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ORIGINAL ARTICLE

Estimation of nitrogen flow within a village-farm model in Fakara region in Niger, Sahelian zone of West Africa

Keiichi Hayashi · Naruo Matsumoto · Evangeline T. Hayashi ·
Tahirou Abdoulaye · Hitoshi Shinjo · Ramadjita Tabo ·
Ryoichi Matsunaga · Satoshi Tobita

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Abstract To determine the efficiency of utilization of organic matter in agricultural production, nitrogen flow was estimated within a village-farm model in the west of Niger, West Africa. Nitrogen was focused on in this study as it is known to be a major nutrient component of organic matter and one of the limiting nutrients in Sahelian soil. Local practices regarding the use of organic matter and pertinent information on traditional practices for soil fertility management were determined by interviews with local farmers. To estimate nitrogen flow in farmlands and consumption in the village through various activities, quantitative measurements of crop yield and organic amendment were carried out. Data on human and livestock excreta were taken from published reports. The size and classification of farmlands were as follows: 0.5 ha

adjacent farmland, 1.6 ha threshing farmland, 6.0 ha transported-manure farmland, 5.5 ha corralling farmland, and 86.5 ha extensively managed farmland (EMF). Levels of nitrogen flow from these farmlands to the studied villages were 0.9, 2.9, 9.6, 15.2, and 94.2 Mg, while the flows to these farmlands were 14.6, 6.3, 13.7, 17.5, and 26.3 Mg, respectively. Upon calculation of nitrogen balance $-8 \text{ kg ha}^{-1} \text{ year}^{-1}$ was estimated in EMF, but there was a positive balance in other types of farmland, which ranged from 4 to 262 $\text{kg ha}^{-1} \text{ year}^{-1}$, indicating inefficient use of nitrogen in the study area for crop production. The results indicated that nutrient flow in the study site was unequally distributed and nitrogen was not recycled. Therefore, efforts should be made to establish efficient utilization of available nutrients by reducing the loss from livestock feed and human consumption. At the

K. Hayashi (✉) · N. Matsumoto · S. Tobita
Japan International Research Center for Agricultural
Sciences, 1-1 Ohwashi, Tsukuba 305-8686, Japan
e-mail: khayash@jircas.affrc.go.jp

E. T. Hayashi
3-7-7, Koyadai, Tsukuba 305-0074, Japan

T. Abdoulaye · R. Tabo
International Crop Research Institute for the Semi-Arid
Tropics, Niamey BP12404, Niger

Present Address:
T. Abdoulaye
International Institute of Tropical Agriculture, Ibadan
PMB 5320, Oyo State, Nigeria

H. Shinjo
Department of Agriculture, Kyoto University, Oiwake,
Kitasirakawa, Sakyo, Kyoto 606-8502, Japan

Present Address:
R. Tabo
Forum for Agricultural Research in Africa, # 12 Anmeda
Street, Roman Ridge, Accra, Ghana

Present Address:
R. Matsunaga
Kyushu Okinawa National Agricultural Research Center,
2421 Suya, Koshi 861-1192, Kumamoto, Japan

same time, more research is needed to improve the management of EMF.

Keywords Organic matter · Nitrogen flow · Soil fertility management · Niger · Sahel

Introduction

Fifty percent of the total population of Africa is engaged in agriculture. On this continent, the major soil types are Arenosols and Acrisols, Ferrasols, and Lixisols, which constitute 20, 11, and 9% of the total land area (FAO 2003). Such highly weathered soils in addition to an erratic rainfall pattern have hampered the ability to meet the food demands of a population growing by as much as 2.5% per year.

Many recent studies have highlighted the need for a dramatic improvement in agricultural production with a particular focus on soil fertility management. Several recommendations stressed the importance of the application of inorganic fertilizer to enhance productivity (Schlecht et al. 2006; Fofana et al. 2008). However, unlike in developing countries in South East (SE) Asia and South America, the use of inorganic fertilizer in West Africa is not prevalent. Statistics show that use of urea in West Africa in 2006 was 14 times lower than in South America and 22 times lower than in SE Asia (FAO 2010). High prices at local retailers in West Africa are one of the reasons for this. In Niger, the price of urea was US\$22 for one 50-kg bag (Hayashi et al. 2009). As such, urea is generally not affordable to farmers, most of whom live below the poverty line.

Owing to this economic constraint on the use of inorganic fertilizer, the role of organic matter in agriculture is critical, and many studies have been conducted on alternative nutrient management (Padwick 1983; Bationo and Buerkert 2001). The effects of the application of crop residues and manure and the importance of organic carbon (Corg) have been well documented (Bationo et al. 1993; Buerkert et al. 1996; Fatondji et al. 2006). Bationo and Buerkert (2001) specifically described the high correlation of Corg with cation exchange capacity (CEC) where the dominant clay mineral in soils is kaolinite, namely, conditions where the CEC is often less than $1 \text{ cmol}_c \text{ kg}^{-1}$ soil.

With an increase in soil CEC by $0.25 \text{ cmol}_c \text{ kg}^{-1}$, Corg increased by 1 g kg^{-1} in soils (De Ridder and Van Keulen 1990). Manu et al. (1991) found that the Corg content of an average soil is 7.6 g kg^{-1} meaning Corg contents in the soil were highly correlated with total nitrogen ($r = 0.97$). Therefore, the management of Corg plays a crucial role in nutrient supply in the Sahel zone where inorganic fertilization in agriculture is not a common practice.

Despite having soil with low carbon sequestration and termite- and temperature-induced rapid turnover rates of organic material, information on the potential of organic resources and nutrient availability for agricultural production in the Sahelian zone is limited. Limited studies on systematic evaluation have highlighted the lack of appropriate guidelines for management of local resources in agricultural production. Schlecht et al. (2004) worked on nutrient budget in different land-use types, but the study was based on a 1994–2001 survey.

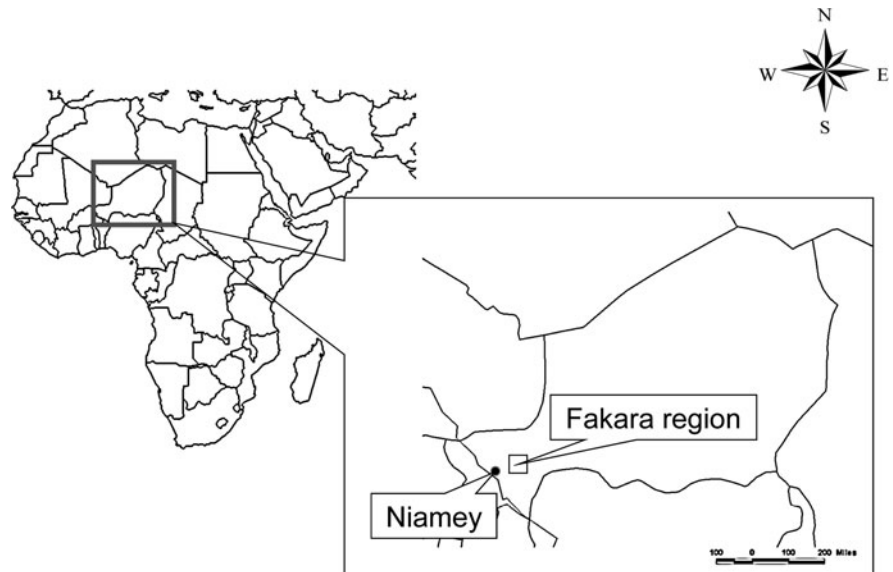
Therefore, to shed more light on this neglected field of study, and to determine the efficiency of utilization of organic matter in agricultural production in Niger in the Sahelian zone, nitrogen flow was estimated within a village-farm model. Nitrogen is focused on as the key element in this study as it is a major nutrient component of organic matter, but one of the limiting nutrients in Sahelian soil. Nutrient flow plays an essential role in crop production, so the potential of locally available organic resources in this area is deemed crucial in the management of farmland. Estimations of the use of organic matter in the villages and farmlands in the studied area, including for household consumption and livestock production were used to calculate nitrogen flow.

Materials and methods

Site description

Data collection of this study was carried out from 2005 to 2008 in the villages of Banizoumou (BZ), Tchigo Tegui (TT), and Ko Dey (KD), in the Fakara region, Dantiandou district of Tillaberi Province, in the west of Niger (60–90 km northeast of Niamey) (Fig. 1). A total of 380 households were included in the study, belonging to the Zarma and Fulani tribes that engage in both crop production and raising livestock.

Fig. 1 The study area in the Fakara region, Dantiandou district of Tillabéri Province, in the west of Niger



Millet (*Pennisetum glaucum* (L.) R. Br.), cowpea (*Vigna unguiculata* (L.) Walp.), and hibiscus (*Hibiscus sabdariffa*) are the major crops grown by the Zarma tribe. Wild plants such as *Alysicarpus ovalifolius*, *Eragrostis tremula*, *Ceratothera sesamoides*, and *Commelina forskalaei* are some of the species commonly used as they are considered important for local livelihoods and livestock animals.

Soil in this region is of the Psammentic Paleustalf type, of which 90% is sand fraction, with a pH of 5.3, 0.16 g kg⁻¹ total nitrogen, 0.2% organic carbon, 4.1 mg kg⁻¹ available phosphorus, and 1.2 cmol_c kg⁻¹ effective CEC (Hayashi 2005). With a monomodal rainfall pattern in which the rainy season occurs from June to September, with a peak in August, the annual average rainfall from 2001 to 2004 was estimated to be about 416 mm (Matsunaga et al. 2006) (Table 1).

Design of model for nitrogen flow in the study area

To understand nitrogen flow in the study site, a model was designed on the basis of land use, land management pattern, and the distribution of agricultural products (Fig. 4). Pertinent information on traditional practices for soil fertility management was obtained by interviews with local members of the Fulani tribe. The size of farmland within the study area was then calculated by ArcGIS 9 (ESRI 2008) using the ILRI database (ILRI unpublished data 1996). Data were also obtained on the distance of farmland from the village and classified according to the previous study

(Hayashi et al. 2008a). Table 2 shows the different variables that were considered in the model.

There were five categories related to farmland in the model, three of which were related to the types of management employed by farmers as follows: land to which household rubbish and farmyard manure was transported, referred to as transported-manure farmland (TMF), land on which corralled livestock excreta were used, referred to as corralled farmland (CF), and land on which crop-fallow rotation was used, referred to as extensively managed farmland (EMF). In contrast to the above categories referring to the local farmers' specific practices, two other subcategories (adjacent and threshing farmlands; AF and TF) were classified in terms of other criteria. In the case of AF, the proximate location of such farmland to local households allows local residents to build lavatories for their own use and to dump rubbish at such sites. TF farmland is where threshing of millet panicles for meal preparation is usually performed, specifically by women. (It was found that millet residue produced after the process was discarded.) Geographical Positioning System (GPS) measurement showed that threshing was practiced in those areas where granaries were present (Fig. 2). It also indicated a demarcation between AF and TF, proving that TF areas were not used for dumping rubbish or human excreta.

The interviews with local farmers confirmed the use of different types of mixed cropping systems along with different types of land management at the study site. With the exception of millet in AF, no mono-

Table 1 Description of the study site

Parameters	Description		
Surveyed village	Banizoumbou	Tchigo Tegui	Ko Dey
Number of households*	145	135	100
Tribe (agriculture)		Zarma	
Tribe (livestock)		Fulani	
Crop		Millet, cowpea and hibiscus	
Soil type**		Psammentic Paleustalf	
Sand fraction**		>90%	
Soil pH (H ₂ O)***	5.2	5.3	5.3
Total nitrogen (g kg ⁻¹)***	0.18	0.15	0.15
Organic carbon (%)***	0.21	0.19	0.17
Available P ₂ O ₅ (mg kg ⁻¹)***	4.36	3.54	4.52
cCEC (cmolc kg ⁻¹)***	1.43	0.92	1.38
Rainfall (4 years average)****		416 mm	
Highest rainfall month		August	

* Hiernaux and Ayantunde (2004)

** Hayashi et al. (2009)

*** Hayashi (2005)

**** Matsunaga et al. (2006)

Table 2 Main components and subcomponents for the model in the study area

Main component	Subcomponent
Farmland	0–99 m: adjacent farmlands (AF)
	100–499 m: threshing farmlands (TF)
	500–999 m: transported-manure farmlands (TMF)
	1,000–1,999 m: corralling farmlands (CF)
	≥2,000 m: extensively managed farmlands (EMF)
Agricultural products	Millet panicle
	Millet leaves and stems
	Cowpea shells
	Cowpea runner (fodder)
	Hibiscus grain
	Hibiscus residue
	Wild grass
Grazing	
Nutrient return to farmland	Human excrement
	Threshing residue
	Farmyard manure and household rubbish
	Harmattan dust
	Livestock excrements through corralling

cropping system was used. Figure 3 shows the two types of mixed cropping system: Type 1: short-cycle landrace millet, taking around 140 days to reach maturity, with landrace cowpea (*Vigna unguiculata* (L.) Walp.); Type 2: long-cycle landrace millet, taking around 160 days to reach maturity, with landrace hibiscus (*Hibiscus sabdariffa*). In terms of distance from the village, type 1 was found more in the range of 0–1,999 m than at ≥2,000 m, while the opposite was true for Type 2. Ninety-four percent of farmers practiced the Type 1 system on farmland less than 1,000 m away from their village while the proportion was 74% for farmland more than 1,000 m and less than 2,000 m away); in contrast, the proportion was only 15% for farmland ≥2,000 m away. As such, Type 1 was considered as a representative system for TF and TMF. The opposite trend was found for the Type 2 system, wherein it was applied on 84% of farmland more than 2,000 m from the village, so it was considered as the representative system for EMF.

Measurements of crop yield and input of organic material

To estimate nitrogen flow, quantitative information on the different variables within the nitrogen flow model was obtained. Details are as follows:

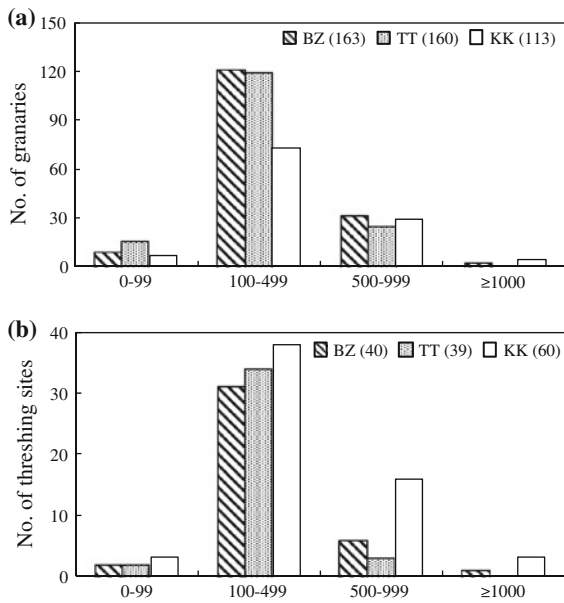


Fig. 2 Histogram of **a** granaries and **b** threshing sites as a function of distance from the village in the study area

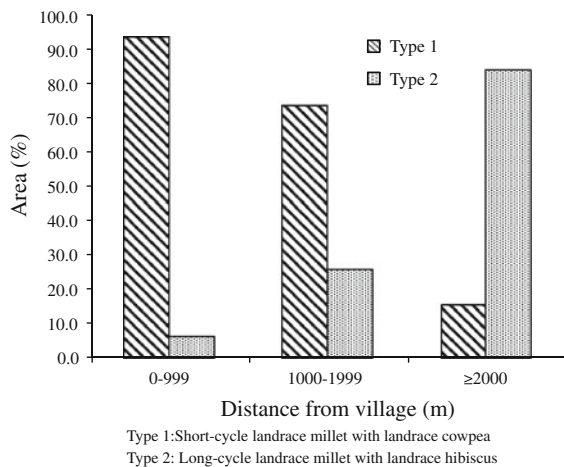


Fig. 3 Different types of mixed cropping systems along with the type of land management in the study area

Crop yield and partition of agricultural products

Crop yields for millet, cowpea, and hibiscus were measured. To quantify the weight of panicles, leaves, and stems of millet, a total of six plots of 10 m × 10 m for the three villages were used for the five types of farm management. All of the above-ground biomass of millet was removed in each plot at harvesting and dried in the field before weight measurement. Thirty

subsamples (two plots × three villages × five types of farmland management) were used to measure the weight of panicles, stems, and leaves. To measure millet flour, bran (edible part), and residue (inedible part including lead), 12 of the 30 subsamples mentioned above were randomly selected. Moisture content of samples was measured by oven-drying at 105°C for 24 h. Plant density, field size, and unit quantity of cowpea and hibiscus were estimated for each harvest. The unit quantity was measured using a 0.01 m³ polystyrene bag, a container commonly used by local farmers to store the grain of cowpea, hibiscus, and threshing residues of cowpea pod and hibiscus. Twelve bags of each type of grain and threshing residue were measured to obtain the average weight of each unit quantity. As cowpea fodder was usually bundled after harvest, 12 bundles were then weighed and measured.

Organic resources and input for farmlands

A mixture of household rubbish and farmyard manure was the source of input of organic material for farmlands, the weight of which was quantified on the basis of the capacity of vehicles used locally to transport such material. The typical vehicle is a cart usually pulled by one or two bulls which has a capacity of 0.68 m³. The cargos of 15 carts were measured for total weight and brought to a research station; each component (household rubbish, farmyard manure, and soil) was then segregated and weighed, and then the nitrogen content was determined by analysis. The nitrogen contents of human excreta were estimated using the published data of Matsumoto et al. (2010).

Livestock

Within the Fulani tribe, two divergent groups were present in the study area. One type stayed in the area only periodically during the dry season, while the other was sedentary, acting as a tenant on a piece of farmland (Shinjo et al. 2008). Considering those both contributing and removing nutrients from the farmlands, interviews were focused on all sedentary Fulani, and particularly dealt with identification of the number and species of livestock in the study area. Noting from a previous study that most of the sedentary Fulani accepted contracted livestock from the Zarma tribe (Shinjo et al. 2008), the data obtained from the present survey were considered to reflect all livestock within

the study area. Contracted livestock included small ruminants, especially sheep, intended for fattening and also used once a year for a religious event; their total number was considered to be replenished each year. It was thus assumed that the total number of livestock that sedentary Fulani owned did not change within a short period of time. A calf, a lamb, and a kid were counted as half of one adult animal.

Since livestock serve as a catalyst for nutrient flow through grazing and corralling processes, the average amount of fecal excreta that they produced was estimated. For instance, the levels of dry matter produced per day per cow, sheep, and goat were 2,383, 345, and 197 g, respectively (Powell et al. 1998). The average amount of individual sheep urine voiding was estimated on the basis of a previous study (Somda et al. 1997), and was 64 g per urine voiding, with a total nitrogen level of 2.98 g kg⁻¹ (Powell et al. 1998).

The number of livestock in the study area was considered as half the total number calculated per year because sedentary Fulani who were normally settled with their animals on a piece of farmland were forced to undertake transhumance during the rainy season. This was done to avoid conflict in their agricultural activities with the Zarma tribe.

Nutrients that were removed by agricultural activities in the form of food and residues were assumed to be returned back to the same farmland by the Fulani.

Distribution of agricultural products in the village

Detailed information on the distribution of agricultural products in the village was obtained by interviews with the members of local Zarma households. Harvested millet panicles for storage were bundled either for daily consumption or for sale at a local market. The locations of granaries and sites of threshing were marked by portable GPS (GPSmap 60CSx, Garmin). Although farmers used certain numbers of millet bundles as offerings as part of traditional customs, in addition to repayment of debts and labor fees, all such transfers were considered to occur between residents within the village and thus did not involve net outflow of resources from the village.

Determination of nitrogen content

To determine total nitrogen content of soil and plant samples, analysis was carried out in the laboratory of

the ICRISAT research station. In total, 15 samples of mixtures of household rubbish and farmyard manure, 12 of millet, 10 of cowpea, and 8 of hibiscus were subjected to analysis using the Kjeldahl method. The data on nitrogen content of organic resources obtained in this way were then applied to the estimation of nitrogen flow in the model (Table 9).

Statistical analysis

Data obtained by the agronomic measurements were subjected to one-way ANOVA using SigmaStat ver. 3.1 (SPSS, Chicago, IL).

Results

Organic matter outflow from farmlands

Crop production, wild plants, and livestock in the study site

Although millet (as a primary staple for the local people in the study site) was cultivated under all types of land management, the yields differed among them (Table 3). The yield of cowpea was found to be extremely low due to low plant density, despite being grown in TF and TMF where organic matter was returned back to the land (Table 4). Being subsistence farmers, inputs for agricultural production like seeds do not suffice requirement for the planting season (Hayashi et al. 2008b). This is one of the key reasons why cowpea and hibiscus are grown at a low density, resulting in a low yield.

For local residents, wild plants are considered as important resources, such as for cash crops, fodder, and as a food substitute. Yield was 1,178 kg dry matter ha⁻¹ year⁻¹ (Shinjo et al. personal communication).

Grazing by livestock owned by the Fulani

All livestock animals are corralled by the Fulani during the dry season and taken for transhumance during the rainy season, a traditional practice that enables grazing on fresh pastures and avoids conflict with the Zarma.

In terms of the numbers of households among the three Fulani villages of BZ, TT, and KD, there were

Table 3 Yield and biomass production for each type of farmland management

	Millet (kg dry matter ha ⁻¹)		Cowpea (kg dry matter ha ⁻¹)			Hibiscus (kg dry matter ha ⁻¹)		Wild plant (kg dry matter ha ⁻¹)
	Panicle	Stem and leaves	Grain	Shell	Fodder	Grain	Residue	
Adjacent farmlands (AF)	680.13	1,770.61	0	0	0	0	0	0
Threshing farmlands (TF)	556.38	1,089.96	111.77	51.90	66.36	0	0	0
Transported-manure farmlands (TMF)	440.55	710.59	123.85	57.51	73.52	0	0	0
Corralling farmlands (CF)	1,609.99	1,457.78	0	0	0	0	0	0
Extensively managed farmlands (EMF)	520.99	699.19	0	0	0	31.81	8.25	1,178.00

differences in the types of activities that were undertaken to maintain good relations with the Zarma. Raising livestock and food production activities were carried out on farmland rented from the Zarma. It was understood that these two tribes have maintained their relationship in order to coexist in the severe environment of the Sahel. However, Shinjo et al. (2008) confirmed a case in which a Fulani tribe was forced to return land owing to increased population pressure and reduced food security among the Zarma.

The total number of livestock in TT was the highest, as this was the village with the largest number of households. The average amounts of excrement for three villages in terms of dry matter produced for each type of livestock per year were calculated as follows: 1,115.1 Mg for all cows, 90.2 Mg for all sheep, and 67.5 Mg for all goats, with a total for all animals of 1,272.8 Mg. Total urine voiding per year was 68.6 Mg, with the values for cows, sheep, and goats being 29.9, 16.7, and 21.9 Mg, respectively. As livestock were grazed in EMF during the day and tied up in CF during the night, the levels of input into farmland of nitrogen from excrement and urine were considered to be equal between these two types of farmland (Table 5).

Organic matter flow in the villages

Agricultural products were collected in the villages and distributed for various purposes (Table 6). Millet panicles were either consumed in households or used as cash crops, millet leaves and cowpea fodder were used as feed for livestock, while millet stems were used as materials for the construction of houses. Trading is one of the main cash-generating activities

of the local residents in the villages, allowing the purchase of household supplies. In total, 95% of millet panicles were supplied for household consumption, while 1.9% was used for trading. In the case of cowpea, 70% was consumed in households and 23% went to trading. More cowpea was sold than millet as the former commands better prices on the market. Overall, 67 Mg year⁻¹ of millet panicles was sold on the market by local households in all three villages, compared with 22 Mg year⁻¹ of cowpea grain.

Among the total of 3,567 Mg year⁻¹ of millet panicles that were threshed, 2,172 Mg year⁻¹ was used for domestic consumption. This subsequently resulted in the production of 1,766 Mg year⁻¹ of millet flour after the refining process. Since this was insufficient for household consumption, 555 Mg year⁻¹ of millet panicles was purchased on the market, which increased the amount of millet grain by 355 Mg year⁻¹. After the refining process, this produced 289 Mg year⁻¹ of millet flour for consumption. The total amounts of byproducts after the threshing and refining processes were 1,524 Mg year⁻¹ of millet residue and 492 Mg year⁻¹ of millet bran. Only millet bran was used as livestock feed; millet residue and leads were just discarded in TF as rubbish.

Organic matter input into the farmlands

Although the villages in this study did not have any specific system for automatic disposal of excreta, such as lavatories, the use of human excreta for agriculture was not practiced for sanitary and religious reasons. Disposal of human waste was therefore carried out on farmland adjacent to the villages. However, this was not expected to result in the retention of many

Table 4 Plant density with different types of farmland management in the study area

Farmland	Distance (m)	Village	Density (plant hole ha ⁻¹)		
			Millet	Cowpea	Hibiscus
AF	0–100	Banizoumbou	7,154.17	1,025.00	0
		Tchigo Tegui	5,979.17	1,508.33	0
		Ko Dey	4,375.00	868.75	0
TF	100–500	Banizoumbou	6,983.33	750.00	0
		Tchigo Tegui	6,295.00	900.00	0
		Ko Dey	4,137.50	1,975.00	431.25
TMF	500–1,000	Banizoumbou	4,954.17	754.17	0
		Tchigo Tegui	5,304.17	681.25	0
		Ko Dey	5,479.17	1,158.33	458.33
	<i>p</i> (Village)		<0.001	0.067	<0.001
	<i>p</i> (System)		0.26	0.56	0.10
	<i>p</i> (Village) × (system)		0.01	0.11	0.06

Table 5 Number of sedentary Fulani and their livestock

	Number of households	Cow	Sheep	Goat
Banizoumbou	35	663	410	306
Tchigo Tegui	57	1,283	658	881
Ko Dey	30	618	366	691
Fakara total	122	2,564	1,433	1,877

nutrients in the soil as human excreta underwent volatilization and run-off by exposure to the environmental conditions that prevailed in the region. On the other hand, the residue produced from the threshing of millet, as previously mentioned, can be considered a potential contributor of nutrients, which was estimated at 1,524 Mg year⁻¹.

The results of the survey on household trash and farm manure transported to the farmlands by carts are shown in Table 7. Transported manure consisted of livestock feces, decomposed organic matter, and soil, which on average consisted of 27, 17, and 56% of the total, respectively. These values reflected the way in which organic resources were collected by local farmers from their backyards. Livestock were kept by each household in a pen at night, allowing their excreta to be deposited on the ground. Household rubbish collected through manual sweeping was combined with farmyard manure and transported to the farmlands. More soil was found in TM than in other resources owing to the manual sweeping activity, which caused soil from the ground layer inside buildings to become dislodged and mixed

in with the rubbish. On average, a total of 1,191 Mg year⁻¹ of TM, which was carried out by 151 number of deposit, was carried by the households to their farmlands. This amount included about 317 Mg of livestock manure, 195 Mg of decomposable organic manure, and 679 Mg of soil.

A previous study confirmed that another factor causing inflow of organic matter for nutrient supply to farmlands in the Sahelian zone is Harmattan dust, a nutrient-rich loess carried by seasonal winds from the Sahara Desert, which deposits nitrogen at a level of 3.0 kg ha⁻¹ (measured by Ikazaki personal communication). Harmattan dust was assumed to be equally distributed in the study area.

Nitrogen flow within a village-farm model

The amount of nitrogen contained within each type of organic resource was calculated to characterize nutrient flow in the study area. Table 8 shows a summary of the amounts of organic resources, percentage of, and nitrogen content for each component. A non-significant variation in the average nitrogen content was observed in accordance with the result reported by Van den Boscha et al. (1998). The information presented in the table is the basis for the detailed model of nitrogen flow developed in Fig. 4 and calculations carried out in accordance with the formulas shown in Table 9. This model will be used to evaluate the current utilization of available nutrients in the study area.

Table 6 Agricultural products collected in the villages and distributed for various purposes

Crops	Mg year ⁻¹ *	Distribution		Partition			Partition			Purpose of use							
		%	Mg year ⁻¹	%	Mg year ⁻¹	%	Mg year ⁻¹	%	Mg year ⁻¹								
Millet panicles	3,567	Local market	1.9	67	Millet grain for seeds	63.9	43	Millet bran	18.7	8							
								Millet flour	81.3	35							
								Millet lead	18.2	12							
					Millet residue	17.9	12										
					Seeds for next season	2.8	101	Millet grain for seeds	63.9	64		Millet bran	18.7	12			
												Millet flour	81.3	52			
		Millet lead	18.2	18													
		Household consumption	95.3	3,399	Millet grain for consumption	63.9	2,172	Millet bran	18.7	406		Livestock feeding					
								Millet flour	81.3	1,766		Household consumption					
								Millet lead	18.2	637		Household rubbish					
					Purchased millet panicles	555		Millet grains	64.0	355		Millet bran	18.7	66	Livestock feeding		
												Millet flour	81.3	289	Household consumption		
Millet lead	18.2										101	Household rubbish					
Millet stems & leaves	4,570		Millet residue	17.9	99	Millet stems	65.2	2,978		Household consumption							
										Millet leaves	34.8	1,592		Livestock feeding			
Cowpea grains	97	Local market	22.9	22													
											Seeds for next season	6.8	7				
Cowpea shell	47									Livestock feeding							
Cowpea fodder	57									Livestock feeding							
Hibiscus grains	140									Household consumption							
Hibiscus residue	36									Livestock feeding							

* Dry matter for millet was 98%

Table 7 Results of the survey on household rubbish and farmyard manure transported to the farmlands by carts

Village	Surface area for depositing TM (ha)	Deposited quantity (kg time ⁻¹ household ⁻¹)		Number of deposits (time per year ⁻¹)	Number of households	Total deposit quantity (Mg year ⁻¹)		
		Livestock feces	Soil			Livestock feces	Decomposed organic matter	
								Soil
BZ mean (5)	3.1	18.2	8.6	121	145	319.2	151.2	785.9
SD	1.2	10.9	1.8	21		95.3	15.4	33.4
TT mean (5)	2.9	24.7	18.0	71	135	235.8	172.0	396.6
SD	1.6	5.2	9.4	14		24.6	44.8	58.9
KD mean (5)	3.6	15.1	9.9	262	100	395.7	260.3	848.1
SD	2.6	5.7	5.7	124		74.2	74.3	242.8

Discussion

In this study on estimation of nitrogen flow within a village-farm model in the Sahelian zone of West Africa, several interesting findings related to local practices were made. In terms of the total nitrogen flow to village-based activities, removed crop grain stems and leaves, as well as wild plants, mainly from EMF, contributed 64% of the total flow to the village. Owing to livestock grazing, the nitrogen in EMF was removed and then transferred to CF during corralling. Maintenance of the fertility of land of CF is therefore heavily dependent on the supply from EMF. There are various sources that compensate for the nitrogen removal from farmland in the study area. These include Harmattan dust, although this makes only a limited contribution. A nitrogen balance of $-68 \text{ Mg-N year}^{-1}$ was estimated in the total area of EMF, equivalent to $-7.7 \text{ kg-N ha}^{-1} \text{ year}^{-1}$ (Table 10). Fertility in EMF in the Sahelian zone used to be maintained by long-term fallow periods of about 15 years. However, a previous study confirmed that this has been drastically shortened, as local farmers left fields fallow for an average of only 3 years after 6 years of cultivation (Hayashi et al. 2008a). This change in the use of fallowing could have contributed significantly to hamper the effective restoration of fertility in these farmlands and thus many studies have recommended the utilization of inorganic fertilizer to sustain the productivity in the Sahelian zone.

In the present study on the Fakara region, sources of nitrogen from the farmlands were once gathered in the villages and partitioned for various purposes, for example, cash crops, human consumption, livestock feed, and materials for constructing houses. Figure 4 shows that nowadays, a large amount of nitrogen is distributed as livestock feed and for human consumption, but this nitrogen was not recycled back into production. Only a small proportion of nitrogen was returned to the farmlands, whereas a large amount was allowed to disperse in the atmosphere. The limitations in terms of basic facilities in rural areas like the Sahel could be one reason for this. It is because lavatories and livestock pens were not for the purpose of nutrient recycling, so the nitrogen in human and livestock excreta was free to dissipate into the air or leave the village-farm model by other means. Large nitrogen losses were also observed in the study by Van den Bosch et al. (1998). There is a need for this situation

Table 8 Estimation of the amount of total nitrogen for each component of organic matter in the study area

Crops		Quantity (Mg year ⁻¹)	Partition	%	Quantity (Mg year ⁻¹)	T-N content	Unit	T-N (Mg year ⁻¹)
Outflow from farmlands								
Adjacent farmland	Millet panicles	36	Grains	63.9	22.8	1.82	%	0.42
			Lead	18.2	6.5	0.39	%	0.03
			Residue	17.9	6.4	0.39	%	0.02
	Millet stem and leaves	93	Stem	65.2	60.6	0.39	%	0.24
			Leave	34.8	32.4	0.53	%	0.17
Threshing farmland	Millet panicles	88	Grains	63.9	56.0	1.82	%	1.02
			Lead	18.2	15.9	0.39	%	0.06
			Residue	17.9	15.7	0.39	%	0.06
	Millet stem and leaves	172	Stem	65.2	111.9	0.39	%	0.44
			Leave	34.8	59.8	0.53	%	0.32
	Cowpea	36	Grains		17.6	3.96	%	0.70
			Shell		8.2	0.97	%	0.08
			Fodder		10.5	2.06	%	0.22
Transported manure	Millet panicles	268	Grains	63.9	170.9	1.82	%	3.11
			Lead	18.2	48.7	0.39	%	0.19
			Residue	17.9	47.9	0.39	%	0.19
	Millet stem and leaves	431	Stem	65.2	281.2	0.39	%	1.10
			Leave	34.8	150.3	0.53	%	0.80
	Cowpea	155	Grains		75.2	3.96	%	2.98
			Shell		34.9	0.97	%	0.34
			Fodder		44.6	2.06	%	0.92
Outflow from farmlands (cont'd)								
Corralling	Millet panicles	891	Grains	63.9	569.4	1.82	%	10.36
			Lead	18.2	162.1	0.39	%	0.63
			Residue	17.9	159.7	0.39	%	0.62
	Millet stem and leaves	807	Stem	65.2	525.8	0.39	%	2.05
			Leave	34.8	281.1	0.53	%	1.49
Extensively managed farmland	Millet panicles	2,285	Grains	63.9	1,460.1	1.82	%	26.57
			Lead	18.2	415.6	0.39	%	1.62
			Residue	17.9	409.4	0.39	%	1.60
	Millet stem and leaves	3,067	Stem	65.2	1,998.5	0.39	%	7.79
			Leave	34.8	1,068.2	0.53	%	5.66
	Hibiscus	176	Grains		139.5	4.18	%	5.83
			Residue		36.2	1	%	0.36
	Wild plant	2,583				1.12	%	28.93
	Livestock grazing	1,273				1.25	%	15.85
Outflow from village to market								
Sale	Millet panicles	67	Grains	63.9	43.1	1.82	%	0.78

Table 8 continued

	Crops	Quantity (Mg year ⁻¹)	Partition	%	Quantity (Mg year ⁻¹)	T-N content	Unit	T-N (Mg year ⁻¹)
			Lead	18.2	12.3	0.39	%	0.05
			Residue	17.9	12.1	0.39	%	0.05
Sale	Cowpea grains	22				3.96	%	0.88
Seed for next season								
Millet	Millet panicles	101	Grains	63.9	64.3	1.82	%	1.83
			Lead	18.2	18.3	0.39	%	0.07
			Residue	17.9	18.0	0.39	%	0.07
Cowpea	Cowpea grains	7				3.96	%	0.26
Inflow to village								
Farmland	Millet panicles	3,567	Grains	63.9	2,279.3	1.82	%	41.48
			Lead	18.2	648.8	0.39	%	2.53
			Residue	17.9	639.1	0.39	%	2.49
	Millet grains	2,279	Millet bran	18.7	426.2	1.82	%	7.76
			Millet flour	81.3	1,853.1	1.82	%	33.73
Local market	Millet panicles	555	Grains	64.0	355.0	1.82	%	6.46
			Lead	18.2	100.9	0.39	%	0.39
			Residue	17.9	99.4	0.39	%	0.39
	Millet grains	355	Millet bran	18.7	66.4	1.82	%	1.21
			Millet flour	81.3	288.7	1.82	%	5.25
	Cowpea grains	68				3.96	%	2.69
Livestock feed								
	Millet leaves	1,592				0.53	%	8.44
	Cowpea shells	47				0.97	%	0.46
	Cowpea fodder	57				2.06	%	1.18
	Hibiscus grains	140				4.18	%	5.83
	Hibiscus residue	36				1.00	%	0.36
	Wild plant	2,583				1.12	%	28.93
House								
	Millet stems	2,978				0.39	%	11.61
Threshing residue								
	Millet lead	750				0.39	%	2.92
	Millet residue	738				0.39	%	2.88
Transported manure								
	Organic matter	584				0.39	%	2.28
	Farmyard manure	951				1.25	%	11.88
	Soil	2,031				0.20	g kg ⁻¹	0.41
Livestock excreta								
	Livestock feces	1,273				1.25	%	15.85
	Livestock urine (L)	69				2.98	g kg ⁻¹	
			Volatilization	50.0				0.00
Inflow to farmland through human excrement								
	Nightsoil	925						11.78

Table 8 continued

Crops	Quantity (Mg year ⁻¹)	Partition	%	Quantity (Mg year ⁻¹)	T-N content	Unit	T-N (Mg year ⁻¹)
Inflow through air							
Harmattan dust		Adjacent farmlands (ha)	52.5		3.00	kg ha ⁻¹	0.16
		Threshing farmlands (ha)	157.6				0.47
		Transported-manure farmlands (ha)	607.2				1.82
		Corralling farmlands (ha)	553.5				1.66
		Extensively managed farmlands (ha)	8,772.4				26.32

to be improved in order for the available nutrients to be efficiently managed. Human excreta, threshing residue, and transported manure were considered to be the major channels for the return of nitrogen to the farmlands. Human excreta were returned to AF, threshing residue was returned to TF, while transported manure was returned mostly to TMF.

Although these returns were supplemented by nutrients from Harmattan dust, its contribution to each type of farmland was small compared with the nutrients collected and returned by human activities, which eventually resulted in overloading of nitrogen in the above mentioned farmlands. As shown in Table 10, nitrogen balance was calculated as being 2–14 Mg-N year⁻¹ of total balance (4–262 kg-N ha⁻¹ year⁻¹ of unit balance).

This implies that nutrient utilization for crop production was not efficient in the study site owing to certain agricultural practices as well as social/religious norms. Although CF showed better nutrient balance than the other types of farmland, the approach used for this type of farmland might not be sustainable owing to the decline in the number of Fulani households (Shinjo et al. 2008).

Drought and other harsh environmental conditions have always been an obstacle to crop production and local livelihoods in the Sahelian zone. Low precipitation and a fluctuating rainfall pattern tend to promote crop failure. Low germination was also identified as a problem, which is caused by low-quality local seeds as well as damage to young seedlings by sandstorms (Bielders and Klaij 1998); this eventually results in a lower crop density than that sowed. AF is supposed to be a suitable area for cowpea production because of its

relatively high nutrient availability. The survey results showed that cowpea was grown relatively close to the village (0–1,000 m) although, because of lower plant density, total production was not as high as that of millet. Moreover, local farmers dislike using AF for intensive crop production with cowpea for sanitary and religious reasons because landrace cowpea variety is a creeping-type. This is despite the fact that erect and semi-erect types of cowpea have already been developed by research institutes and, in fact, some of these varieties have already been introduced into the area (Ly et al. 1998). However, poor distribution systems have impeded the spread of these varieties among farmers (Matsunaga et al. 2006). If these new varieties were more widely available, more efficient nutrient use could be achieved. Another way to improve the efficiency of nutrient use is to consider the use of traditional cowpea varieties from a different perspective. Owing to sensitivity to pests and diseases, cowpea cultivation is more labor-intensive than that of millet or hibiscus. Farmers are forced to attempt to counter these difficulties manually as the high cost of pesticide precludes its purchase. As such, the yield of cowpea was greatly reduced as no adequate treatment was applied during the cropping season (Matsunaga et al. 2006). As a result, the majority of cowpea harvest was from fodder production, which is less sensitive to pest and disease stresses than grain production. Growing a variety of cowpea that is a specific and suitable variety with fodder would be less labor and cost-intensive and could generate income through trading at local markets.

Since data on livestock and human excreta were obtained from secondary sources (Somda et al. 1997;

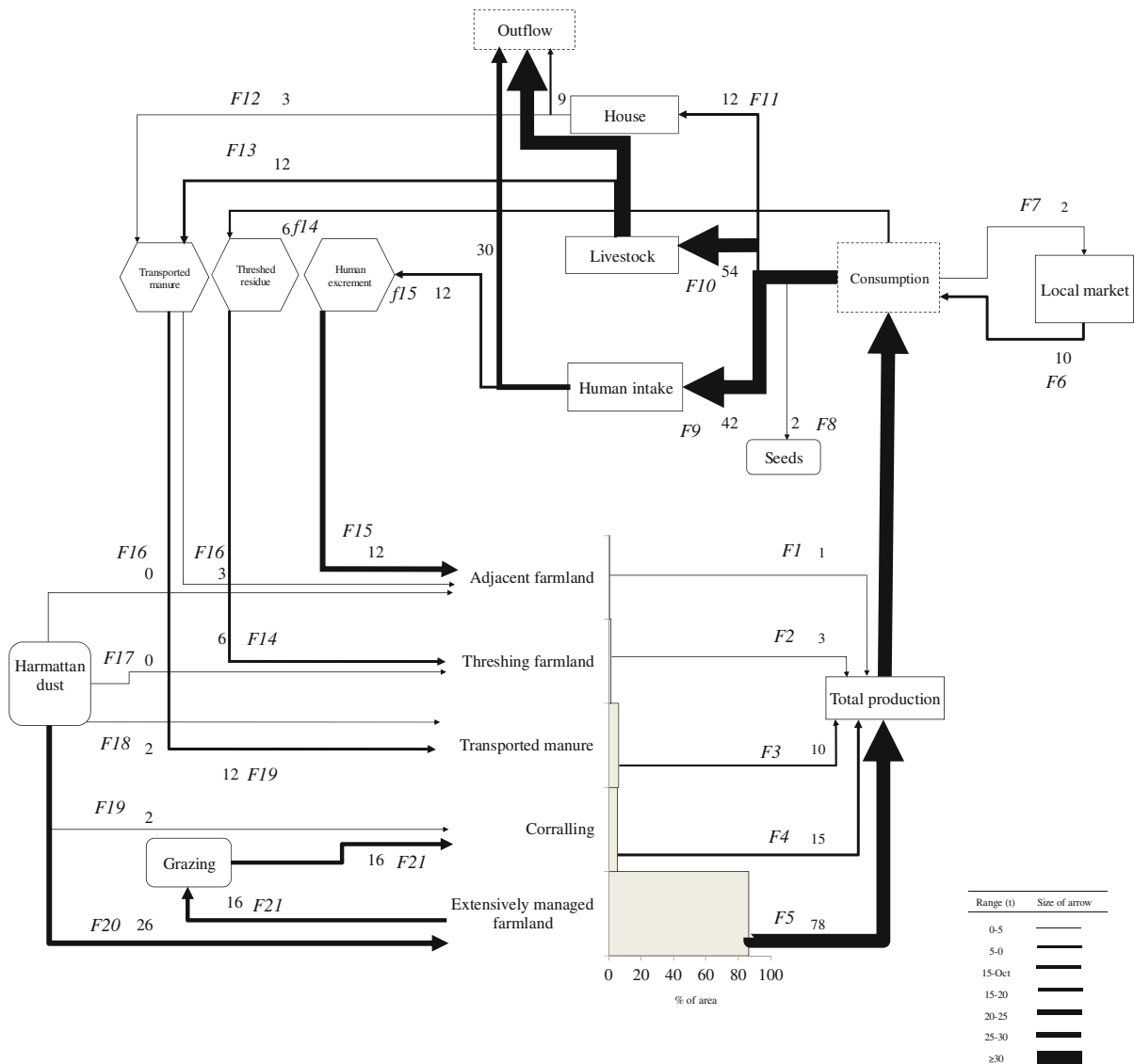


Fig. 4 Estimation of nitrogen flow within the village-farm model in the study area

Powell et al. 1998; Matsumoto et al. 2010), uncertainties may be taken into consideration and some possibilities on the variation of results might be expected. Therefore, the actual nitrogen flow in the area focused on in this study may differ from the estimated values. Although phosphorus is essential and one of the limiting nutrients for crop production, this study focused on nitrogen as a major nutrient component of locally available organic matter. In order to obtain a more comprehensive understanding of the nutrient flow in the Sahelian zone, future studies could focus on both phosphorus and nitrogen.

Conclusion

This study showed that agricultural production in the location where this study was carried out is heavily dependent on EMF. However, owing to high nitrogen output but negligible input in EMF, nutrient management was poor, as reflected in a negative nutrient balance of $-7.7 \text{ kg-N ha}^{-1} \text{ year}^{-1}$. On the basis of the ratio of nitrogen output to input, nitrogen utilization in AF, TF, and TMF farmlands was found to be inefficient. Besides the nutrient balance in farmlands, the large loss of nitrogen from livestock feed and

Table 9 Calculation of types of nitrogen flow

No. of flow	Calculation
F1	\sum (Grains, lead, residue/millet panicles) + \sum (Grains, lead, residue/millet stem and leaves) in adjacent farmland
F2	\sum (Grains, lead, residue/millet panicles) + \sum (grains, lead, residue/millet stem and leaves) + \sum (grains, shell, fodder/cowpea) in threshing farmland
F3	\sum (Grains, lead, residue/millet panicles) + \sum (grains, lead, residue/millet stem and leaves) + \sum (grains, shell, fodder/cowpea) in transported manure
F4	\sum (Grains, lead, residue/millet panicles) + \sum (grains, lead, residue/millet stem and leaves) in Corralling
F5	\sum (Grains, lead, residue/millet panicles) + \sum (grains, lead, residue/millet stem and leaves) + \sum (grains, residue/hibiscus) + \sum (livestock grazing) in extensively managed farmland
F6	\sum (Grains, lead, residue/millet panicles) + \sum (cowpea grains) in inflow to village
F7	\sum (Grains/millet panicles) + \sum (cowpea grains) in outflow from village to market
F8	\sum (Grains/millet panicles) + \sum (cowpea grains) in seed for next season
F9	\sum (Millet flour/millet grains/farmland) + \sum (Millet flour/millet grains/local market) + \sum (cowpea grains) in inflow to village
F10	\sum (Millet bran/millet grains/farmland) + \sum (millet bran/millet grains/local market) in inflow to village + \sum (millet leaves, cowpea shells, cowpea fodder, hibiscus grains, hibiscus residue, wild plant) in livestock feed
F11	\sum (Millet stems) in house
F12	\sum (Organic matter, soil) in transported manure
F13	\sum (Farmyard manure) in transported manure
F14	\sum (Millet lead, millet residue) in threshing residue
F15	\sum (Nightsoil) in inflow to inflow to farmland through human excrement
F16	\sum (Adjacent farmland/harmattan dust) in inflow through air
F17	\sum (Threshing farmland/harmattan dust) in inflow through air
F18	\sum (Transport manure/harmattan dust) in inflow through air
F19	\sum (Corralling/harmattan dust) in inflow through air
F20	\sum (Extensively managed farmland/harmattan dust) in inflow through air
F21	\sum (Livestock feces, livestock urine) in livestock excreta

Table 10 Nutrient balance (total nitrogen) of the farmlands in the study area along with the type of land management

	Area (ha)	% of total area	Input (Mg)	Output (Mg)	Total N balance (Mg)	Unit N balance (kgN ha ⁻¹)
Recycling						
Adjacent farmland	52.5	0.5	14.6	0.9	13.7	261.8
Threshing farmland	157.6	1.6	6.3	2.9	3.4	21.5
Transported manure	607.2	6.0	13.7	9.6	4.1	6.7
Corralling	553.5	5.5	17.5	15.2	2.3	4.2
Extensively managed farmland	8772.4	86.5	26.3	94.2	-67.9	-7.7

human consumption in the villages also resulted in inefficient nutrient utilization.

The results indicated that nutrient flow at the study site was unequally distributed and nitrogen was not recycled. Generally, for agricultural production in the

Sahel, nutrient deficiency is a ubiquitous problem due to inadequate resources. However, in this study, rather than a deficiency, it was revealed that nutrient supply at the studied site was not managed efficiently. Therefore, emphasis should be placed on the efficient

utilization of nutrient supply by reduction of loss from livestock feed and human consumption. At the same time, more research is needed for EMF to improve its management, including its current unfavorable fallowing practices. Improvement of current nutrient flow should be the most effective approach to improve production while campaigning for the use of commercial inputs.

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