Innovation systems co-design report (cropping and farming systems) in Senegal

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1. Introduction

The strategy of the WP1 of the Agroecology Initiative in Senegal was to build on the systems co-design activities of the FAIR Sahel project. The results of these activities have been fed into discussions within the LLA, and hence at DYTAEL in Fatick, with the aim of providing project partners with scientific evidence that could be used for advocacy.

Agro-ecological intensification (AEI) can provide sustainable solutions to help producers in the Sahel develop agriculture that is more resilient to climatic hazards and increase their food security. Technical solutions exist, but they often need to be adapted, optimized and combined into innovative agro-ecological intensification systems, thanks to a new dynamic of collaboration between research, development and farmers. Institutional actors interacting with farmers at local level (local research, education and training institutions, development actors, NGOs, producer associations, private market and commodity chain actors, etc.) also need support to better understand the benefits of AEI and to be able to support its development.

The general objective of the FAIR Sahel project is to create the conditions for small-scale producers in the Sahel to adopt innovative agro-ecological intensification (AEI) technologies that will enable them to manage resources more efficiently and sustainably, improve their incomes and make their farms more resilient to climate change in the three project countries. A more specific objective is to redefine the role of research so that institutional, political and technical actors have access to the necessary knowledge to provide effective support to organized and willing producers and create favorable conditions for AEI.

The FAIR Sahel project is financed by the European Union and the French Development Agency. It is implemented by a consortium of 13 partners (AMSP, AOPP, AVSF, CIRAD, CSIC, ENDA Pronat, IER, INERA, IRD, ISRA, UNCPB, WUR and ZALF) with the support of 5 third parties (AGRISUD, CARI, DIOBASS, GRAAP and GRET). The interventions covered Burkina Faso, Mali and Senegal for a period of 4 years (2021-2024).

In Senegal, the FAIR Sahel project worked at different scales to co-design systems (plot, farm and territory). The report refers to work at plot and farm level in the Sudano-Sahelian dry cereal and legume zone, in the communes of Diouroup and Ndiob (Fatick region) in the peanut basin of Senegal.

2. Codesign of agroecological technologies and trials

The aim of the cropping system co-design activity was to co-construct multidimensional agro-ecological intensification systems with producers, while ensuring a privileged/balanced role for women and young people. Specifically, the aim is to: (1) adapt options and systems to farmers' contexts; (2) understand farmers' evaluation criteria; (3) help farmers evaluate innovative options and systems; and (4) help farmers innovate themselves.

The farming system co-design activities were carried out in the department of Fatick, specifically in villages of the communes of Ndiob and Diouroup, from 2021 to 2024 (Figure 1). The villages were selected according to the following criteria

- Villages visited during the preliminary diagnosis;
- Existence of agro-ecological initiatives;
- Located within a 30 km radius of the main town;
- High agronomic potential.

Thus, 14 villages were selected in the commune of Ndiob and 6 in the commune of Diouroup (Figure 1). It should be noted that some of the villages are small, similar to hamlets, hence the large number of villages.

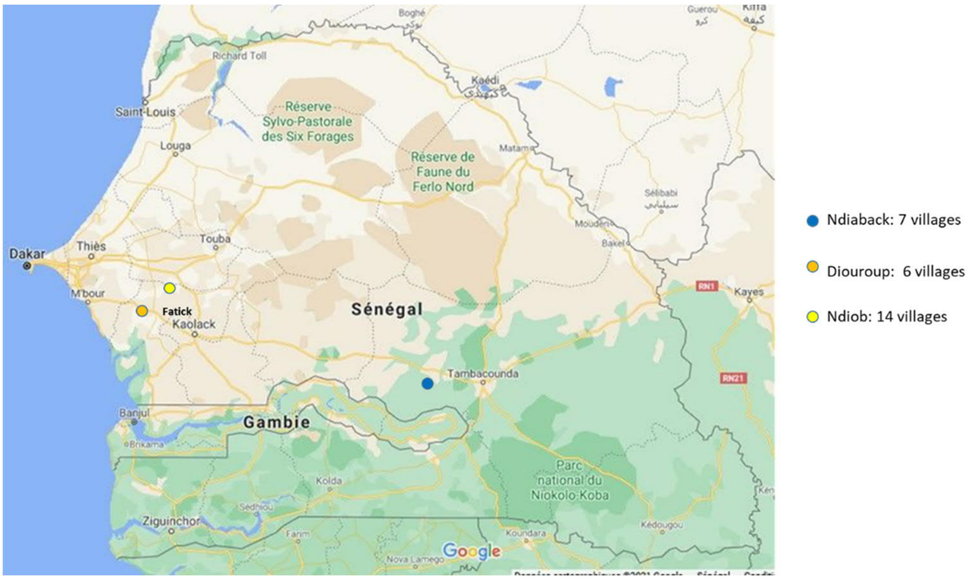


Figure 1: Map of the communes of the Fatick department (Ndiob and Diouroup) where the village workshops took place.

The different stages that made up the co-design activities of the farming systems were diagnosis, participatory prototyping, experimentation and co-evaluation. These different stages operated in a loop throughout the project. Different tools (workshops, experiments, etc.) were used during these different stages.

2.1. Diagnosis and prototyping

2.1.1. Diagnosis and prototyping methodology

An initial diagnosis was carried out to gain an overall understanding of the constraints on farming. A large survey was conducted for this purpose. However, as there were delays in analysing the survey data, a rapid diagnostic workshop was organised to move the process forward. To avoid falling behind in the first campaign, the rapid diagnostic workshop provided an opportunity to initiate prototyping. The workshop was organised in three sessions: (A) a brief presentation of the project idea, the workshop objective and the key concepts/principles of agroecology, (B) feedback and validation of the salient findings of the pre-diagnostic and other constraints/values of the current systems, and (C) identification, using a rapid diagnostic approach, of innovations or options for agroecological intensification systems to be tested locally.

Session A was devoted to a presentation of the team and the partners present, followed by a presentation of the FAIR Sahel project, its objectives and components, and finally the objectives of the workshop. Following these presentations, discussions focused on the importance of agroecology for soil conservation and thus for future generations, on organic matter for sustainable agriculture, and on the role of women in healthy and sustainable agriculture, given their role in food production.

In session B, the results of the pre-diagnosis carried out earlier were presented. Following this presentation, a number of constraints were highlighted by the participants. To go one step further, this session provided an opportunity to identify and characterize current farming systems. The work was carried out along a transect through the community, from north to south in each community. The transect listed the different cropping systems along with their potential and constraints, soil types and different crop formations. Following this description, a zoning plan was drawn up showing the similarities and differences between the cropping zones of the commune. Discussions were held on the zoning factors (soil type, landscape, crop, cropping system (hut fields and bush fields), pest management, fertilization).

- Session C consisted of group work. Three groups (young people, men and women) were formed to work on 4 main questions:
- What are the constraints observed in the farming systems?
- What alternatives have been developed in the face of these constraints?
- Which of the alternatives did not work or were not effective?
- What options do they think should be tested or experimented with to improve farming systems?

A second workshop, this time for prototyping, was organised to confirm the different options with the farmers and also to define the technical itineraries for carrying out the tests. During this prototyping workshop, the stakeholders (researchers, technicians and farmers) discussed and selected the different systems to be implemented and the technical routes to be tested in comparison with the usual practices.

The workshops were held in April and May and were attended by farmers (men, women and young people) from the different villages, researchers (ISRA, CIRAD), the development service (NGO ENDA Pronat) and technical services (Agricultural Council, Water and Forests). It has helped to capitalise on the endogenous knowledge of producers, the field experience of technicians and the results of research.

Figure 2: Group work with women to identify constraints and agroecological initiatives in farming systems

2.1.2. Rapid diagnostic results

A total of 103 participants attended the workshops, including 24 women (23%). Different profiles were recorded: mainly local farmers, representatives of local technical services and other development actors working in the target villages.

2.1.2.1 Diouroup commune

The main constraints in the commune of Diouroup are presented below.

Youth groups

Question: 1 What are the constraints on local farming systems?

- Soil:

    o Increasing salinity.

    o Soil poverty (export of crop residues).

    o Insufficient OM on farms.

    o Gradual disappearance of fallow land

- Pests and diseases: Control of millet pests such as striga, leafminers, soum, nematodes in vegetables, other pests such as watermelon bugs and others.

- Obsolete agricultural equipment

- Water:

    o The water table is becoming too low for market gardening (around May and June the wells run out of water for market gardening).

    o Quality and quantity of water for horticulture

    o Manual pumping for market gardening (manual wells).

    o Reduced rainfall (delayed planting and early harvesting).

- Seeds:

    o Difficulties in preserving groundnut and cowpea seeds / attack by worms/sucking insects

    o Loss of old long-cycle millet varieties (e.g. Tialangue long-cycle millet).

    o Quality of vegetable seeds sold in the market, which are not resistant to fruit rot (for pepper 'burkina', for bitter aubergine 'keur mbir ndaw', 'keur mbir plus' and 'sokhna').

- Lack of agricultural land (unplanned urbanisation, population growth, loss of solidarity).

- Animals running at large (among themselves).

- Problems with the storage and sale of horticultural and agricultural products.

- Lack of labour due to the exodus of young people from the countryside.

Question: 2 What innovations/initiatives are there in existing AE practices in response to the constraints?

- Fertilization practices :

    o Combining crops, which also helps to maintain diversity

    o Use of soil taken from under the kadd as compost for nurseries or spread on crops.

    o Spreading OM to fertilise the soil.

    o RNA to regenerate the forest.

    o Practice of zaï, with fish residues obtained near Mbour.

- Groundnut shells to combat salinity (but in competition with fodder).

- Pest control practices:

    o Neem leaves to preserve groundnut seeds.

    o Bantamaré (cassia occidentalis) combined with vegetable crops to control nematodes.

    o Seed preservation by introducing broken millet 'sankal' into the groundnut seed, which attracts ants that attack all the larvae of groundnut seed predators.

    o Seed preservation in pits about 50 cm deep with layers of neem leaves.

- Practices to prevent weed growth: scraping and weeding the soil before sowing.

Question: 3 What innovations have you tried that didn't work? What do you think are the problems?

- Use of the Souna 3 variety (irregular rainfall, lack of control over the technical route, attacks by granivorous birds during early harvesting),

- Organic pesticides (soap, garlic, neem, papaya leaf and chilli) ineffective in preventing fruit rot in the vegetable garden.

Question: 4 Do you think there are other AE options/innovations that should be tested locally?

- Test the cultivation of maize, a staple food that saves millet stocks. Every month, a bag of maize is bought for 12,000 francs. Mastering the cultivation of maize will reduce expenditure because a bag of maize costs money).

- Trials of bio-pesticides to eradicate fruit rot in horticulture, especially tomatoes and peppers.

- Means to desalinate land and water for growing rice and vegetables.

Women's group

Question 1: What are the constraints on local farming systems?

Table 1 : Constraints on local farming systems enumerated by womens

Fields of huts	Bush Fields
Seeds: Quality/variety, seed preservation	
Soil: Difficulties in soil preparation (materials/equipment), fertilization problems, salinity	
Soil: Difficulties in soil preparation (materials/equipment), fertilization problems, salinity	Irregular rainfall
Lack of agricultural equipment	Overwork/exertion
Roaming animals	
Waste/recycling management: production, transport	
Phytosanitary constraints: caterpillars, mites, insects, squirrels .... etc.	

Question 2: What AE initiatives exist to address the above constraints?

- Seeds:
  - o Some women produce their own seeds (Fatou Diouf, Senghor village)
  - o Preservation with neem leaves and ash,
  - o Mixing millet and peanut seeds to preserve peanuts
  - o Mixture of sand + cowpea + chilli pepper
  - o Cow dung
  - o Sorting (weight aspect) of seeds
- Fertilization:
  - o Composting of household waste to bring to the bush fields
  - o Addition of organic manure
  - o Millet husks and peanut shells to combat salinity
  - o Biogas

o RNA practice

o Ploughing the soil without removing weeds to fertilize the soil

o Mulching with combretum reticulatum

o Neem-based liquid compost for spraying millet fields and for pest control.

- Pest control:

o Khaaya senegalensis bark mixed with water for pest control

o Use of 'Guédiane' to control termites in millet fields

o Oil + ash + water to control termites

Question 3: What innovations have you tried that didn't work / where do you think the problem lies?

- Local convention on divagation: problem of application due to family ties, conflicts, etc.
- Use of sanitary products on peanuts: lack of knowledge
- Off-season market gardening, micro-gardening, tree nurseries
- Tree planting (cashew, mango, lemon) + market gardening failed in Keur Martin: according to her, this may be due to the soil.
- Anti-salt dam in Senghor
- Use of chemical seed preservatives (tablets)

Question 4: Do you think there are other AE innovations that should be tested locally?

- Establishment of composting systems (collection/recycling) for field crops (groundnut, millet, cowpea)
- Awareness raising on the application of the local convention
- Household waste management
- Introduction of biopesticide production techniques based on local knowledge of cowpeas
- Seed preservation techniques based on local knowledge
- Adapted varieties
- Equipment
- Mulching techniques

Women's expectations

- Rice harvesters/combines
- Good quality vegetable seeds
- Red of Thies (okra seeds)

Men's Group :

Constraints

- Loss of soil fertility (there used to be many trees, but salinity has infiltrated the soil)
- Rainfall interruptions
- Seeds
- Pests and diseases
- Migration
- Farm machinery (replacement / quality)
- Deforestation

- Lack of training

Alternatives

- Adding organic manure
- Parking
- Chemical fertilizer
- Use of local seeds
- Neem tree to preserve seeds
- Physical barrier against flies on peanuts
- Initiatives for agricultural equipment with support from Enda through the creation of a village fund
- Government support (DPV)

Initiatives to be tested

- Conduct trials on millet and groundnut to increase soil fertility and yield (parking; adding organic matter; compost).

Recommendation

- Produce reports to be made available to the population to avoid repeating the same work for future donors.

2.1.2.2 Ndiob Community

The main constraints identified by the youth, women and men groups are listed in Table 2.

Table 2: Constraints affecting local farming systems and their prioritization enumerated by youth in Ndiob

Groupe 1 (MENS)	Groupe 2(WOMENS)	Groupe 3 YOUTH
- Soil poverty - Seed availability and quality - Lack of farm equipment - Availability of labour - Accessibility of pesticides - Rainfall - Marketing - Lack of arable land/dispersal of plots - Ageing of plantations	- Difficult access to land - Difficult access to farm equipment (draft animals, seeders, hoes, stump grinders, carts) - Drifting animals - Declining fertility and difficult access to inputs (seeds and synthetic chemical fertilizers) - Difficulty in mobilising family labour (lack of decision-making power) - Lack of power/skills to control pests - Salinity and lack of water Melting of vegetable seeds	1. Arable crops - Decline in soil fertility - Agricultural equipment (drill, hoe) - Insufficiency and quality of seeds (peanuts, millet) - Decrease in rainfall - Rainfall interruptions - Pest control - Seed preservation - Animal migration - Crop protection - Marketing - Training 2. Market gardening - Water scarcity and quality - Lack and quality of inputs - Livestock straying - Insufficient seeds - Equipment: motor pump, well - Pest control

		- Lack of marketing - Lack of training - Salinisation - Declining fertility

Access to inputs remains very difficult for women, who are sometimes replaced by their sons. There are several reasons for the decline in soil fertility: demographic growth has put strong pressure on resources, especially land; fallowing, which used to be used to restore the land, has become impractical; and the organisation of land, which would allow farmers and herders to rotate between grazing and cropping areas, has become very difficult due to lack of space. Livestock farming remains difficult due to the decline in pastureland.

In the light of these constraints, the various options proposed are set out in Table 3. These proposals were put forward by the various working groups in response to the question 'Do you think there are any AE innovations that should be tested locally?

Table 3: Basket of relevant AE options/innovations to be tested proposed by producers in the commune of Ndiob

Groupe 1 (HOMMES)	Groupe 2(FEMMES)	Groupe 3 (JEUNES)
Bushfields: use certified seeds, install a living hedge system, add organic matter (COMPOST and/or MANURE), combine the main crop (SOUNA 3 millet) with a legume (NIEBE BAYE NGAGNE).	Groundnut combined with a small amount of cowpea and fertilised with slurry Trials of pest control products/practices	Bush fields/case fields Combination: Millet/cowpea/M.O/fertilizer Cowpea is sown at the same time and has a 40 day cycle. Vegetable crops: Mulching/Wind on water efficiency

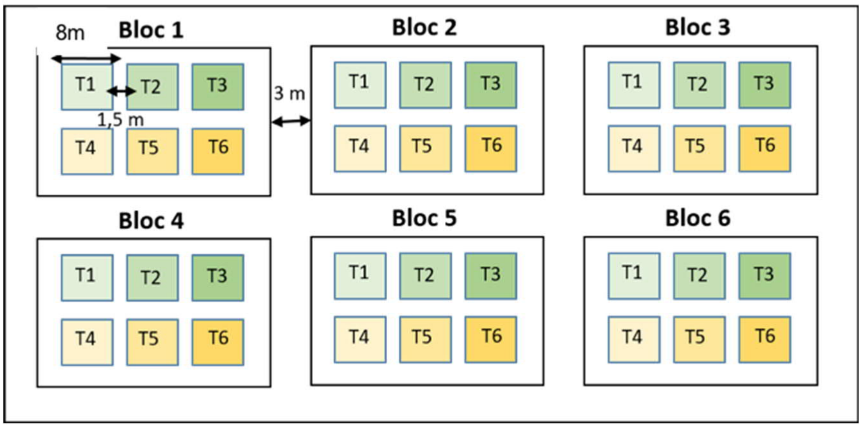
2.1.3. Prototyping results

The results of the prototyping workshop were the cropping systems to be tested and the technical routes. These were essentially groundnut + cowpea with or without organic inputs, or millet + cowpea with or without organic inputs, with various adaptations by the farmers. The control treatments were either groundnut only or millet only. In all 2 communes, the cropping system practised is a rotation of pure millet and groundnut in the bush and a succession of pure millet in the huts.

2.1.3.1 Diouroup commune

Farmers proposed a variety of options for testing, with priority given to biological control and soil fertility. For biological control, one farmer suggested testing a lemon-based cream to control pests on watermelon grown in winter. To control groundnut pests, one grower suggested using shade-dried neem leaves to coat groundnut seeds before sowing. Others would add ash to neem in nurseries and for seed preservation. Mature neem seeds can also be dried and powdered for use as a pest control solution for vegetable crops. To improve soil fertility, the farmers suggested testing a millet/arachid rotation and a combination with cowpea or sorghum in a field under ANR with the addition of organic matter (manure + household waste), maintaining root biomass with a live hedge. This was the option finally chosen by the farmers.

Discussions with the farmers initially focused on the fields available with a groundnut precedent, RNA, root biomass and living hedge. Given the difficulty of combining all these components on the same field, the group eventually decided on the following system:



T1 = Millet only, traditional local variety (it has no name, a 90-day cycle and medium-sized ears)

T2 = Cowpea only, Ndiassiw variety (fodder)

T3 = millet + OM

T4 = Cowpea + OM

T5 = millet + cowpea

T6 = millet + cowpea + OM

Figure 3: The experimental design in Diouroup

The technical itinerary for the T6 trial was discussed with the growers and the following points were agreed: the millet-cowpea combination will be planted in 2 rows, with 2 millet-cowpea stems interspersed, followed by 1 row of millet alone, then 2 millet-cowpea lines, and so on.

Table 4: The identified technical itinerary of the main cropping system in Diouroup

Sowing of millet at 80 cmx 80 cm apacing (late june)	1st weeding	Millet thinning (4 pants/hole) + Fertilization with horse manure	Sowing of cowpea (2 grain per hole), spacing 80 cm of seedline	2nd weeding	3rd weeding
	10-15 days after emergence	15 JAL	Just after thinning	30-35 DAS	40-50 DAS

Farmers' comments: Fodder cowpea (Ndiassiw) is creeping, but when combined with millet, it starts creeping only after the millet is harvested.

2.1.3.2 The commune of Ndiob

In the commune of Ndiob, given the limitations of experimenting with the options proposed by the women and young people, Option 1 proposed by the men was chosen. However, these options could be tested in subsequent years or by other farmers in satellite fields. Discussions then focused on the further development of option 1.

Table 4: The identified technical itinerary of the main cropping system in Ndioub

Components of the option to be tested	Producer proposals
Type of field	It is difficult to have 1 hectare in a hut field, so it is recommended that the field be in the bush, but not too far from the houses. Moussa suggested that the previous crop should be peanuts. Seed variety
Seed variety	Diappal is not suitable for bush fields because it is highly palatable to birds. Kolonding was therefore chosen.
Types of fertilizer	Horse and cattle manure. For 2021, the FC proposes

Cowpea association	If millet and cowpea are combined, the cowpea yield will be low but could have a positive effect on the millet; there could be plots of millet alone, cowpea alone and others with millet/cowpea. Some farmers prefer not to combine Moussa: If we combine them, we can compare the productivity of the haulms, grains, fertility, soil moisture and pests with fields that are only cultivated with millet. Some people think that millet should not be combined with other crops because it is too demanding. The proposed variety is Melakh because it has a short cycle of 60 to 70 days.

The system proposed by ISRA consists of 6 blocks of 6 100 m2 each. The total field area is approximately 0.7 ha.

2.2. The experiment

2.2.1. Experimental methodology

Once the cropping system to be tested and the technical itinerary had been defined, the next step was to identify the villages and fields where the experimental set-up would be located. A visit was made to some of the villages in the community, to producers who offered to make land available to the project for the trial. This co-designed trial site was called the 'central field' and was managed by the research team, the development department and the farmers. The experimental design and cultivation were carried out in a participatory manner with the growers. The aim of such a system, which includes replications, is to facilitate the process of co-designing agro-ecological intensification options and systems. The central fields were installed in 2021 and have been repeated each year of the project.

During the first campaign, farmers visited the central field regularly. In 2022, each farmer was inspired by the 2021 central field systems and volunteered to replicate a central field system on their farm in consultation with the research team. The farmers were free to adapt the system to their own needs. This system was called a satellite field. The plots were managed by volunteer farmers with the support of field technicians. In the satellite plots, the system was based on dispersed complete blocks where the farmer formed a replicate. Each satellite field is divided into two elementary plots: one for the usual practice (monoculture), the other for the system chosen by the prosecutor based on the central field, adapted or not. In each elementary plot, three (3) plots or yield squares (4 m × 4 m) were installed for monitoring and data collection. The location of the plots was chosen with the help of the farmer, who was familiar with the heterogeneity of his field. These are located on a diagonal of the plot if the field is homogeneous on a plateau; at the top, middle or bottom of the slope if the field is homogeneous on sloping land; on different parts of the plot if the field is heterogeneous.

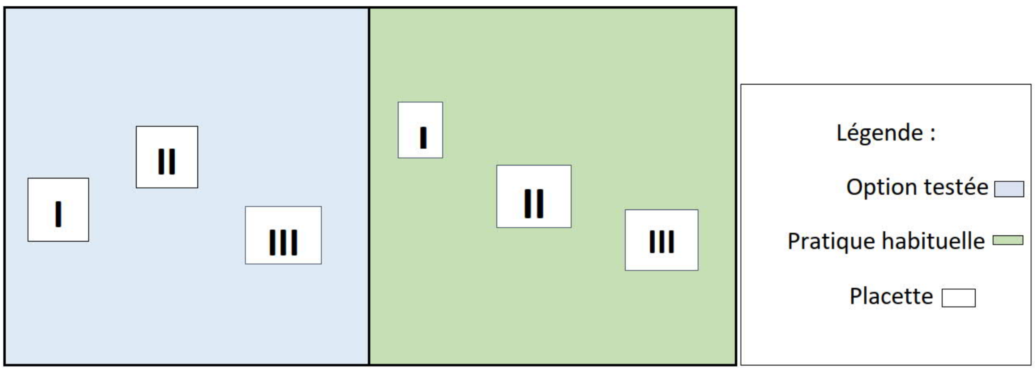


Figure 4 : Satellite field system. This system was used by all volunteer farmers in all villages in the communes of Ndiob and Diouroup.

2.2.2. Experimental results

The agronomic results are presented for 2 central plots in 2 villages in the commune of Ndiob (Mbatar and Ndiourbel Sine). For the satellite trials, results are presented for 2 villages in the commune of Ndiob (Bacco Sérère and Bacco Mboy Tollé) and 2 villages in the commune of Diouroup (Diouroup and Ndiongolor).

In the village of Mbatar (Ndiob commune), the central field experimental design is a randomised Fischer block with 3 replications and 7 treatments. T1: groundnut alone (control), T2: cowpea + horse dung (4 t/ha), T3: groundnut + cowpea alone, T4 = cowpea alone, T5 = groundnut + cowpea + horse dung (4 t/ha), T6: groundnut + horse dung (4 t/ha), T7 = groundnut + cowpea + compost. The groundnut variety '55-437' and the cowpea variety 'Mabaye Ngagne' were used. At sowing, 5 kg of groundnut seeds were mixed with 10 g of cowpea seeds in the seed drill and sown at the same time. For a treatment of 108 m², 0.8 kg of mixed seeds were sown, i.e. 74 kg/ha. Manure and compost were applied at sowing over the entire treatment area. Pod and haulm yields of both crops were assessed. Soil samples were collected for laboratory analysis.

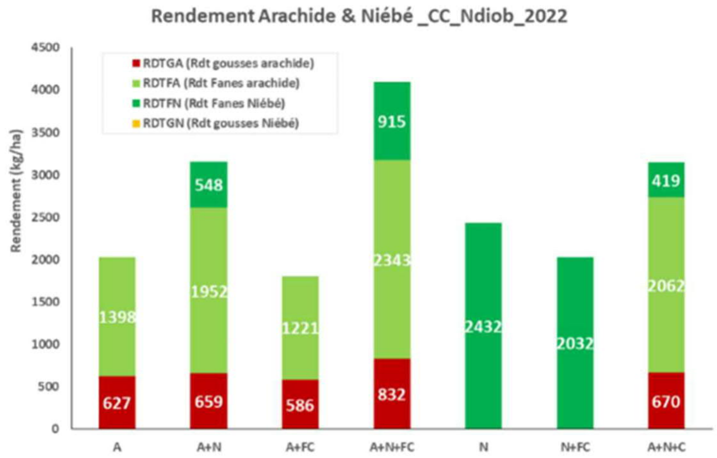


Figure 5: Yields of two crops in the different options tested

In 2022, peanut combined with cowpea produced a significant increase in pods (+32 kg/ha or +5%) compared to peanut grown as a monocrop. This increase was particularly significant for haulm production (+554 kg/ha, or +40%). The LER (Land Equivalent Ratio) was 1.05 for pod production and 1.62 for haulm production. The combination was therefore more effective than the monoculture. In other words, cowpea combined with peanut 'stimulated' peanut production in terms of pods and especially haulms. For cowpea, no pods were produced in 2022 in this central field.

The addition of horse manure (A+FC) to peanuts compared to peanuts alone (A) seems to slightly 'depress' crop production; the opposite is true for the 2021 season. The hypothesis is that the quality of the manure and/or the heavy rainfall recorded during this season may have contributed significantly to nutrient leaching. The best productivity was recorded by the groundnut-cowpea + fertilizer combination (A+N+FC).

In the village of Ndiourbel Sine (commune of Ndiob), the central experimental design was a randomised Fischer block with 3 replications and 6 treatments. The millet variety Souna 3 was planted in 2022.

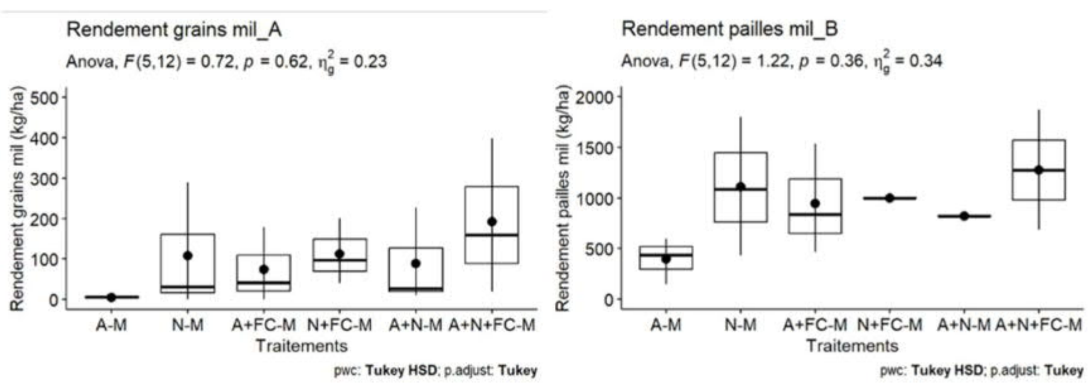


Figure 6: Millet grain yield (A) and straw yield (B)

The results show that there was no significant difference between treatments for either grain or straw yield. Moreover, for both yields, the cowpea preceding crop (N) was more effective than the groundnut preceding crop (A). The lowest yields were obtained with the groundnut preceding crop. The highest yields (192 kg/ha for grain and 1700 ±942 kg/ha for straw) were obtained by combining two legumes with manure (A+N+FC).

In the village of Bacco Sérère (Ndiob commune), the purpose of the satellite field (adaptation) was to evaluate the agronomic performance of two cowpea varieties in combination with peanuts. The system consisted of dividing the field into two homogeneous "strips" in terms of soil type and topography. All strips were sown with the same groundnut variety. However, the first strip was planted with the creeping cowpea variety known locally as 'Mbaye Ngagne' and the second strip with the semi-ripe cowpea variety 'Melakh' introduced by the project. In each strip, three plots of 16 m² each were established to monitor the crop and the management practices. The 2 treatments are

_ Groundnut + Mbagye Ngagne (A+Nb) ;

_ groundnut + Melakh (A+Nm).

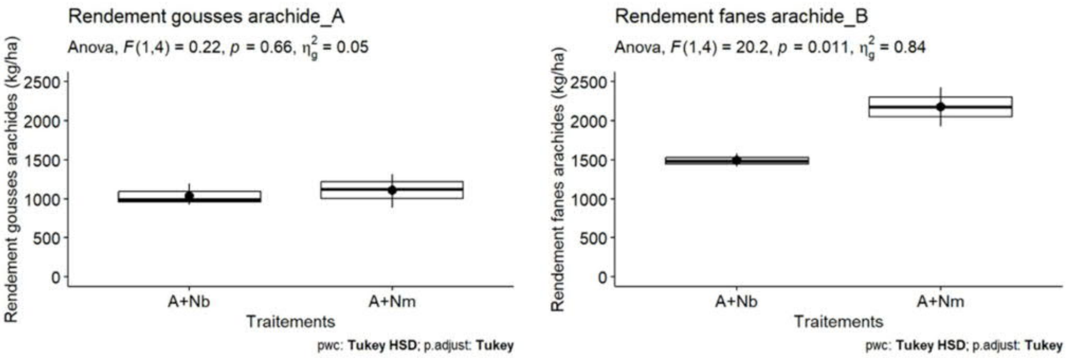


Figure 7: Groundnut pod yield (A) and groundnut stalk yield (B)

The results show that groundnut intercropped with cowpea Melakh (A+Nm) produced an increase of 70 kg/ha of pods, or 7%, compared to those intercropped with cowpea Mbaye Ngagne (A+Nb). There was no significant effect on pod yield. On the other hand, groundnut intercropped with Melakh (2178±251 kg/ha) produced significantly more pods (p=0.011) than those intercropped with Mbaye Ngagne (1491±84.1 kg/ha), an increase of 46% (+687 kg/ha). Thus, the Melakh cowpea variety remains more efficient than Mbaye Ngagagne for the production of pods and especially peanut haulms for the 2022 season.

In the village of Bacco Mboy Tollé (Ndiob commune), the objective of the satellite field was to assess the effect of cowpea on groundnut production in combination with groundnut. The design was similar to the previous one. The field was divided into two homogeneous 'strips'. The first strip was planted with groundnut (variety 55-437, locally known as 'fourré') and the second strip with the same groundnut variety combined with Mbaye Ngagne cowpea. In each strip, three plots of 16 m² each were established to collect crop and soil data. The treatments were

_ groundnut (A) ;

_ peanut + cowpea (A+N).

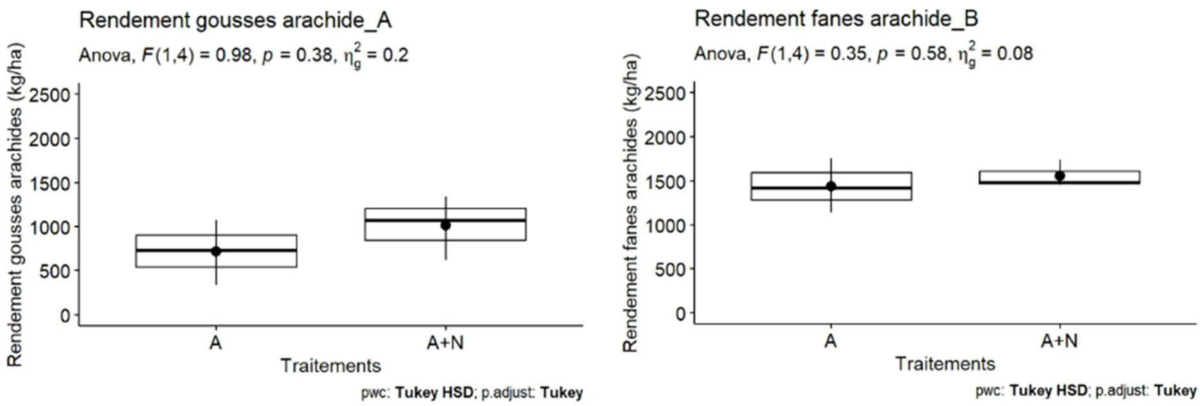


Figure 8. Yields of groundnut pods (A) and haulms (B)

The results show that there was no significant effect between groundnut alone (A) and groundnut combined with cowpea (A+N). However, groundnut pod and haulm yields were higher when combined with cowpea. The groundnut pod yield was 1010 ±336 kg/ha and 715 ±365 kg/ha for A+N and A respectively, an increase of 41% (+295 kg/ha). The increase in haulm yield was 8% (+119 kg/ha).

In the village of Diouroup (commune of Diouroup), the aim of the satellite field was to assess the productivity of millet with or without cowpea in 2 farmers' fields. Each field was divided into two homogeneous "strips". The first strip was sown with millet (M) and the second strip with millet combined with cowpea (M+N). In each strip, three plots of 16 m² each were established to collect crop and soil data. Cowpea was sown as a catch crop at the same time as millet. This delay allowed the cowpea to continue growing on its own after the millet had been harvested, thus limiting competition for the various environmental resources. However, the forms of association are not identical for the two producers. For one (called C), the cowpea is sown between 2 bundles of millet for 1 of the 2 millet lines; for the other (A), the cowpea is sown between 2 bundles of millet for each millet line. In other words, the cowpea density in A is 2 times higher than in C. The treatments are therefore :

- Millet (M) ;

- millet + cowpea (M+N).

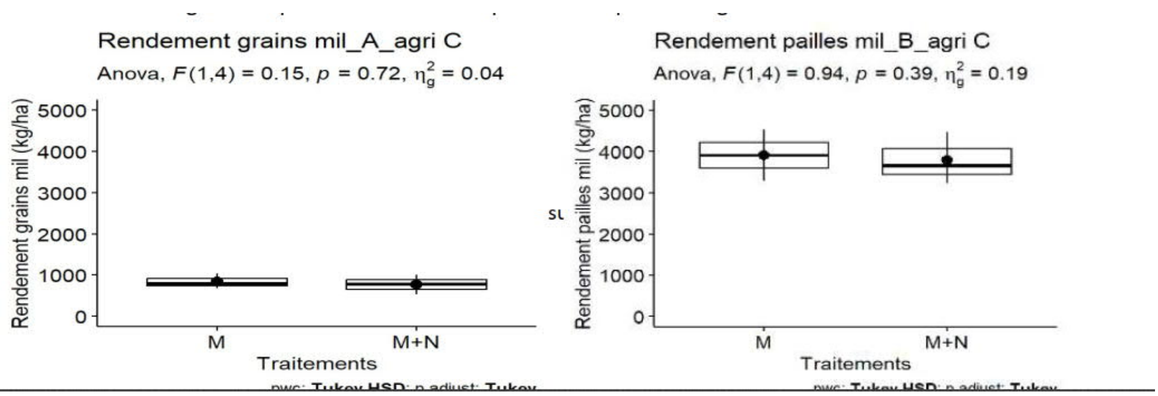


Figure 9. Millet grain (A) and straw (B) yields for farmer C.

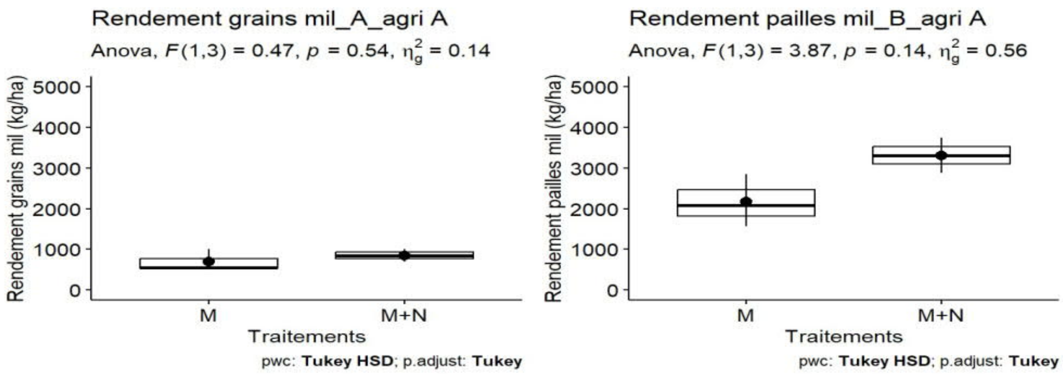


Figure 10. Millet grain (A) and straw (B) yields for farmer A.

There was no significant difference between grain and straw yields in the two plots. Grain yields were higher in farmer C (836±182 kg grain ha-1 for millet alone, 770±238 kg grain ha-1 for millet combined with cowpea) compared to farmer A (690±268 kg grain ha-1 for millet alone, 849±221 kg grain ha-1 for millet combined with cowpea). In addition, the productivity of millet combined with cowpea was better in farmer A than in farmer C.

In the village of Ndiongolor (Diouroup commune), the satellite field at 2 farmers' sites was designed to assess the effect of cowpea on groundnut production. The field was divided equally into two homogeneous "strips". The first strip was planted with groundnut and the second strip with the same groundnut variety combined with cowpea. In each strip, three plots of 16 m² each were established to collect crop and soil data. The system was set up in two satellite fields, one called I and the other A. The treatments are

- Peanut (A);

- Peanut + crop residues (A+N).

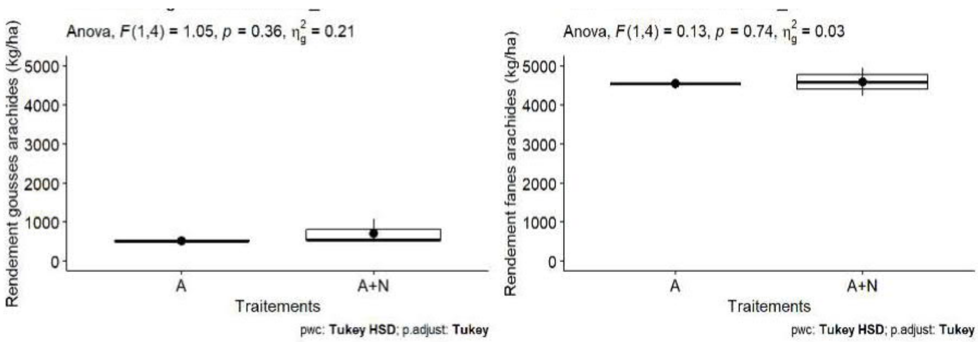


Figure 11. Groundnut pod and haulm yields for farmer I

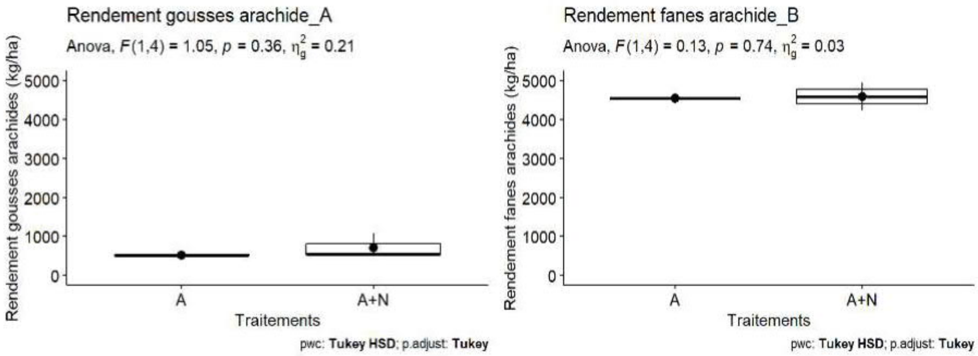


Figure 12. Groundnut pod and haulm yields for farmer C

There was no significant difference between the two options tested in any of the fields. However, the two crops behaved differently depending on the field. For farmer I (Figure 9), the groundnut monocrop produced more pods (927±280 kg/ha) and haulms (3611±860 kg/ha) than the groundnut and cowpea combination (850±180 kg/ha and 3135±268 kg/ha), although the difference was still small. On the other hand, for farmer C (Figure 10), the opposite was true for the pod yield, with 708±316 kg/ha for groundnut combined with cowpea (A+N) and 522+-15.8 kg/ha for groundnut monocrop (A), with a high difference between the two yields. This hypothesis is related to the high fertility of plot I. In fact, oxen are often parked in this plot.

Conclusion

Compared with peanut alone, peanut intercropped with cowpea in the central field at Ndiob produced a surplus of pods and peanut vines. With the addition of organic inputs, these yields increased even more. Nodal analysis showed that peanuts grown with cowpeas had twice as many nodules as peanuts grown alone. Similar results were found in the farmers' satellite fields. In the various tests, the Land Equivalent Ratio (LER) obtained for the combination was greater than 1. This shows that there is a beneficial symbiosis between the two crops, with the association being more beneficial in terms of land use than the millet crop alone.

2.3. Co-evaluation

2.3.1. Co-evaluation methodology

The central and satellite field systems were evaluated by all the stakeholders involved in the process. Co-evaluations took place during vegetative development, at harvest and in each year of the project. Two approaches were used: (i) qualitative and (ii) quantitative. In 2021, the qualitative approach was mainly used. It consisted of recalling the process that led to the establishment of the central field and a qualitative assessment by the farmers of the performance of the crops, option by option, according to the repetitions. Farmers gave an overall assessment of crop growth through "better vegetative development of plants" between options and provided explanations.

In the 2022 season, co-evaluation was characterized by the introduction of indicators that allowed farmers to give their assessment of parameters other than agronomic ones. The qualitative approach was combined with a quantitative one in which farmers voted in groups, classifying treatments as 'good', 'average' and 'poor' and noting the reasons for their choice. The tools were developed as part of a thesis on multi-criteria analysis. The proposed and reorganized methodological and organizational approach is summarized in the diagram below.

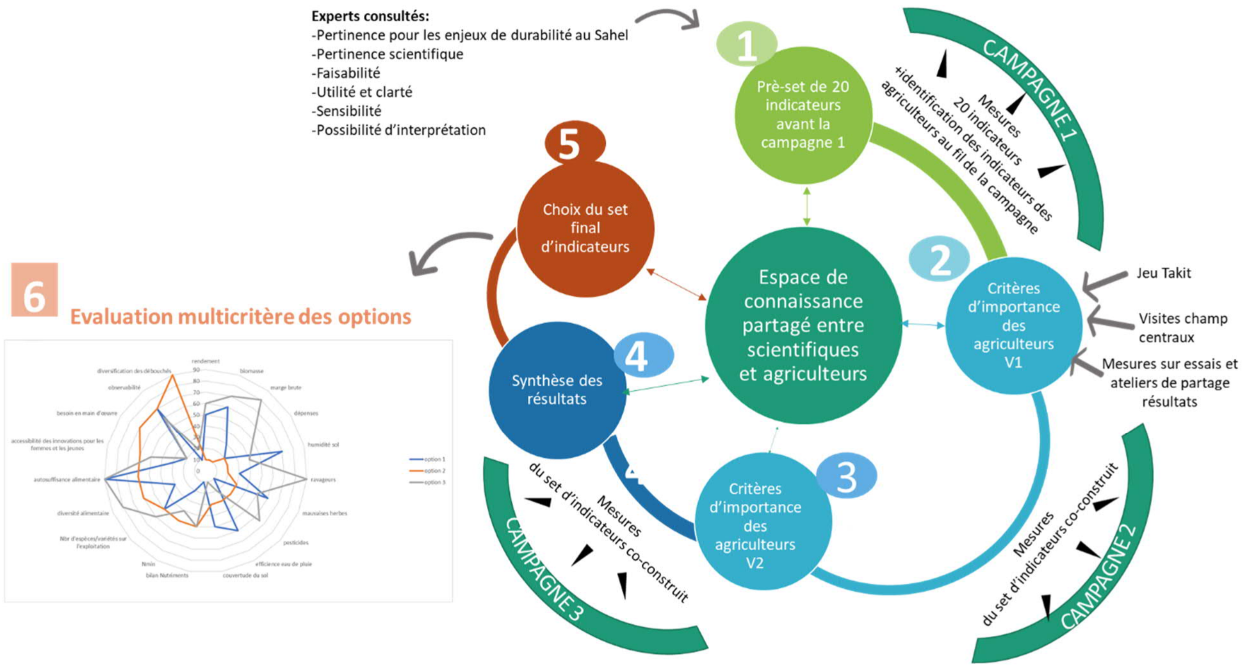


Figure 13: methodology of identification of multi assessment indicators

2.3.2. Results of co-assessments with farmers on the central field at Ndiob

2.3.2.1 Year 2021

Two co-evaluations were carried out in 2021: on 11 August (photo 1), 35 days after sowing, and on 14 September 2021 (photo 2), about 70 days after sowing. The first involved 38 participants (21% women and 50% young people) from 11 villages. The second involved 32 participants (25% women and 20% young people) from 10 villages.

For the first co-evaluation, three sequences were used: (i) first the farmers recalled the process that had led to the establishment of the central field, the crops chosen and the options tested, then (ii) the options were presented to the farmers by the technicians (Enda and ISRA) in a repetitive way, and finally (iii) a discussion was opened by asking the farmers to give their assessments. The discussions focused on the following points

1. No difference between peanuts alone (A) and peanuts with horse manure (A+FC). The following arguments were presented:

- 3 years ago manure was applied to the whole plot; this masked the difference;
- The amount of manure applied is small enough to make a difference;
- The break in rainfall did not allow the fertilizer to have its effect;
- The fertilizer is not 'mature';
- The effect of the fertilizer on the crop will not be felt until the following season;
- It is very early (35 days) to assess the effect of the fertilizer.

2. The following issues must be mobilized

- The causes of the presence of Striga in millet fields;
- The effect of legumes in controlling Striga;
- The impact of organic fertilizer (manure) and mineral fertilizer.

In the second co-evaluation (14 September 2021), the following observations were reported by each group:

Group 1: (groundnut vs. groundnut + FC)

- Peanut without fertilizer has many yellow leaves;

● Peanut + FC shows good development and the leaves are green;

● Insufficient amount of fertilizer.

Group 2: groundnut + cowpea combination vs groundnut + cowpea + FC combination

● Pests (insects) present in both treatments but less when manure is added to the combination;

● In the absence of manure, there are more missing plants;

● With the addition of manure, density, number of branches, number of pods and flowers are greater.

Group 3: Cowpea vs. Cowpea + FC

● Cowpeas without manure are less developed and have fewer flowers and pods;

● No insect attack on cowpeas without manure because they are less developed;

● Cowpea with manure application shows better leaf development, notable presence of pods but also insects.

Correlations between co-evaluation results and agronomic performance of options

What can we learn?

The co-assessments showed that the positive effect of manure on crop growth and development 70 days after sowing was confirmed by the pod and haulm yield results. On the other hand, in these co-assessments, there was a lack of appreciation by farmers between the groundnut monoculture (A) and the groundnut and cowpea combination (A+N). However, the final results show that the difference is much more spectacular when groundnut is combined with cowpea (Figures 7 and 8) than when FC is applied to groundnut. Farmers also paid close attention to the presence or absence of pests in the treatments. However, we (the researchers) lack quantitative data to assess the infestation rate and severity of attacks and their relationship with growth parameters, development and final crop production.

2.3.2.1 Year 2022

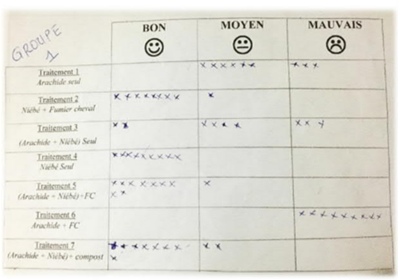
As in 2021, two co-assessments were carried out in 2022, on 27 August, in the middle of the campaign, and on 1 October, as the harvest approached. A total of 63 people in 16 villages participated in the first co-assessment (photo 3), 21% of whom were women and 40% young people. In the second co-evaluation (photo 4), 44 people (14 villages) participated, of whom 25% were women and 30% young people. The detailed results of these co-evaluations are presented in the co-evaluation reports.

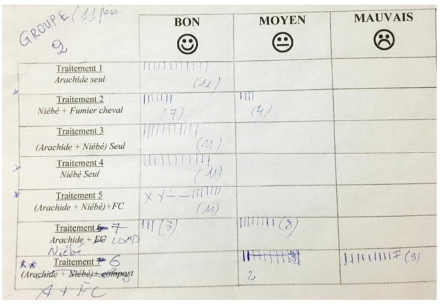
Three groups were formed to compare specific treatments treatments in each replicate:

- Group 1: groundnut compared to groundnut (A) plus FC input (A+FC);
- Group 2: Cowpea (N) vs. cowpea + fertilizer (N+FC)
- Group 3: groundnut plus cowpea (A+N) vs groundnut+cowpea plus manure (A+N+FC) vs groundnut+cowpea plus compost (A+N+C).

For each group the results are are presented in a Paddex (Figure 14).

Thus, in replicates 1 and 2 for group 1, the peanut treatment with the application of horse manure (A+FC) was considered 'poor', while peanut alone was considered 'average'. On the other hand in replication 3, A+FC is 'good' and A is 'average'.





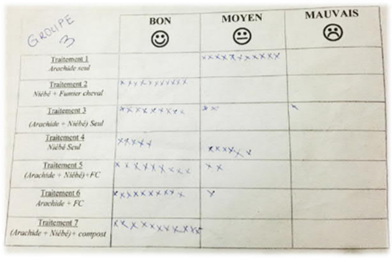


Figure 14. Treatment observation sessions and results recorded in paddexes

The application of manure to cowpea was rated 'good' in all 3 replications, including cowpea alone without manure application. In addition, the two companion crops combined with manure or compost application were rated positively by the farmers.

Links between co-evaluation results and agronomic performance of options

What can we learn from this?

Some of the farmers' observations were consistent with the final results. In central field 2, peanut plus manure application was considered 'poor' in 2 out of 3 replications. The results for pod and haulm yields were indeed higher with peanut alone than with peanut plus manure, which contradicts the results for central field 1 in 2021. On the other hand, the application of compost to the two companion crops was considered positive, although its contribution (compost) was almost negligible compared to groundnut + cowpea without compost.

3. Co-design at farm level

The scenario co-design activity is part of the general framework of the co-design of innovative agro-ecological intensification systems. The activity uses a farm modelling tool based on the data collected in the satellite plots and in the other systems of the project. The farm modelling tool can be used to stimulate discussions with producers as part of a co-innovation process at plot level, as close as possible to their production context.

The scenarios are designed and evaluated in practice with volunteer producers, in collaboration with technicians from the development structure. The definition of the scenarios involves the participation of the producer (with his family assets if possible), the researcher or a research technician familiar with the approach. The whole interactive process and the supporting tools are explained in detail so that they can be understood by the farmer and the technician.

The objectives of the activity are (1) to carry out an ex-ante assessment of the agronomic, economic and environmental impacts of introducing an agroecological (crop) system at farm level, (2) to provide a simple tool (Excel or even a mobile application) for use by technicians from POs and development organizations to discuss possible changes on farms with farmers, (3) to use the data collected in all systems in the three countries (satellite trials, central fields, station) in a database on the performance of agroecological systems.

3.1. Methodology

The scenario co-design activity used a simple farm modelling tool. The modelling tool was built in several stages, progressively during the second phase of the FAIR Sahel project. The stages involved were database construction, model development and testing the model in a real-life situation. The construction of the databases and the development were carried out simultaneously because of the number of iterations required to adapt the model to the structure of the databases. However, due to the duration of the project and the time needed to build the model, it was not possible to test the scenarios resulting from the simulations on farmers' plots during this campaign.

3.1.1. Construction of the databases

Two databases were constructed. These are the Crop System Performance Database (BDCP) and the Livestock System Performance Database (BDSE). They contain a list of systems as well as the performances associated with these systems and references for indicator calculations. At present, the database structures have been finalized, but the databases are still being populated.

The creation of the databases followed a participatory approach in several stages. The first stage was to draw up specifications describing the tool, its purpose, its inputs and outputs and the link with the operating model. The second stage was to present the idea of the farm model to the farmers to get their opinions and suggestions on the tool and the performance indicators to be calculated. This second phase was carried out through workshops in the villages of Ndiob. The farmers who attended these meetings were those with satellite fields in the project. During these workshops, the farmers expressed their interest in this type of tool. They made some suggestions for performance indicators (at household level). The producers then gave their opinion on the tool and their suggestions for improvement and/or reorientation, particularly with regard to the criteria to be considered.

In addition, the workshops provided an opportunity to review the crops and cultivation practices carried out according to soil type in each locality. Producers also indicated the agro-ecological practices they would like to test using the tool.

3.1.2. Data sources

In the database, cropping systems are defined by a combination of the main cropping practices (tillage, planting, spatial arrangement, fertilization and phytosanitary treatment), with the soil types dominating in each zone.

The database was created by combining several sources and types of data. The data were collected in the FAIR Sahel research projects. The databases were supplemented by secondary data from the literature (scientific articles, technical datasheets, etc.) and discussions with stakeholders (producers, researchers, experts, technical agents).

In 2024, 10 farms were monitored as part of the OneCGIAR Agroecology Initiative project to complete the database and test the model with this limited network. This monitoring was carried out with volunteer farmers selected according to production orientation (farmers or agro-pastoralists), farm size (household members and equipment) and crop diversity. The system involved identifying all crop and livestock units and completing a number of variables. Data were collected at household level (members and management) and then at plot and livestock unit level. For each plot, the soil types, the different elements of the technical itinerary, the cultivation practices and the different inputs were recorded. For the livestock units, management practices, types of feed and maintenance (vaccination and worming) were recorded. Performance measurements were carried out.

3.2. Operations modelling tool

The modelling strategy adopted is to start with a very simple model. Therefore, a model already used by the WUR team (Ronner et al., 2018) was used. It is a simple modelling tool in the form of an Excel file with different tabs for input data, output indicators and scenarios. However, in the course of discussions with stakeholders (researchers, producers, development technicians), the modelling tool became slightly more complex by considering elements of the farming system and also by the number of indicators to be calculated. The farm model is contained in the same Excel file as the databases, with different sheets linked by formulas. It contains different tabs for calculations and for storing the references used to calculate the indicators.

3.2.1. Model input data

Input data for cropping systems and livestock enterprises are entered in the same tab. For the cropping system, this includes the geographical location of the parcels (agro-ecological zone and halo), the biophysical environment (soil type), the crops (main crop, associated crop and previous crop), the type of cropping system and, if applicable, the type of cropping association. The farming practices, equipment and products used are also part of the input data. The types of fertilizers and pesticides applied to the parcels, the equipment used and the methods of application are also recorded.

For livestock holdings, the input variables include the geographical location of the holdings, the husbandry and feeding methods used, animal care (vaccines and wormers) and livestock facilities (stables, feeding troughs, drinking troughs and haylofts).

3.2.2. Output variables

The output variables of the model consist of indicators covering the areas of sustainability: agronomic, social, environmental and economic indicators. The expected outputs of the model are crop yields, economic profitability of the cropping system and its contribution to household food security (for the crop in question) and environmental criteria.

3.2.3. Development of the tool and stakeholder involvement

During 2022, several meetings were held with researchers and development technicians to prepare the activity before the agricultural season. The purpose of these meetings was to define the objectives of the activity, to discuss the methods of implementation and the data collection required for its implementation. Subsequently, the methods for developing the model were discussed with the farmers during the database compilation workshops.

3.3. Simulation results for Amy Diop's farm

3.3.1. Presentation of Amy Diop's farm

The farm model was used to simulate a scenario for Amy Diop's farm in the commune of Ndiob. Amy's household consists of 18 people, including 5 adults (2 men and 3 women who participate in agricultural activities) and 13 children, of whom 5 are young and 8 are old. They participate in agricultural activities during the growing season (July to September). During the year, the 18 members of the household live on the farm.

Amy has 5 plots of land and 4 goats on her farm. In 2024, Amy produced

- Plot 1: 1.825 ha of pure peanuts;
- Plot 2: 1.0125 ha of millet;
- Plot 3: 0.8125 ha of cowpea fodder;

- Plot 4: 1.13 ha of cowpea fodder;
- Plot 5: 0.84 ha of millet.

3.3.2. Scenario to be tested

Amy participated in the co-design activities of the systems. She appreciated the benefits of the groundnut/cowpea combination that had been tested in her locality. She therefore decided to introduce this innovation on her farm. To do this, she decided to divide plot 1 into 2 parts: on 1 ha, she will grow groundnuts in combination with cowpeas, and on the rest of the plot (0.825 ha), she will maintain her usual system. The cropping systems on the other plots will remain the same. In addition, Amy has decided to introduce a 4-head sheep fattening unit in addition to the goat unit. The household labor force remains unchanged.

3.3.3. Impact of the tested scenario on the indicators

The parameterization of the agricultural model has not yet been completed. For this reason, we have only analyzed the impact of the tested scenario on one social indicator, food security, by comparing household protein and energy needs with availability.

Amy uses 25% of her millet production for animal feed. The rest is used for household consumption. She sells 75% of her groundnut production and keeps 25% for family consumption. Cowpeas are used only for family consumption.

An adult need 2250 calories (energy) and 50g of protein per day. A child needs 1850 calories (energy) and 21.5g of protein per day. Millet grains contain 11.2% protein, peanuts 26% and cowpeas 22.4%. Millet grains contain 4090 kcal/kg, peanut grains 4320 kcal/kg and cowpea grains 3910 kcal/kg.

The results are shown in the following figures:

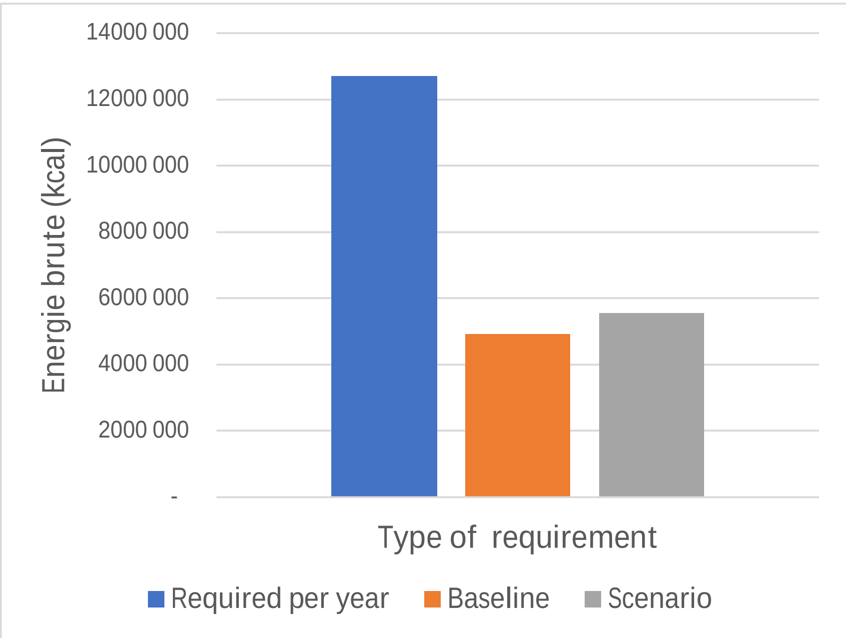


Figure 15: Household energy requirements and energy availability for the Baseline and the scenario tested

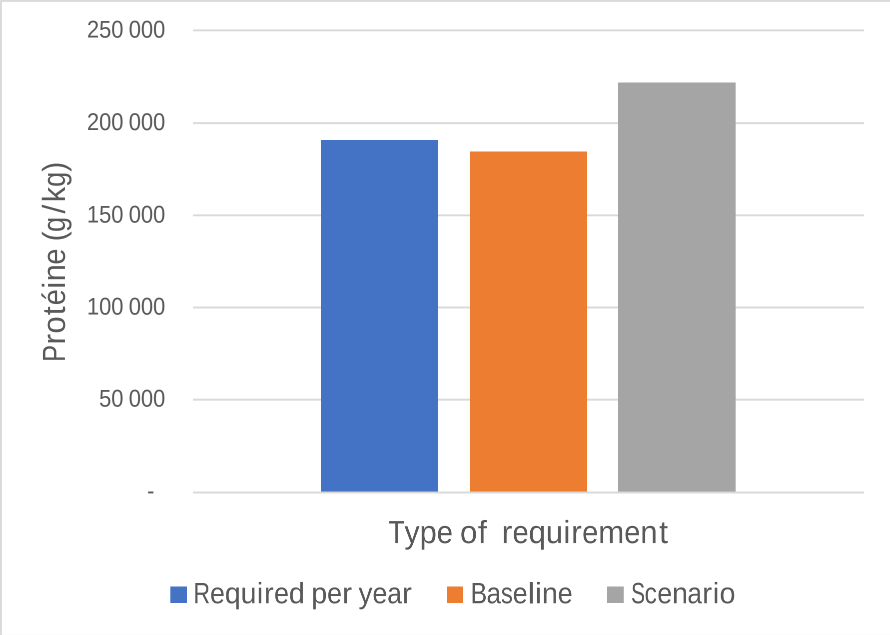


Figure 16: Household protein requirements and availability for the baseline and tested scenario

The Baseline and scenario energy supplies are 61% and 56% lower than the household's needs, respectively, and the household will have to make up the difference through external inputs, generally through purchases. However, the scenario improves the energy balance by 13% compared to the baseline. For protein, the baseline falls just short (-3%) of meeting the household's needs. However, the test scenario manages to meet the household's protein needs with a surplus of 16%. This increase is mainly due to an improvement in groundnut productivity in the association, but also to the contribution of cowpeas.

4. Conclusion

The scenario simulation activity was initiated following co-design at plot level in the FAIR Sahel project with the following objectives: (1) to carry out an ex-ante assessment of the agronomic, economic and environmental impacts of introducing an agroecological (cropping) system at farm level, (2) to provide a simple tool (Excel or even a mobile application) for use by farmers' organisations and development technicians to discuss possible changes to farms with farmers, (3) to use the data collected in all the systems in the three countries (satellite trials, central fields, station) in a database on the performance of agroecological systems. Due to the time required for data collection and parameterization, the work presented below presents only partial results for the food security indicator. However, the model is capable of calculating other social, agronomic, environmental and economic indicators. The parameterization, of the model will continue in the second phase of the Agroecology Initiative project, which is expected to start in 2025, and will enable all the objectives of the model development activity to be achieved.

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