoots (grain and stover/straw). Since the amount of N applied in YSS practice was large (138 kg N/ha), high removals in these sites were associated with high grain yields. Most of the YSS-practice maize plots therefore had a negative N balance compared to FP practices (Table 24.14). The Ibumila site had no negative balance, which could be associated with limited plant nutrient uptake due to poor root growth caused by Mn toxicity. With respect to phosphorus balance, the results showed positive balance for YSS practice in all sites (Table 24.14), suggesting that the amount of P applied was sufficient. However, P balances under farmers' practice were negative at Kichiwa in 2011, Ibumila in 2012, Matiganjola in 2012 and SUA in 2012, showing depletion of soil reserves. The amount of P applied during planting under FP treatment in the form of DAP was only 5 kg P/ha at Njombe, and the amount was low in these strong acidic soils, whereby high amounts of applied P were retained in soils. This usually happens in such soils (Szilas 2002). In order to sustain high yields in such soils, elevated rates of P are required and the use of other soil amendments such as lime and manure improve P availability for the plants. Potassium balance was negative for both practices, and the higher the biomass the higher the removal of K (Table 24.14). More K is found in stover than in grain; therefore, K can be recycled into soils by incorporating crop residues into the soil. This practice should be encouraged because even where K was applied as fertilizer it was not sufficient for plant demand and thus most of it was taken up from soil reserves. These will ultimately lead to soil degradation through nutrient mining.

Nutrient removal by grain only (Table 24.15) showed positive nutrient balance for N, P and K. These results show that if crop residues are not removed from the fields' nutrient mining to a large extent, especially with respect to K (Table 24.15), will be reduced to a large extent. However, under farmers' practice or a low input system, even if the crop residues are recycled there still will be a negative nutrient

Table 24.14 Nutrient balance (inorganic fertilizer inputs minus total removal) under the two practices in maize crops

Practice	N applied	N total removal	Balance	P applied	P total removal	Balance	K applied	K total removal	Balance	S applied	S total removal	Balance
Kichiwa 2011												
YSS	138	141.2	−3.2	30	24.2	5.8	28	134.6	−106.6	18	11	7
FP	69	97.3	−28.3	5	13.6	−8.6	0	119.0	−119	0	7.8	−7.8
Kichiwa 2012 (2011 + 20 % of previous rate)												
YSS	165.6	153	12.6	36	14.9	21.1	33.6	251	−217.4	21.6	12	9.6
FP	69	14.9	54.1	5	3.1	1.9	0	14.1	−14.1	0	1.3	−1.3
Ibumila 2012 (YSS Inputs (2011 – 20 % of previous rate))												
YSS	110.4	73.8	24	24	10.5	13.5	22.4	100.6	−78.2	14.4	8	6.4
FP	69	57.5	5	5	8.1	−3.5	0	94.9	−94.2	0	5.3	−5.4
Ibumila 2011 (Only stover)												
YSS	138	59.8	78.2	30	5.7	24.3	28	142	−114	18	6.5	11.5
FP	69	16.1	52.9	5	3.6	1.4	0	87	−87	0	4.1	−4.1
Welela 2012												
YSS	138	139.7	−1.7	30	15.7	14.3	28	265.5	−237.5	18	13.3	4.7
FP	69	28.7	40.3	5	2.3	2.7	0	59.6	−59.6	0	2.8	−2.8
Matiganjola 2012												
YSS	138	147.5	−9.5	30	15.1	14.9	28	207.7	−179.7	18	13.4	4.6
FP	69	51.8	17.2	5	6.1	−1.1	0	72.8	−72.8	0	4.9	−4.9
SUA 2012												
YSS	138	188	−50	30	18.1	11.9	28	260.8	−232.8	18	13.1	4.9
	0	75.3	−75.3	0	10.4	−10.4	0	106	−106	0	7.0	−7

Nutrient balance = Nutrients applied – Nutrient removed in maize shoot

Table 24.15 Nutrient balance (fertilizer inputs minus grain removal) under the two practices in maize crops

Practice	N applied	N removal	Balance	P applied	P removal	Balance	K applied	K removal	Balance	S applied	S removal	Balance
Kichiwa 2011												
YSS	138	98.4	39.6	30	20.3	9.7	28	24.4	3.6	18	7.1	10.9
FP	69	97.3	−28.3	5	13.6	−8.6	0	119.0	−119	0	7.8	−7.8
Kichiwa 2012 (2011 + (20 % of previous rate)												
YSS	165.6	73.7	91.9	36	13.0	23.0	33.6	15.5	18.1	21.6	5.4	16.2
FP	69	9.45	59.55	5	1.92	3.08	0	2.0	−2.0	0	0.76	−0.76
Ibumila 2012 (YSS Inputs 2011 – 20 % of previous rate)												
YSS	110.4	32.0	78.0	24	5.6	18.4	22.4	7.5	14.9	14.4	8	6.4
FP	69	57.5	5	5	8.1	−3.5	0	8.7	−8.7	0	2.8	−2.8
Ibumila 2011 (Only stover)												
YSS	138	59.8	78.2	30	5.7	24.3	28	142	−114	18	6.5	11.5
FP	69	16.1	52.9	5	3.6	1.4	0	87	−87	0	4.1	−4.1
Welela 2012												
YSS	138	76.1	61.9	30	11.2	18.8	28	14.8	13.2	18	6.2	11.8
FP	69	15	54	5	1.6	3.4	0	2.4	−2.4	0	1.0	−1.0
Matiganjola 2012												
YSS	138	75.9	62.1	30	10.5	19.5	28	16.0	12.0	18.0	6.0	12.0
FP	69	25.8	43.2	5	4.1	0.9	0	6.3	−6.3	0	2.0	−2.0
SUA 2012												
YSS	138	94.1	43.9	30	12.8	7.2	28	14.6	13.4	18.0	6.6	11.4
	0	44.4	−44.4	0	7.3	−7.3	0	8.6	−8.6	0	3.5	−3.5

Nutrient balance = Nutrients applied – Nutrient removed in maize grain balance. This is because even the residues under such practice have insufficient plant nutrients to restore positive balance in the field. These results therefore show that nutrient inputs are crucial not only for higher yields but also for preventing land degradation.

24.3.5 Plant Nutrient Removal by Rice Grain and Straw

Removal of nitrogen and phosphorus by both rice straw and grain resulted in negative balances at all sites for both YSS and farmers' practices (Table 24.16). These results implied that large rates of N (110 kg/ha), P (15 kg/ha) and K (32 kg/ha) applied under YSS practices were not satisfactory enough to offset negative nutrient balances. This could be due to high plant uptakes of nutrients through both the straw and grain. There is a possibility that some proportion of fertilizer applied to soil was not available to plants because of certain processes in soil, such as leaching, erosion and conversion to less soluble forms, especially phosphorus. Moreover, regular flooding in rice fields may lead to loss of fertilizer due to water flow, especially in irrigated fields. This is a big challenge for fertilizers and other inputs among irrigated rice. Actually, inefficient application of nitrogen fertilizers in rice production systems promotes the release of nitrous oxide, one of the most important greenhouse gases. The problem is currently being solved in DRRI by building strong sub-plot banks in order to control water flow.

However, positive nutrient balances for N and K under YSS practice were obtained when straw removal was not considered (Table 24.17), suggesting that if straw could be incorporated into soils it will restore nutrients in the field. Phosphorus balances were negative for both practices even if removal was through grain alone, showing that most of the P applied was not available to plants, though some of it was probably retained in the soils. Under farmers' practice the nutrients N, P and K had negative balances at all sites. These results indicate that planting crops without nutrient inputs leads to nutrient mining from soil reserves, which may lead to land degradation. In addition, smallholder rice farmers normally burn their rice crop straw after harvest, thus increasing K deficiency in their rice field soil. Moreover, burning crop residues such as straw contribute to greenhouse gas emission as rice cultivation is an important sequester of carbon dioxide from the atmosphere.

Reports have showed that continuous and intensive cropping without restoration of the soil fertility depletes the nutrient base of most soils (Zingore 2012). Therefore, any move to improve and sustain agricultural growth must depend upon improved soil productivity rather than on expansion of areas under cultivation. The soil fertility in intensified farming can only be maintained through integrated plant nutrient management with efficient recycling of organic materials such as crop residue, compost or manure in combination with mineral fertilizers. Furthermore, studies have shown positive interaction between fertilizer and

Table 24.16 Nutrient balance (inorganic fertilizer inputs minus total removal) under the two practices in rice crops

Site	Practices	N applied	N total removal	N balance	P applied	P total removal	P balances	K applied	K total removal	K balances
Dakawa	YSS	110	132.4	−22.4	15	26.9	−11.9	32	232.9	−209
	FP	63	90.3	−27.3	0	20	−20.0	0	157.8	−157
Dihombo	YSS	110	142.9	−32.9	15	31.7	−16.7	32	233.2	−207.2
	FP	63	103.1	−40.1	0	24.6	−24.6	0	147	−147
Mkula (Nov. 2011)	YSS	110	164	−54	15	48.5	−33.5	32	272.4	−240.4
	FP	63	134.3	−61.3	0	40.1	−40.1	0	216.3	−216.3
Mkula (July 2012)	YSS	110	102.5	7.5	15	26.1	−11.1	32	119.4	−87
	YSS	63	87.1	−24.1	0	23	−23	0	145.4	−147

Nutrient balance = Nutrients applied – Nutrient removed in rice shoot

Table 24.17 Nutrient balance (fertilizer inputs minus nutrient removal by grain) under the two practices in rice crops

Site	Practices	N applied	N removal	N balance	P applied	P removal	P balances	K applied	K removal	K balances
Dakawa	YSS	110	75.2	34.8	15	16.7	−1.7	32	20.6	11.4
	FP	63	50.8	12.2	0	11.8	−11.8	0	15.1	−15.1
Dihombo	YSS	110	76.7	33.3	15	17.9	−2.9	32	20.9	11.1
	FP	63	58.6	4.4	0	14.1	−14.1	0	16.9	−16.9
Mkula (Nov 2011)	YSS	110	85.15	24.85	15	21.11	−6.11	32	26.5	5.5
	FP	63	76.6	−13.6	0	19.5	−19.5	0	24.9	−24.9
Mkula (July 2012)	YSS	110	68.4	41.6	15	17.4	−2.4	32	17	15
	FP	63	46.2	38.8	0	12	−12	0	13.3	−13.3

Nutrient balance = Nutrients applied – Nutrient removed in rice grain manure, with the benefits of manure increasing productivity while decreasing soil fertility (Zingore et al. 2008; Mtambanengwe and Mapfumo 2005).

Maintaining soil's organic matter through incorporation of crop residues or application of animal manure is a key component of sustainable land use management (Buresh et al. 1997). Organic matter acts as a source for plant nutrients. Other important benefits resulting from the maintenance of soil's organic matter in low-input agro-ecosystems include retention and storage of nutrients, increasing buffering capacity in low-activity clay soils, and increasing water-holding capacity.

24.4 Lessons Learned

Under farmers' practice, fertilizers are not applied adequately, and in some cases are not applied at all. When applied, the fertilizers used were composed of N and P in DAP and N only in urea, while other plant nutrients such as K, Ca, Mg, S, Zn, B and Mo were not applied. Plants obtained these nutrients from soil reserves. This practice produces very low yields and leads to nutrient mining, which in turn leads to soil deterioration and a reduced soil capacity to support good yields. The condition becomes worse if the crop residues are not incorporated into the soil to replenish some of the nutrients removed from the soil by crop harvesting. The results from this study as in other studies showed that crops remove large quantities of N, P, K and S (Zingore et al. 2008; Mtambanengwe and Mapfumo 2005). Using low input systems, in addition to small amounts of inorganic fertilizers, farmers should be encouraged to incorporate crop residues and, wherever possible, the use of animal manure. Furthermore, for acidic soils with low fertility, such as those in Njombe, incorporation of crop residue and manure is a prerequisite for good soil management and to improve carbon stock in soils, to replenish plant nutrients and to improve soil structure and sustain crop yields.

24.5 Conclusions and Recommendations

The results from this study have demonstrated that: (i) Smallholder farmers can increase productivity of maize and rice with optimal inputs; (ii) Improved agronomic practices can be designed to facilitate sustainable intensification of maize and rice (staple food crops for millions of people) and thus reduce expansion of cultivated land, leading to more conservation of natural resources under the effects of climate change; (iii) Farmers' livelihoods can be strengthened, enabling greater flexibility in cropping and ensuring more income expenditure in acquiring agricultural inputs; (iv) Since maize and rice crop residues have high levels of N, P and K, it is recommended that, with intensification, crop residues should be incorporated into the soil of the same field so as to avoid heavy soil mining of plant nutrients; (v) Njombe soils are strongly acidic and inherently low in fertility (sandy clay), so the recommended management of these soils could be liming in order to reduce exchangeable Al and Mn, which are likely to occur under waterlogging conditions. Application of manure and incorporation of crop residues are highly recommended in order to improve soil structure and the recycling of plant nutrients. The results from this study suggest that there is a need to: (i) carry out further studies on the effects of intensification on the environment and biodiversity, and (ii) create workable plans to advance these results to wider parts of the country.

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