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Evaluation of Strategies for Soil Fertility Improvement in Northern Nigeria and the Way Forward

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Abstract: Available literatures on recommended strategies for soil fertility improvement in Northern Nigeria were evaluated. Rapid population growth has made the traditional systems of soil fertility maintenance through bush-fallow both unpopular and non-feasible. The use of animal manure, which has become common since the 1930s, is limited by low nutrient content, due to poor storage and huge quantities required to satisfy crop needs. Green manuring and incorporation of crop residues were recommended to improve soil organic matter content but farmers commonly remove crop residues from the field for livestock feed, fencing, roofing and other purposes. Of all cropping systems, crop rotation involving legumes with high nitrogen fixing capacity has the greatest potential for maintaining soil fertility at reasonable level. Despite the great potential of mineral fertilizers identified in the research institute in 1937 and actual farmers usage in the late 1940s, high prices, unavailability and lack of good market infrastructure have made their application minimal among many smallholder farmers in Nigeria. Several studies have shown that combined use of organic resources supplemented with mineral fertilizers improves soil fertility and produce superior crop yields. This strategy has now shifted towards Integrated Soil Fertility Management (ISFM) which involves various stakeholders in the research and development process due to the realization that 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 approach may provide the much desired solution to soil fertility decline in Northern Nigeria.

Key words: Fertilizer, integrated soil fertility management, Northern Nigeria, soil fertility

INTRODUCTION

Soil degradation due to nutrient mining, erosion and desertification is the major threat to food production in Northern Nigeria (Balasubramanian *et al*., 1984; Singh and Balasubramanian, 1979; Bationo *et al*., 1996; Chude, 1998). The reasons for the widespread of these ecological problems have been fairly well documented, but adequate solutions have not yet reached the application phase. The problem of soil fertility in the Northern States of Nigeria like most sub-Saharan African countries is driven by a wide range of biophysical, chemical and socio-economic factors. The first one is the geologic origin of the parent material on which the soils have developed. The parent materials consist of old and weathered materials, which probably have never contained many nutrient-bearing minerals. The second cause of low fertility is nutrient depletion. Nutrient balances are negative for many cropping systems indicating that farmers are mining their soils. Current estimates in the country indicate that in 1983, for a total of 32.8 million hectares of land cultivated, soil nutrient mining amounted to a total loss of 111,000 tonnes of nitrogen (N), 317,000 tonnes of P_2O_5 and 946,000 tonnes of K_2O (Stoorvogel and Smaling, 1990) equivalent to over US$800 million of N, phosphorus (P) and potassium (K) fertilizers. The third factor which indirectly influences restoration of soil fertility in Northern Nigeria is the farmers' socio-economic conditions. Macro-economic policies also play a pivotal role in influencing the accessibility, availability and the type of inputs a farmer can use. Unfavourable exchange rates, poor producer prices, high inflation, poor infrastructure and lack of markets contribute to low fertilizer use by farmers.

The major cereal crops grown in Nigeria are maize, millet, sorghum and rice. These crops are predominantly grown in Northern Nigeria due to suitable soil and climatic conditions. Generally, there w as decline in yield of these crops in the last one decade (Table 1). Of particular

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Table 1: Yield trend and growth rates of cereals in Nigeria, 1996-2005

	Maize		Millet		Sorghum		Rice	
Years	Actual (kg ha^{-1})	Growth (%)	Actual (kg ha^{-1})	Growth (%)	Actual (kg ha^{-1})	Growth (%)	Actual (kg ha^{-1})	Growth (%)
1996	1326		1061		1144		1750	
1997	1251	-5.67	1076	1.41	1107	-3.22	1596	-8.82
1998	1320	5.52	1000	-7.03	1133	2.29	1602	0.41
1999	1381	4.63	1064	6.37	1126	-0.59	1496	-6.65
2000	1027	-25.64	1050	-1.28	1120	-0.54	1500	0.27
2001	1143	11.32	944	-10.05	1021	-8.81	1247	-16.86
2002	1044	-8.68	990	4.81	1090	6.72	1010	-18.99
2003	1070	2.49	1030	4.04	1135	4.13	956	-5.45
2004	1070	0.00	1030	0.00	1140	0.88	960	0.00
Mean	1195	-2.29	1027	-0.25	1109	0.00	1395	-8.01

Source: Federal Ministry of Agriculture and Rural Development (FMARD), Abuja, Nigeria

interest is the lower yield of rice despite government efforts at revamping rice production in the country. This was attributed to farmers' inability to obtain good quality and high yielding seeds (NAERLS, 1999) and shortage in supply of fertilizer during the period. Of the 163,700 metric tones of fertilizer approved by the government for 2002 wet season, only 104,024 metric tones (63.5%) were delivered.

On the basis of amount of annual rainfall, Northern Nigeria can be divided into four major agroecological zones (AEZ) namely, Sahel, Sudan, Northern and southern Guinea savanna zones (Lombin, 1987). Considering the importance of soil moisture for crop growth and for the uptake of plant nutrients, it is obvious that soil fertility improvement measures will differ considerably between the four zones, especially since soils and farming systems are closely related to the rainfall regimes (FAO, 1986). The decline in rainfall experienced in most of the areas in Northern Nigeria has resulted in decrease in vegetation cover (Hess *et al*., 1995; Nicholson *et al*., 2000). With this, much of the soil is left bare and therefore directly exposed to the vagaries of wind and water erosion. Land degradation due to water erosion is more severe in the Guinean zone than in the Sudano-sahelian zone. Infiltration rate is higher in the weakly crusted surface of the sandy Sahelian soils than the Alfisols of the Guinean zone, which is poorly structured and highly prone to crust and compaction (Ogunwole *et al*., 1999; Wuddivira *et al*., 2000). In Samaru (Northern Guinea savanna) with a slope of 0.3% only 25.2% runoff was recorded with soil loss of 3.0 t year^{-1} on sorghum field, whereas in Ougadougou (Sahel) with a slope of 0.5% on sorghum field a total runoff of 40.6% was recorded resulting in soil loss of 10.2 t year^{-1} on sorghum field (Bationo *et al*., 1996).

It is apparent that no single measure could be recommended to tackle the problem of soil fertility in Northern Nigeria. The technical actions, which are envisaged to enhance and restore soil fertility, have to be selected and designed in accordance with the specific constraints and potentials of these very diverse environments (Dudal, 2002). It is therefore logical that several technological and institutional innovations that can solve soil fertility decline were developed based on specific constraints and potentials.

PHYSICAL ENVIRONMENT OF NORTHERN NIGERIA

Climate: Northern Nigeria extends between latitude 6° 27^1-14°N and longitude 2°44^1 - 14°42^{1}E (Kowal and Knabe, 1972) covering approximately two-thirds of the country's total land area. The region is sub-divided into four ecological/agro-climatic zones. The Sahel zone (lat. 12°-14°N) forms the Northern-most extremity with about 400-500 mm o f rainfall, all of which falls within about 90 days between June and September. The Sudan zone (lat. 10°- 13°N) has a mean annual rainfall of about 700 mm falling mostly within four months between May and September. The Guinea savanna, which lies between lat. 6°27^1 and 10°N, is sub-divided into the Northern Guinea which receives between 900 and 1400 mm of rainfall within five to six months and the southern Guinea/Derived savanna zone which receives 1500-1800 mm rainfall distributed over seven to eight months (Lombin, 1987).

Rainfall and particularly the length of the rainy season, has a direct influence on the vegetation of the savanna zones, which ranges from semi-arid and near desert conditions in the Sahel to the Northern fringes of the forest zone. The total amount, duration and distribution of rainfall, together with solar radiation, are the most important determinants of the types of crops that can be grown. The far north, with less than 700 mm annual rainfall, has millet as the most important cereal crop. In the Sudan and Northern Guinea savanna, with higher rainfall, sorghum replaces millet. However, there has been a dramatic change in the farming practice and food habits of the people within the savanna region leading to increased maize cultivation and consumption in preference to sorghum (Lombin, 1987).

Table 2: Major soils in Northern Nigeria and their classification

Descriptive grouping	Soil taxonomy	Classification (USDA)	Distribution
Less leached, mature upland soils	Alfisols	Haplustalfs, Paleustalfs, Plinthustalfs.	Dominant
Well-drained, shallow, immature soils	Entisols and Inceptisols	Orthents, Psamments, Tropepts.	Dominant
Tropical Black Earths	Vertisols	Torrerts	Moderately
		Usterts	Dominant
Hhydromorphic soils #		Tropaquepts (Entisols) Tropaquepts	Less
		(Inceptisols) Tropaqualfs (Alfisols)	Dominant

Adapted from Lombin (1987). #: Soils with seasonally fluctuating groundwater table and shallow depth

Table 3: Physical and chemical properties of some selected soils in Northern Nigeria

Locations	Ecological zone	Texture	Soil pH (water)	Org. matter (g kg^{-1})	Total N (g kg^{-1})	Avail. P (mg kg^{-1})	CEC (cmol kg^{-1})
Bakura	Sudan S.	SL	4.6	6.9	0.14	4.90	0.45
Bauchi	NGS	"	5.6	8.6	0.70	14.00	3.50
Bokkos	"	"	4.5	18.2	0.84	7.00	1.84
Dambatta	Sudan S.	Sand	5.9	3.1	0.28	4.20	1.87
Daura	"	"	6.2	3.4	0.42	18.20	0.69
Dutsin-Ma	"	SL	5.9	3.4	0.28	1.40	0.88
Gombe 1	NGS	LS	5.7	2.8	0.42	12.60	0.46
Gombe 2	"	Sand	5.4	20.6	0.56	4.90	0.29
Gummi North	Sudan S.	SL	5.8	5.5	0.28	1.40	1.98
Gummi South	"	Loam	5.5	3.1	0.28	3.50	0.38
Gusau	"	SL	5.0	5.2	0.28	34.80	1.65
Hadejia	"	LS	6.3	4.1	0.42	4.20	1.80
Hoss 1	SGS	Clay	4.6	18.6	0.98	0.70	2.20
Hoss 2	"	"	5.2	21.3	0.98	0.70	2.76
Ikara	NGS	SL	5.4	5.8	0.70	7.00	1.20
Kafin Maiyaki	Sudan S.	"	6.2	8.0	0.28	2.45	2.55
Kankiya	"	LS	5.9	5.8	0.70	4.20	2.27
Katsina	Sahel S.	SL	4.5	3.8	0.28	4.20	0.62
Lafia	SGS	"	4.8	9.9	1.12	3.50	1.50
Maigana	NGS	Loam	5.3	7.9	0.84	2.45	2.10
Malumfashi 1	"	SL	6.3	4.2	0.56	24.50	1.63
Malumfashi 2	"	"	6.7	13.2	0.56	1.40	2.81
Ringin	Sudan S.	Sand	6.4	4.1	0.42	3.50	1.17
Samaru 1	NGS	Loam	5.2	6.2	0.70	13.3	1.52
Samaru 2	"	"	5.3	7.9	0.56	6.30	1.20
Soba	"	"	5.9	8.3	0.56	22.40	2.92
Sokoto	Sahel S.	SCL	5.2	9.3	0.28	16.96	6.12
Talatan Mafara	Sudan S.	SL	5.1	4.5	0.28	4.90	1.53
Wudil	Sudan S.	LS	6.9	4.5	0.70	2.45	1.77
Wurno	Sahel S.	"	5.5	6.9	0.28	4.90	1.54

Adapted from Abdu (2007). NGS and SGS = Northern and Southern Guinea savanna, respectively

The mean air temperature ranges between 21 and 32°C and permits the production of both the cool season (C_3) and the warm season (C_4) crops, the optimal temperatures for which have been given as 15-2 and 30-40°C, respectively (Black, 1971). The Northern Nigerian agro-ecological zones are well suited to the production of most tropical cereals and some temperate crops.

Table 4: Percentage change of soil fertility over 50 years in farmers' fields under continuous cultivation in the savanna zones of Nigeria

	Exchangeable cations			
Zone	Ca	Mg	K	Soil pH
Sudan	21.0	32.0	25.0	4.0
Northern Guinea	18.6	26.8	33.0	3.8
Southern Guinea	46.0	50.6	50.0	10.0

Adapted from Balasubramanian *et al.* (1984)

Soils: The major soils of Northern Nigeria may be grouped into four descriptive categories and classified according to the USDA (Anonymous, 1975) as shown in Table 2.

Surface soil (0-20 cm) samples were collected from 30 different locations across the various agro-ecological zones of Northern Nigeria and analyzed for some important physical a nd chemical properties (Table 3). The results show that the soils range from sandy loam to loam in texture, moderately acidic in reaction, low in Organic Carbon (OC), available phosphorus, total nitrogen and Cation Exchange Capacity (CEC) according to the classification made by FMNAR (1990)

The data in Table 4 indicate that continuous cultivation of the weakly buffered soils of Northern Nigeria will result in a rapid decline of exchangeable cations and soil acidification. Soil calcium and pH will decrease by 21 and 4%, respectively in Sudan savanna, these soil properties will also decrease by 46 and 10% in the southern Guinea.

MANAGING SOIL RESOURCES OF NORTHERN NIGERIA

Bush fallow: Many years ago, farmers in Northern Nigeria have realized that continuous food crop production cannot be achieved without restoration of soil fertility. Traditionally, farmers have maintained soil fertility through bush fallow (Van Reuler and Prins, 1993) whereby arable land is allowed to revert to fallow after 3-4 years of continuous cultivation. The fields are abandoned for 7-10 years so that natural vegetation could regrow. During the fallow period, soil fertility could, at least partially, be restored. Mounting demographic pressure and other socio-economic pressures have forced farmers to shorten the fallow period, by increasing the cultivation period. With conversion of shifting cultivation systems to (semi) permanent agriculture, soils no longer have time to recuperate after a period of cropping. The consequence of this development is that the fertility of these soils decline and yields continue to decline also. Therefore alternative farming system(s) had to be developed to arrest the declining situation so that there will be enough food for the teeming population.

Improved land use systems

Crop rotation/Intercropping: Legumes have long been recognized as an important component of cropping systems in the tropics and intercropping of grain legumes with cereal crops is a common feature. The crop combinations and planting arrangements are infinitely variable and range from mixed cropping, in which many species are sown randomly in a field, to more strict row or strip intercropping (Francis, 1986). Although intercrops can produce greater yields than sole cropping, they generally do so by extracting more nutrients from the soil than sole crops (Dalal, 1974; Mason *et al*., 1986) and may therefore cause more rapid decline in soil fertility. Cereal/legume rotations rather than monocropping have been suggested as an effective means to increase soil productivity. In addition to improving soil physical and chemical properties, legume-based rotations may also decrease pest and disease incidence and addition of growth promoting substances (Giller, 2001).

Although the potential of legumes in improving soil fertility is clear, the actual contributions to many cropping systems are surprisingly variable. Yields of maize grown after soybean on an Alfisol were increased from 2.5 to 4.0 t ha^{-1}, compared with only 1.8 t ha^{-1} in continuous cropping, where all the legume stover had been removed (Kasasa *et al*., 1999). Similarly, Carsky, *et al*. (1997) recorded increased maize yield in the Guinea savanna of West Africa following soybean cultivation with post-soybean 20 kg N ha^{-1} (Table 5) while Bala *et al*. (2003) recorded maize grain yield of only 600 kg ha^{-1} with post-soybean 40 kg N ha^{-1} application when all aboveground residues, except litter falling from leaves before harvest were exported from the fields following the present farmer practice. When the area of land sown to legumes is taken into account, estimate for inputs from N_2-fixation come to less than 5 kg N ha^{-1} $year^{-1}$ for cropped land in most cases (Giller *et al*., 2000). Thus the amounts of organic residues available in most cropping systems limit their role in maintaining soil fertility.

Table 5: Effect of 1993 maize or soybean on 1994 maize grain dry matter yield (kg ha^{-1}) at 10 locations in the Northern (1to 5) and southern (6 to 10) Guinea savanna of Nigeria

	Maize yield following previous crop		
Location	Maize	Early soybean	Late soybean
1	3440	4080	5850
2	1720	3380	3440
3	4320	3790	4100
4	2230	2730	2950
5	1930	1910	1860
NGSN mean	2730	3180	3640
6	1790	2960	3910
7	1120	1340	1900
8	2680	3240	5580
9	2620	3910	4020
10	1670	1560	2010
SGSN mean	1980	2600	3480

Adapted from Carsky *et al.* (1997); NGSN = Northern Guinea Savanna of Nigeria, SGSN = Southern Guinea Savanna of Nigeria

Green manures: In contrast to the economic role of grain legumes, a green manure legume is grown wholly for use as a source of organic manure for a subsequent crop. This obviously maximizes the amount of N from the legume available for the next crop. Green manure legumes usually contain adequate N to promote mineralization shortly after soil incorporation. Examples are Crotolaria, Mucuna and Sesbania species, where research has indicated that over 100 kg N ha^{-1} was accumulated in the above-ground plant parts under favourable soil and climatic conditions (Giller and Wilson, 1991). Juo and Kang (1989), assessed the performance of Mucuna and Pueraria as green manures in rotation with maize and found that maize yields were maintained at 2-3 t ha^{-1} over at least 10 years without fertilizer application. Although it has been consistently demonstrated that soil fertility and crop yield could be effectively maintained in this way (Carsky *et al*., 1999), its acceptance by the peasant farmers was hampered by the tedium of land preparation with native hoes and the economics of the practice. It was not an easy problem convincing a farmer to adopt a system that includes unproductive fallow.

Organic sources of nutrients: Organic resources not only supply many nutrients for crop production including micronutrients but are also a valuable source of Soil Organic Matter (SOM). Increasing the SOM content improves soil structure or tilth, increases the water

Table 6: Effects of farm yard manure and single superphosphate on sorghum grain yields

Years	Treatments A	B	C
Sorghum grain yield (kg ha^{-1})			
1958	1110	1901	1639
1959	1430	1371	1830
1960	2082	1542	2371
1961	1869	1799	1852
1962	1200	1177	1748
1963	1217	1300	1669
1964	2166	2162	1650
1965	1577	1242	2000
1966	1770	1971	2130
1967	2584	2073	3023
1968	2254	1623	2663
Mean	1457	2077	1788

Adapted from Tarfa and Iwuafor (2002); A = 2.5 t ha^{-1} FYM, B = 62.5 kg ha^{-1} SSP, C = 7.5 t ha^{-1} FYM

holding capacity of coarse-textured sandy soils, improves drainage in fine-textured clay soils, provides a source of slow release nutrients, reduces wind and water erosion and promotes growth of earthworms and other beneficial organisms. SOM also contributes to greater efficiency of fertilizer use (Dudal and Roy, 1995; Rosen, 2003). The various organic sources of plant nutrients in Nigeria are not discussed in this paper. A comprehensive literature on this subject is available (Karikari and Yayock, 1987; Tarfa and Iwuafor, 2002). Significantly high crop yields were obtained in both short and long-term with the application of increasing rate of farmyard manure. The yield obtained was similar to that obtained with the application of inorganic fertilizer (Table 6). The organic component of the mixture may give additional benefits in the longer term.

Mineral soil amendments

Phosphate rock: Next to N, P is the most limiting nutrient to crop production in Northern Nigeria. However, the region is endowed with deposits of Phosphate Rock (PR) which can serve both a sustainability goal (restoring the P stock of the soils) and a productive goal (immediate yield increases). A lot of research has been conducted within the West African sub-region to devise ways of using this natural resource with maximum efficiency and at minimum cost, for the benefit of resource-poor farmers. The use of PR for direct application has been subject to much controversy (Khasawneh and Doll, 1978). Greenhouse and field studies in several locations in Northern Nigeria showed that Crystalizer Super Fertilizer (Blend of Sokoto PR + Magnesite) could be a viable alternative to the soluble P fertilizers (Yusuf *et al*., 2003). The main disadvantages of directly applied PR are lack of immediate agronomic value on non-acid soils and difficulties in handling and transporting. Despite these disadvantages, it is believed that direct application of PR is an important part of an integrated natural resource management strategy, as the fundamental factors affecting the agronomic efficiencies of this natural resource become well understood (Lyasse *et al*., 2002). Research at IITA showed that certain herbaceous or grain legumes are able to utilize P from PR due to rhizosphere processes enhancing the P availability (Lyasse *et al*., 2002). The replenishment of soil P through PR in combination with judicious field management practices to overcome other nutrient limitations and crop growth constraints, would provide benefits of increased crop production and income to farmers, as well as certain environmental benefits (Izac, 1997).

Mineral fertilizers

History of fertilizer use in Northern Nigeria: The first indication on the potential value of mineral fertilizers in Northern Nigeria was given by Hartley (1937) who reported the response of cereals to small application of farmyard manure and showed that these responses were very well matched by the responses to application of super phosphate containing quantities of phosphate equivalent to that in the farmyard manure. This work continued until 1939, when he showed that aside from cereals, groundnuts also gave good responses to application of super phosphate in the former Kano and Katsina provinces (now Kano, Jigawa and Kastina States). The scope of fertilizer investigations expanded from 1952 onward to cover all the major crops in the region. Early trials undertaken indicated economic responses to only N and P (Greenwood, 1951; Obi, 1959), therefore most fertilizer programmes in the region have been confined to these two main limiting nutrients. In 1962 -3, areas of different responses were identified with the Northern part delineated as areas of high response to P while the Southern part was observed to show high response to N. Continuous cultivation and introduction of high yielding varieties have led to accelerated exploitation of the soil so that, potassium which was hitherto considered adequately supplied in the soils has also become a problem. In 1965, requirements of N and P were passed to the Ministry of Agriculture and the use of compound fertilizers was recommended. Some evidence of deficiencies of boron, Zn and manganese have recently been reported, with indications that the deficiencies will spread rather quickly with intensive and continuous cropping (Chude, 1998).

In nutrient terms, fertilizer consumption decreased consistently between 1995 and 2000 following sudden disengagement of government from fertilizer importation under the liberalization policy (Fig. 1). This scenario lasted till 1999 when government restored fertilizer subsidy at 25% under market stabilization programme. From year 2000, however, there had been a noticeable upward trend in fertilizer consumption to date.

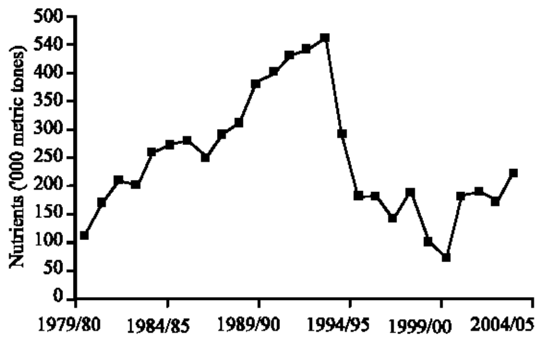

Fig. 1: Trend in fertilizer consumption from 1979/80-2004/05. Source: Federal Fertilizer Department, FMARD, Abuja

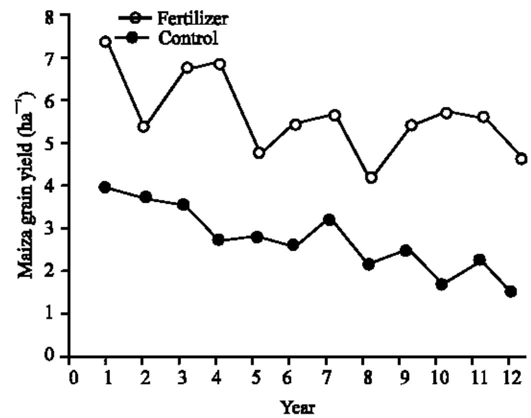

Fig. 2: Effect of nutrient inputs on maize yield in a maize-cowpea rotation on a Nigerian Alfisol. Adequate rates of N, P, K, Mg, S and Zn were applied to each maize crop. Cowpeas received no fertilizer (Adapted from Smaling, 1993)

Crop response to mineral fertilizer in Northern Nigeria: The effect of fertilizers on crop yield can only be understood fully by studying the results of field experiments that test increasing dressing of each nutrient and also show how the nutrient use together interact to build up yield (Mokwunye, 1990). In a 3^3 factorial experiment using N at 0, 90 and 180 kg ha^{-1} and 0, 45 and 90 kg ha^{-1} each of P and K, a mean grain yield of 4059 kg ha^{-1} for all the 27 treatment combinations was obtained in the Northern Guinea savanna of Nigeria (Yusuf, 2003). Yield increases of 94.8 and 179.3% were obtained at 90 and 180 kg N ha^{-1}, respectively. Yaro *et al.* (2003) also observed increase in maize yield with application of mineral fertilizer. Goldsworthy (1967) reported that 18 kg P_2O_5 ha^{-1} and 26 kg N ha^{-1} were most economic rates of phosphate and nitrogen fertilizers respectively for sorghum in the Nigerian savanna. Heathcote (1972) has also reported significant responses of maize to K at Mokwa. These results were obtained from short-term trials. However, in long-term trials, yields generally decreased after several years despite fertilizer application (Fig. 2). The limiting factors might be other nutrients not included in the fertilizer formulation (e.g., micronutrients), distortion in soil physical, chemical and biological conditions. In addition to yield decrease, continuous cropping and fertilization with inorganic fertilizers have impaired many soil properties in the Nigerian savanna. Reduced cation exchange capacity, exchangeable cations and upset in the cationic balance have been reported by Agbenin and Goladi (1997). For farmers to maintain high yields and improve soil fertility under intensive, continuous cultivation, they have to rely on alternative sources of nutrients that will be affordable, accessible, sourced locally or generated within the farm.

Integrated nutrient management; combined use of organic and mineral fertilizers: In recent years, the focus of soil fertility research has been shifted towards the combined application of organic resources and fertilizers as a way to arrest the ongoing soil fertility decline in sub-Saharan Africa (Vanlauwe *et al*., 2001). This is simply because experience has shown that the most rewarding benefits occur when different technologies are combined. When applying organic resources and mineral fertilizer simultaneously, one hardly ever observes negative interactions, indicating that even without clearly understanding the mechanisms underlying positive interactions, applying organic resources in combination with mineral inputs stands as an appropriate fertility management principle. Several authors working in Northern Nigeria have demonstrated the benefits of complementary use of mineral fertilizers and manures (Yaro *et al*., 2003; Yusuf *et al*., 2003; Tarfa *et al*., 2001). Jones (1971) in Samaru, found that, in the absence of fertilizers, it required at least the application of 7.5 t ha^{-1} of manure to measure an increase in soil C and N. When fertilizers were added, the manure rate dropped to 5.0 t ha^{-1}. In the same location, Hartley (1937) observed no significant difference in seed cotton and sorghum grain yield with the application of fertilizer and 2.25 t FYM ha^{-1} compared to double the rate of the fertilizer. Recently, Iwuafor *et al.* (2002) reported a similar trend in maize yield on farmer-managed demonstration trials in the NGS of Nigeria (Table 7). An ideal combination of organic and mineral fertilizers does not exist. The optimum combination depends on the targets and the situation of the particular farm. The major constraint to use of FYM is the large quantities required to satisfy crop need. For example, 100 kg of 10-0-10

Table 7: Maize grain yield in farmer-managed demonstration trials in the Northern Guinea savanna of Nigeria

Treatments	Grain yield (kg ha^{-1})
Farmers' practice	1600
NPK 145:45:45 (SG 2000 recommended practice)	2350
6.0 t ha^{-1} organic manure + NPK 86:20:20	2400

fertilizer contains about the same amount of N-P-K as 2,000 kg of FYM. Thus FYM needs to be applied at very high rates to make up for their low nutrient content and to supply enough humus to improve the soil physical condition. Even then, availability of the nutrients to plants depends on the handling method used to conserve and store the manure before field application. Tremendous nutrient losses due to volatilization and leaching are encountered during storage and application if FYM are not properly handled. The targets refer to the levels of SOM and yield that are attainable within the managerial and economical constraints of the farm (Janssen, 1993).

The way forward: Integrated soil fertility management: Despite diversity of approaches and solutions and the investment of time and resources by a wide range of institutions as enumerated above, soil fertility degradation continues to prove to be a substantially intransigent problem and as the single most important constraint to food security in the African continent (Sanchez and Leakey, 1997). Return to investment in soil fertility has not been commensurate to research outputs (AHI, 1997). Farmers are only likely to adopt sound soil management if they are assured of return on their investment. Integrated Soil Fertility Management (ISFM) is now regarded as a strategy that helps low resource endowed farmers mitigate many problems and the characteristics of poverty and food insecurity by improving the quantity and quality of food, income and resilience of soil productive capacity (Kimani *et al*., 2001).

ISFM is the adoption of a systematic conscious participatory and broad knowledge intensive holistic approach to research on soil fertility that embraces the full range of driving factors and consequences such as biological, physical, chemical, social, economic and political aspects of soil fertility degradation. The approach advocates for among others, careful management of soil fertility aspects that optimize production potentials through incorporation of a wide range of adoptable soil management principles, practices and options productive and sustainable agro-ecosystems. This approach is being tested in a joint project between the Institute for Agricultural Research Samaru, Nigeria and the International Fertilizer Development Centre (IFDC-Africa Division) in some selected villages in Northern Nigeria. The project which started in the year 2000 with less than 100 farmers in 6 farmers' groups now has a membership of over 3000 with 50 registered farmers' associations. The technology being used involves application of PR on the acid soils of the project site coupled with adoption of improved crop planting pattern of soybean/maize or soybean/sorghum in ratio 4:2. This was compared with Farmers Practice (FP) of intercropping soybean with maize or sorghum. The crops are rotated in the following year thus providing two crops for the farmers in the same year and residual N and other rotation benefits are utilized in the following year. In the second year of the project crop residues are either incorporated in the field or fed to livestock and the manure is returned to the field. Average maize grain yield obtained from the initial six participating farmers' groups is presented in Fig. 3. The farmers have been linked to agro-processing companies and other government agencies who buy surplus of their produce at prices relatively above the current market price. The paradigm embraces the full range of multiple purpose options (MPOs) and driving factors and consequences of soil degradation in different farming systems and land types.

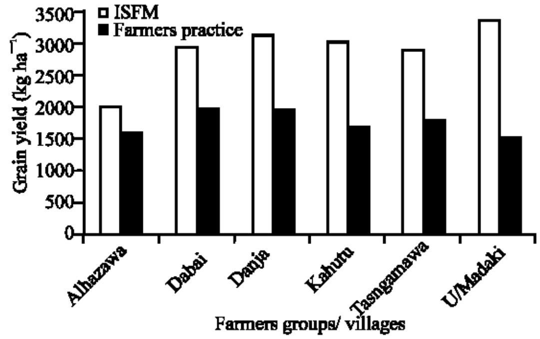

Fig. 3: Average maize grain yield obtained from six participating farmers' groups in the ISFM project (see text for treatments details)

CONCLUSIONS

This research has demonstrated that a wide range of technologies is available for soil fertility improvement in Northern Nigeria. However, wide scale adoption of these technologies has been hampered by unfavourable socio-economic and political conditions. The lack of economic motivation, the scarcity of markets to sell a surplus and the paucity of credit facilities have been major constraints to improved soil fertility in Northern Nigeria. There is no comprehensive, integrated rural development programme that looks at the entire farm as a system comprising other subsystems. Most of the recommendations are plot-based and do not consider within farm variability. A complete redress of soil fertility decline in Northern Nigeria cannot be achieved without commitments from State and National governments. Government should articulate the views and concerns of all stakeholders; identify gaps in knowledge and information and outline processes to fill them. The ISFM is a new research approach that seeks to overcome the shortcomings of the past conventional approaches. It links the development of resource conserving technologies, support to institutions and farmer groups and provision of enabling policy environment for agricultural investment. The approach advocates for participatory farmers research; a holistic approach to address many and complex farming systems problems so as to achieve wide validity and adoption of agro-ecosystems that operate with dynamic natural and economic environment.

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