International Atomic Energy Agency

Division for Africa Department of Technical Cooperation

PROJECT IAEA MLI/5/021

- -

Sustainable low input farming systems in Southern Mali:

use of isotopes methods in developing improved N fertilization of sorghum-based systems

Mission report

in Mali

03 to June 09, 2007

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IAEA Expert

June 2007

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THANKS

We make a point of thanking the general direction for the IER for having allowed us to carry out this mission, for its organization and the means placed at our disposal. Thank you also with the Delegation of Cirad for it support.

Our thanks go in particular to Boubacar Traoré co-ordinating of the Project, for its determination to make success this project and which spared no trouble so that our mission is most effective possible.

CALENDAR

Sunday 03/06/07
Arrival in Mali

Monday 043/06/07
Working session with B.Traoré after midday with the hotel

Tuesday 2053/06/07
Working sessions to the IER at Sotuba

Wednesday 063/06/07
Working sessions to the IER at Sotuba

Thursday 07/06/07
Visit in the rural community of Fana (village of Zanguena)

Friday 08/06/07
Working sessions to the IER of Sotuba
Meet with the Director of the station of Sotuba, Dr Doré Guindo

Saturday 09/06/07
Working session to the hotel with B.Traoré and G. Dembélé, professor of agronomy to the IPR of Katibougou.
Departure of Mali

ABBREVIATIONS LIST

CC = Cellular Content

IER : Institut d'Economie Rurale (Mali)

INRA : Institut National de la Recherche Agronomique (France)

IPR : Institut Polytechnique Rural de Formation et de Recherche de Katibougou (Mali)

LETHE : Laboratoire d'Etude de Transferts en Hydrologie et Environnement (France)

NDF = Neutral Detergent Fibre

NFix: part of total N of aerial part of plant derived from N_2 fixation expressed in N kg ha^{-1} or in proportion or in % of total N

OES: Optical Emission Spectrometer

OM: Organic Matter

PNT: Phosphate Naturel Tricalcique (Rock Phosphate)

SOM: Soil Organic Matter

TDR: time-domain reflectometry

1 – OBJECTIVES OF PROJECT MLI/5/021 AND OF THE MISSION

Project

To increase the production of Sorghum in Southern Mali by improving the effectiveness of N fertilization. Phase-I (2007-2008) will be devoted to the assessment of present soil fertility status, a survey of practices and crop yield (base line) in the study areas, and the initiation of developing improved N fertilization of sorghum production systems. Phase-II (2009-2010) will be devoted to complete the technology improvement, pilot-testing in farmers' fields for disseminating the new technologies.

Mission

a) to assess national capacities to conduct soil fertility investigations and advise on the establishment of the working team ; b) to refine the work plan of the project including guidelines for the experimental work ; c) to define the IAEA inputs (experts, training and equipment) required for implementing the project.

2 – STATEMENT OF THE PROBLEM

21 - Regional problems

Diagnosis: the soils and their use (Gigou et al., 1998; Traoré et al., 2004)

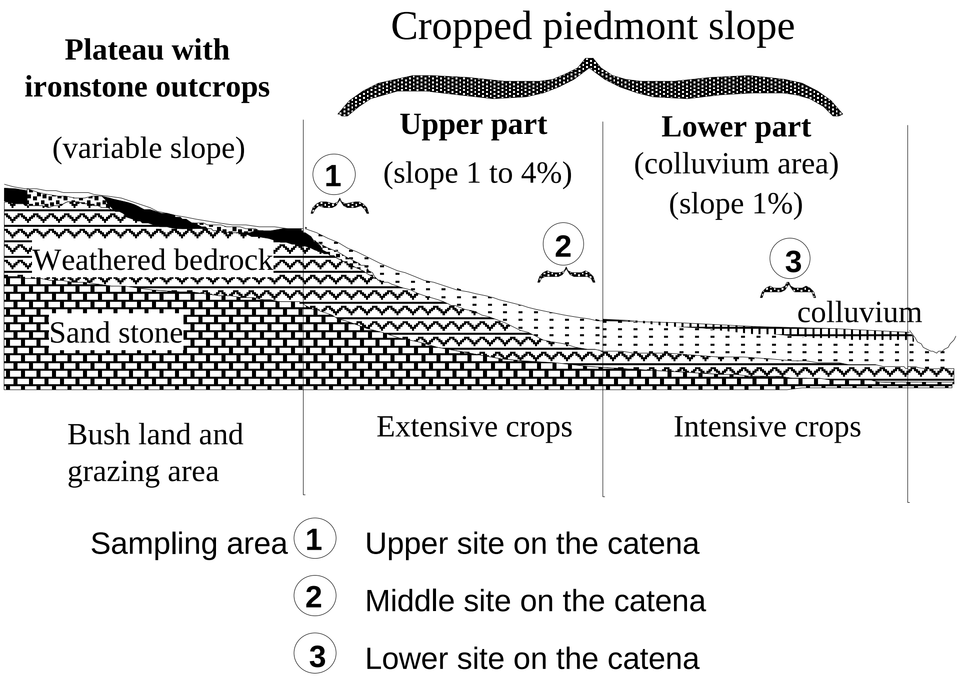
The soils are developed on sandy clays derived from Precambrian sandstone material containing pelites. In spite of the gentle slope (1-4%), they are affected, during drier of Quaternary era, by erosion in the upper part of slope and deposition of colluvium in the lower slopes (see schematic representation below). A typical soil catena is made of fossil ironstone pans at the top, then chromic luvisol, then gleyic luvisol (AISS/ISRIC/FAO, 1999). Soils at the top and in the middle of the slope may contain gravel. Those at the lower part may be affected by temporary periods of waterlogging during the rainy season. These soils were described by Pieri (1970) for the “arrondissement” (district) of Fana near to Konobougou (Table 1).

The upper site has been cleared recently. The middle site has been cultivated since 1956.

The bottom site has been cultivated for a long time, probably more than one hundred years. It was manually cultivated and regularly put under fallow until the 1960s. Then, around 1970, it was brought under oxen-ploughing and cultivation every year.

Table 1: Soil chemical analysis for a profile in the Fana area (Pieri, 1970)

	Mid slope soil				Luvisol gleyic unit			
Depth (cm)	0-15	15-35	35-70	70-95	0-9	9-20	20-45	45-75
pH in water	5.7	4.9	4.6	5.5	6.1	5.5	5.5	5.9
Clay %	4.8	7.0	9.6	25.2	13.5	30.1	45.9	
C %		0.35			0.51	0.39	0.33	
N mg g^{-1}		0.44			0.67	0.56	0.48	



Schematic representation from Traoré et al. (2004)

Three great types of soils are distinguished by peasants: (1) gravelly soils, (2) sandy soils, (3) black soils. The black soils are cultivated with cotton plant. They do not present current major problems of fertility; they are well provided in P because of the repeated fertilization of cotton plant but are threatened more and more by the deficiency in K because removal of minerals.

This diagnosis of the Research and of the Extension services corroborates the observations of the peasants who announce a fall of the soil fertility and a need increased for manure to face there (manure itself being more and more impoverished in K). With regard to N, fertilizer and manure seem to provide for it.

The sandy soils are traditionally little cultivated owing to the fact that strong constraints are opposed to their development: acidity, P depletion and risk of high run-off at the beginning of the culture. Since a few years, under the demographic pressure, they are cultivated more and more (sorghum, cowpea, watermelon) in spite of their brittleness and their low natural potential.

The gravelly soils are seldom cultivated, with millet if rainfall is sufficient, and constitute grazingland, zones of course for the animals.

A high priority: to upgrade this land of the middle site on the catena
The urgency to propose solutions to upgrade this area of sandy soils, let us to choose this zone to carry out our experiments, which implement in particular the isotopic techniques.

22 – State of knowledge

(1) Rainwater conservation based on contour lines (Gigou et al., 2006)

This land management use contours which was put into practice on an individual field scale. The main aim of the trial was to conserve rainwater in order to produce an immediate increase in yield. The results apply to the cotton-growing regions of Mali, Burkina Faso, and Northern Côte d'Ivoire where oxen are used for animal traction on gently sloping banks. The practice involves creating earthen ridges along the contours using an ox-drawn plough. The additional water infiltration is equivalent to about 10% of the total rainfall. The yield increase is around 30% and higher in dry years. This practice reduces annual yield variations. However, external help is needed for marking out the contours. This service is provided by an NGO from Koutiala at a modest price.

(2) The tree parkland management (Traoré et al., 2004)

In sudan-sahel zone, the traditional farming crops are often associated with trees. Application of these systems characterised by low input levels, have enabled farmers to obtain sustained production without any substantial changes in yields for over 20 years. It is therefore hypothesized and shown by (Traoré et al., 2004) that the tree parkland contributes in maintaining soil fertility and ensuring the sustainability of the farming systems. In Mali, the shea tree (*Vitellaria paradoxa*) that constitutes the principal tree of the parkland is quite sensitive to soil water availability: the trees are more numerous on the bottom of the catena that benefits from runoff. Farming systems based on contour lines improve the rainwater conservation and as such facilitated the young tree regeneration. These trees, in turn, improve the infiltration of rainwater. Through their leaves, the shea trees restore nutrients to the soil. In addition, CaO and MgO allowed to prevent soil acidification. Leaves from shea trees efficiently fertilise crops, mainly due to their rapid decomposition.

(3) Soil organic management: importance of organic manure (Ganry et Badiane, 1998)

The soil organic management must aim two major functions: to maintain or increase the humus stock of soil (amendment function), to mainly ensure the plant nutrition (fertilization function)

Amendement function

The agricultural development of tropical sandy soils is often hindered by the fact that the decay of SOM is much more rapid than in clayey soils. This acceleration results not only from the low level of clay but also from the pattern of hygrometry throughout the year, both emphasizing the oxidation of organic matter. The phenomenon is made all the more intense by the low soil protective colloids content. The main question is: what is the relation between the SOM and land productivity? Until the 1990s, the literature assumed that the relation between SOM and productivity was more or less linear.

Today, many authors admit the existence of a critical SOM content in tropical zone, below which the sustainability of the crop productivity and the conservation of the resource ground are not ensured any more because of a degradation of the properties of the soils significant and irreversible (sheet erosion). Other indicators in organic and/or biological matter are to be taken into account to maintain the SOM stock on a sufficient level.

The quality of the OM added or the cover crop is an essential factor in C storage in the soil. Besides the C/N ratio of OM is an essential indicator but not sufficient to characterize it. Plant materials with a high C/N ratio can markedly enrich the soil in C as long as the fibre/cell content (NDF/CC)[1] is high enough (for example, composted groundnut pods which have an NDF/CC ratio of 28). In contrast, sorghum straw has the same C/N ratio but contains less fibre (NDFF/CC = 0.8) and when added to the soil will induce over-mineralization of the SOM. This leads to a clearly negative SOC balance.

For that, one recommends composted organic matters (i.e. composted manures) and/or the agroforestry (i.e. the parkland) whose leaves answer condition of quality.

Fertilization fonction

[1] NDF = Neutral detergent fiber ; CC = cellular content

To give an order of magnitude, here is two estimates: in Senegal one ton of fresh manure (45% dry matter) produced in stalling during the rainy season, with weekly provision of straw and including 35% humiferous soil[2] returns the following [minimum, maximum] amounts in kg to the soil: N [5.0, 6.0], P_2O_5 [1.5, 2.0], K_2O [6.5, 7.0], MgO [2.5, 3.0] and CaO [4.0, 4.5]. Five ton of manure per ha (a realistic quantity for the sudan-sahel zone) containing 45% dry matter including humiferous soil would provide approximately 30 kg N, 10 kg P_2O_5 and 35 kg K_2O. In Burkina, similar median values were found: 23 N, 8 P_2O_5 and 34 K_2O but did not specify the percentage of soil in the manure.

One sees all the interest of organic manure in the systems with low-input crops, especially since the farmers concentrate their manure on more reduced surfaces, what increases the amount per unit area.

3 – RESEARCH PROJECT

31 – Strategy implementation to increase soil fertility

The sustainability of future sorghum-based systems will depend on our ability to combine agrosylvopastoral innovations and enhanced knowledge on the functional ecology of the catena. This strategy is founded upon five practices:

(1) Increase soil water availability
Farmer-led contour ridging can reduce water runoff in African savannahs. This field reorganisation improves the rainwater conservation and as such facilitated the young tree regeneration. These trees, in turn, improve the infiltration of rainwater
(2) Increase number of trees
Through their leaves, the trees (mainly shea trees: *V. paradoxa*) can restore to the soil fertility and in addition, CaO and MgO allowed to prevent soil acidification. Leaves from shea trees efficiently fertilise crops, mainly due to their rapid decomposition.
(3) Rock phosphate application
Soils of upper and middle site on catena don't receive fertilizer except rock phosphate (PNT).
(4) Promoting the N_2 fixation (NFix) of the grain legume.
The 3 major sources of N are fertilizer, manure and legume NFix. NFix can improved Nfertility of soil directly through root system or indirectly through manure (via the straws consumed by the animals). N fertilizer is applied on cotton plant at the lower site of catena but not on the others soils. Organic manure is applied on the cultivated whole of the soils but especially with the not very fertile soils. One thus sees all the importance of legume plant and the manure for upgrading the sandy soils
(5) Increase quality and quantity of manure
Traditional manure often called "poudrette" contains sand, is not composted and is of poor fertilizing, sanitary and organic quality, reason for which we have to improve organic manure.

IAEA project contributes to the study of points 1, 4 and 5

32 – The field trials: location and experimental design

[2] Humiferous soil is the last layer of manure in contact with the soil in a manure pit or stalling.

Field trials are farm-scale-tests; they were carried out in the Zanguena village (close to Fana, to 120 km in the Western North of Bamako) with the agreement and the participation of the peasants.

The major types of soils are indicated to us by the peasants (see above). The trials are located in the sandy soils zone (2). Each experimental design is a two-level factorial design (split block) with 5 replicates: 3 principal treatments (3 varieties of cowpea in crop rotation with sorghum) and 2 secondary treatments (with or without organic manure) (annexe a, figure 2).

In the village, the 3 trials are carried out in 3 different peasants. Each peasant uses a variety of sorghum given: Miksor86-30-01, Midsor88-10-01 or Mipsor90-30-23. The objective is to specify the agronomic performance of each one of these varieties for a same cropping system and operational sequence (annexe a, figure 3).

It is a multiannual experiment envisaged on 4 years. The location of the plots with application of ^{15}N in 2007, 2008, 2009 and 2010 must be now planned (annexe a, figure 2).

321 - Fertilization

Let us remind that in the implemented strategy, the N source is NFix provided to the plant directly and via organic manure, the K source is organic manure and the P source is PNT. But this system will be able to reach its maximum effectiveness only at the end of several years (in particular for K and P). This research project is situated on short time (4 years); therefore, a dressing of P and K must be applied.

The whole of the trials receives mineral fertilizer (P and K) and rock phosphate for correcting P deficiency and acidity of soil.

322 - Varieties

Cowpea: V1; V2; V3
Reference crop: soybean var. G 116 or 117 (100 days); sorghum var. Malisor 92-1 (95 d)
Sorghum (cultivated in 2008): var. 30-41 or 10-01 extended in rural community[3] .

33 – Isotopic techniques implementation (study with ^{15}N)

These techniques are implemented for:
- measurement of the N_2 fixation of cowpea (NFix)
- measurement of the efficiency of the organic manure on sorghum

331 – Measurement of the NFix

[3] These varieties were selected and on-farm experimented with the support of the IAEA.

The A-value method (AV) is used:

- measurements will be carried out in 2007 and 2009;

- choice of reference crop (or *non-nod*) : use of two non-nod is highly desirable when we cannot use the same variety for *nod* and *non-nod*. We try to find *non-nod* with the following conditions: date and duration of sowing-harvest period, depth of root system and N uptake pattern, are the same than cowpea. Unfortunately these variables differ always more or less from those of the nod, reason for which it is preferable to have at least two *non-nod*. We retains, in fine, *non-nod* which presents higher atomic excess. This concern of exactness is necessary in the method AV whose validity is often called into question. In this respect, we chose a variety of sorghum with short straw (Malisor 92-1) and a variety of soybean (G 196 or 197). The first, as a matter of fact, is a *non-nod*, and second is potentially *nod* but its fixing capacity is low in soil never cultivated with soybean and in absence of inoculation by *Rhizobium japonicum*. These two non-nod are cultivated on only one sub-plot (see diagram annexes a).

- labelled fertilizer is applied under liquid shape (not under solid) for reasons of homogeneity of the mixture "fertilizer not labelled" and "fertilizer labelled". The experimental procedure of preparation and application to the soil of the labelled fertilizer is illustrated in annexe b.

332 – Measurement of organic manure efficiency on sorghum (in 2008 and 2010)

Indirect technique (A-value method) will be used to study plant N uptake from manure. ^{15}N tracer is added to the soil and treatments with and without manure (no-manure controls) are set up. But it is important not to add ^{15}N label and manure simultaneously for avoiding the effects of pool substitution which makes the method inappropriate. Soil pre-labelling can be applied by adding a carbon source and ^{15}N fertilizer simultaneously to soil.

34 – Water balance monitoring

The main constraint of NFix is moisture stress. When moisture is decreasing, NFix is affected by moisture stress before plant growth. In this respect, it is very important to measure moisture in the root profile of legume (cowpea) during growing season (with probes TDR) and to simulate water balance. It will be also important to measure the effect of control methods against run off on moisture content in the root profile of trees therefore on a depth greater than the previous (with neutron probe).

4 - THE RESPONSIBLE TEAM

This team is made up specialists in laboratory questions (one laboratory technician) and agronomic questions (three researchers from IER and a teacher from IPR of Katibougou) under coordination of Boubacar Traoré.
Laboratory: Mahamadou Soumaré, laboratory technician, trained in 2002 at the LETHE of Grenoble (France) to the use of the neutron probe, and in 2005 at the INRA of Bordeaux to the measurement techniques of phosphorus
Water balance: Kalifa Traoré **(**IER),

Farming system: Diby Diakité (IER),
Biological N_2 fixation: Gabriel Dembélé (IPR Katibougou),
Rural extension: Mrs. Diarra (IER)

5 – NEED OF LABELLED FERTILIZER AND ^{15}N ANALYSES

51 - Labelled Fertilizer

Need for 3 kg urea a.e 10 % (in 2007, B Traoré used the sulphate of ammonia that it had in stock is 4,4 kg of sulphate a.e 10 % equivalent to 2,1 kg urea**)**

52 - ^{15}N analyses

Normally these analyses should have been made in Dakar by Mrs Fatou Gueye on the optical emission spectrometer (OES) but this apparatus is out of order and must be repaired by IAEA. Our proposal which has the approval of Mrs. Fatou Gueye and Boubacar Traoré: we take into account repair of the OES Dakar apparatus at the end of 2007. Then, we envisage a formation about the analyses ^{15}N on the OES for Mahamadou Soumaré (see § 4 above) which would benefit from it to carry out the analyses ^{15}N.

Our point of view: we think that at present in western Africa, it would be desirable to have two laboratories which can measure the ^{15}N (Dakar and Bamako) which coordinate themselves for these measures; therefore, if one of two device is out of order, the other one assures (insures) the dosages.

6 – NEED OF EQUIPMENT

- probes TDR (time-domain reflectometry) for soil water content measuring under grain legume (cowpea) http://www.sdec-france.com/produits.php?numprod=158&lg=fr ;
- two automatic voltage stabilizers and Uninteruptible Power Supply (UPS) equipment. The UPS will maintain electric power for about 30 minutes after a disruption in supply. The recommended specifications for the automatic voltage regulators are as follows: Input: 180-250 V; Output: 220 V; Power: 2 KVA; Frequency: 50 Hz; Phase: Single Wave form: Sine wave;
- one optical emission spectrometer (already envisaged).

7 – NEED OF TRAINING

71 - Fellowship:

- 1 fellowship 3 m/m for OES (optical emission spectrometer) used.
  Suggestion: Mahamadou Soumaré; end of 2007; Dakar.

- 1 fellowship 2 or 3 m/m for studing the biological potentiality of arid soils in relation with their constraints (i.e water balance, acidity). Suggestion: one researcher coming from research unit of G. Dembélé (IPR Katibougou); end of 2007 or 2008; Laboratoire des symbioses tropicales et méditerranéennes (UMR Lstm), Dr Marc Neyra specialist of these questions.

72 - Visite scientifique:

- 1 visite scientifique for Boubacar Traoré in 2007 to Montpellier at UMR Lstm (Dr Marc Neyra above mentioned);

- 1 visite scientifique for Boubacar Traoré in 2008 to Dakar at ISRA/IRD laboratory (Mme Fatou Gueye)

- 1 visite scientifique for Mme Aminata Diarra (IER) in 2009 on adaptative research and farmer participatory (our purpose is to adapt technical innovations in a whole of socio-economic and environmental conditions, particularly our approach in this project).
Suggestion: Cirad

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Annexe a

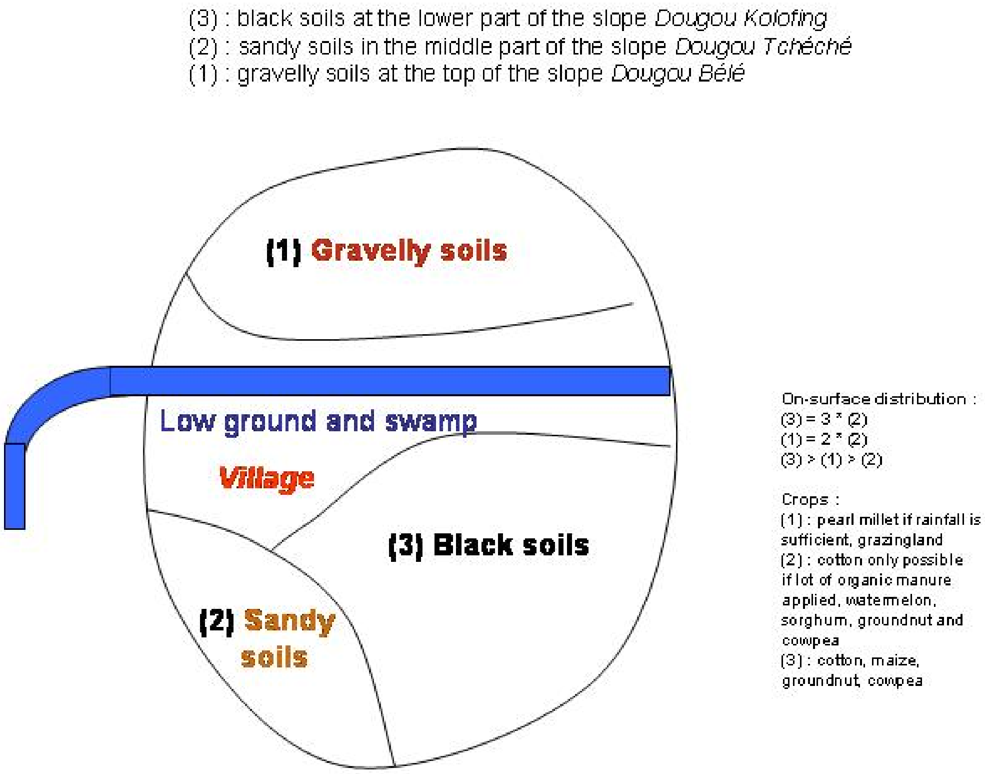

Figure 1 : Distribution of the 3 types of soils in Zanguena village

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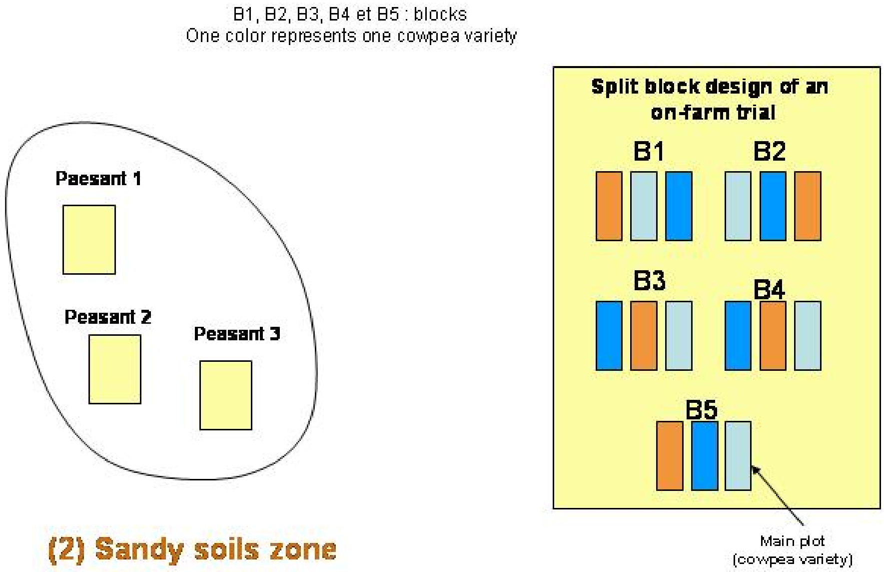

Figure 2 : Location of the various trials in the village area. Zanguena village

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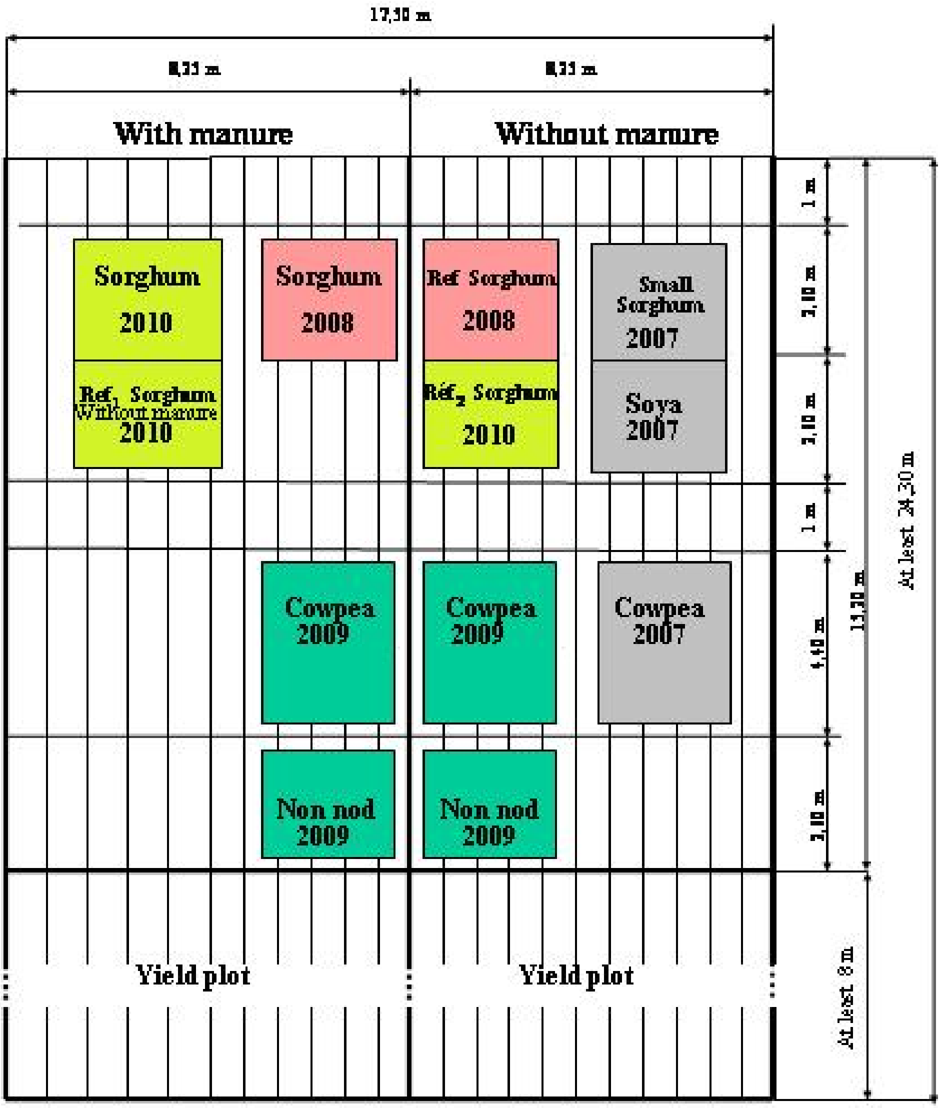

Figure 3 : Main plot of split block design : it indicates the location of ^{15}N plot planned on 2007-2010 (dates indicate the year of ^{15}N application).
Crop rotation : cowpea in 2007 and 2009, and sorghum in 2008 and 2010.
A more detailed ^{15}N plot is illustrated at figure 2.

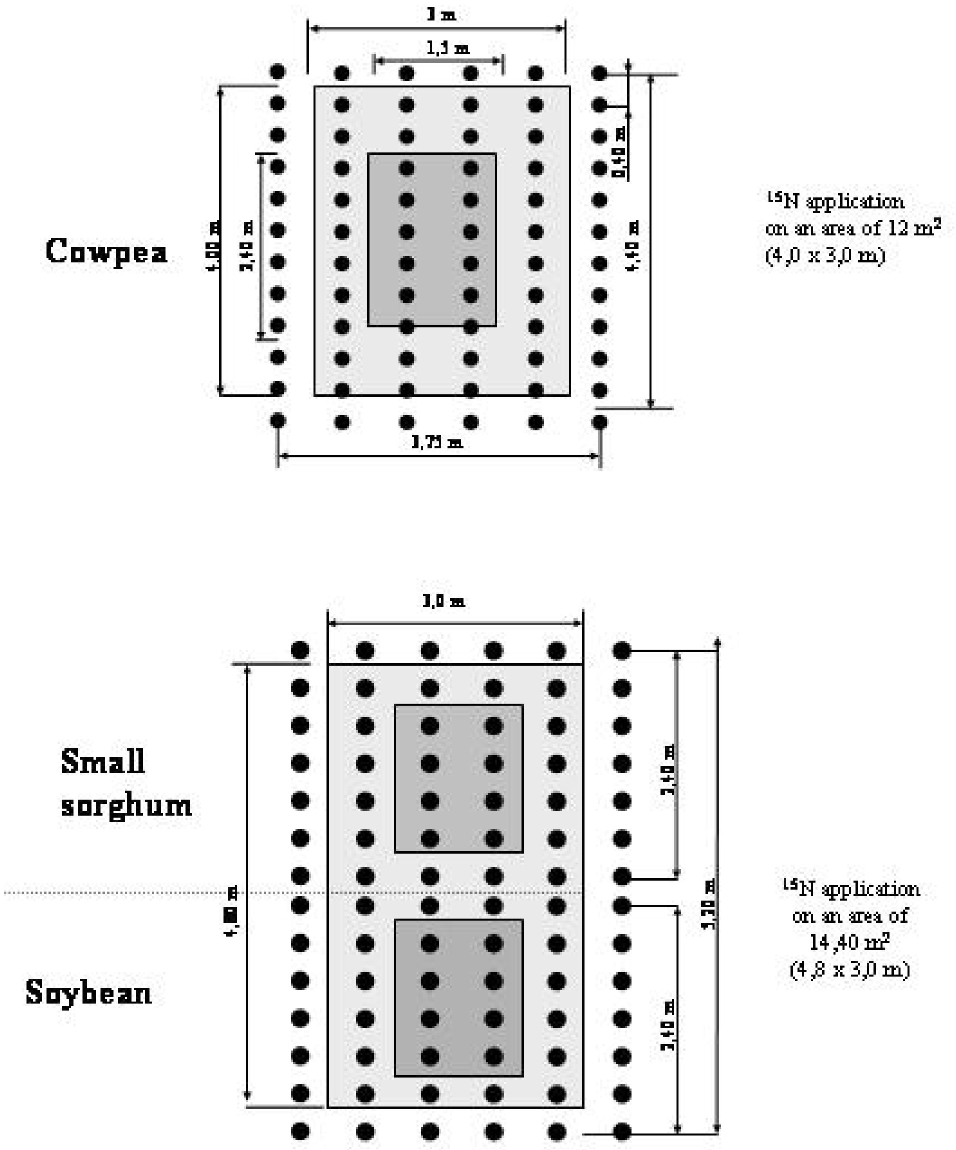

Figure 4 : Schematic layout of ^{15}N plot for a 75*40 cm space between the plants

Annexe b

Modalité pratique d'apport de l'engrais marqué

(This protocol was discussed and handed to B.Traoré during our mission so that he can start the implementation of the trials)

1 – <u>Calcul des quantités</u>

3 sites x 3 variétés x 5 répétitions = 45 parcelles ^{15}N

11 – Parcelles en niébé

Surface parcelle = 12 m^2
Surface totale = 540 m^2
Dose N apportée = 15 kg N ha^{-1}

Q sulfate marqué à 1,5 % nécessaire :

$$1g \times \frac{1000 \times 15 \times 540 \times 100}{10000 \times 21,2} = 3820 \text{ g arrondi à } 3850 \text{ g}$$

3850 g sulfate marqué à 1,5% soit 577 g de sulfate à 10 %, arrondi à 580 g

12 – Parcelles « non nod »

Surface parcelle = 14,4 m^2
Surface totale = 648 m^2
Dose N apportée = 80 kg N ha^{-1}

Q sulfate marqué à 0,17% nécessaire :

$$1g \times \frac{1000 \times 80 \times 648 \times 100}{10000 \times 21,2} = 24453 \text{ g arrondi à } 24500 \text{ g}$$

24500 g sulfate marqué à 0,17 % soit 416 g de sulfate à 10 %, arrondi à 420 g

2 – <u>Modalités d'apport</u>

21 – Parcelles en niébé

Peser 577 g de sulfate à 10%
Peser 3850 – 580 = 3270 g de sulfate normal
Dissoudre ces 2 quantités dans un volume de 3 à 4 l d'eau. Dans une bonbonne avec robinet apporter la solution de sulfate ainsi préparée plus un complément d'eau de façon à obtenir 9100 ml exactement. *Ceci constitue la solution mère*

Sur le terrain, on choisit de prendre un volume déterminé i.e 200 ml de cette solution qui sera apportée sur chacune des parcelles : pour ce faire, on étendra ces 200 ml à environ 2 l qu'on épandra par un arrosage le plus uniforme possible. Le reliquat, soit environ 100ml sera conservé au réfrigérateur.

22 – Parcelles « non nod »

Peser le reste de sulfate à 10%, soit 420 g
Peser 24500 – 420 = 24080 g de sulfate normal

Appliquer le même protocole que précédemment avec la variante suivante liée au fait qu'il y a une grande Q de sulfate à dissoudre.

Prévoir de commencer la dissolution des 25 kg de sulfate dans environ 12 l d'eau puis étendre exactement à 18100 ml.

Sur le terrain, on prendra exactement 400 ml de cette solution mère qu'on apportera par parcelle ^{15}N : pour ce faire, on étendra ces 400 ml à environ 2 l qu'on épandra par un arrosage le plus uniforme possible. Le reliquat, soit environ 100ml sera conservé au réfrigérateur.

3 – <u>Besoins engrais et matériel</u>

- besoin en sulfate marqué à 10% = 580 + 420 = 1000 g ; besoin en sulfate normal : 3270 + 24080 = 27350 g ;
- besoin de verrerie : un ballon de 3 ou 4 l ; fiole de 2 l et/ou éprouvette de 1 l ; fiole de 200 ml et 400 ml (pas obligatoire pour ces dernières) ; petits flacons plastiques pour mettre le reliquat solution mère ;
- besoin d'une bonbonne avec robinet de 10 l et de 20 l.