Chapter 1
Overview of Long Term Experiments in Africa

A. Bationo, B. Waswa, A. Abdou, B.V. Bado, M. Bonzi, E. Iwuafor, C. Kibunja, J. Kihara, M. Mucheru, D. Mugendi, J. Mugwe, C. Mwale, J. Okeyo, A. Olle, K. Roing, and M. Sedogo

Abstract The prevailing low food production in sub-Saharan Africa is an issue of great concern especially since Africa south of the Sahara is the only remaining region of the world where per capita food production has remained stagnant. This chapter reviews long-term experiments in Africa in the context of shifting paradigms related to tropical soil fertility management from first external input paradigm right through to the current Integrated Soil Fertility Management (ISFM) approach, which is a culmination of the participatory methods developed along the paradigm shift. Long term experiments (LTE) are an important source of evidence for soil fertility decline and provide crucial datasets for the development of sustainable management practices for tropical land-use systems and the amelioration of global climatic and environmental change impacts. A survey was undertaken to identify

A. Bationo (✉)
Alliance for a Green Revolution in Africa (AGRA), Accra, Ghana
e-mail: abationo@agra-alliance.org

B. Waswa
Tropical Soil Biology & Fertility Institute of International Centre
for Tropical Agriculture (CIAT-TSBF), ICIPE Duduville Campus off Kasarani Road,
P.O. Box 823-00621, Nairobi, Kenya

University of Bonn, Bonn, Germany

A. Abdou
Tropical Soil Biology and Fertility (TSBF), International Center for Research
in the Semi-Arid Tropics (ICRISAT), Niamey, Niger

B.V. Bado
AfricaRice, BP 96, Saint Louis, Senegal

M. Bonzi • M. Sedogo
INERA, 04 BP, 8645 Ouagadougou 04, Burkina Faso

E. Iwuafor
Ahmadu Bello University, Zaria, Nigeria

A. Bationo et al. (eds.), *Lessons learned from Long-term Soil Fertility Management Experiments in Africa*, DOI 10.1007/978-94-007-2938-4_1,

some ongoing long-term trials distributed across east, south and western Africa and in different agro-ecological zones. A long-term Experiment was defined as that extending over a period of over 5 years and more. Results from these trials are discussed in detail. Inference has been drawn from these findings and includes the following key findings: a) All long term trials showed yield decline, often with a relatively rapid fall to a low level equilibrium; b) At all sites, there were positive yield responses to one or more nutrients added as mineral fertilizers, which were consistent for the duration of the experiments highlighting the effectiveness of mineral fertilizers in increasing yield in arable farming systems in Africa; c) Soil organic matter (SOM) also declines significantly when land is cultivated; d) Prolonged treatments using only inputs of organic matter also showed yield declines, although the positive impact were sustained longer than for inorganic fertilizers alone in most cases; e) Rotational treatments, including sequences with legume crops and fallow periods had lower yield declines than monocultures; f) The best results invariably were those treatments that combined inorganic and organic inputs.

Keywords Long-term experiments • Integrated soil fertility management • Soil organic matter • Inorganic fertilizers • Organic inputs

Introduction

Africa south of the Sahara is the only remaining region of the world where per capita food production has remained stagnant over the past 40 years (Sanchez 2002). About 180 million Africans – up 100% since 1970 – do not have access to sufficient food to lead healthy and productive lives, making them more susceptible to the ravages of malaria, HIV-AIDS, and tuberculosis. Absolute poverty-characterized by

C. Kibunja
Kenya Agricultural Research Institute National Agricultural Research Laboratories (KARI-NARL), Nairobi, Kenya

J. Kihara • K. Roing
Tropical Soil Biology and Fertility Institute of International Centre for Tropical Agriculture (CIAT-TSBF), ICIPE Duduville Campus off Kasarani Road, P.O. Box 823-00621, Nairobi, Kenya

M. Mucheru • J. Mugwe
Department of Environmental Resource Conservation, Kenyatta University, Nairobi, Kenya

D. Mugendi
Kenyatta University, Nairobi, Kenya

C. Mwale
Zambia Agricultural Research Institute, Chilanga, Zambia

J. Okeyo
University of Wyoming, Wyoming, USA

A. Olle
Department of Soil Sciences, SLU, Uppsala, Sweden

incomes of less than U.S. $1 per person per day is coupled with an increasingly damaged natural resource base (Pinstrup-Andersen et al. 2000). Low food production in the continents is as a result of the breakdown of traditional practices and the low priority given by governments to the rural sector (Sanchez et al. 1997).

Over decades, small-scale farmers have removed large quantities of nutrients from their soils without using sufficient quantities of manure or fertilizer to replenish the soil. This has resulted in a very high average annual depletion rate – 22 kg of nitrogen (N), 2.5 kg of phosphorus (P), and 15 kg of potassium (K) per hectare of cultivated land over the last 30 years in 37 African countries – an annual loss equivalent to U.S. $4 billion in fertilizer (Sanchez et al. 1997; Lynam et al. 1998). The potential of genetically improved crops cannot be realized when soils are depleted of plant nutrients. A recent study shows that while the rates of adoption of improved crop varieties have been similar in Asia, Latin America, the Middle East, and Sub-Saharan Africa during the last 38 years, such varieties are responsible for 66–88% of the crop yield increases in the first three regions, but only 28% in Africa (CGIAR 2001). As a result there is need to invest more in soil fertility management if Africa is to benefit from the benefits improved crop varieties.

Paradigm Shifts Related to Tropical Soil Fertility Management

Over the years, the paradigms underlying soil fertility management research and development efforts have undergone substantial change because of experiences gained with a specific approaches and changes in the overall social, economic, and political environment the various stakeholders are facing.

During the 1960s and 1970s, an external input paradigm was driving the research and development agenda. The appropriate use of external inputs, be it fertilizers, lime, or irrigation water, was believed to be able to alleviate any constraint to crop production. Following this paradigm together with the use of improved cereal germplasm, the 'Green Revolution' boosted agricultural production in Asia and Latin America in ways not seen before. Organic resources were considered less essential. However, application of the 'Green Revolution' strategy resulted only in minor achievements in Sub-Saharan Africa (SSA). Concerns of environmental degradation resulting from massive applications of fertilizers and pesticides in Asia and Latin-America between the mid-1980s and early-1990s (Theng 1991) and the abolition of the fertilizer subsidies in SSA (Smaling 1993), imposed by structural adjustment programs led to a renewed interest in organic resources in the early 1980s. The balance shifted from mineral inputs only to low mineral input sustainable agriculture (LISA) where organic resources were believed to enable sustainable agricultural production. The potential of LISA was hindered by several constraints both at the technical (e.g., lack of sufficient organic resources) and the socio-economic level (e.g., labour intensive technologies).

In this context, Sanchez (1994) revised his earlier statement by formulating the Second Paradigm for tropical soil fertility research that recognized the need for both mineral and organic inputs to sustain crop production, and emphasized the need for all inputs to be used efficiently. The need for both organic and mineral inputs was advocated because (i) both resources fulfil different functions to maintain plant growth, (ii) under most small-scale farming conditions, neither of them is available or affordable in sufficient quantities to be applied alone, and (iii) several hypotheses could be formulated leading to added benefits when applying both inputs in combination. The second paradigm also highlighted the need for improved germplasm, as in earlier days, more emphasis was put on the nutrient supply side without worrying too much about the demand for these nutrients.

From the mid-1980s to the mid-1990s the shift in paradigm towards the combined use of organic and mineral inputs was accompanied by a shift in approaches towards involvement of the various stakeholders in the research and development process, mainly driving by the 'participatory' movement. One of the important lessons learnt was that the farmers' decision making process was not merely driven by the soil and climate but by a whole set of factors cutting across the biophysical, socio-economic, and political domain. This understanding led to evolution of the Sustainable Livelihoods Approach (DFID 2000), the Integrated Natural Resource Management (INRM) research approach and eventually the Integrated Soil Fertility Management (ISFM) paradigm. ISFM forms an integral part of the INRM research approach with a focus on appropriate management of the soil resource. Although technically ISFM adopts the Second Paradigm, it recognizes the important role of social, cultural, and economic processes regulating soil fertility management strategies. ISFM is also broader than Integrated Nutrient Management (INM) as it recognizes the need of an appropriate physical and chemical environment for plants to grow optimally, besides a sufficient and timely supply of available nutrients.

Justification for Long-Term Trials

Long term experiments (LTE) and monitoring are an important source of evidence for soil fertility decline. The studies provide the most convincing set of data as they highlight trends and dynamics rather than the static snapshots of most other measures. LTE serve as living laboratories providing opportunities for experimentation in which the effects of manipulation may be separated from other variables (Southwood 1994). This is clearly essential in understanding processes of soil fertility change. Long-term experiments can be viewed as living laboratories that provide opportunities for experimentation in which the effects of manipulation may be separated from other variables. Once a system is understood in this amount of detail, it is possible to manipulate almost any part and to be confident that one is able to assess the corresponding impacts.

An entirely different product of long term experiments has been the development of many of the statistical techniques used today (Southwood 1994). In the last few decades, Rothamsted has developed efficient statistical methods to analyse large data sets, methods that owe their origins to the seedbed of long-term experiments, but which are now used worldwide. With these statistical tools and this background, models can be developed which permit the inclusion of time into decision-making processed.

The increasing importance accorded to the development of sustainable management practices for tropical land-use systems and the apprehension of the potential impact of global climatic and environmental change has raised new interest in the datasets from these experiments as well as the possibilities for new initiatives in long-term monitoring and experimentation (Swift et al. 1994).

Long Term Experiments in Africa

There have been a substantial number of long-term experiments in Africa addressing a wide range of purposes. There is however no comprehensive inventory of these experiments. A number of these trials are still extant and actively researched, some have been judged to have reached the end of their useful existence and yet others have been discontinued or diminished in intensity because of lack of resources. The existence of these experiments provides opportunities to investigate the effects of different nutrient management practices on soil fertility and crop yields. Several reviews have been done on long term trials across Africa (Swift et al. 1994; Bekunda et al. 1997; Greenland 1994; Pieri 1995). Ever since more trials have been established and some key lessons from the old and new trials will be discussed in the next section.

A majority of the ongoing or terminated long-term soil fertility management trials in Africa were designed to determine the effects of inorganic fertilizers and organic inputs on crop yields and soil properties. Effects of rotations have also been investigated. Although yields were measured in all the experiments, climatic and soil variables were documented in only a few trials. The highest frequency of soil analysis was biannual, with most trials reporting soil analysis at only the beginning and end of the trial. No evidence of other measurement factors outside the treatments variable which would influence yields, such as pests, diseases incidences and economic parameters were measured.

This paper evaluates the experiences from a selection of ongoing long term experiments in east, south and western Africa.

Methodology

A survey was undertaken to identify some ongoing long-term trials in Africa. The trials are distributed across the content- east, south and western- and in different agroecological zones (Fig. 1.1). For the purpose of this review, we define long-term experiments as those extending over a period of over 5 years and more. Table 1.1

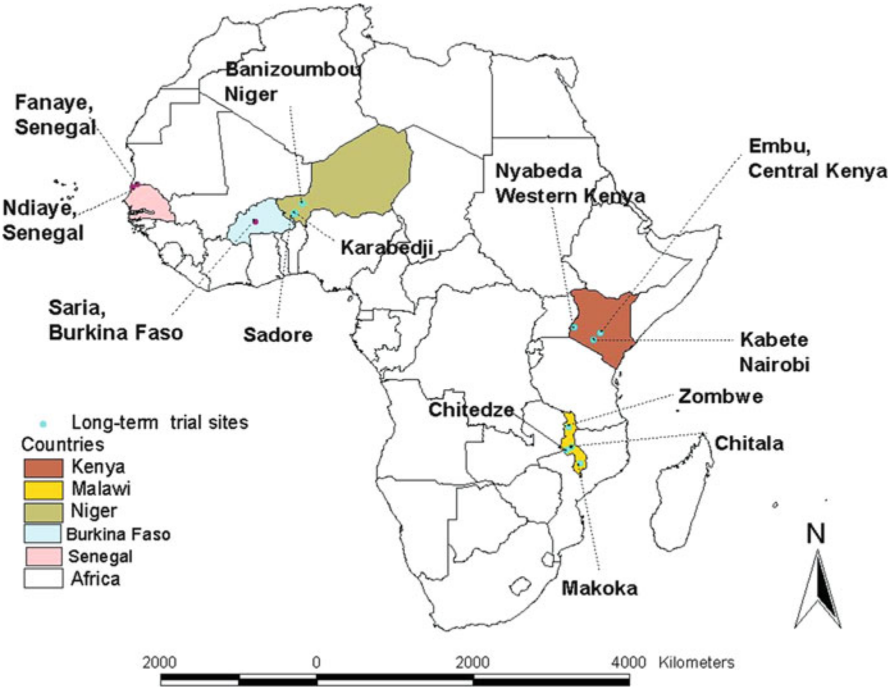

Fig. 1.1 Map showing location of selected long term trials in Africa

gives the general site information of some of these trials. The trials have varying lifespans and were established to achieve different objectives. Results from these trials are discussed in the subsequent section.

Long-Term Trials in West Africa

Long Term Trials in Saria, Burkina Faso

The long term trial in Saria Burkina Faso was started in 1960 with the purpose of evaluating the fertility of soils under different management systems. Sorghum and peanuts were the main test crops until 1987 when the legume was changed from peanuts to cowpea (Fig. 1.2).

An assessment of the long-term (over 20 years) effect of organic and inorganic fertilization on soil organic matter (SOM) fractions and sorghum performance resulted into different SOM concentrations (Mando 2006; Mando et al. 2005). Twenty years of continuous cultivation without external inputs (the control treatment) depleted SOM levels to below 50% of those under fallow. Sole urea application further depleted SOM status, presumably because of alleviation of nitrogen

Table 1.1 General information about the long-term trials in Africa

Experiment	Site/location	Year of est.	No. of cropping seasons	Longitude	Latitude	AEZ	Av Rainfall	Temp.		Initial soil properties				
								Max	Min	Soil Type	C (%)	N (mg/kg)	P (mg/kg)	pH
Long term trials in Saria	Saria, Burkina Faso	1960		2°9′W	12°16′N	Southern Sahelien	800	45	30					
Long-term crop residue management trial	Sadore, Niger	1982	25	2°17′E	13°14′N	Sahelian	560	30–41	17–27	Sandy	0.12	3	2	4.3
CR: Long-term effect of manure, crop residue and fertilizers	Sadore, Niger	1993	14	2°17′E	13°14′N	Sahelian	560	30–41	17–27	Sandy	0.12	0.3	2	4.3
Kouaré cowpea trial	Kouaré, Burkina Faso	1995	5	0°19′W	1159′N	Southern Sahelien					0.5	427 kg N		5.5
Effect of degraded and non degraded soils on millet production	Karabedji, Niger	1999	08	2°21′E	13°18′N	Sahelian	450	30–41	17–27	Sandy	0.16	4	1.9	4.2
N&P: fertilizer N and P equivalency of manure on millet	Banizoumbou, Niger	2001	06	3°19′E	14°21′N	Sahelian	360	30–41	17–27	Sandy	0.12	5	1.5	4.4
OPSCAR: operational scale research	Sadore, Niger													
Long-term fertility experiment trial	Ndiaye/Senegal	1991	32	16°14′W	16°14′N		180	45	10	Gleysol	1	0.08%	4	6.5

(continued)

Table 1.1 (continued)

Experiment	Site/location	Year of est.	No. of cropping seasons	Longitude	Latitude	AEZ	Av Rainfall	Temp. Max	Temp. Min	Initial soil properties: Soil Type	C (%)	N (mg/kg)	P (mg/kg)	pH
Long-term fertility experiment trial	Fanaye/Senegal	1991	32	15°46′W	16°33′N		230	45	7	Vertisol	0.7	0.05%	5	6.8
Kabete long term trial	National Agricultural Research Laboratories (NARL), Kabete, Kenya Kenya	1976		36°46′ E	01°15′ S		950							
HI Embu trial	Embu Regional Research Centre, Embu, Kenya	1992	22	37°30′ E	0°30′S		1,200–1,500	25	14					
N1 Kabete trial	National Agricultural Research Laboratories (NARL), Kabete, Kenya Kenya	1999	15	36°46′ E	01°15′ S		950	23.8	12.6	Loam	1.6	1.35	27	5.4
Kirege trial	Chuka, Eastern Kenya	2000	12	36°46′ E	01°15′S		1,200–1,400	20						
INM2 trial	Maseno, Western Kenya	2001												
CT1 trial	Nyabeda, Western Kenya			34°34′E	0° 06′N									
Chitedze trial	Chitedze, Malawi	1995/1996	12	33°38′E	13° 59′S	Subtropical mid altitudes	892	24	16	Sand clay loam	2.39	0.16		5.4
Chitala trial	Chitala, Malawi	1995/1996	12	34°15′E	13°39′S	Subtropical lowlands	800	28	16	Sand clay loam	1.07	0.07		5.6
Makoka trial	Makoka, Malawi	1998/1999	9	35° 11′E	15°32′S	Subtropical lowlands	1,044	34.4	8.5	Sandy loam	0.30	0.02		5.3
Zombwe trial	Zombwe, Malawi	1998/1999	9	33°49′E	11°19′S	Subtropical mid altitudes	1,035	27	17	Sand clay loam	0.68	0.05		5.3

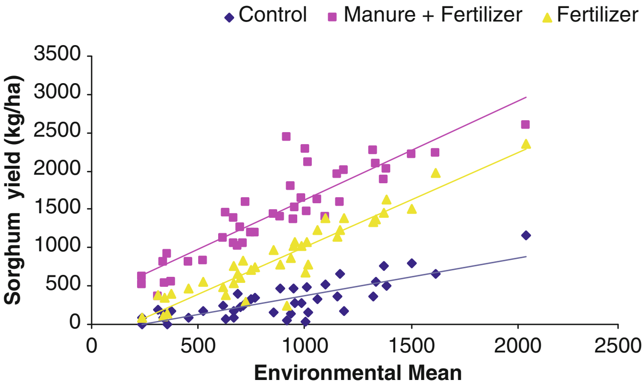

Fig. 1.2 Sorghum grain yield in relation to Environmental mean for a long-term trial (1960–2006) at Saria (Source Data: SARIA long-term (1960–2006) data)

limitations to decomposition. SOM depletion as compared to the fallow treatment seemed less pronounced in case of application of organic material with a relatively low C/N ratio such as manure. The adverse effect on soil organic matter and nitrogen status mostly affected the fraction of SOM >0.053 mm (Particulate Organic Matter, POM). The POM concentrations in the control, straw and urea-only plots were about one-half of the POM concentrations in the fallow plots. POM concentrations increased in the following order: urea < control < straw with or without urea < manure with or without urea < fallow. The fraction of SOM <0.053 mm (fine organic matter, FOM) was greater than POM in all plots except in fallow and manure + urea plots. Total nitrogen concentration followed the same trend as soil organic matter, but cultivation led to a decline in both POM-N and FOM-N. Crop yield was greatest in the manure plots and lowest in the straw, control and urea only plots. Results indicate that under Sudano-Sahelian conditions, SOM, POM and FOM fractions, fertilizer recovery fraction and crop performance were better maintained using organic resources with a low C/N ratio (manure) than through organic materiel with a relatively high C/N ratio (straw). Urea improved the effect of the organic material with high C/N ratio (straw) on crop yield and SOM concentration

Long-Term Crop Residue Management Trial (Sadore, Niger)

This randomized complete block design started in 1982 with main objectives being to assess soil fertility changes over time as affected by crop residue (CR) management. Later, a cereal-legume rotation was included in the system and each plot was split in two split-plots. The yield data that are available shows the advantage of combining organics (CR) and mineral fertilizers (Table 1.2). Application of both crop residues and fertilizer increase millet production from about 700 kg/ha to over 2,000 kg/ha compared to 96 kg/ha to about 400 kg/ha for the no input (control) treatment. Similar trend was observed for the millet totals dry matter.

Table 1.2 Millet grain yield in the long term crop residue management trial at Sadore, Niger, over 17 years

Treatments	Millet grain yield (kg/ha)
No CR, no fertilizer	285
CR, no fertilizer	591
Fertilizer, no CR	840
CR + fertilizer	1,344
SE	26
CV	28%

Table 1.3 Millet grain and TDM yields in the operational scale research trials at Sadore, Niger, 1998–2006

Treatments	Millet grain yield (kg/ha)	Millet TDM yield (kg/ha)
Traditional practices	129	943
Animal traction (AT) + no rotation +Intercropping + P	645	2,522
Animal traction (AT) + rotation +Intercropping + P	967	3,614
Hand cultivation (HC) + no rotation +Intercropping + P	546	2,414
Hand cultivation (HC) + rotation +Intercropping + P	871	3,502
Animal traction (AT) + no rotation+ Pure millet+P	639	2,796
Animal traction (AT) + rotation + Pure millet + P	998	4,343
Hand cultivation (HC) + no rotation + Pure millet + P	669	3,018
Hand cultivation (HC) + rotation + Pure millet + P	948	4,110
Traditional practices (local millet variety)	288	1,947

Results from this experiment showed that tillage using animal traction and hand cultivation resulted in significant increase in millet grain and biomass production (Table 1.3) compared to the traditional practices. This could be attributed to benefits of tillage such as improved water infiltration, soil aeration and root penetration. Systems involving crop rotation and intercropping had higher crop yields compared to those no rotation or intercropping. Rotation and intercropping systems involving cereals and legumes are known to result in improved nitrogen fixation as well as soil organic matter build up that can benefit current and subsequent crops.

Long-Term Effect of Manure, Crop Residue and Fertilizers (Sadore, Niger)

A factorial experiment was initiated in 1993 at a research station of ICRISAT Sahelian Center (ISC) at Sadore, Niger to assess the long-term effect of manure, crop residue and fertilizers on millet yields. Analysis of variance indicated that fertilizer, crop residue and manure application resulted in significant effect on both pearl millet grain and total dry matter yields. Of all the factors considered, fertilizer accounted for the highest total variation in the millet grain and dry matter. This was followed by manure.

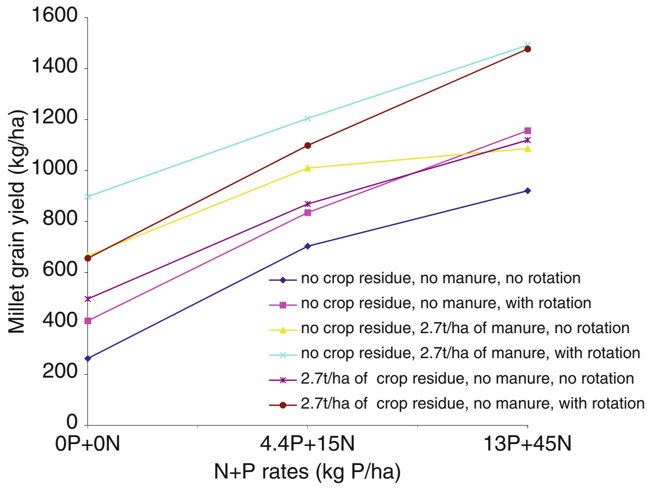

Fig. 1.3 Effect of fertilizer, CR, manure and rotation on pearl millet grain yield, Sadore, Niger, 1998–2006

Figure 1.3 illustrates the millet yield data over 9 years obtained. In this experiment, the farmer practice comprising of minimal crop residue retention, minimal manure application and no crop rotation yielded 262 kg/ha (Figure 1.3). However, application of 13 kg P/ha and 45 kg N/ha increased yields to 921 kg/ha. Combination of mineral fertilizer with manure and crop residues at the rate of 2.7t/ha each in a cowpea rotation system yielded over 1400kg of millet grain yield.

In 2001, the N and P fertilizer value of manure and crop residue was 27 and 13 respectively and the N and P equivalency of manure was 113% and 153% for crop residue (Table 1.4). These high values of fertilizers equivalencies of manure and crop residue over 100% suggest that the organic amendment have beneficial roles other than the addition of plant nutrient such as addition of micronutrients and better water holding capacity. In addition, the high fertilizer equivalencies could be due to improved synchrony between mineralization and plant nutrient uptake.

Effect of Degraded and Non Degraded Soils on Millet Production (Karabedji, Niger)

Soil degradation is a major problem in most of African farming systems. A trial was established in Karabedji, Niger in 1999 to assess the effect of degraded and non degraded soils on millet production (Karabedji, Niger). Mineral fertilizers were applied on two major type of soils: Farms close to the village where household waste, human excreta and farm yard manure are commonly used were considered as non-degraded fields while farms far from the village and which received no organic material added were considered as the degraded fields. Results from this experiment

Table 1.4 Fertilizers equivalency of manure and crop residue at Sadore, Niger, 2001 cropping season

Parameters	Grain (kg/ha)	Total dry matter (kg/ha)
Absolute control	236	1,523
% N in manure	0.71	0.71
% P in manure	0.18	0.18
% N in crop residue	0.71	0.71
% P in crop residue	0.03	0.03
Yield at 2.7 t/ha of manure in continuous cropping	800	3,461
Yield at 2.7 t/ha of crop residue in continuous cropping	634	2,527
Equivalent N and P of the manure	27	58
Equivalent N and P of the crop residue	13	58
Fertilizer N and P equivalency of manure (%)	113	243
Fertilizer N and P equivalency of crop residue (%)	153	290

showed higher fertilizer P response in home gardens as compared to the away farms. These results support the observation that fertilizer response are higher in fertile than in degraded soils.

Long Term Trial at Kouaré, Burkina Faso

A study was conducted in Kouaré, Burkina Faso to assess the contributions of cowpea and fallow to soil fertility improvement (Bado 2002). Five rotation treatments (cowpea-sorghum, sorghum-cowpea, fallow-sorghum, sorghum-fallow and sorghum-sorghum) were used as first factor and four fertilizer treatments (chemical Nitrogen (N), Phosphorous (P) and Potassium (K) fertilizer; NPK + Dolomite; P + Manure and Control without any fertilizer) were used as second factor

A overall analysis of data of the 5 years indicated that all fertilizer treatments improved sorghum grain and stover yields (Table 1.5). Chemical NPK fertilizer improved sorghum grain yields but higher yields were obtained when chemical NPK fertilizer was associated with dolomite. The application of chemical P fertilizer (in lack of N and K) associated with manure was as effective on sorghum grain yield as chemical NPK fertilizer alone.

Sorghum produced less than 500 kg/ha of grain in mono cropping but produced highest grain yields when fallow or cowpea was used in the cropping system (fallow-sorghum or cowpea-sorghum rotation). The succeeding sorghum grain yields increased from 75% to 100% when it was rotated with fallow and cowpea respectively. The effects of rotations increased over time and cowpea was most effective on sorghum yield increase during the last 3 years (Fig. 1.4). Total N uptake by succeeding sorghum increased from 26 kg N/ha in mono cropping of sorghum to 31 and 48 kg N/ha when sorghum was rotated with fallow or cowpea respectively (Bado 2002; Bado et al. 2006) (Table 1.6).

Table 1.5 Sorghum and cowpea yields (kg/ha) as affected by fertilization and cropping systems during 4 years (1996–1999) at Kouaré, Burkina Faso

	Sorghum		Cowpea	
Fertilization	Grain	Stover	Grain	Haulms
NPK+ Dolomite	914[a]	4,489[a]	611[ab]	1,228[a]
P+ manure	746[bc]	3,769[c]	649[a]	1,284[a]
NPK	798[b]	4,205[ab]	510[c]	1,028[a]
Control	346[d]	1,611[d]	265[d]	380[b]
Cropping systems				
Cowpea-Sorghum	938[a]	4,281[a]	na	na
Fallow-Sorghum	819[b]	3,493[b]	na	na
Sorghum-Sorghum	467[c]	2,912[c]	na	na

Values followed by the same letter in the same column are not significantly different at $p<0.05$, according to Fisher's test
na Not applicable

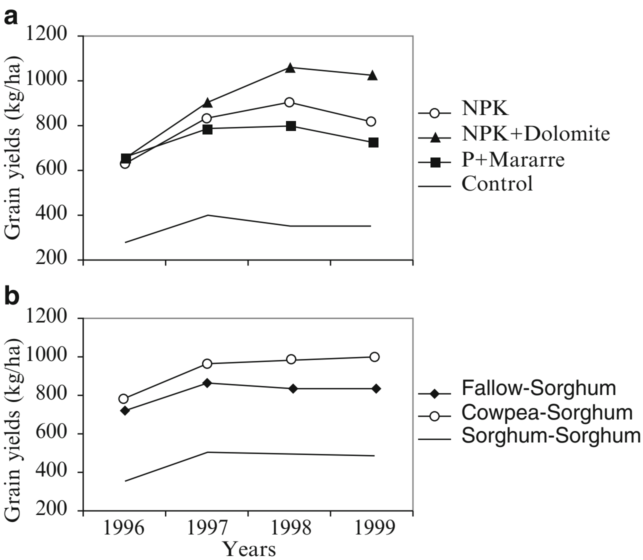

Fig. 1.4 Effects of (**a**) fertilizer applications and (**b**) crop rotations on succeeding sorghum grain yields during 4 years (1996–1999) at Kouaré, Burkina Faso

After 5 years of cultivation (1994–1999), soil organic carbon was significantly affected by crop rotation ($p<0.05$), but fertilization did not affect soil organic C (Table 1.7). The highest concentration of organic C was observed in soils of fallow-sorghum rotation and lowest quantities were observed in mono cropping of sorghum and cowpea-sorghum rotation. As observed with organic C, the highest quantity of N was observed in soils of fallow-sorghum rotation and lowest quantities were observed in mono-cropping of sorghum and cowpea-sorghum rotation.

Table 1.6 Effects of cowpea and fallow on total N uptake by succeeding sorghum, fertilizer N use efficiencies (FNUE) and N derived from soil (Ndfs) and fertilizer (Ndfs) in 1999 after 5 years of cultivation

Cropping systems	Total N uptake, kg N/ha	FNUE, %	Ndff, kg/ha	Ndfs kg/ha
Fallow-Sorghum	31[b]	26[a]	10[a]	21[b]
Cowpea-Sorghum	48[a]	22[ab]	8[ab]	40[a]
Sorghum-Sorghum	26[c]	17[c]	6[bc]	20[bc]

Values followed by the same letter in the same column are not significantly different at $p < 0.05$, according to Fisher's test

Table 1.7 Some soil (0–20 cm layer) properties as affected by fertilizers and crop rotations after 5 years of cultivation (1995–1999)

	pH	C. org	Total N	K+	Ca++	Mg++	ECEC	Bases	Al
	KCl	(%)	Kg/N	Cmol/kg	Cmol/kg	Cmol/kg	Cmol/kg	(%)	(%)
Cropping systems									
Fallow-Sorghum	5.3	0.39[a]	360[a]	0.11	1.43[a]	0.44	2.10	95	3
Cowpea-Sorghum	5.2	0.29[b]	294[b]	0.09	1.09[b]	0.53	1.84	94	3
Sorghum-Sorghum	5.3	0.29[b]	335[b]	0.14	1.07[b]	0.35	1.68	94	3
Fertilization									
P+Manure	5.2[b]	0.32	318[a]	0.10	1.15	0.33	1.72	93[b]	4[b]
NPK	5.0[c]	0.33	317[a]	0.10	1.12	0.27	1.70	88[c]	6[a]
NPK+Dolomite	5.6[a]	0.32	270[b]	0.10	1.38	0.62	2.17	99[a]	0[d]
Control	5.3[b]	0.32	237[c]	0.15	1.13	0.54	1.91	97[a]	2[c]
Original soil	5.5	0.50	427	0.13	1.59	0.51	2.30	99	0

Values followed by the same letter in the same column are not significantly different at $p < 0.05$, according to Fisher's test
EA Exchange acidity, *ECEC* Effective Cation Exchange Capacity

Compared to original soil, all rotations and fertilizer treatments decreased soil N. All fertilizer treatments increased soil N and highest quantities of N were observed in manure containing treatment (PK + manure). Dolomite increased soil pH and maintained soil bases (Ca^{++} and Mg^{++}), ECEC and Al^{3+} saturation at the same levels as the original soil. Soil pH and bases saturation were significantly greater with combined application of P and manure than chemical NPK fertilizer alone. Chemical NPK fertilizer increased Al^{3+}. But manure application decreased Al^{3+} saturation.

Long-Term Fertility Experiments (LTFE) for Irrigated Rice in the West African Sahel: Agronomic Results

The LTFE were started at WARDA's two research farms in Ndiaye and Fanaye, Senegal, in the 1991 (Haefele et al. 2002; Bado et al. 2010). The intention was to monitor changes in soil fertility and rice yield response to N, P and K fertilizer input in the intensive monocropping system of irrigated rice. The trial consists of six treatments.

Table 1.8 Average grain yields in the long-term fertility experiment at Ndiaye and Fanaye during 20 continuous seasons between 1991 and 2001 for the wet season (WS) and the hot dry season (HDS)

	N-P-K doses	Ndiaye		Fanaye	
Treatment	(kg/ha)	WS (t/ha)	HDS (t/ha)	WS (t/ha)	HDS (t/ha)
T1	0-0-0	3.2	3.5	3.7	2.0
T2	120-26-50	6.7	7.0	6.9	6.5
T3	120-52-100	6.5	6.8	7.1	6.5
T4	120-0-0	5.3	5.3	5.8	4.4
T5	180-26-50	6.6	7.5	7.6	7.6
T6	60-26-50	5.6	5.8	5.8	4.9
Average		**5.7**	**6.0**	**6.2**	**5.3**

Average grain yield of all treatments was highest in the Fanaye WS (6.2 t/ha), intermediate in the Ndiaye WS and HDS (6.0 and 5.7 t/ha, respectively), and lowest in the Fanaye HDS (5.3 t/ha), (Table 1.8). T1 had always the lowest yield (2.0–3.7 Mg/ha) and was always significantly different from all other treatments. T5 resulted in the highest yields (6.6–7.6 Mg/ha) except for the WS in Ndiaye.

Long Term Trials in East Africa

Long Term Experiment, Kabete, Kenya

The Long term experiment at the National Agriculture Research laboratories (NARL) Kabete, Kenya was established in 1976 to study small-scale farmers' methods of improving and sustaining soil fertility (Kibunja and Gikonyo 2000). The primary objective of the trial was to find appropriate methods for maintaining and improving the productivity of the soils through repeated use of inorganic fertilizers (in particular nitrogen and phosphorus), farm yard manure and crop residues under continuous cropping following the husbandly practices of small-scale farmers. This sections presents only a summary of the key lessons and more detailed results from this experiment are discussed in Chapter 4.

At the onset of the experiment, yields averaged slightly over 3.5 t/ha. However, great variations have been recorded due to treatment effects, rainfall amounts and distribution as well as timeliness in planting. In general, application of chemical fertilizers gave higher yields than FYM alone for the first 6 years. However, after the tenth year, maize yields for NP treatments were significantly lower than for FYM alone. During the next 10 year period of continuous cropping, the differences between FYM and FYM+NP combination became increasingly minimal and the yields tended to decline more rapidly where only chemical fertilizers were applied. To date the results indicate that 5–10 t/ha of FYM applied singly or in combination with 60 kg N and 60 kg P_2O_5 chemical fertilizers is the most promising nutrient

Table 1.9 Long term mean maize grain yield (t/ha) for selected treatments at Embu, Kenya (1993–2005)

Treatment	Mean Grain Yield (t/ha)
Calliandra alone	2.7
Leucaena alone	2.7
Calliandra+30kg N/ha	3.1
Leucaena+30kg N/ha	3.1
Recommended fertilizer rate (60 kg N/ha)	2.3
Control	1.6

management strategy for long-term improvement and maintenance of soil fertility. Other studies on this experiment have shown that there was a general reduction in soil organic matter (SOM) across all the treatments. However, SOM fractions were more favorably influenced by the addition of FYM than stover retention (Kapkiyai et al. 1998, 1999).

Hedgerow Intercropping Trial in Embu

Recognizing the potential of leguminous trees species to improve soil fertility, the Hedgerow Intercropping (HI Embu) trial was initiated in 1992 at the Kenya Agricultural Research Institute (KARI) Regional Research Centre (Embu) in the central highlands of Kenya (Mugendi et al. 1999). The experiment sought to investigate feasibility of using leguminous trees for soil fertility improvement. The leguminous shrubs used were *Leucaena leucocephala* (Lam.) de Wit and *Calliandra calothyrsus* Meissn applied as biomass transfer (from outside) or as insitu (from the hedgerow prunnings). The trial consists of ten treatments set out in a randomized complete block design (RCBD) with four replicates.

The average maize grain yields obtained across the 11 years (22 seasons) indicated that treatments receiving both organic and inorganic nutrient sources recorded the highest yields that were compareable to the continous fertilizer application treatment (Table 1.9). Leucaena alley cropped treatment with prunings incorporated (Treatment 2) gave an average yield of 2.8 t/ha whereas the equivalent calliandra treatment (Treatment 1) recording an average yield of 2.0 t/ha. The above yields are compared to the recommended fertilizer and the control treatment yields of 2.3 and 1.6 t/ha respectively.

Treatments with prunings incorporated with fertilizer gave better maize grain yields compared to treatments with only prunings applied. This could be due to the provision of additional physical, chemical and biological benefits (besides N) by the organic materials or due to the prevention of other nutrients deficiencies and/or enhanced nutrient fluxes (Sanchez and Jama 2002).

Kirege Experiment, Eastern Kenya

Kirege trial, in Chuka location, Meru South District Eastern Kenya was established in March 2000 to evaluate the potential of various soil fertility management technologies

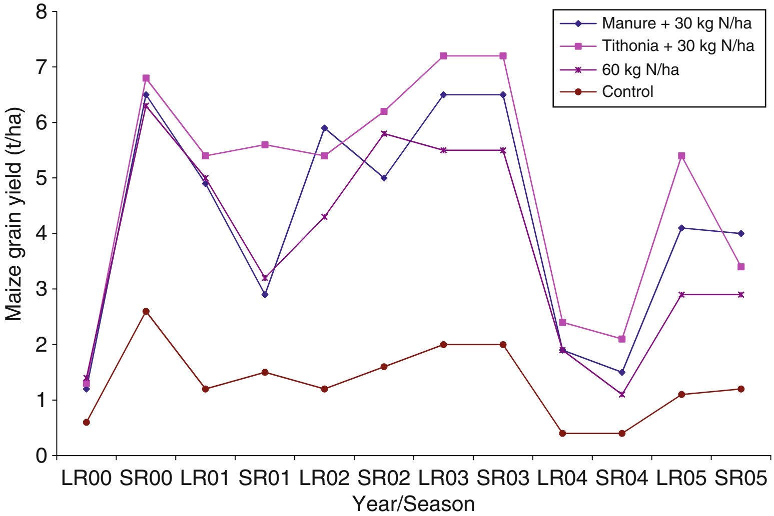

Fig. 1.5 Maize yields under different technologies in Chuka, Meru South District during the period 2000 to 2005

to improve soil fertility. The experiment was laid out as a randomized complete block design (RCBD) with the plot sizes measuring 6 m×4.5 m replicated thrice. Nine external soil fertility amendment inputs were applied every season to give an equivalent of 60 kg N/ha, the recommended rate of N application to meet maize nutrient requirement for an optimum crop production in the area (FURP 1987). These treatments were compared to an absolute control where no external inputs were applied.

The average maize grain yields in the different treatments across the 12 seasons are presented in Fig. 1.5. The maize grain yields monitored across 12 seasons (6 years) were significantly different ($p < 0.05$) among treatments. On average, treatments involving a combination of organics and inorganic fertilizer resulted in higher yields compared to the sole fertilizer or the absolute control treatment (Fig. 1.5).

This could be due to the provision of additional physical, chemical and biological benefits (besides N) by the organic materials or due to the prevention of other nutrients deficiencies and/or enhanced nutrient fluxes (Sanchez and Jama 2002). The control gave consistently low yields across the 12 seasons and it reflects to a large extent the yields attained on most farmers' fields where very low inputs or none are applied.

Nitrogen Fertilizer Equivalence Experiment Kabete, Kenya

The Nitrogen Fertilizer Equivalence Experiment (N1 Kabete) was established in 1999 with the objective of assessing the fertilizer equivalencies of the organic materials used for soil fertility management (Kimetu et al. 2004). Three organic resources

(*Tithonia diversifolia, Senna spectabilis* and *Calliandra calothyrsus*) were compared with the recommended rate of fertilizer and the absolute control.

Results from this trial indicated that combination of tithonia with inorganic fertilizer was the best treatment over the cropping seasons averaging 7 t/ha compared to 6.5 t/ha for sole mineral fertilizer and 4 t/ha for the control (data not shown). On average, the three organic materials (calliandra, senna and tithonia) gave fertilizer equivalency values of 50%, 87% and 118%, respectively indicating that tithonia biomass can be used in place of mineral fertilizer as a source of nitrogen.

Long Term Trials in Southern Africa

Some long term trials were established in Malawi in 1995/1996 to predict long-term changes in organic C, N and texture under different cropping systems. The trials were initially established at five sites: Chitala, Chitedze, Lisasadzi, Makoka and Zombwe.

The design was a split plot with cropping systems allocated in main plots and residue management in subplots. Factors under study were three cropping systems with or without fertilizer and two crop residue management options (Table 1.10).

Initial site characteristics are indicated in the Table 1.11. Soil pH ranged from 5.3 (Zombwe and Makoka) to 5.6 (Chiatala). Soil pH is in the good range to support crop production. All sites had low initial soil nitrogen that made all sites suitable for this study. Initial soil nitrogen ranged from 0.002% to 0.16%. Sites had different levels of soil organic carbon ranging from 0.30% to 2.07%.

Average annual total rainfall varied across years and sites (Fig. 1.6). More critical was the high monthly variations which often occurred during planting and flowering and grain filling stages (January and February). Dry years were observed in 1995, 1999, 2000, 2001, 2004 and 2005.

Maize grain yield recorded from the four sites differed significantly due to treatment effects, site differences in soil types and climatic conditions (Figs. 1.7 and 1.8). Despite differences in the sites, the response trend in maize yields to different cropping systems remained the same. The highest grain yield across sites were obtained when maize were grown in rotation with pigeon pea followed by maize/pigeon pea intercropping. The maize/pigeon pea rotation treatment gave similar yields in all the sites when compared at the same fertility level. This shows that pigeon pea had the largest nitrogen residual effect to benefit the subsequent maize crop.

Highest maize yields were obtained in the initial year across sites of the trial as indicated in (Figs. 1.9 and 1.10). Average maize yields decreased with time. Deflection in maize yields in some years and sites was attributed to drought conditions and change of the trial variety index from MH18 to DK3031. The initial maize variety index MH 18 was changed because the former variety became scarce on the market due to its high susceptibility to foliar diseases such as Grey Leaf Spot. Normally DK 8031 has a higher yield potential than MH18.

Table 1.10 Main and subplot treatment description at Chitedze, Chitala, Makoka and Zombwe

		Cropping system	Residue management	
Plot	Fertility	Main plot	Subplot 1	Subplot 2
1	No fertilizer added	Sole maize	Minus stover	Plus stover
2		Maize/pigeon pea rotation	Minus pigeon pea stems + pigeon pea leaves	Plus pigeon pea stems + pigeon pea leaves
3		Maize/pigeon pea intercropping	Minus p/pea stems +p/pea leaves	plus maize residues + p/pea leaves + p/pea stems
4	Fertilizer added (area specific recommendation)	Sole maize	Minus stover	Plus stover
5		Maize/pigeon pea rotation	Minus pigeon pea stems + pigeon pea leaves	Plus pigeon pea stems + pigeon pea leaves
6		Maize/pigeon pea intercropping	Minus p/pea stems +p/pea leaves	plus maize residues + p/pea leaves + p/pea stems

Table 1.11 Initial soil physical and chemical characteristics of experimental sites

Site	pH (H_2O)	OC	N	Clay	Silt	Fine sand	Coarse sand	Soil texture
		Percentage (%)						
Chitala	5.6	1.07	0.07	26	9	25	40	SCL
Chitedze	5.4	2.39	0.16	28	21	21	30	SCL
Lisasadzi	5.8	0.59	0.04	4	4	36	56	SL
Makoka	5.3	0.30	0.02	16	6	28	50	LS
Zombwe	5.3	0.68	0.05	22	4	30	44	SCL

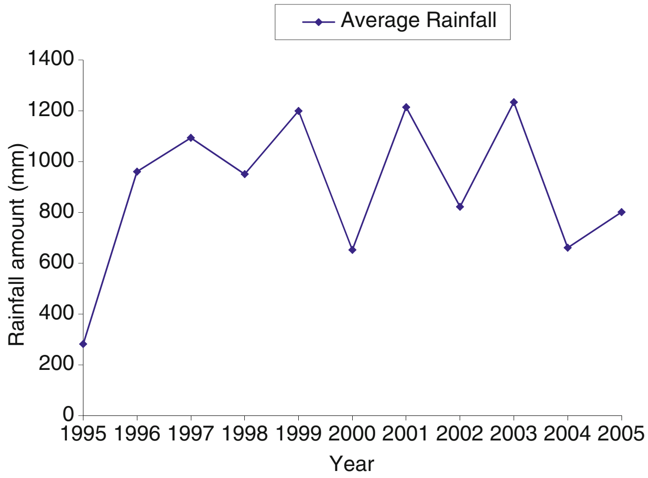

Fig. 1.6 Rainfall means (mm) across years for 10 years (1995–2005)

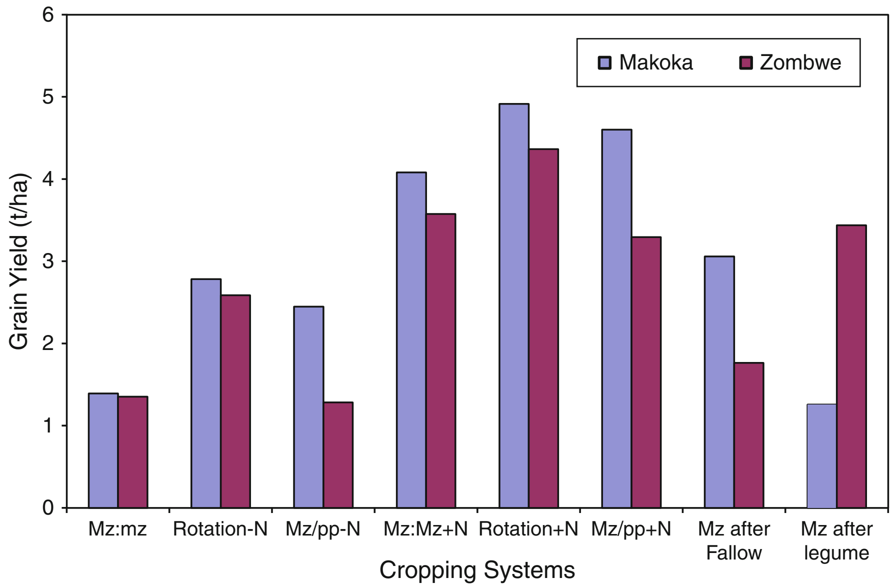

Fig. 1.7 Maize yield response to different cropping systems over a period of 5 years (2000–2005) at Makoka and Zombwe

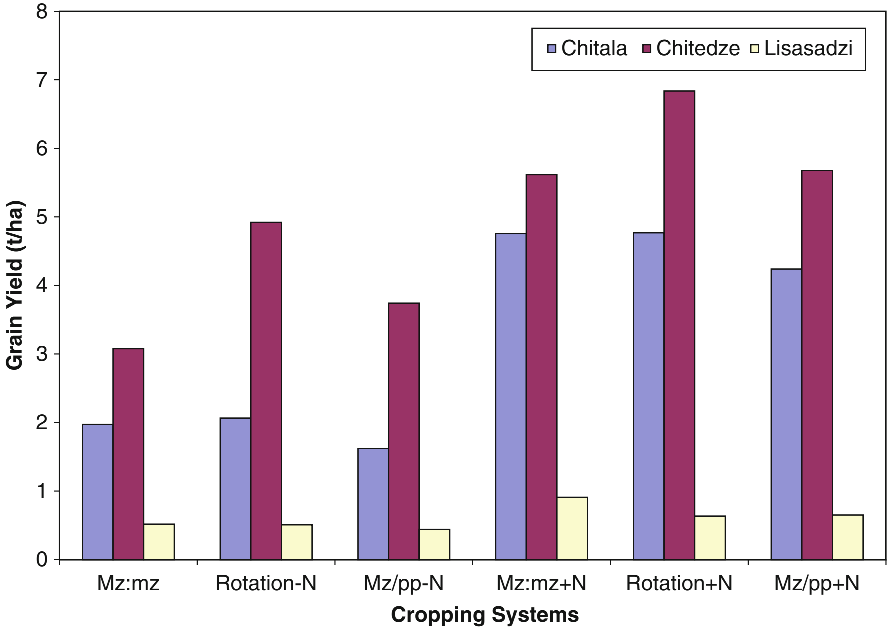

Fig. 1.8 Maize yield response to different cropping systems over a period of 6 years (2000–2005) at Chitala, Chitedze and Lisasadzi

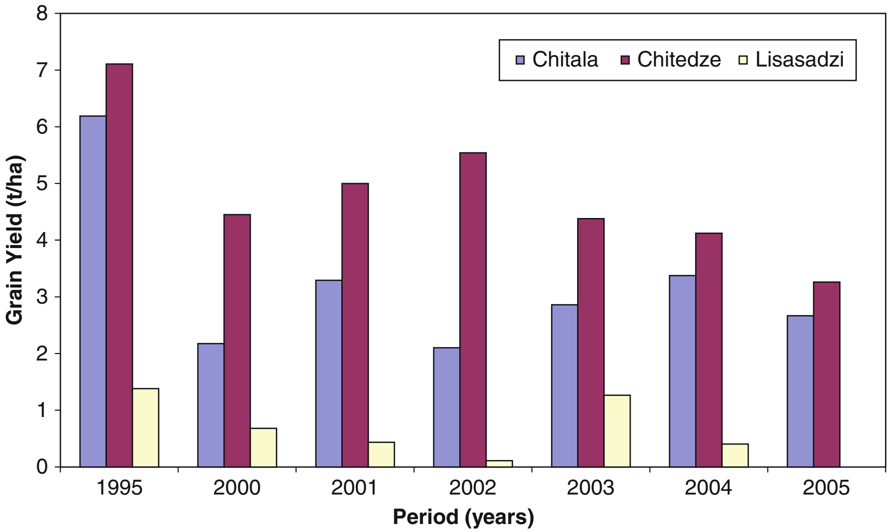

Fig. 1.9 Maize yield trend over a period of 7 years (1995–2005) at Chitala, Chitedze and Lisasadzi

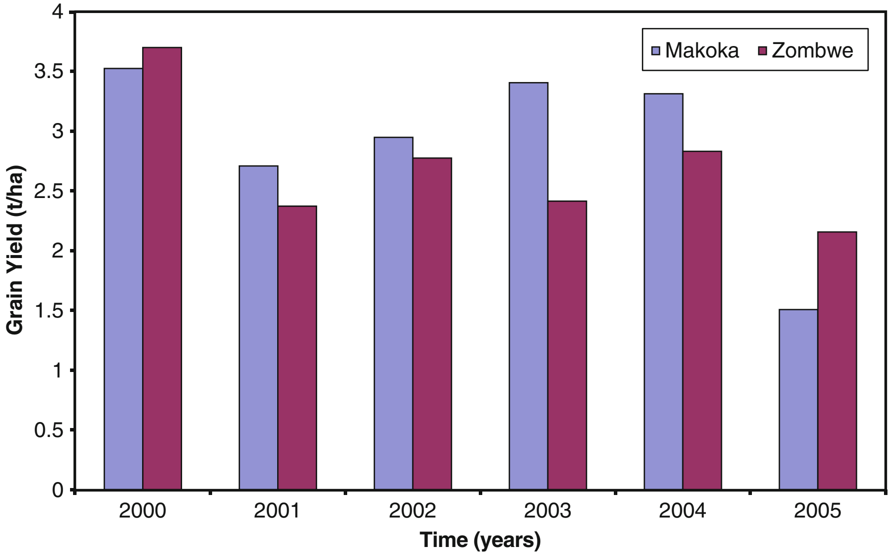

Fig. 1.10 Maize yield trend for 6 years (2000–2005) at Makoka and Zombwe

Key Lessons from Long-Term Experiments in Africa

A review of these experiments highlights a number of key findings:

All long term trials showed yield decline, often with a relatively rapid fall to a low level equilibrium. Such yield dynamics are highly correlated with available nutrients and soil organic matter. For example a long term trial in Senegal showed how organic matter declined from nearly 3% under forest conditions to under 1% when farmed continuously (Siband 1974).

At all sites, there were positive yield responses to one or more nutrients added as mineral fertilizers. The responses were consistent for the duration of the experiments. This highlights the effectiveness of mineral fertilizers in increasing yield in arable farming systems in Africa. This potential is recognized by largescale farmers, who have been able to sustain relatively high yields of maize (Kenya, Zambia and Zimbabwe), tobacco (Nicotiana tabacum L.; Malawi and Zimbabwe), and coffee (Coffea Arabica L.; Kenya) for periods of up to 30 years.

Soil organic matter (SOM) also declines significantly when land is cultivated. In West Africa, long term experiments show a range between over 5% loss of SOM per annum on sandy soils to around 2% on better textured soils (Pieri 1995) After a certain point, a threshold is reached where decline does not continue significantly (around 1%, Lal 1995). However, at low levels of SOM, crop response to inputs is relatively poor and it is difficult to maintain yields with inorganic fertilizers alone (Greenland 1994).

Prolonged treatments using only inputs of organic matter (animal manure, green manure, crop residues, etc.) also showed yield declines, although the positive impact were sustained longer than for inorganic fertilizers alone in many cases. However, the amount of organic matter required to sustain yields was considerable, with very large application rates needing to be applied in many experiments.

Rotational treatments, including sequences with legume crops and fallow periods had lower yield declines than monocultures. Such treatment also had lower rates of SOM loss (Pieri 1995). Most showed that reducing tillage frequency, including no-till options, reduced the rates of organic matter loss (Pieri 1995), although the impact on overall yield was often mixed.

The best results (in term of long-term sustained yield response) invariably were those treatments that combined inorganic and organic inputs. For example, over 18 years in Kabete, in the favorable highland conditions of Kenya, maize consistently yielded highest under the combined treatment. This was attributed to the achievement of the appropriate nutrient input (most easily through the choice of appropriate inorganic fertilizers mixes) with good soil structure (through effective organic matter management).

Limitations of the Long Term Trials

All of the long term experiments were located on research stations and were managed by researchers. Although early experiments tended to look at a variety of treatments, including rotations, green manuring, and animal manuring, later experiments shifted to look more specifically at inorganic fertilizers, and failed to capture the range of farmer's practices.

Only a few of the long term experiments in Africa spanned a period of longer than 20 years, making it difficult to assess longer term dynamics. Termination of these trials has been mainly due to lack of funds to maintain the experiments.

Relatively few of these experiments provide details of soil changes, so they can not be used to test for patterns of soil fertility decline or nutrient removal over time. Other factors that have limited interpretation of these time-series data include variations in the inter-annual, seasonal and cyclical changes in rainfall or pest and disease incidences.

Results from long-term trials have not been used satisfactorily to influence policy or management recommendations.

The Way Forward

Results obtained from short-term experiments cannot provide the appropriate scientific information and could produce misleading technological recommendations. Long term trials hold key to understanding the processes and functioning of many of the cropping systems in tropical Africa. These trials could be used especially by researchers and higher education students interested in basic research about the various systems. Data from these trials can be used for simulation and prediction of potential changes in production or soil properties as thus improving on decision making process to adapt to the changing conditions. Despite these importance, only a handful of such trials with lifespans of over 20 years exist across the continent. Those in existence have faced problems of inconsistency in management and data collection. In addition, most of these trials lack comprehensive one-stop databases hence it is difficult to monitor their performance.

Long-term experiments are costly to maintain over time, as they require constant and valid management as well as accuracy and adequacy in data collection and management (Pieri 1995). This financial burden may be considered excessive particularly by national, regional or even international research organizations working in developing countries which prefer to address the most pressing agronomic issues with short-term trials. Long term funding is required to maintain long term trials in Africa. This can be achieved through national support and from collaborative research leading to MSc and PhD with various local and foreign research institutions and universities.

References

Bado BV (2002) Rôle des légumineuses sur la fertilité des sols ferrugineux tropicaux des zones guinéennes et soudaniennes du Burkina Faso. Thèse de Doctorat (PhD) Département des sols et Environnement, Université Laval, Quebec, 145 p

Bado BV, Bationo A, Lompo F, Segda Z, Cescas MP, Sedogo MP (2006) Long-term effects of cropping systems and fertilization on crop production, soil characteristics and nitrogen cycling in the Guinean and Sudanian savannah zones of Burkina Faso (West Africa). In: Zapata F, Nguyen L-M (eds) Management practices for improving sustainable crop production in tropical acid soils. Results of a coordinated research project organized by the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture, IAEA Proceedings Series. International Atomic Energy Agency, Vienna, pp 47–64

Bado BV, Aw A, Ndiaye M (2010) Long-term effect of continuous cropping of irrigated rice on soil and yield trends in the Sahel of West Africa. In: Bationo A, Waswa, BS, Okeyo J, Maina F, Kihara J (eds) SI: Innovations as Key to the Green Revolution in Africa: Exploring the Scientific Facts. Nutr Cycl Agroecosyst 88:133–141

Bekunda MA, Bationo A, Ssali H (1997) Soil fertility management in Africa: a review of selected research trials. In: Buresh RJ, Sanchez PA, Calhoun F (eds) Replenishing soil fertility in Africa. SSSA Special Publication No. 51. SSSA, Madison

CGIAR (2001) Special panel on impact assessment, Contributions Made by the CGIAR and Its Partners to Agricultural Development in Sub-Saharan Africa. Consultative Group on International Agricultural Research, Washington, DC

DFID (2000) Sustainable livelihoods guidance sheets. The Department for International Development, London

FURP (1987) Description of the first priority trial sites in various districts. KARI, FURP, Nairobi, Kenya, pp 1–31

Greenland DJ (1994) Long-term cropping experiments in developing countries: the need, the history and the future. In: Leigh RA, Johnson AE (eds) Long-term experiments in agricultural and ecological sciences. CAB International, Cambridge

Haefele SM, Wopereis MCS, Wiechmann H (2002) Long-term fertility experiments for irrigated rice in the West African Sahel: agronomic results. Field Crop Res 78(2002):119–131

Kapkiyai JJ, Karanja NK, Woomer PL, Qureshi JN (1998) Soil organic carbon fractions in a long-term experiment and the potential for their use as a diagnostic assay in highland farming systems of Central Kenya. Afr Crop Sci J 6(1):19–28

Kapkiyai JJ, Karanja NK, Qureshi JN, Smithson PC, Woomer PL (1999) Soil organic matter and nutrient dynamics in a Kenyan nitisol under long-term fertilizer and organic input management. Soil Biol Biochem 31(13):1773–1782

Kibunja C, Gikonyo E (2000) Maintenance of soil fertility under continuous cropping in a maize-bean rotation (Long-term trial, NARL-Kenya). TSBF Report 1997–1998. UNESCO, Nairobi

Kimetu JM, Mugendi DN, Palm CA, Mutuo PK, Gachengo CN, Bationo A, Nandwa S, Kungu JB (2004) Nitrogen fertilizer equivalencies of organics of differing quality and optimum combination with inorganic nitrogen source in Central Kenya. Nutr Cycl Agroecosyst 68(127–135):2004

Lal R (1995) Technological options for sustainable management of Alfisols and Ultisols in Nigeria. In: Lal R, Stewart BA (eds) Soil management: experimental basis for sustainability and environmental quality. Lewis Publishers, London

Lynam JK et al (1998) Nutrient balances as indicators of productivity and sustainability in sub-Saharan African agriculture introduction. Agric Ecosyst Environ 71:1; Drechsel P, Gyiele LA (1999) The economic assessment of soil nutrient depletion. International Board for Soil Research and Management, Bangkok

Mando A (2006) Effect of long-term addition of organic input of contrasting quality on soil carbon and crop performance under Sudano-Sahelian conditions. 18th World Congress of Soil Science, Philadelphia, Pennsylvania, 9–15 July 2006

Mando A, Bonzi M, Wopereis MCS, Lompo F, Stroosnijder L (2005) Long-term effects of mineral and organic fertilization on soil organic matter fractions and sorghum yield under Sudano-Sahelian conditions. Soil Use Manag 21:396–401

Mugendi DN, Nair PKR, Mugwe JN, O'Neill MK, Woomer PL (1999) Alley cropping of maize with calliandra and leucaena in the subhumid highlands of Kenya. Part 1. Soil-fertility changes and maize yield. Agrofor Sys 46(1):39–50

Pieri C (1995) Long term management experiments in semiarid Francophone Africa. In: Lal R, Stewart BA (eds) Soil management: experimental basis for sustainability and environmental quality. CRC Press, Boca Raton, pp 225–266

Pinstrup-Andersen P, Pandhya-Lorch R, Rosengrant MW (2000) World food prospects: critical issues for the early 21st century (1999) and food security: problems, prospects and policies (2000). International Food Policy Research Institute, Washington, DC; available at www.ifpri.org

Sanchez PA (1994) Tropical soil fertility research: towards the second paradigm. In: Inaugural and state of the art conferences. Transactions 15th World Congress of Soil Science. Acapulco, Mexico, pp 65–88

Sanchez PA (2002) Soil fertility and hunger in Africa. Science 295(5562):2019–2020

Sanchez PA, Jama BA (2002) Soil fertility Replenishment Takes off in East and Southern Africa. In: Vanlauwe B, Diels J, Sanginga N, Merckx R (eds) Integrated plant nutrient management in Sub-Saharan Africa: from concept to practice. CAB International, Wallingford, Oxon

Sanchez PA, Shepherd KD, Soule MJ, Place FM, Buresh RJ, Anne-Marie N, Izac A, Mokwunye U, Kwesiga FR, Ndiritu CG, Woomer PL (1997) Soil fertility replenishment in Africa: an investment in natural resource capital. In: Buresh RJ, Sanchez PA, Calhoun F (eds) Replenishing soil fertility in Africa. SSSA Special Publication No. 51 Soil Science Society of America. Madison, Wisconsin, pp 1–46

Siband P (1974) Evolution des caractéres et de la fertilité d'un sol rouge de Casamance. L'Agronomie Tropicale 29:1228–1248

Smaling EMA (1993) An agro-ecological framework of integrated nutrient management with special reference to Kenya. Wageningen Agricultural University, Wageningen

Southwood TRE (1994) The importance of long-term experimentation. In: Leigh RA, Johnson AE (eds) Long-term experiments in agricultural and ecological sciences. CAB International, Cambridge

Swift MJ, Seward PD, Frost PGH, Qureishi JN, Muchena FN (1994) Long-term experiments in Africa: developing a database for sustainable land use under global change. In: Leigh RA, Johnson AE (eds) Long-term experiments in agricultural and ecological sciences. CAB International, Cambridge

Theng BKG (1991) Soil science in the tropics – the next 75 years. Soil Sci 151:76–90