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Intensification of Agriculture in Semi-Arid Areas:
Lessons from the Kano Close-Settled Zone, Nigeria

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This Gatekeeper Series is produced by the International Institute for Environment and Development to highlight key topics in the field of sustainable agriculture. Each paper reviews a selected issue of contemporary importance and draws preliminary conclusions of relevance to development activities. References are provided to important sources and background material.

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EXECUTIVE SUMMARY

The Kano Close-Settled zone (CSZ) has been the site of an intensive farming system for many years, and for the last 30 years at least, all available land has been under annual cultivation. Observers have wondered at the apparent sustainability of this farming system. This paper presents the results of a two year case study into soil fertility management by three farmers within the Kano CSZ. Fertilizer use (inorganic and manure), harmattan dust deposition, and biological nitrogen fixation by leguminous crops were quantified at the field level. Chemical analysis of the main inputs to the farming system and harvested products enabled a nutrient balance for the farming system to be calculated. The balance varied according to farmers' management of individual fields, especially application of traditional and inorganic fertilizers, and the effect of rainfall on the size of the harvest, which is the main determinant of nutrient removal from fields.

The results were used to develop a model of nutrient cycling within the farming system. The key to the farming system is the integration of crop and livestock production. Small ruminants consume crop residues, in particular those of groundnuts and cowpeas, which are good quality fodder. The fixed nitrogen in the residues of leguminous crops is converted to manure, which is transported with compound waste back to farmers' fields for use as fertilizer. Legume grains are sold, earning cash which farmers may use to purchase inorganic fertilizer if they wish. Cations and micronutrients are added to the system when harmattan dust is deposited on farmers' fields during the dry season.

This study shows that despite being one of the most densely populated areas in semi-arid West Africa, such an intensive farming system can be both productive and sustainable. Analysis of the conditions specific to this system found that the key elements for its success included high labour availability, plentiful livestock, and recycling of nutrients through the use of crop residues as livestock fodder.

These findings contrast with those of other workers who suggest that such intensive farming over a long period is not possible in similar parts of West Africa, without large areas of rangeland to support the system. The author demonstrates how increasing population densities and labour availability contribute to the processes necessary to support sustainable agricultural intensification, such as the increasing use of crop residues to feed livestock, and the eventual shift to full crop-livestock integration. In conclusion, the author recommends that the sustainability of such intensive systems can be further supported through promoting legume cultivation and the keeping of small ruminants.

INTENSIFICATION OF AGRICULTURE IN SEMI-ARID AREAS:

LESSONS FROM THE KANO CLOSE-SETTLED ZONE, NIGERIA

Frances Harris

Introduction

Semi-arid West Africa has been the focus of much debate on whether agriculture will be able to support its increasing population without damaging the environment. Many people are concerned that the traditional farming systems which involve fallowing and little or no use of external inputs of nutrients will not be able to continue under frequent or continuous cropping. This debate has centred on the sustainability of farming practices in the light of competition for use of resources between farmers and herders. To increase yields farmers may either increase the area under cultivation or cultivate existing areas of farmland more frequently. It is feared that overuse of land will lead to land degradation. Indeed, reports of "soil mining" are increasing (Smaling, 1993; van der Pol, 1992).

Despite these concerns, however, the intensively cultivated area of the Kano close-settled zone (CSZ) in northern Nigeria has supported intensive cultivation for many years, without suffering from land degradation (Mortimore et al., 1990). To investigate how and why this is the case, a detailed investigation of nutrient dynamics within the farming system of the Kano CSZ was carried out. This paper outlines the findings, and assesses what lessons can be learned from this example of an intensive farming system. In determining how a supposedly sustainable farming system works, we can understand how the dynamics of farming systems are likely to change as population density increases, and how sustainable intensification can be supported.

The Kano Close-Settled Zone

The Kano CSZ lies within the sudan savanna, and supports a rural population density of 250 - 500 people/km2 (Mortimore, 1993). The population of the Kano CSZ is estimated to be 2 million (National Population Bureau, 1991). Of these, an unknown percentage is urban or non-farming, possibly up to 30%. Mean annual rainfall (1906 - 1985) is 822 mm at Kano, which falls in a five month rainy season (May - September). Rainfall is variable, 560 mm fell in 1993, yet 895 mm fell in 1994. Farming intensity on rainfed upland soils reached 78% of land in 1950 and rose to 86% of land in 1971 (Turner, B. 1994), since when it has not increased, as the remaining land is occupied by villages, roads, cattle tracks and lowland or fadama.

The farming system of the Kano CSZ is based on the production of crops, livestock and tree products. Farmers cultivate four main crops - millet, sorghum, groundnut and cowpea - in a variety of intercropping patterns. Subsidiary crops include cassava, maize, sesame and peppers. Fields are divided by hedgerows of henna (*Lawsonia inermis*) or grass (*Andropogon gayanus* and *Vetiveria nigritans*) which are also harvested. Farmers protect trees which are grown in their fields and yield fruit, edible leaves and silk cotton, as well as firewood. This practice gives rise to the landscape known as farmed parkland. Farmers also keep small ruminants and fowl in their compounds.

The high land use intensity means that there is virtually no grazing land available during the rainy season, so farmers keep their livestock tethered in their compounds during this time, and feed them on crop residues stored from the preceding year, as well as weeds and grass collected and brought to them. As there is high demand for livestock fodder, farmers collect all crop residues and store them to feed their own livestock. Only stubble is left in the fields. The residues of legumes are particularly good quality fodder. Oxen and donkeys used for traction are also fed in this way. During the dry season livestock roam the fields to graze on stubble, but return to the compounds at night. Little manure is left in the fields while animals graze (see Annex A), but there is a build up of manure in the compound which can be used to fertilize fields the following season. Farmers transport this manure to their fields by donkey, or occasionally by headload. Application of manure is rotated around fields, with most fields receiving manure every two to three years. In addition to animal manure, most farmers use inorganic fertilizer on some of their fields, and legumes contribute nitrogen to the farming system. During the dry season the harmattan wind brings nutrient-rich dust which settles on the land (McTainsh and Walker, 1982).

Methodology

The aim of the research was to learn whether farmers had developed a sustainable farming system, and if so, how. The research was carried out in a hamlet (Gamji Tara) of the village of Tumbau. This village is composed of a rural farming community, and is located approximately 30 km east of Kano, about 10 km from any tarred road, and further still from the main road. Thus it is not under the direct influence of the markets and businesses of Kano city. Gamji Tara contains approximately 20 households, and the main economic activity is farming. Low-lying grey hydromorphic soils known as fadama land are located about 5 km away, but do not interest many of the households. A small market on Friday morning in Tumbau trades locally made products and foodstuffs.

It was decided that the research should focus in detail on three farmers, as the detailed sampling and analytical work required to determine reliably the major nutrient movements within the system for a larger number of farmers would have been impossible. The farmers were selected after interviews with many of the farmers in the village. Their landholdings vary according to size and distribution of fields (Table 1), and encompass the range of land ownership conditions found in the village. The amount of cultivated land per capita in the Local Government Area (Gezawa) at the time of the 1991 census was close to that found in the three farming households of this study, i.e., over 80% of the area is cultivated (Mortimore, pers. comm..)

Fieldwork consisted mostly of observation of farmers' practices[1]. Monitoring at the farm level permitted detailed measurements to be made, and related to the circumstances of the individual farmers. Each farmer's land was surveyed to measure field and landholding size, and soil samples were taken. Previous planting and fertilization practices were discussed, as well as past yields, animal ownership and family size (Table 1). Locally, farmers distinguish between a red soil, a white soil and a yellow soil. Superficial soil samples do not differ significantly, and the topsoil (0-15 cm) of all three soil types is approximately 80% sand, with low amounts of nitrogen, organic carbon and phosphorus. Differences are much more apparent at depth, where red soils have coarser texture.

The various pathways of nutrient cycling in this farming system were quantified by monitoring farming practices and chemical analysis of nutrient additions and removals from the system for the 1993 and 1994 growing seasons and the intervening dry season (Harris, F.M.A. and Bache, B.W., 1995). More details of the methodological approach can be found in Annex A.

Farmers' landholdings consist of several fields (Table 1). Observation and monitoring was done on a field-by-field basis. Inputs, outputs and yields were determined for the whole of each field, and later combined to give a picture of the entire landholding. Boundary and hedgerow crops are important components of the farming system, and so were included in the monitoring.

The data was used to calculate a nutrient balance to understand whether the system is losing or gaining nutrients, or remaining stable. The balance was calculated as kg of nutrients gained or lost on a landholding basis, and then converted to a standard area basis (kg per hectare).

Understanding the Nutrient Cycle

The results of monitoring the farming practices of three farmers over two seasons, and quantifying nutrient inputs and outputs from landholdings, showed that:

- farmers applied a mean of 4.3 t/ha manure to landholdings (average from 1993 and 1994), with application on individual fields ranging from 0 to 14 t/ha in 1993 and 0-17.5 t/ha in 1994;
- farmers use small amounts of inorganic fertilizer annually, providing approximately 7.5 kg N/ha, 1.6kg P/ha and 2.23 kg K/ha;

1. A separate research project entitled "Soils, cultivars and livelihoods in north-east Nigeria ", carried out by the University of Cambridge, and Bayero University, Kano has been investigating agropastoral strategies within this village since 1992, collecting information on crop varieties, natural vegetation, farming practices and land tenure in the hamlet of Gamji Tara. During the rainy season of 1994 they monitored the daily activities of all members of 12 households. The data they gathered has contributed to the labour data in this study, and was used with the permission of Michael Mortimore.

Table 1. Summary of Farmers' Characteristics

	Malam Isiyaku		*Malam Yahuza*		*Malam Sani*	
	1993	1994	1993	1994	1993	1994
Domestic statistics						
Farm size *(hectares)*	1.4	1.1	3	3	0.66	0.66
Number of fields	3	*3*	4	4	5	5
Location of fields	near compound		3 near, 1 far		widely dispersed	
Predominant soil type	red	red	white	white	yellow	yellow
Family size	4	4	9	11	2	2
Family labour *pool(man-equivalents')*	1.7	1.7	6.4	7.1	1.7	1.7
Family labour per hectare	1.2	1.2	2.1	2.3	2.6	2.6
Grain requirement *(kg) (200kg/person)*	800	800	1800	2200	400	400
Excess grain *(kg/ha)*	229	609	104	123	8	564
G'nut and cowpea production *(kg/ha)*	235	262	277	172	58	627
Inputs						
Field labour *(man days/ha)*	97		92		92	
Taki application *(t/ha)*	3.9	5.3	3.2	5.1	4.5	4
Nitrogen fixation *(kgN/ha)*	10.55	16.4	11.1	25.39	5.89	20.25
Inorganic fertilizer application *(kg/ha)*	63	62	27	32	0	36
Outputs						
Total harvest *(t/ha dm)*	5	9.3	3.5	5.2	3.2	6.2
Sold crops *(kg/ha)*	861	1399	717	608	153	1372
Nutrient balance						
Nitrogen balance *(kg/ha)*	-5.5	-21.6	-10.6	2.5	0.6	-28.2
Phosphorus balance *(kg/ha)*	2.4	-3.4	1	2.9	0.2	-3

***Labour Weightings**			
Adult male	1	Adult female	0.7
Aged male > 65 years	0.7	Aged female > 65 years	0.5
Young male C. 9-14	0.7	Young female c.9-1 4	0.5
Male child	0.3	Female child	0.3
Infant	0		

- nitrogen fixation by legumes contributes approximately 15 kg N/ha (range 0-37kg N/ha) depending on the specific cropping pattern and density of legume plants in the field;

- farmers achieve mean yields of 1 t/ha cereal grain;

- farmers produced sufficient cereal grain to meet their family's food requirement, with a mean surplus of 273 kg/ha;

- farmers achieve mean yields of 280 kg/ha of legume grain (cowpea and groundnut); and

- farmers harvest a mean of 1.8 t/ha of fodder from their farmland, made up of legume residues, other palatable crop residues and some weeds.

Manure use was comparable with that reported in other areas of the Kano CSZ (Mortimore et al., 1990), but probably higher than that in less intensively farmed regions. Millet and sorghum grain yields are typical of smallholder farmers (Landon, 1991), but the yields of groundnut and cowpea were low. This is believed to be due to the fact that the production of the legume crops is secondary to that of the cereals (Mortimore et al., in press). Nitrogen fixation was lower than that reported elsewhere (Giller and Wilson, 1992), probably because legumes were intercropped with cereal grains, and there was no inoculation with rhizobia.

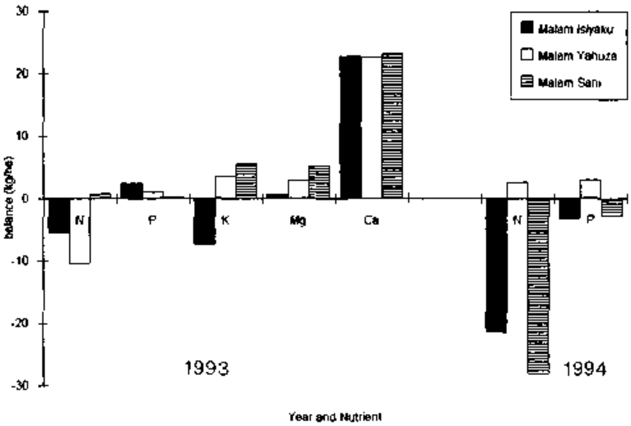
Determining the Sustainability of the Farming System

The results were used to calculate the nutrient balance for each farmer's landholding (Figure 1). The data indicated that the cation nutrients K, Ca and Mg were unlikely to be limiting, so during 1994 work concentrated on nitrogen and phosphorus only. The farmers' nutrient balances vary from field to field, depending on fertilization practices and crop rotations. This is to be expected, as farmers rotate the application of manure or use of inorganic fertilizer across fields over several years. Planting a legume crop ensures a large nutrient input to that field through nitrogen fixation.

Year to year variability of inputs is high, especially as the methodology used does not take into account the residual effect of manure application that may last up to three years, and that fixed nitrogen in legume roots will be released into the soil after the roots decay. Year to year variability of nutrient outputs depends on rainfall and its effect on the size of harvest. Yields and rainfall also affect nutrient inputs for the following year as they control fodder supply and so manure availability for the following years. In addition to variability, factors such as the role of trees in nutrient cycling, non-symbiotic nitrogen fixation, denitrification, volatilization of nitrogen from inorganic fertilizer application have not been measured. These have not been included because of the difficulty of obtaining accurate field data on these gains and losses. However they are likely to be small in the context of this farming system.

Sustainability is determined by the balance of nutrients over time. The quantification of the

Figure 1. Nutrient Balance of Landholdings (Kg/ha)



nutrient flows on the three landholdings has shown that there is considerable variability both from field to field and from year to year. However, in the longer term the differences will balance (Box 1). The sustained use of farmland in the Kano CSZ, without evidence of land degradation or declining yields, confirms that nutrient inputs and outputs must be balanced over the long term.

Box 1. Balancing Yields and Nutrients

Malam Sani owns five small fields, totalling only 0.66 ha. These are widely dispersed, some very far from the village. He does not own a donkey and therefore usually carries things to and from his fields by headload. He borrowed a donkey to transport manure to his fields in 1993 and 1994. In each year most of that manure was taken to one of the fields which was closest to his home. Fields further away received less manure, and the furthest field received none.

When asked why he repeatedly concentrated his efforts on one field, he replied that he always put lots of manure on this field, always planted sorghum, and always got good yields. While digging soil pits at the end of the 1993 season it became apparent that this field lies over an impermeable pan of clay which retains soil moisture. This makes this field very suitable for growing sorghum, a crop which matures after the rains have finished, relying on residual soil moisture.

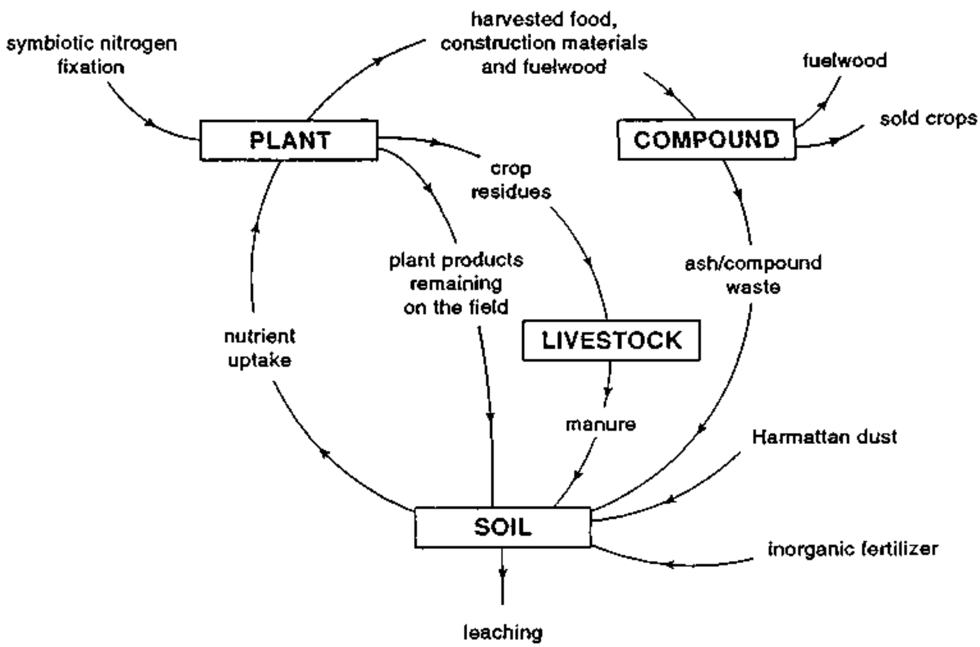
In 1993, when rainfall was 560 mm, this field yielded 464 kg/ha of sorghum grain, and 322 kg/ha of sorghum stalks. However, in 1994 the higher rainfall allowed Malam Sani to harvest 3 t/ha of sorghum grain, and 4.2 t/ha of sorghum stalks from this field. The grain stalks contained 12 kg of nitrogen. This contributed to his negative nitrogen balance (Figure 1). This bumper harvest of sorghum was the result of circumstances - good rain and a field suited to take advantage of it. This is probably an unusual occurrence, and so the nutrient balance of Malam Sani's land was unusually low that year.

Yields fluctuate from year to year, and in years of low rainfall and low yields there is probably an accumulation of nutrients in the soil, which is reduced in good years. Over a long period of time, nutrient gains and deficits may even out.

Nutrient Dynamics of the Farming System

Despite the small scale of this study the results provide a detailed understanding of nutrient dynamics within the farming system. The data from monitoring farmers' practices, combined with the chemical analysis, were developed into a nutrient cycling diagram, as shown in Figure 2. The results indicate the magnitude of nutrient transfers (for details see Harris, F.M.A. and Bache, B. W., 1995), and suggest how different practices may affect nutrient pathways. This was discussed with farmers to identify constraints to the farming system.

Figure 2. Nutrient Cycling in the Kano Close-Settled Zone



Farmers recycle nutrients through the farming system as efficiently as possible. Several important factors are:

- *legume crops*, which fix nitrogen, provide high protein animal fodder, and whose grain can be sold. Legumes are intercropped between the cereals.
- *small ruminant livestock*, who convert crop residues into manure, which is more readily incorporated into the soil.
- *manure*, applied in large amounts to fertilize the soil and improve the physical properties of these sandy soils, especially the water-holding and cation exchange capacity.

- *labour*, required to harvest crop residues as well as grain, for weeding and for transporting the manure back to the fields. Land scarcity has been compensated for through the use of more labour intensive farming practices, made possible by the high labour / land ratio.
- *harmattan wind*, which bears dust containing cations (especially K, Mg and Ca) and micronutrients to the area.

The key to the success of the farming system is crop-livestock integration, which allows farmers to manage an efficient nutrient recycling system centred around small ruminants, who convert the nitrogen fixed by legumes into manure when legume crop residues are used as fodder. This involves high labour inputs by farmers, who must keep animals tethered within the compound during the rainy season, and collect crop residues and weeds for fodder, then transport their manure back to the fields.

Other characteristics of the Kano CSZ which have been important in the development of the farming system include:

- *high population density*, which provides labour and a source of agricultural innovation;
- *high livestock density* - the Kano CSZ supports remarkably high population densities of small ruminants and donkeys, first noticed by Hendy (1977), and more recently by Bourn and Wint (1994);
- *land tenure* - farmers in the Kano CSZ have usufruct rights over the land they farm;
- *dispersed settlement patterns* - farmers live relatively close to their fields, so that time taken to reach fields, and transportation of crop residues and manure between fields and the compound, is relatively easier than in other areas of West Africa;
- *absence of compound gardens* - in other areas farmers often use the majority of compound waste and manure in small gardens near the compound. Farmers in the Kano CSZ do not do this, instead they distribute all of the compound waste and manure on their fields;
- *investment in oxen, ploughs and cultivators* by a few farmers has been viable because they hire out the ploughing and cultivation service to other farmers. Were too many farmers to do this, there would be insufficient business to make the investment profitable. Ox-carts, while useful, are not as popular as in more rural areas, due to the fact that this farming system is not remote;
- *diversity in the farming system* - farmers engage in crop production, livestock production and tree production, so diversifying income sources. Many also practise non-farming economic activities, especially during the long dry season. This diversity allows them to cope with risks, whether environmental (eg drought) or economic (eg price fluctuations);
- *low dependency on external inputs* which permits farmers to be independent of the fluctuations in the economy, and the effect of inflation. Farmers use little inorganic fertilizer, and maintain seed lines of favoured indigenous cultivars, rather than using seed of commercially supplied high yielding varieties.

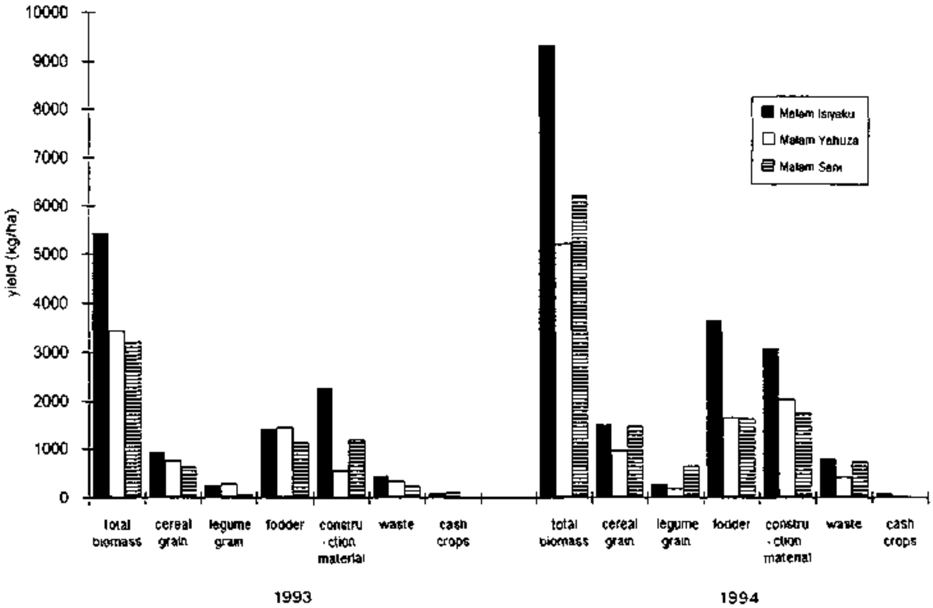
Constraints to Production

This study of three smallholders has also highlighted considerable differences between these farmers, as well as the major constraints they face. Understanding the reasons for these differences and constraints will help remove some of the bottlenecks to increased production.

The data on nutrient balances and nutrient dynamics have been presented with little reference to the farmers themselves. However, the advantage of a case study is that the circumstances surrounding each farmer can be considered and related to the data on nutrient cycling. The farmer is central to the farming system: he is the manager of nutrient inputs, of the harvest, and of labour.

Each farmer operates under slightly different conditions, in terms of the characteristics of his fields (location, drainage), labour availability, technology, and his own skill as a farmer. Thus their lives are moulded by the land and knowledge they inherit, their own abilities to make the most of the resources available to them, and an element of chance. Farmers' ability to control nutrient cycling and so maximise soil productivity can be compared when harvest yields are calculated on a per hectare basis (Figure 3).

Figure 3. Farmers' Yields from Landholdings (Kg/ha dm)



In the Kano CSZ, labour contributes to the ability of a farmer to recycle nutrients in legume residues through livestock and back to the field as manure. Family size determines the size of the labour pool. If it is insufficient, the farmers need to pay hired labour if they are to cultivate all of their land (Box 2). Timeliness of planting and weeding operations is important to maximise yields. Farmers can reduce the manual labour needed by paying for ploughing or cultivating. In order to afford this, farmers must produce sufficient grain to be able to sell some to raise cash, or rely on alternative sources of income (non-farming economic opportunities).

Box 2. The Dynamics of Yields and Labour

If efficiency is defined as the ability to gain the highest yields from the land available, then Malam Isiyaku was the most efficient in 1993 in terms of production per hectare. He achieved the highest yields of cereal grain each year. Malam Yahuza and Malam Sani saw very different yields in each of the two years. The reasons for their varying efficiencies may be due to their relative abilities to invest in technologies that will increase their yields.

Malam Isiyaku consistently produced and sold more food than Malam Yahuza and Malam Sani (Figure 4). The ratio of family labour to land area is lowest for Malam Isiyaku, being about half that for Malam Yahuza and Malam Sani. Yet Malam Isiyaku's land receives slightly more labour than the others. In order to achieve this, he hires labourers. To raise money to pay for labourers and ploughing Malam Isiyaku must produce sufficient yields to allow him to sell in the market.

If Malam Isiyaku had a larger family, he could reduce the costs of labour inputs by using family labour rather than hired labour. He would have less need to produce such high yields. Perhaps as his son gets older he will be able to ease the labour constraint faced by his father.

Manure and inorganic fertiliser are used to maintain yields. Farmers keep small ruminants to convert the crop residues to manure, so ensuring that the nutrients are recycled to their own fields. Farmers complain that it is difficult for them to collect all the crop residues from the field before the village livestock are released to roam the fields (by general agreement all the village livestock are released shortly after the harvest). Transporting crops and residues to the compound and manure to the fields is easier and faster if the farmer has a donkey or ox-cart. This affects nutrient recycling and soil fertility conservation.

Money is acquired through the sale of grain surplus to the family's needs. However, farmers often have to sell more grain than they would like to meet the family's financial needs, at times selling grain required for the household food supply. If farmers could delay selling grain until later in the dry season, when prices are higher, they could receive a greater profit from their farming labour. Legume grain is sold soon after harvest, because of the risk of damage by insects if stored for longer. Some farmers sell grain to pay off bills incurred during the farming season, and then have to buy in grain later in the season, when the price is higher. A grain bank which would allow farmers to store grain legumes, and to sell grain to pay off debts from the farming season without the risk of prices soaring before the dry season would be beneficial to farmers.

Labour and Intensification

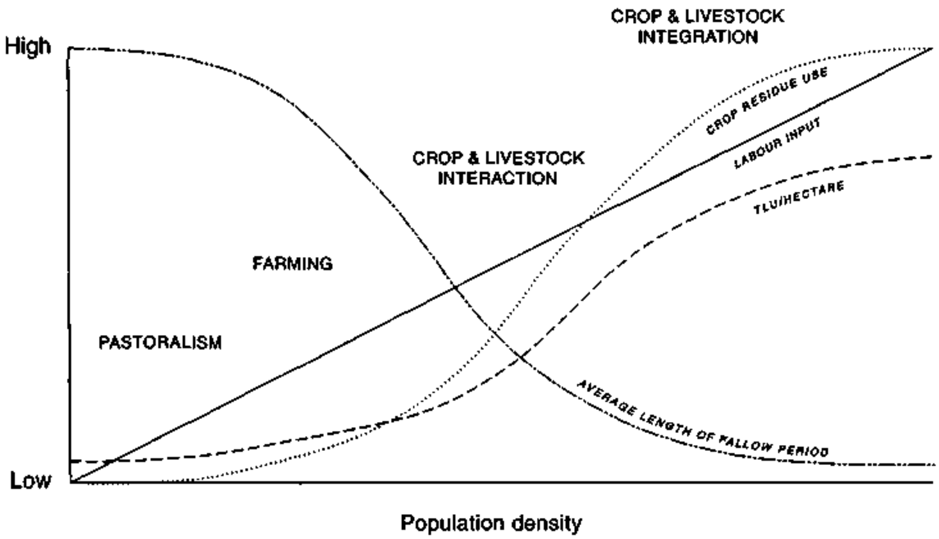
The Kano CSZ is an example of a farming system which has reached the point in the intensification process at which all land is under cultivation, all palatable crop residues are used as fodder, and trees are conserved. As a result of this study we have a better understanding of how an indigenous farming system works. These results contrast with those of other workers who suggest that such intensive farming over a long period is not possible (Turner, M. 1994; Van der Pol, 1992). For example, researchers in Francophone West Africa have calculated the amount of rangeland required to support the livestock necessary to provide sufficient manure to maintain annual production of cereal crops on 1 ha without reducing soil fertility (Schlecht et.al, 1995; Turner, M. 1994). Calculations vary, but they suggest that 23-40 ha of rangeland is required to support 1 ha of cropland. This corresponds to a cropping intensity of 2.4 - 4.2%. However the cropping intensity of the Kano CSZ is 86%. There is virtually no grazing land (Turner, B. 1994). Owing to a decline in rainfall in West Africa in recent years, rainfall in the Kano CSZ is now comparable to areas such as southern Mali and southern Niger. Research carried out in Niger, Burkina Faso, Mali and Senegal on farming systems in semi-arid areas suggests that these areas could not develop farming systems as intensive as that of the Kano CSZ (Schlecht et a/., 1995; Turner, M. 1994).

Northern Nigeria has much higher population densities than its neighbouring Francophone countries, and the Kano CSZ in particular has land use intensities of 86%. The evidence from the Kano CSZ and other areas (Tiffen et. al, 1994; Prudencio, 1993) prove that more intensive, yet sustainable, farming systems are possible. While there are many differences between the Kano CSZ and other farming systems in semi-arid west Africa, the main reason other farming systems are not as intensive as in the Kano CSZ is lack of labour. While intensification occurs as a result of many factors, including access to knowledge, availability of capital to invest in soil fertility conservation measures, equipment or herds and access to markets (Tiffen et al., 1994), availability of labour is an important factor.

Areas of high population density have more labour available to transport manure from compounds to fields, and so increase soil fertility. Bourn and Wint (1994) have shown that these areas also support higher livestock populations. In studies carried out in Francophone countries of West Africa, with lower population densities and farming systems where average landholding size ranged from 3-10 ha, farmers did not find it worth their while to transfer fodder to the compound and tether livestock, and then return the composted manure to the fields. Livestock holdings in less densely populated areas were insufficient to provide enough manure to fertilize such large landholdings, even if sufficient fodder was available (Williams et. al, 1995). Although some legumes are grown in the less densely populated areas, the farmers have not yet realized the role that legumes can play in providing fodder for livestock, nitrogen through biological nitrogen fixation, and a saleable cash crop to enable purchase of inorganic fertilizer.

These conclusions are presented diagrammatically in Figure 4. At low population densities there is little agriculture, plenty of uncultivated land for pastoralism and overall production is low. As population density increases, the area under cultivation increases and fallow decreases. Under these conditions crop residue use increases to feed livestock. Crop-livestock interaction then becomes a necessity and productivity increases. As more land has to be used, farmers and pastoralists integrate crop-livestock production. The transition from separate pastoral or arable crop enterprises to crop-livestock interaction and ultimately crop livestock integration requires increased labour, and so can only proceed as population increases (Boserup, 1965).

Figure 4. Population Density and Agricultural Intensification



Sustainability requires a balanced nutrient budget. Soil fertility decline can be overcome if labour can be used to reduce nutrient losses by recycling of nutrients, most obviously by collecting leguminous crop residues for animal fodder and transporting manure to the fields. Farmers in semi-arid West Africa can intensify production if they conserve soil nutrients through the use of labour.

Implications for Smallholder Farming in Semi-arid West Africa

The Kano CSZ is one of the most densely populated areas in semi-arid West Africa (Snrech et al., 1995). This study has shown how farmers in areas of high population density can intensify cultivation sustainably, and so provides an example of how less intensive farming systems may develop as population increases. The key to this is crop-livestock interaction, and high labour inputs, readily available in this densely populated area.

In particular, the study has shown the importance of integrating crops and livestock to enhance nutrient cycling within the farming system. Increases in livestock populations should be balanced by an increase in the use of crop residues for animal fodder, and the inclusion of legume crops (which provide better quality animal fodder) in the farming system. Crop-livestock interaction will be adopted as the human population increases and provides the required labour. As the population increases further, the integration of crop and livestock production will occur. Farmers will keep livestock to provide them with the manure they need for their fields, and fodder will be transported to compounds.

The farming system of the Kano CSZ can be further supported through the encouragement of crop-livestock integration which maximises nutrient recycling. The individual steps needed to achieve this are the promotion of legume cultivation and keeping of small ruminants, and the use of donkeys or ox-carts to facilitate transportation of crop residues and manure. Grain storage facilities (especially for legume grains) would allow farmers to store grains and sell when the prices are higher, and so invest in their farming through the purchase of labour saving equipment such as ploughs and cultivators, or inorganic fertiliser. The study also has implications for research, by demonstrating what can be learnt from indigenous farming methods. Farm-scale nutrient cycling studies offer direct measurement of sustainability in input-output terms at the level where management decisions are actually made and the constraints affecting those decisions (knowledge, labour, capital, etc.) can be investigated. Although nutrient cycling projects require detailed research and a full season of monitoring, they provide important information which cannot be obtained in any other way. The results provide much more quantitative information than surveys. Long-term studies based on household or farm surveys which enquire into changes in farming practices identify the social and economic constraints faced by farmers, but are inadequate for quantitatively assessing the nutrient balance at the farm, and thus the environmental sustainability of the management practices used by farmers.

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Annex A

Inputs such as animal manure, compound waste and inorganic fertilizer were weighed, and sub-samples taken for chemical analysis. Donkey loads of manure taken to farmers' fields were counted and weighed, and samples taken for nutrient analysis to determine the contributions of manure to the nutrient balance. Quadrats were used to estimate the amount of manure deposited directly onto fields by grazing animals, and showed that this contribution to the nutrient balance was very small (17g manure/ha). The amount and type of inorganic fertilizer used on each field was noted. The input by nitrogen fixation was dependent on the area planted to legumes and the intercropping pattern. Nitrogen fixation was measured by N-difference (Hauser, 1992), by a trial with groundnut and cowpea planted in typical intercrop with sorghum, and maize as the control crop. This results in a value for nitrogen fixation per plant, which was then used to calculate nitrogen fixation in fields of different cropping patterns. Deposition of harmattan dust in Tumbau was measured by a ground level wet dust trap.

At the end of each season, the crops harvested were recorded, and samples of each type of vegetation taken for chemical analysis. Time of planting, weeding, ploughing, intercropping patterns and harvest dates were also recorded. The major loss of nutrients from the farming system was from the harvest. The harvest of grain, crop residues, weeds and hedgerow crops from farmers fields was recorded, and samples taken for analysis to determine nutrient content. Nitrogen losses from leaching were negligible, as nitrate content of the soil was approximately 1 ug/g.