BEST DEVELOPMENT TECHNIQUES AND APPROACHES FOR AGRICULTURAL IMPROVEMENT IN THE SAHEL

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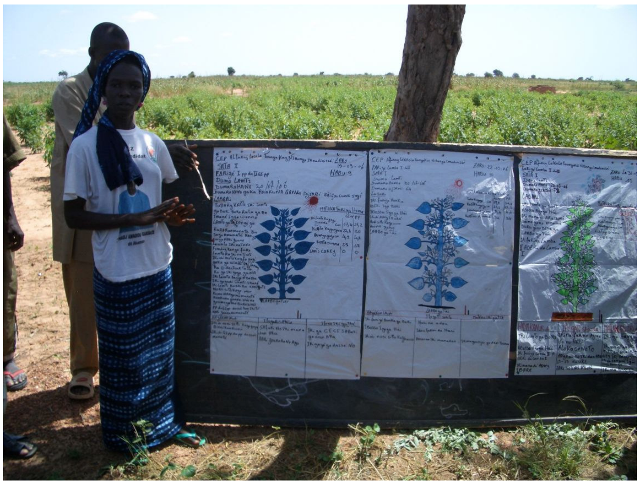

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INTRODUCTION

The goal of this web page is to present the best approaches and practices for improving agriculture in Sahelian countries. The technologies presented are those for which there is scientific documentation and that are already in the process of being adopted by farmers. The intention is to present technologies and interventions as possible opportunities. It is important to underscore that the approach to be used varies depending on rainfall, soil quality, input availability, cost of inputs, integration into the market, access to credit and farmers' ability to adopt new farming techniques and approaches.

The Internet page is mostly developed for areas where rainfall ranges between 400 and 800 mm. This corresponds to the Sudano-Sahelian zone (400-600 mm) and the Sahelo-Sudanian area (600 – 800 mm) (Hiernaux and Houerou 2006) where rainfed farming is practiced.

This web page is prepared in order to inspire all actors working in the agricultural development sector in Sahelian countries. It will be updated as new promising practices appear.

Thus, all actors involved in research and development will have access to it in order to feed into it through scientific articles and publications.

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1. AGRO CLIMATOLOGY AND WEATHER FORECASTS

Climatic variability is one of the factors making agricultural development difficult in the Sahel. Rainfall diminishes as one moves toward the northern part of the Sahel. The trend is that the lower the rainfall, the higher the climatic variability. In addition, overall rainfall in the season may be satisfactory, but poor distribution may significantly reduce agricultural output.

Short term and seasonal weather forecasts are developed in the Sahel. The African Centre of Application of Weather Forecasting to Development (ACMAD) provides in May of each year a rainfall forecast for the following season in West Africa. The probability for a season to be good, normal or poor is given based on sea temperature (El Niño effect) (ACMAD 2006). In July, a review of the seasonal weather forecast is given. The AGRHYMET (a CILSS institution) uses this data, together with the hydrological assessment and the prospect of locust attacks, to develop a forecast in August on yields and food situation at the time of harvest in the different Sahelian zones (AGRYHYMET 2006). This can serve as an early warning in each country. According to the AGRHYMET, the food crisis in Niger in 2005 was predicted well before it was disclosed in the media. As for the locust attacks, the AGRHYMET can provide early warning one year in advance.

As far as future climate is concerned, there is no clear trend following different long-term climatic models (CIFOR 2005). However, it is likely that temperatures will rise without being able to say more on rainfall.

2. ANNUAL CROPS IN THE SAHEL

The principal annual crops in the Sahel are pearl millet and sorghum, often cultivated in association with cowpea. Groundnut is an important cash crop. Sesame and hibiscus are also cash crops which are being introduced on a large scale in the Sahel. Some varieties of rice are also cultivated through irrigation thanks to dams and major rivers such as the Niger.

2.1 PEARL MILLET AND SORGHUM

Pearl millet and sorghum are the most important crops in the Sahel (ICRISAT 2006 a, b). Millet is mostly cultivated on sandy soils while sorghum is more adapted to sandy limonous soils. Late varieties are not adapted to the Sahel while more early varieties have low yield potential.

Establishment of millet and sorghum farming is often difficult in the Sahel and replanting is often necessary. Rodents, insects and fungus often attack seeds. Mildew attacks particularly represent a major problem (ICRISAT 2006 b). Two weedings are necessary in order to adequately control weeds.

Most varieties of millet and sorghum are photosensitive. For each variety, there is a specific flowering date that is independent of the seed date. The earlier varieties ripen after 75 days while the later ones require 120 to 150 days. The late varieties may be used as fodder varieties in the Sahel. Fodder millet must be cut before flowering otherwise the stem lignifies and loses its nutritional value. Fodder millet may be more profitable than grain millet. The production of seeds of fodder millet varieties may represent a problem as they are late varieties and there are risks of making genetic blends with traditional varieties.

The striga is weed reduces millet and sorghum yields. The striga has great genetic variability. This makes it difficult to develop striga resistant varieties. Certain sorghum varieties are tolerant to striga attacks.

2.2 COWPEA

Cowpea is the most important source of protein in West Africa (Singh et al. 2001). It is an important crop in the Sahel because cowpea is tolerant to drought and improves soil quality through nitrogen fixation (IITA 2006). In addition, the grain contains 25% protein and the haulms contain 10 to 14% protein. The value of the cowpea haulms (in dried matter) is 50% to 80% that of the grains.

Certain varieties mostly produce grain, while others produce fodder, and others again are dual-purpose varieties – grain as well as fodder production. Grain producing varieties are often erected while fodder varieties are creeping. Grain producing varieties lose their leaves when they ripen.

Cowpea is very sensitive to insect attacks particularly in the flowering period and it is difficult to cultivate it without using spray against the thrips (Magalurothrips sjostedti) and the pod borer (Maruca vitrata). In Northern Nigeria, the average yield of cowpea production is 411 kg/ha if no insecticide treatment is used, 737 kg with one application at flowering time and 904 kg/ha with two applications (Ajeigbe and Singh 2006). The cost-benefit value of an application is 16.3 and 12.3 for two or three applications respectively. It is therefore recommended to spray two to three times. If no spraying is done, the most highly resistant varieties such as the IT90K-277-2 must be chosen. This variety ripens in 71 days.

Cowpea planted as a pure crop with high density often gives higher yield than millet in pure stand. However, insect attacks tend to increase when density is high. The cowpea is normally planted after the first weeding of millet. Cowpea planting is an additional operation for farmers and not all farmers have the necessary manpower to that end.

Although cowpea fixes nitrogen, it can benefit from better soil fertility. The microdose method is also useful in order to have a good start in cowpea farming (see chapter on microdose).

2.3 GROUNDNUTS

Groundnut is a cash crop in Sahelian countries. It is mostly cultivated in areas recording rainfall levels exceeding 500 to 600 mm, on well drained sandy /limonous soils. The cropped varieties ripen after 75 to 120 days. The potential yield of the groundnut is 6 to 7 tons per hectare while farmers in Sahel countries harvest in the order of 400 to 700 kg for the same area. The late varieties are more productive and carry up to 200 pods per plant while the early varieties yield about 100 pods. As the grains develop in the soil, it becomes necessary to plough well before sowing. Groundnuts are very sensitive to drought at the time of harvest. It is normally planted after a significant rainshower and requires good rains the first week after sowing. The groundnut grains have very high nutritional quality. They contain about 50% lipids, 25% proteins, and 20% glucides/carbohydrate (ICRISAT 2006c).

Groundnut demands a high amount of plant nutrients. It is recommended to apply 200 to 300 kg of NPK (15-15-15) as baseline fertilizer (ICRISAT recommendation). One month later, an input of 200 kg of calcium ammonium nitrate (CAN) is recommended. At the time of grain formation, it is recommended to add 200 kg of gypsum per hectare. The calcium and sulphur in the gypsum help to promote grain development. However, very few farmers are in a position to follow these recommendations.

Groundnuts, like cowpea, are sensitive to insect attacks at flowering, which intervenes between August 15 and September 15, and an insecticide treatment contributes to increase yields.

After harvest, the groundnuts are dried on the ground. This often causes insect and fungus attacks. A new system to dry grains has been developed, as shown in the picture.

Figure 1: Improved drying of groundnuts
Photo: ICRISAT

2.4 OTHER RAINFED CROPS

Several other annual crops can be produced during the rainy season, including sesame, hibiscus, watermelon, okra, and tomatoes.

Sesame and hibiscus could become new cash crops. They are well adapted to the agro-ecological conditions of the Sahel and hibiscus can grow on degraded soils. For hibiscus, it is the flowers that are harvested.

Watermelon is a species well-adapted to the conditions in the Sahel. The normal planting date for watermelon is around August 20th. Insect attacks are more severe if the planting is done earlier (source D.Pasternak ICRISAT). Prior to planting, it is recommended to do continuous weeding from the beginning of the rainy season in order to increase soil humidity. Watermelon reacts well to organic or mineral fertilizers. Watermelon is ready for harvesting in November. It is preferably cultivated as a pure crop. One of the problems with this crop is that protection is needed in the months of October and November when animals return to graze in the fields. The Malali variety, which originates from Israel, is the most resistant to drought and more productive than Sahelian varieties.

Tomatoes are normally difficult to cultivate during the rainy season, but ICRISAT has identified a new tomato variety – the ICRIXINA – that may also be produced in the rainy season.

3. SEED PRIMING

By Adama Coulibaly (IER, Mali) and Jens B. Aune (Noragric)

Seed priming is a method which consists in submerging the seed in water for about 8 hours, but maize needs a soaking time of 15 hours. Then the seeds are surfaced and dried in order to facilitate sowing the same day. The priming of seeds may take place after some significant rain. The priming has multiple effects on plant development. The effects that have been reported are the following (Harris 2006):

- Germination time diminishes from 1 to 3 days
- Plant collection is more uniform
- Plant vigour is higher
- The time between planting and harvesting is reduced
- There is more resistance to insect and fungus attacks
- There is higher output

Seed priming is effective for crops such as pearl millet, sorghum, maize, cowpea, wheat, chickpea, cotton, and rainfed rice. The method is particularly interesting in marginal environments such as the Sahel. As far as wheat is concerned, there is no effect of priming if the yield is higher than 2 tons per hectare. In marginal conditions, replanting is often required. The priming method reduces the necessity to replant. One of the effects of priming seems to be that plants are more resistant to higher temperatures after planting. For peal millet, it has also been shown that plant establishment is better, particularly where the soil is not humid. The rapid development of plants after planting also increases the accumulation of nutritious elements such as nitrogen in the plants (Harris 2006).

If the grains are dried on the surface, it is also possible to mix the seeds with fertilizer. This is a method used in India.

It is possible to dry the seeds back to the humidity they had before the seed priming started, but the effect on yield will be less significant if such seeds are sown. It is possible to store dried seeds for a few days.

Seed priming also reduces mildew attacks on pearl millet.

Seed priming is a method that is already adopted in India, particularly for chickpea and rainfed rice. DCG is testing the priming method in Mali and Ethiopia and the preliminary results are promising.

On-farm tests by DCG in Mali in 2007 have shown the synergetic effect of seed priming and microdose of fertiliser (see the next chapter). This method leads to a noticeable increase in crop yields of about 92% for millet and 138% for sorghum in comparison to the absolute reference/control farms (with neither seed priming nor use of fertilisers). On the other hand, seed priming alone hastens the sprouting of the seeds and improves the crop yields by about 48% for millet and 52% for sorghum compared to the absolute reference/control farms (with neither seed priming nor use of fertilisers). Beside these effects, the use of the seed priming technique in combination with the microdose of fertilisers increases crop yields by about 60% and 30% for sorghum and millet respectively as compared to the use of seed priming alone.

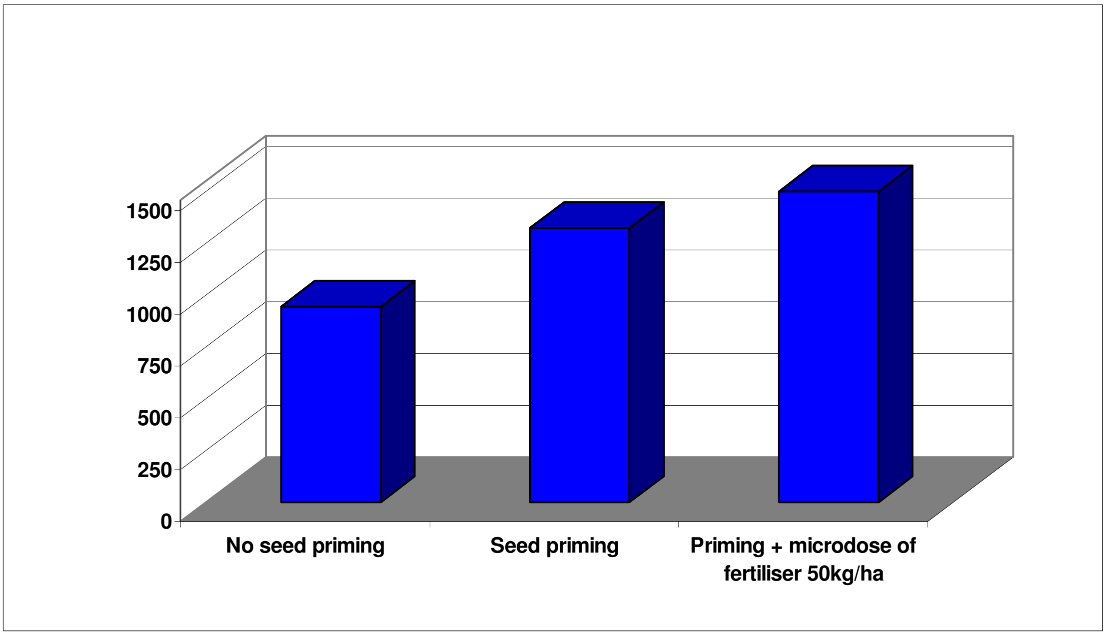

Figure 2: Effect of seed priming on sorghum yields in 2006 in Konobougou, Mali
Source: A. Coulibaly and Dr J. B. Aune

4. FERTILIZATION

In areas with more than 300 mm rains per year, the yields are more limited by the low supply of plant nutrients than by rainfall. Phosphorous is the deficient element, but also nitrogen deficiency reduces yields. The nitrogen input does not produce any effect in case of phosphorus deficiency. Phosphorus is important at the beginning of the season particularly for root development. All crops can benefit from better soil fertility.

Without fertilizer input in the 300 mm to 600 mm rainfall range, millet yield is only about 300 kg/ha. It is possible to harvest up to 2500 kg/ha of millet with a good management of soil fertility.

Long-term trials have shown that one needs to preferably combine mineral fertilizer inputs with organic fertilizers (Bationo and Buerkert 2001). It is important at the same time to reduce the loss of nutritious elements in soils through erosion and leaching (Aune et al.1999). Millet yield will diminish in the course of the years if only mineral fertilizer is used. Thus, it is recommended to use all the organic fertilizer available and in addition to use a small amount of mineral fertiliser (microfertilisation). However, the quantity of organic fertilizers available per farmer is often very low because the organic fertilizer is put to other uses. The use of mineral fertilizers may increase the amount of organic fertilizers available for increased yield.

Several methods can be combined in order to increase soil fertility. These methods are described below.

4.1 ORGANIC FERTILIZER

It is recommended to recycle all organic matter available such as manure, household waste, straw, and ash. Organic fertilizer does not only improve the chemical conditions of soils, but also their physical conditions such as their capacity to retain water. It is easier to apply organic matter in fields near houses, but is often difficult to have adequate organic matter for fertilizing fields in the bush. Transport also is a major challenge in order to fertilize distant fields.

Manure contains an average of 0.23 to 1.76 % N, 0.08 to 0.1 % P and 0.2 to 1.46 % K. Good quality manure contains over 1.6% N and a ratio of C/N<10. Low quality manure contains less than 0.6 % N and a C/N ratio higher than 17. The quality of the manure varies according to the animal. Chicken excrement has better quality, followed by that of goats. Cows produce lower quality manure.

If the soil is poor in phosphorus, fodder and manure also become poor in phosphorus content. It is possible to improve the quality of compost through natural phosphate. Compost is produced from household waste, manure and straw. Rock phosphate may be added at a ratio of 100 kg for about 1000 kg of dry matter of the organic substrate (Lompo, 1993). Such mixture is composted over 4 to 6 months during the dry season. Compost pits are filled at a ratio of 600 kg of mix per m3 pit. The compost is subsequently applied on the field during the following rainy season. Compost is particularly important in relation to gardening.

If the soil is phosphorus deficient, the fodder and manure also become phosphorus deficient.

4.2 MICRODOSE

It is recommended to use microdosing in order to fertilize millet, sorghum and cowpea. This method is characterised by adding a small quantity of fertilizer into the pocket where the millet, sorghum or cowpea is sown. Fertiliser and seeds can be mixed in a 1:1 ratio (Doumbia et al. 2005). This mixing of seeds and fertiliser must be undertaken just shortly before sowing in order to avoid prolonged contact between seeds and fertilizer. The quantity of fertilizer to be used is about 0.3 g per pocket, corresponding to 3 to 10 kg of fertilizer per hectare. DAP is the fertilizer which is recommended the most. However, the NPK 15-15-15 may also be used. In Mali, this fertiliser method has increased millet and sorghum yields by an average of 50%. This approach is particularly interesting for farmers who are not very well off.

The second fertilizer input (after that of 0.3g) consists in applying 2g DAP or 6g NPK per pocket at the time of initial weeding, about 20 days after planting. An input of this quantity of fertilizer can more than double millet yields (Buerkert et al 2000). ICRISAT/JIRCAS research has demonstrated that delaying fertiliser application until 20 days after sowing does not decrease yield significantly as compared to applying fertiliser at the time of sowing. It is also possible to wait until 45 days after planting without the yield significantly diminishing compared to application of fertiliser at the time of sowing. It is more profitable to apply 2g of

DAP than 6g of NPK, but the quantity of phosphorous applied is the same. This corresponds to 20 to 40 kg of DAP per hectare or 60 to 120 kg of NPK per hectare. The second fertilizer application may vary according to the rainfall and purchasing power of various farmers. Farmers may cancel or delay the second application in case of drought. In order to save fertilizers, the second application can only be given to plants that seem capable of producing more. A third application with urea is possible at the time of heading if the season is promising.

Dry sowing is practiced in the northern parts of the Sahel. In such conditions, resowing is often necessary. The necessity to resow is reduced if 0.3 g of fertilizer is used, compared to 2 to 6 g of fertilizer per pocket. The application of 2 to 6 g will lead to a loss if resowing is required.

4.3 CEREALS AND COWPEA INTERCROPPING

Intercropping or rotation with leguminous crops such as cowpea is important for nitrogen fixation and for controlling striga. Millet and sorghum yield in continuous cropping diminishes over the years, but millet/cowpea or sorghum/cowpea intercropping are more sustainable systems. Farmers often practice millet/cowpea intercropping, but the density of the cowpea is often low; hence, the residual effect of the cowpea is low. In semi-arid regions in Nigeria, farmers plant cowpea with a much higher density than is found in Mali and in Niger. This difference may be linked to the existence of a well developed cowpea market in Nigeria. In Sahelian countries, there is often a lack of good quality seeds.

It is recommended to plant millet/ sorghum and cowpea in alternate rows or to alternate 4 rows of cowpea with 2 rows of millet. The following year, either millet or sorghum is planted in those rows where cowpea had been cultivated the previous year. With the cowpea-millet rotation, about 10 to 15 kg of nitrogen per hectare is added if the haulm is not retained in the field. It is often necessary to protect the cowpea with two insecticide sprayings.

4.4 MULCHING

It is recommended to add 1500 to 2000 kg of straw per hectare (ICRISAT 1997). This corresponds to a yield of about 500 kg of millet grain per hectare. Mulching may increase yield by 50%. The straw lowers the temperature on the surface, reduces erosion, improves the phosphorous content and increases soil organic matter content (Buerkert et al 2000). However, it is difficult to have such straw quantities without microdosing. Thus, microdose makes mulching more feasible. The straw must be cut just after the harvest and the stems must be left in the field. This also helps reduce attacks by stem borers. However, it is difficult to practice mulching because of roaming animals in the dry season, leading to reduced quantities of the available straw.

Certain trees can be used for mulching. The most promising tree in the production of green manure is the Acacia tumida. According to a study by ICRISAT, Acacia tumida leaves do not decay rapidly and the nitrogen release is not significant in the course of the first years. The effect of the Acacia tumida mulch is rather to lower soil temperature, reduce erosion and to increase soil organic matter. Moreover, the Acacia tumida live fence will reduce the speed of the wind and consequently the loss of water from the fields (see chapter on the tree).

4.5 ROCK PHOSPHATE INPUT

Several Sahelian countries have good rock phosphate deposits. The problem is that this fertiliser is in a powder form and the application becomes difficult making it difficult to persuade farmers to use this fertilizer. Access to natural phosphate is often difficult in Sahelian countries given that several mines are no longer operational.

4.6 REGENERATION OF DEGRADED LANDS

The soils in the Sahel are often composed of a lateritic layer covered with sand. In case of erosion, the solid laterite appears on the surface.

The principal methods used to regenerate degraded lands are: the stone bunds, ridge, half moon, the zaï (a basin to keep the water) and area enclosures. Area enclosures are mostly used to regenerate grazing lands while the establishment of the half moon is an approach that can be combined with tree plantation. The zaï and the stone bunds may be used to regenerate degraded lands. The use of the zaï in Niger is a profitable approach to increase yields.

The *Acacia senegal*, *Ziziphus mauritania*, and *Acacia tumida* are well adapted trees to lateritic soils.

5. INTEGRATED CONTROL OF WEED, PESTS AND FUNGUS

Integrated control against plant diseases, insects and weeds consists of combining different methods such as resistant varieties, cultivation techniques, and insecticides/fungicides/herbicides. Integrated control aims at minimizing the use of pesticides and these products are only used as a last resort to reduce the problems linked to diseases and insects.

5.1 INTEGRATED CONTROL OF STRIGA

Striga is a parasitical weed attacking cereals and cowpea. There are two species (types) of striga: the striga hermonthica, which attacks millet, sorghum, maize and rainfed rice, and the striga gesneroides, which attacks cowpea and wild leguminous plants. Striga attack increases in general when soil fertility diminishes. A striga attack may have a very harmful effect on millet yield. It is difficult to control striga because striga grains may remain alive in the soil for at least 5 years.

Several methods must be combined in order to efficiently control striga (Ly et al. 1998).

1. Resistant varieties: The Sangaranga and Korobalen varieties of cowpea are resistant to striga. Such resistance is absolute. For millet, it is difficult to develop resistant varieties. In sorghum, tolerant varieties have been developed.
2. Three weedings are required in order to control striga development. The third weeding must occur late in the season in order to avoid that striga produces grains.
3. A mineral fertiliser or manure input may contribute to reducing striga attacks because fertilization makes plants stronger. Microfertilising also reduces striga attacks.
4. The intercropping of cereals with crops such as cowpea, which is resistant, and groundnuts, which are not attacked, can considerably reduce striga attack.

5. Late planting can also reduce striga attack if this method is combined with weeding.

5.2 INTEGRATED CONTROL OF STEM BORERS

The larva of the Stem borer (Coniesta ignefusalis) cause considerable damage to millet crops. The insect survives from one year to another in the millet stem (Ly et al 1998). It has been demonstrated the population of stem borers can be significantly reduced if the stem is cut just after harvest and spread out on the soil surface. Heat and desiccation cause the death of the stem borer. If the stems are not cut or are used as construction material, the survival of this insect will not be affected. This method of reducing stem borer attacks also contributes to lower the soil temperature and to reduce erosion.

5.3 INTEGRATED CONTROL OF MILDEW

Mildew is a fungus which reduces plant growth and development. The seed may be infected by mildew spores or mildew spores in the ground may infect young plants. The treatment of seeds with Apron Plus is an efficient method to reduce mildew attacks. At the Ségou research station in Mali, it has been demonstrated that seed treatment with Apron Plus increases millet yield by 30% (ISNAR 2007).

6. TREES IN THE SAHEL

Trees are very important for the household food security in the Sahel. They are used as fuel wood, construction material, for fruit production, improving soil fertility, animal fodder, live fences, and for environmental protection (windbreaks, dune fixation, etc.) A tree may often be used for various purposes. Tree establishment is difficult in the Sahel because of roaming animals in the dry season and because of an unfavourable climate.

6.1 THE SYSTEM OF AGROFORESTRY PARKS – FROM TRADITIONAL AGROFORESTRY

The system of agroforestry parks – an agroforestry system whereby the trees are disseminated in the fields – is found all over in the Sahel where it has been practiced for centuries.

6.1.1 Many types of agroforestry parks identified

By Cheick Oumar Traoré (ICRAF) and Jens B. Aune (Noragric)

The mode of management and use of whatever system of agroforestry parks depends on the types of agroforestry parks. The type of agroforestry park varies in turn according to pedologic and climatic conditions. The ICRAF team used a climatic gradient to design the mapping of the types of agroforestry parks and to establish typologies.

The driest zone mapped was the region of Dori in the Northern part of Burkina Faso with an annual rainfall of 300 to 400 mm. In that region, research activities made it possible to identify five (5) types of agroforestry parks. The most common one was the pure *Faidherbia albida* system which occupied about 30% of cultivated land followed by the mixed *Faidherbia albida – Hyphaene thebaica* system (about 25 % of cultivated lands); the pure

Balanites aegyptiaca system (15 %); the mixed *Hyphaene thebaica - Balanites aegyptiaca* system (10 %); the pure H*yphaene thebaica* system (8 %) and others (12 %).

In the less arid regions of Gondo-Morondo in Mali where the annual rainfall reaches about 500 mm, the studies enabled to identify 17 types of agroforestry parks among which many are dominated by tree species like *Faidherbia albida, Balanites aegyptiaca, Sclerocarya birrea* and *Acacia raddiana* (Table 1).

Table 1: Types of agroforestry parks in the Gondo-Morondo region in Mali

Types of agroforestry parks	Area covered (Ha)	% of total surface area
Sclerocarya birra-Balanites aegyptiaca	92 300	21,05
Terminalia avicenioïdes-Combretum glutinosum	92.000	20,99
Faidherbia albida	57 100	13,02
Banalites aegyptiaca-Acacia raddiana	53 600	12,23
Prosopis Africana	2 700	12,02
Balanites aegyptiaca-Faiodherbia albida	36 600	8,35
Sclerocarya Birrera	16 600	3,79
Sclerocarya Birrea – compretum glutinosum	16 100	3,67
Faidherbia albida-Piliostigma reticulatum	4 100	0,94
Balanites aegyptiaca-Combretum glutinosum	3 800	0,87
Sclerocarya birrea-Piliostigma reticulatum	3 700	0,84
Lannea microcarpa	2 200	0,5
Combretum glutinosum	2 200	0,5
Anogeisus leiocarpa	1 900	0,43
Faidherbia albida-Vitellaria paradoxa	1 400	0,32
Piliostigma reticulatum	1 400	0,32
Adansonia digitata	700	0,16

Source: ICRAF.2000. Bilan de l'agroforesterie au Sahel

In the Bani-Niger region in Mali, with an annual rainfall of 700 to 800 mm, 18 types of agroforestry parks are identified, each type of park corresponding to the dominant tree-species in the system (table 2). These data clearly show the importance of species like *Vitellaria paradoxa*, *Adansonia digitata*, *Faidherbia albida* and *Sclerocarya birrea*.

Such knowledge of the diversity of the species in the different types of agroforestry park systems and their respective functions is fundamental for the evaluation activity we are currently undertaking on the enrichment methods of the agroforestry parks and the rehabilitation of the strained traditional system.

Table 2: Types of agroforestry parks in the medium basin of the Bani-Niger river

Type of agroforestry park	Surface area covered(ha)	% of total surface area
Vitellaria paradoxa	112 400	27.04
Sclerocarya birrea-Vitellaria Paradoxa	109 700	26.39
Borassus aethiopum	39 200	9.43
Sclerocarya birrea-Prosopis Africana	31 900	7.67
Vitellaria paradoxa-Adansonia digitata	29 700	7.14
Faidherbia albida	26 600	6.40
Vitellaria paradoxa-Prosopis africana	16 900	4.07

Vitellaria paradoxa-Faidherbia albida	12 700	3.06
Terminalia avicenioï-Prosopis africana	10 300	2.48
Faidherbia albida-Adansonia digitata	6 500	1.56
Andansonia digita	5 800	1.40
Andasonia digitata–Prosopis africana	4 200	1.01
Combretum micranthum/ghazalense-Prosopis africana	3 300	0.79
Parkia biglobosa-Terminalia avincenioïdes	2 600	0.62
Adansonia digitata-Sclerocarya birrea	2 300	0.55
Borassusaethiopum-Hyphaene thebaica	900	0.22
Pterocarpus erinaceus-Faidherbia albida	400	0.10
Faidherbia albida-Hyphaene thebaica	300	0.07

Source: ICRAF.2000. Bilan de l'agroforesterie au Sahel

There are no longer many possibilities of practicing fallow in the Sahel because there is less available land (Mortimore and Turner 2005). If a farm is under continuous agricultural use, the trees tend to disappear after a period of 20 years (source A. Nikiema, ICRISAT). The roots of the young trees are cut/hurt mainly when ploughs are used.

Natural regeneration occurs if the farmers protect the trees when they perform their farm activities. But in case very little natural regeneration takes place, it is necessary to plant additional trees by directly sowing seeds or planting potted trees. The artificial regeneration is only possible if the farmer is convinced of the usefulness of having more trees in his field. For *Parkia biglobosa* (Néré), we can have up to 23 trees per ha in a farm without negatively impacting on the millet yields. The density of *Parkia biglobosa* population is less than 23 trees per ha in many fields. As for *Vitellaria paradoxa* (Shea), we can have higher densities.

6.2 ESTABLISHMENT OF A PLANT NURSERY AND TREE PLANTING

The plant nursery is used to supply communities with trees that will provide food, income, fodder, wood, fences, and environmental protection. Often, a rural plant nursery produces about 1000 trees per year. In order to have a successful plant nursery, it is advised to plant trees for which there is a high demand. These types of trees bring more income to the owner of the nursery

Here is some advice about establishing a rural plant nursery:

1. Before establishing the nursery, the nursery must be protected with dead wood or with a live fence.
2. A well, which can supply good quality water, is required.
3. Access to a compost pit is required.
4. To ensure a good development of trees, access to shade is required, otherwise the plants will not develop well. The shade of trees is not optimal because the light under the tree is often too dim.
5. In order to facilitate work in a nursery, the plants, the well and the compost pit must be arranged in a way so as to make the work easy.
6. In the nursery, it is recommended to use plastic sacks in order to establish trees. The sacks are filled with a mixture of 2 doses of fine sand for a dose of compost.
7. It is often necessary to protect fruit trees against insects and diseases.

8. The key equipment in a nursery is a grafting knife, plastic ribbon, and sharpening stone.
9. Grafting is a good approach to improve the quality of plant material particularly for fruit trees.
10. Grafting is a method for plant propagation whereby the plant material (the scion) from one species or variety is fused with the rootstock of another species or variety. One of the methods consists in cutting the bark in a T shape in the rootstock. In this T, the scion will be introduced and a good contact between the scion and the rootstock is secured by tying them together with a plastic band. Subsequently, the grafted plant will be covered with a plastic sack. This method is appropriate for trees of the citrus family.
11. Grafting is difficult to achieve if the tree from which the scion is originating is in bloom.
12. Before planting the trees in the field or an orchard, they have to be gradually accustomed to grow under natural conditions. Watering is reduced in the last weeks before planting and the trees are more exposed to the sun. The trees need to be watered very well in the last days before planting them.

The establishment of trees in the fields is difficult. In order to minimize the need for watering, the best time to plant trees is the months of July and August. The animals that come to browse the trees can also create problems in the course of the first years. In order to avoid this problem, the trees need to be protected by for example using thorny branches. Another method consists in mixing manure with water and glue. This mixture is applied on the plants by using a brush. The plants must be treated two to three times a year. A test carried out at ICRISAT demonstrated the efficiency of this method (source: D. Pasternak).

It is often necessary to prune the trees one or two years after planting. If the fruit trees are not pruned, the fruits will be small and it is also difficult to spray efficiently.

6.3 USE OF TREES IN THE SAHEL

The trees in the Sahel are used for different purposes such as firewood and wood for construction, fodder for the animals, human nutrition (fruits and leaves), oil production (fern and shea butter), organic fertilizer, windbreaker, live and dead fence, and territory marking.

6.3.1 Leaf producing trees for food

Moringa

Moringa oleifera and Moringa stenophetala are leaf-producing trees that can significantly improve the quality of nutrition in the Sahel. Moringa oleifera has become a very popular tree in Niger and in Northern Nigeria. Moringa oleifera is mostly cultivated in gardens as it cannot produce much without irrigation if rainfall is below 700 mm. Moringa trees can be propagated through cuttings, planted in pots or by direct seeding as in Niger (Larwanou and al. 2005). The space between plants is 1 x 1 meter. The tree must be pruned when it reaches a height of 1.5m in order to promote leaf production. In order to avoid the Moringa becoming an erect tree, the sprouts (adventives) need to be removed. The new Indian variety PKM1 has a higher productivity than other Moringa varieties. Moringa responds well to organic or mineral fertilizers.

Moringa stenophetala can be planted in millet farms even if rainfall is less than 700 mm. This Moringa species is more resistant to drought, but has a different taste than that of Moringa oleifera.

The growing of Moringa in gardens in Niger is much more profitable than that of tomatoes and other vegetables.

The Moringa tree, green or dry, is excellent food for humans and particularly for children between 1 to 3 years old. Moringa leaves are preferably eaten in fresh, but they may also be dried. If they are dried under the shade, they keep more vitamin A. An intake of 100 g of fresh leaves by a 1 to 3 year old child can cover the needs in vitamins A and C, 75% of his iron needs and 50% of his protein needs (Fuglie 2000). Even a quantity of 20 g of fresh leaves may cover the needs of Vitamin A and C, those vitamins that are most in deficit in the Sahel.

For the pregnant or breastfeeding mother, the Moringa contributes to ensure a good nutrition and also stimulates milk production (ICRISAT 2000). Moringa can also be used to treat malnourished children.

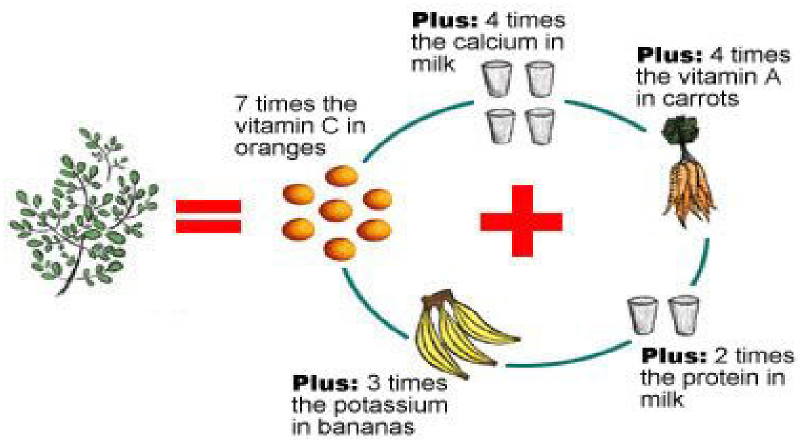

Figure 3: The nutritional qualities of Moringa
Source: http://www.treesforlife.org/project/moringa/default.en.asp

Moringa seeds can also be used for purification of water and production of vegetable oil (Trees for life 2006). Moringa oleifera grains contain 40% of lipids. In order to extract the oil, the ripe grains are burned, pounded and soaked in boiling water for a period of 5 minutes. An oil layer will form on the surface of the liquid (Flugelie 2006).

6.3.2 Trees to increase soil fertility

To increase soil fertility, it is necessary to increase the recycling of organic matter. One approach is to plant trees that can produce green manure. Research conducted at ICRISAT in Niger showed that Acacia tumida is a species which produces a lot of green manure (see chapter on soil fertility). Acacia tumida can be planted in areas where the rainfall is higher than 300 mm. The Acacia collei has also been tested, but this species is less resistant to drought than the Acacia tumida. After the second year, each Acacia collei tree produces 14 kg of organic matter. A study carried out in Niger demonstrates that the Acacia tumida can grow by 2.4 m in 14 weeks (Houérou 2006, http://www.fao.org/AG/aGp/agpc/doc/gbase/DATA/PF000365.HTM).

The advantage of Acacia tumida is that the leaves of this tree are not grazed by animals from the second year after their establishment. The Acacia tumida trees just need to be protected during the first year.

The Acacia tumida may be planted with a space of 10 metres between the rows and 5 meters within rows (source D.Paternak). This corresponds to 200 trees per hectare. In addition, it is possible to plant the tree as a fence around the field. The Acacia tumida leaves slowly decompose in the soil. Even after 2 years, the leaves do not add much nitrogen to crops. During the initial years, mulching rather reduces erosion and protects plants against wind. Termites contribute to decomposing Acacia leaves. It is possible to plant millet and cowpea near Acacia tumida fences without producing any negative effect on the yield.

The Acacia tumida must be pruned each year or every two years in order to produce green manure. The pruning time is April, after the pods are harvested.

Another advantage of the Acacia tumida is that the grains are edible and there is a market in Europe for these grains. The grains are also consumed by the Aboriginal people in Australia. These grains also constitute good food for hens as they have 18% protein content.

In order to establish a hedge of Acacia tumida fence, seedlings raised in nurseries are used. Direct seeding is too risky. The Acacia tumida fence is an effective windbreak and it has a net effect on the speed of the wind. This contributes to reducing evapo-transpiration.

6.3.3 Fruit trees

There is a great demand for fruit trees in the Sahel. The trees are often easy to maintain and they are also more profitable than vegetables. The markets for various fruits in the Sahel are seasonal and the prices of fruits drop during the harvest season. Good conservation of fruits may stimulate and develop fruit production. Fruit production in the Sahel may develop through the production of juice from various fruits. In Europe, there is a strong demand for different tropical juices. For the time being, there are three juice-producing companies in Burkina Faso. Another way to preserve fruits is to dry them.

Dates

The Sahel has an appropriate climate for date production. The date palm in the Sahel begins producing fruits 6 to 7 years after plantation. It is advised to plant 100 date trees per hectare. Each date palm can produce 5 kg of dates per year, corresponding to 500 kg of dates per hectare. The date has a high energy content and can be well preserved (IPALAC 2006). However, the varieties of dates grown in the Sahel do not fulfil the quality condition required for export and ICRISAT has imported better quality varieties from Arab countries.

The date has male and female plants. Pollination is a necessity to produce dates. Pollination can occur naturally or in an artificial manner. During the rainy season, each plant needs an average of 100 litres of water per day while in the hot season the need is 500 litres per day (source D.Pasternak). The date palm requires more water than any other plant.

The Sahel apple

Zizyphus mauritania is a common tree in the Sahel. ICRISAT has given the popular name of Sahel Apple to this tree. The tree is highly appreciated thanks to its sweet fruits. The fruits are quite small, but it has been demonstrated that it is possible to graft improved varieties of

Zizyphus mauritania from India to the rootstock of local Zizyphus Mauritania. The grafted zizyphus produce much larger and sweeter fruits and the yield is also much higher than local varieties. Each grafted Zizyphus Mauritania plant can produce 30 kg of Sahel apples per year. To have such a yield, fertilizer application is required, and so are treatments against the fruit attacking flies. An initial spraying with Karate insecticides three weeks before harvest and a second spraying with the Malathion near harvest are recommended. The Sahel apple must also be pruned each year as the fruits develop on new branches. The Katheli and Bengourion varieties are less attacked than the Gola variety. However, the latter is the most widely found in the Sahel. The Gola variety must therefore be replaced by the two new varieties (source D.Pasternak). It is recommended to plant 100 trees per hectare. This corresponds to a production of 3000 kg per hectare in normal circumstances. The medium price for the Sahel apple is FCFA 300 per kg, which yields a gross return of FCFA 900,000 per hectare.

The mango tree

The mango tree is a fruit tree from India that was introduced into West Africa in the 19th century. This is an important tree in areas with a rainfall level higher than 700 to 800 mm. It is a good source of vitamin A. In rural areas, mangos are often available only 2 to 3 months. By introducing new varieties, it is possible to extend the period when mangoes are available. This can contribute to improving nutrition and increasing farmers' revenues.

Mango trees are normally planted with a space of 10*10 meters (Vannière and al.2004) 12 to 16 months after sowing the stocks.

The Amelie, Kent and Keitt varieties are the most important on the export market (Rey and al.2004). The Amelie variety is the earliest, but it can be stored less time than the other varieties. The Kent variety ripens between May and July in Bamako. The Keitt variety is the latest-maturing of these three varieties. This variety produces fruits until August in Bamako.

Other fruit trees

The other important fruit trees in the Sahel are the tamarind, the fig tree, Saba senegalensis, Lannea microphylla and Sclerocalaria microphylla.

The tamarind produces a very popular fruit with a highly appreciated juice. This tree must not be pruned. This species is well adapted to degraded soils.

The fig tree is very productive in Sahelian countries if the rainfall is above 700 mm. Saba senegalensis and Lannea microphylla are trees producing sweet and bitter fruits. The Sclerocalaria berrea is a fruit tree which is well adapted to degraded soils.

6.3.4 The production of gum Arabic by the Acacia Senegal

Gum Arabic is normally collected on naturally growing trees Acacia Senegal trees. The tree is much widespread in the Sahel (CNI 2006).

It is possible to establish plantations of Acacia Senegal to produce gum Arabic. In order to achieve a good production, it is important to choose high gum producing varieties of Acacia Senegal. The most vigorous trees produce the most gum.

ICRISAT has grafted an Acacia Senegal variety originating from Sudan on a local variety. The grafted trees produce 5 times as much gum Arabic as local non grafted trees (source D. Pasternak, ICRISAT).

The Acacia Senegal may start producing gum 5 years after plantation. The revenue per hectare of gum Arabic is approximately the same as that of a hectare of millet.

6.3.5 The live fence

Trees are also used as live fences. Live fences may serve several functions including protection of gardens against animals and wind erosion (windbreaks), and for land delimitation.

About 80 % of gardens are protected with dead wood (Yossi 2006), but this type of fence often needs repair. The live fence is on the other hand permanent. A live fence must be protected by a dead fence during the first years. Farmers choose trees to use for the live fence based on their protective capacity, the pace of establishment, the manpower required for maintenance, the value of the products, and potential nutritional or medicinal qualities (Levasseur 2004, Yossi 2006).

The trees are planted in a hole (Yossi 2006) in which 0.5 kg of manure or compost is added at the time of plantation or sowing. The space between trees on the rows may be about 0.5m. The live fence may be constituted of one or two rows. In case the fence is constituted of two rows of trees, the latter must be planted in a quincunx in order to increase the fence's effectiveness. However, a two-line fence has drawbacks in the sense that it is difficult to weed between the lines and the risk of bush fires increases (Yossi 2006). Planting is done when the rainy season has really set in. An application of mineral fertilizer can further increase plant growth. After a year, it is recommended to add manure. ICRAF has shown that direct sowing with A. nilotica is an easy way to establish a live fence.

Maintenance after installation is very important. It is recommended to undertake two weedings during the rainy season. Two years after the installation of the fence, it is recommended to cut it back to a height of 0.5 m in order to have a thicker fence.

Local trees which are most often used are the *Acacia nilotica*, *Acacia senegal*, *Bauhinia rufescens*, *Zizyphus mauritania*, *Ziziphus mucronata* (Yossi 2006) and *Zizyphus spina-christi*. The *Acacia nilotica* is often used in live fences. Tannin, which is used for the production of high value leather, is produced from green pods from *Acacia nilotica*. The young Acacia nilotica pod is good fodder as well. The *Acacia senegal* provides gum while the *Zizyphus spina-christi* is used for various ends.

The *Ziziphus rotundifolia* is also a species originating from India which could be used as a live fence (source D. Paternak). This species establishes more rapidly than local species such as Acacia nilotica. It produces fruits that are highly appreciated by humans. This tree must be cut when young so that it may form a denser live fence.

Henna is another alternative as a live fence, but goats graze this tree if there is no other plant. Henna is an important species in the Sahel. It is mostly used by women for various purposes. An Indian variety has a twofold yield and a higher resistance to drought than local varieties.

7. LIVESTOCK PRODUCTION IN THE SAHEL

Livestock rearing is one of the most important economic activities in the Sahel. The most economically important animals in the Sahel are cows, sheep, goats, camels and chickens. Cows are generally more exposed to droughts than other animals. Goats and camels are the most resistant animals to drought as these animals are browsers (can graze on trees). In the Sahel, one can distinguish two types of livestock breeding: sedentary livestock systems and transhumance livestock systems. Conflicts sometimes arise between these groups concerning the use of grazing lands and wells.

In the Sahel, animals may be considered as a bank and most farmers who can afford it buy animals. It is difficult to improve the management of pasturelands in the Sahel as rainfall varies considerably from one year to another. For this reason it is difficult to determine an optimal number of livestock in the Sahel.

An animal's weight varies considerably in the course of a year; in general, animals gain weight during the rainy season and lose it during the dry season. This is due to the poor availability and poor quality of fodder during the dry season. The effect of this variation in fodder quantity and quality is that the growth rate of animals is low and the speed of reproduction is low.

Several methods may be used to improve the availability and quality of fodder such as production of fodder plants, the treatment of straw with urea, and the provision of animals with multi-nutritional blocks.

7.1 FODDER PRODUCTION

The production of dual-purpose cowpea varieties (grain and fodder) is a traditional method to get access to high quality fodder. The groundnut haulm is also generally considered a good quality fodder. For groundnuts, the straw decays often after harvest because the plants are left to dry on the ground. A better method for drying the groundnut pod has been developed as shown in figure 1. Another alternative in order to get access to good quality fodder is to establish fodder banks with Gliricidia sepium. The leaves of this tree must be dried before being given to animals. Fodder banks must be protected against roaming animals.

The use of the microdose method also doubles the millet and sorghum straw yield and represents a source of fodder for intensification of Sahelian farming.

Another approach to improve the quality and quantity of fodder is to promote regeneration of Faidherbia albida in the millet fields. The leaves of this tree have good fodder quality. Assisted natural regeneration is less costly than planting trees.

Production of hay is another method to improve quality and quantity of fodder. Wild grasses can be cut at the time of flowering and dried in the field or under a shed. This is a low cost method for improving the quality of fodder.

Another low-cost method is to harvest cereals at the time of physiological maturity instead of at full maturity. At the time of physiological maturity the grain yield is at its peak, but the quality of the straw is much higher. The inconvenience is that the grains and straw will have to be dried after harvesting in order to be stored safely. At the time of physiological maturity the grains are turning hard.

7.2 TREATMENT OF STRAW WITH UREA AND PHOSPHOROUS SUPPLEMENT

Urea treatment of straw is a method to improve the digestibility of straw and its nitrogen content. The method is mostly interesting where there is surplus of straw of poor quality. Such situations can exist where paddy rice is produced. The method consists of adding to the straw water containing 5% urea: about 50 litres of water (mixed with urea) is applied for 100 kg of straw. The straw thus treated is hermetically covered with a plastic sheet for a period of 20 to 30 days. It is subsequently aired in the open air for three hours before being given to animals for food. An ox can consume about 7 kg of this fodder per day. It may take some time before the animals get used to consuming urea treated straw.

Another method developed by ILRI to fatten cows consists of supplying them with a supplement of 6 g of superphosphate, 7 g of salt and 600 g of millet bran per day (Ayantunde and al.1998). Results from a study showed that the animals receiving this fodder ration gained 100 g additional weight per day, while those animals not receiving it lost 95 g per day. The millet bran contributes to increase the protein content of the ration as this nutrient contains 16% protein.

7.3 FATTENING

This activity consists in fattening animals for two to three months for feast celebrations such as the Tabaski. This is an interesting activity for poor people, particularly women, because fattening does not require a major investment and the market is assured. The animals to be fattened are selected in the herd or are purchased in the market. Traditionally, the sheep are tethered and fed with available fodder such as millet bran, groundnut or cowpea haulm or millet straw. The animals eat everything that is made available to them. The sheep that are selected for fattening weigh about 25 kg at the beginning and they are sold when their weight reaches about 35 kg. Without supplementary feeding, the animals lose weight during the dry season. If the Tabaski intervenes in the period between July and October, there is no need for supplementary feeding.

The International Livestock and Research Institute in Niger has developed a low cost method of increasing the profitability of fattening (Ayantunde 2006). The method consists in giving a ration of 400 g of millet bran and 300 to 600 g of cowpea haulms to each sheep per day. The advantage of this ration is that the animals do not eat more than they need and wastage is reduced. By practicing this method, the livestock farmer may earn FCFA 6000 per animal if the fodder is purchased, while the profit would be FCFA 10,000 per animal if the cowpea and millet bran come from his own production. This method of practicing animal fattening has become popular in Niger.

Urea treated straw can also be used as fodder for fattening.

7.4 POULTRY PRODUCTION

Poultry is important in the Sahel, as it is useful in sacrifices and serves as exchange objects and source of income (Kondombo et al 2003). Livestock breeding at household level usually begins with hens. The hens are normally fed with household waste and sometimes with termites. The hens eat anything they can find near the house. One of the principal threats to poultry farming is Newcastle's disease. There is a vaccine against this disease but the vaccine is rarely used.

An increased yield of millet also increases chicken's access to food. Planting Acacia tumida trees could significantly contribute to improving chicken nutrition as the grains from this tree have a very high protein content.

8. THE LADDER OF INTENSIFICATION OF AGRICULTURAL PRODUCTION IN THE SAHEL

The processes of agricultural intensification will vary according to rainfall, type of soil, market access, relations between input prices and product prices and means available to farmers. Intensification may signify increased production per area unit or production per working hour, or both. The ladder for agricultural intensification which is presented here may be considered as a possible model of intensification. The use of organic and mineral fertilizer is presented here a starting point for intensification of farming in the Sahel because the other technologies such as the new varieties have little impact if soil fertility is not improved. Thus, soil fertility is the foundation on which it is possible to build sustainable agriculture in the Sahel.

The ladder of intensification of agriculture

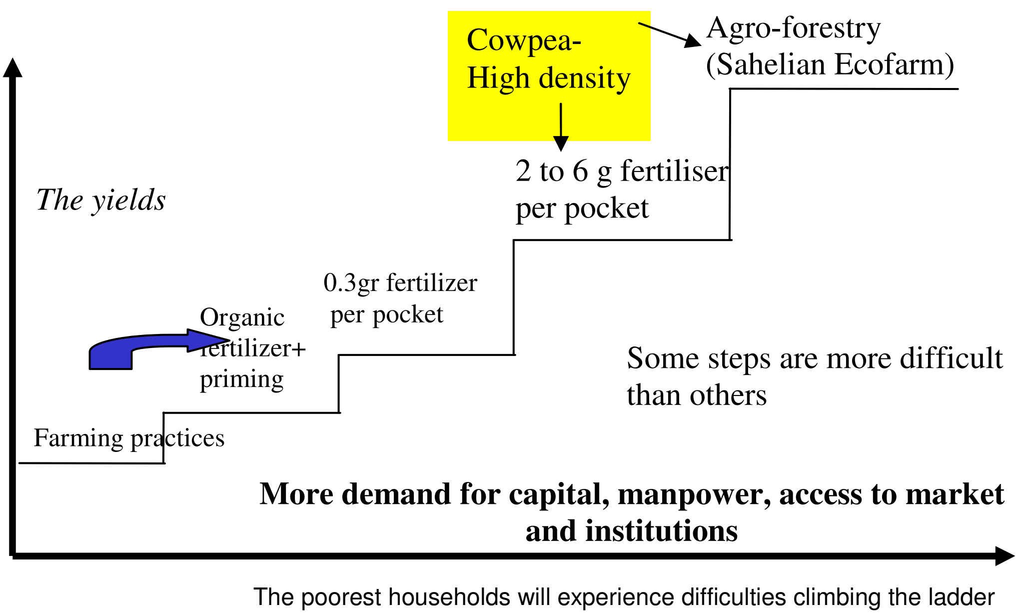

Figure 4: The ladder of intensification of agriculture in the Sahel

The process of intensification is comparable to climbing a ladder. On this ladder, the distances between the different steps are not the same, which means that some steps in the process of intensification of agriculture are more difficult than others. The process of intensification presented here is hypothetical, but it represents possible steps based on the means of the farmers. When one climbs one step, the steps climbed represent the foundation for climbing to another step.

At the bottom of the ladder the farmers' practises are characterized by the use of fallow and limited use of organic inputs. Yields are low, in the order of 200 to 300 kg of grain/ha. The first step in agricultural intensification is the use of organic matter, as it is important to recycle as much organic matter as possible. It is recommended to use organic fertilizer in gardens and fields that are near homes because the transport of organic fertilizer to distant fields is a real challenge in terms of manpower and means of transport. The use of organic fertilizer may be combined with seed priming. In case of runoff (loss of water) it also becomes necessary to establish structures such as the zaï or stone bunds. An assisted regeneration of Faidherbia albida may also be one of the first steps of intensification. The regeneration of this tree will improve the quality of the soil and will facilitate access to fuel wood. The approaches proposed here as initial steps do not require capital, but considerable manpower.

The third step in the process of intensification of agriculture is the input of 0.3 g of mineral fertilizer per pocket of millet, sorghum or cowpea. This low cost method helps increase agricultural yield without any need for additional manpower.

The fourth step could be the application of 2 g of DAP or 6 g of NPK. This second fertilizer input may intervene around the first weeding if the water conditions of the soil are favourable. The application of 2 g of fertilizer per pocket is most appropriate for farmers who can normally afford to sell a portion of their grain harvest or those who have access to other sources of income such as the profits from the sale of animals or money transfers by migrant relatives. At this stage of intensification of agriculture, it is also interesting to increase the density of cowpea. The fodder produced by the cowpea coupled with increased millet grain and straw production due to fertilizer application constitutes an opportunity for intensification of livestock production through fattening and poultry farming.

The fifth step consists in introducing agroforestry systems and cash crops. Important cash crops can be sesame and hibiscus. The Ecofarm system in the Sahel as proposed by ICRISAT is an example of an agroforestry system. This farm is composed of *Acacia tumida* rows 10 meters distant from one another in the middle of which rows of *Ziziphus mauritania* are planted. Seasonal crops such as millet, cowpea, and hibiscus are planted in rotation between tree rows.

Certain farmers in the Sahel have already passed the steps presented in this ladder. These farmers have enough means and are cultivating cash crops by using advanced irrigation systems as in Europe. But for the majority of farmers in the Sahel, this type of agriculture is beyond reach.

It is important to point out that the higher one climbs up the ladder, the more demanding the intensification becomes in terms of access to the market, manpower and capital requirements. It is difficult for farmers who are distant from the market or who have little means to participate in such an intensification. For such farmers, adopting just the first steps of intensification would be the only feasible option. An intensification which requires up to 0.3g of fertilizer does not necessitate the use of credit as very little fertilizer used. The use of 2 g of fertilizer per pocket is almost 7 times as demanding in terms of capital. Such method also doubles the manpower requirement at the time of planting. As a result, it is easier to climb the initial steps of intensification than the final ones.

The initial steps of intensification of agriculture do not require profound changes in the production system as is the case with agroforestry. The introduction of agroforestry in the form of planting hedges and fruit trees such as the *Ziziphus mauritania* require another type of land management. It is particularly important to protect the trees against roaming animal. The adoption of the agroforestry system may increase farmers' income, but it is difficult for a farmer to do it alone. This requires a community approach and the development of institutions in charge of land management. For this reason, the development of the agroforestry system is much more complicated than the initial steps of intensification.

Credit is not absolutely necessary if the technology is profitable. Farmers may sell a few goats or sheep in order to purchase inputs with the income from such sales. For the poorest groups, however, it might be necessary to contract a loan but the latter are reluctant to buy fertilizer on credit, as food security is their first priority

The risks increase when moving up the ladder because of more use of inputs and more dependence on the market. These risks are addressed in the following chapter.

9. REDUCING RISKS IN THE PRODUCTION SYSTEM

Risks in agricultural production in the Sahel are agro-ecological, economical, and social in nature. The agro-ecological risks are the rainfall variability and attacks by insects, fungus, weeds, and birds. The fact that the prices of inputs and agricultural products are not known at the time of planning the agricultural campaign also increases risks for farmers. Other factors that make the planning of the season uncertain are the social insecurity related to human illness and the difficulty to get access to manpower at an appropriate time. Such risks, combined with the low purchasing power, difficult access to inputs and credit, account for the low use of inputs in the Sahel.

However, the farmers' ability to cope with risk should not be underestimated. According to Schults, Economics Nobel Prize laureate, farmers are rational decision makers. If they deem that technologies are not convenient to them, they do not use them. This also means that farmers are capable to assess production related risks. If they estimate that a particular technology is too risky, they will not adopt it.

9.1 THE AGRO-ECOLOGICAL RISKS

The entry point for inputs is the introduction of microfertilisation. This method is economically feasible with over 50% yields' increase compared to farmers' practices. However, the use of this method remains modest in the Sahel. Several factors, such as the difficult access to fertilizers and risks related to production, explain this situation. Access to fertilizers is rather a political and organizational matter while production related risks can be reduced by manipulating the factors potentially influencing such risks. The first risk in the Sahel is rainfall variability. One way to diminish risks related to the use of fertilizers for the production of millet, sorghum, and cowpea is to add 0.3g of fertilizer (mixture of fertilizer and seed in a 1:1 proportion) per pocket. If the farmer has sufficient means, he may add 2g of DAP or 6g of NPK at the time of the first weeding if the water conditions of the soil are adequate. In the case of drought, the farmer can either postpone the second fertilizer application until the conditions become favourable or cancel it in case of prolonged drought. Weather forecast can also help farmers make adequate decisions. Microdose combined with soaking further lessens the risk.

It has also been demonstrated that mulching can improve the water condition of the soil by lowering the surface temperature and diminishing runoff. That is why it is preferable to combine microdosing and mulching in order to reduce the climatic risks. One can use millet straw or leaves from trees such as Acacia tumida for mulching.

Mineral fertilizer is best used on a non degraded soils compared to a degraded soil as the risk of failure with the microdose is higher on the degraded soil, particularly where the runoff is significant. On a soil with physical degradation (soils with a surface crust), it is not recommended to apply the 2g dose of DAP or 6g dose of NPK per pocket. The risk will be reduced if these quantities are combined with methods such as the stone bunds and the zaï. Establishing windbreaks with Acacia tumida may also reduce the water stress of plants.

Plant establishment in the Sahel is often difficult because of insect attacks and fungus. Investment in microdose and other inputs might be useless if the plant growth is reduced due to these attacks. Treatment of millet seeds with Apron Plus might significantly reduce mildew attacks and attacks by other fungi which affect the growth of young plants and it is recommended to treat seeds if mildew attacks are a serious recurring problem every year.

Cowpea is mostly vulnerable to attacks by insects such as the thrips at blooming. The pod borer is a problem at the time of pod formation. Two sprayings, one at the time of blooming and another at the time of pod formation, may contribute to reduce this risk.

Technologies such as priming, microdose, mulching, zaï, combined with the possible use of phyto-sanitary products are necessary for reducing risks.

Preliminary results of comparative studies of agriculture development by ICRISAT in several villages over a period of 20 years in Niger and Burkina Faso show that it is more difficult to intensify agriculture in regions where rainfall is about 400 mm as compared to areas where rainfall is about 600mm. The study by Mortimore and Turner in 2005 confirms this same observation. Livestock is the most important economic activity where rainfall is about 400 mm, whereas in areas with 600 mm agriculture is the dominant economic activity. The conclusion that can be drawn from these observations is that the emphasis should be given to an agriculture that can support livestock production in areas with 400 mm rainfall. The production of millet and cowpea for fodder production may become an important economic activity in these regions.

9.2 PRICE RELATED RISKS

The price of millet varies considerably from one year to another as demonstrated in Table 3 (Abdoulaye and Sanders 2006, Vitale and Sanders 2005). The price of the kilogram of millet at the end of a bad agricultural season is about FCFA 130, while it is FCFA 50 at the end of a good season. The price of millet continues to increase for many months after harvest if the yield has been low and inversely for years when yields have been high. Farmers grow millet and sorghum as sources of income and in order to meet their cereal needs for their own consumption. From the standpoint of profitability, it is surprising that it would be more profitable to use fertilizers during a bad season than during a good season as Table 3 demonstrates. This is a consequence of price increase after poor harvests. A high price after a bad season is beneficial for farmers who are able to sell cereals, but at the expense of those who must buy them. The risks of the price of millet going down after a good year are high as table 3 demonstrates. In such a case, the profitability of the use of fertilizers is low if not negative. In Sahelian countries there are no established mechanisms helping to avoid a dramatic fall in prices. An approach that farmers can use is to use the surplus production for fattening, for plough oxen or to feed chickens (Vitale and Sanders 21005). Farmers can rapidly increase their poultry production after a good season. Another alternative to reduce overproduction is to develop the food and agricultural industry. The transformation of millet grain into couscous is a growing industry in the Sahelian countries and such transformation may contribute to reduce the fall of millet prices (Vitale and Sanders 2005). The yield prediction that AGRHYMET gives each year in August can help farmers make informed decisions concerning investments in animals.

Table 3: Production risk (based on data over 70 years), yield and variation of millet prices between different years for Fakara, Niger (average rainfall of 450 to 500 mm).

	Proba-bility %	Millet yield-without fertilization	Millet yield - Manure + 8 kg NPK/ha	Millet price at harvest FCFA	Millet price 6 months later FCFA
Catastrophic	14	0	0		
Mediocre	17	288	332	128	164
Normal	43	359	415	92	114
Good	28	431	498	50	64
Very good	12	467	539	36	36

9.3 RISKS RELATED TO THE PURCHASE OF INPUTS (FERTILIZER)

Access to inputs remains a problem for intensification of agriculture in the Sahel. It can be risky for farmers to purchase large quantities of fertilizer prior to a drought year. The seasonal rainfall forecasts by AGRHYMET may help farmers make appropriate decisions concerning the purchase of fertilizer. If there is a high probability that the year will have a deficit in rainfall, farmers could only purchase the fertilizer quantities necessary for the application of the method of 0.3 g of fertilizer per pocket.

10. DEVELOPMENT OF SUSTAINABLE AGRICULTURE IN THE SAHEL

In order to eliminate poverty in the Sahel, agricultural development is one of the key factors. The percentage of the population suffering from malnutrition is estimated at 20%, 36%, 36%, and 44% for Mali, Burkina Faso, Niger, and Ethiopia, respectively (FAO 2003). Cereal production per capita remains stable in the Sahel countries (Ndjeunga and Bantilan 2005) and the adaptation of new technologies is low.

The International Food Policy Research Institute has identified 5 key factors for agricultural development (Hazel 1999). These factors are designated as 5 ‘I’s: Innovations, Inputs, Infrastructures, Institutions and Incentives (a favourable policy).

It is difficult to promote agricultural development because all the ‘I’ factors must be in place; otherwise, the absence of one of these factors might hamper such development.

10.1 INNOVATIONS

Innovations are important for any agricultural development. Farmers, the private sector, or the research community may develop innovations. Chapters 2, 3, 4, 5, 6, and 7 present a few possible innovations for the Sahel. Cash crop farmers are more willing to use agricultural innovations such as mineral fertiliser and water harvesting systems (Ndjeunga and Bantilan 2005).

Demonstrations are efficient for introducing new technologies. A study conducted in Niger reveals that those who participated in demonstrations on the use of microdose or who have seen the tests tended to adopt the technology (Abdoulaye and Sanders 2005). In Mali, the information sessions and the ICRAF radio programs have contributed to the promotion of live fences (Yossi et al. 2006).

The farmer field school approach helps disseminate new technologies and teach farmers how to make their own diagnosis of their farming practices. The field school approach is to learn by observation and experimentation (FAO 1999). The field school approach may also be used to introduce themes related to livestock breeding or renewable energies.

Setting up of a field school in a village normally begins with a diagnosis in order to determine the constraints and opportunities in the village (FAO 1999). Based on the diagnosis, farmers choose a theme of interest to them. In each village, groups of 5 to 10 people are formed. Each group is supervised by a facilitator. The facilitator could be a farmer who has received an in-depth training or a resource person such as a researcher or an NGO agent.

Plots for testing new technologies are established such as plots for microfertilisation or integrated control of striga. New practices are always compared to farmers’ practices. Farmers’ associations originating from different villages regularly visit the village of the trained farmer. The group makes observations together in the experimental plots and discusses the lessons learned. In the course of each meeting, a table indicating participants’ major observations on, for example plant development and rodent attacks, is presented in the national language. Each member also has his own plot in which he/she may conduct his/her own tests. Each trained person is in turn responsible for training 5 other farmers in his/her own village. Another possibility is to establish experimental plots in each village and to invite trained farmers to visit them on a regular basis.

Use of innovation may also increase prices to farmers. The use of microdose and other yield increasing technologies influences the relation between product prices and input prices. As the price of millet increases (up to three times) during the 10 months after the harvest, the profitability of microdose is much higher if the farmers delay sales up to 10 months after harvesting. As the microdose method increases yields by at least 50%, farmers may put off the sale of a major portion of their crops in order to increase their profit.

10.2 INPUTS

Important inputs for agricultural development in the Sahel are seeds, fertilizers, veterinary products, phyto-sanitary products and small agricultural implements such as the hoe, the seeder, the plough, the cart, etc. Access to inputs is often difficult in the Sahel.

In Niger, FAO is promoting input shops (FAO 2005) managed by farmers. In normal conditions, a development project (FAO and others) subsidises the purchase of the initial stock which will become a revolving fund for the operation of the shops.

In the Sahel countries, many farmers have received training in seed production, but their harvest is not sold at a higher price than other seeds. This is discouraging for seed production in the Sahel.

10.3 INFRASTRUCTURES

Those farmers who are not well integrated in the market encounter difficulties in the development of their agriculture (Ndjeunga and Bantalin 2005). To develop sustainable agriculture, infrastructures and means of communication such as roads and telephones must be established. The use of inputs is often difficult in arid zones because of poor road conditions. This increases the price of inputs and reduces the price of agricultural products. It is also difficult to have access to inputs at the appropriate time where road and communication infrastructures are not well developed.

The development of mobile networks is a true revolution in Sahelian countries. This facilitates communication and farmers' participation in the market. Price information is particularly easier to obtain.

10.4 INSTITUTIONS

The institutions have a major role to play in the promotion of agricultural development as certain problems cannot be solved at the individual level, but require collective action. The development of credit institutions is important for agricultural development. Farmers generally have to sell their production just after harvest in order to reimburse their debts and pay for necessary commodities. The 'warrantee/guarantee approach developed in Niger consists of farmers depositing the grain in a store after the harvest. The credit fund (local institution) then pays the value of the stored grain. Farmers may invest this money in activities such as gardening, purchase of fertilizer or other. About 6 months later, they may reimburse the credit and they receive the grains that they had deposited in the store. Subsequently, they may sell part of the grain that they do not need in order to get some income. The price of the millet is normally higher at that time than during the harvests.

10.5 INCENTIVES

A policy that improves the relationship between input price and the price of agricultural products is a key factor for agricultural development in the Sahel. If this relationship is not favourable, the effect of other factors influencing intensification such as credit will be reduced. One of the major factors that can account for the low use of inputs is the low profitability of new technologies. This is related to the fact that farmers must sell their production after harvest while prices are low. The fall of prices of traditional crops during good seasons favours consumers over producers (Vitale and Sanders 2005).

In Sahelian countries, there are cereal reserves under governmental control and the sale of this stock has a major effect on the price of cereals in the market. In Niger, the government often starts selling cereals when the price is higher than FCFA 200 per kg. This policy is beneficial for the urban populations who purchase cereals, but at the expense of farmers.

Emergency aid characterized by free distribution of imported cereals also affects cereal prices in a negative manner. For this type of distribution not to have a harmful effect on cereal production in the future, it is important to make a distinction between a bad season and a catastrophic one. The distribution of imported cereals during a bad year undermines internal cereal production (Abdoulaye and Sanders 2006) and farmers are less motivated to develop agriculture and use of inputs becomes less attractive. It is appropriate only to import cereals after catastrophic years.

The USAID monetization program implemented by some American NGOs may have a harmful effect on the price of cereals in Sahelian countries (IATP 2005). The NGOs receive USAID support in the form of rice and American vegetable oil. These products are sold in the Sahelian countries and the returns are used to finance the development activities of these American NGOs. Although millet or sorghum is not sold, there is a substitution involving the different cereals.

Mineral fertilizer was subsidized in the past, but the Structural Adjustment policy imposed by the International Monetary Fund and the World Bank has suppressed this subsidy. However, subsidizing fertilizer can be justified as the problem of soil fertility is not only a concern for farmers, but is also a public and national concern.

In many countries of the Sahel, trees were government properties in the past. The current development is towards a usage right of trees. This has contributed to a greater awareness by farmers of the management of trees in Niger (source C. Reij).

The probability for the agricultural season to be catastrophic is about 14% in those areas where rainfall does not exceed 400 mm of rain per year in Niger (Abdoulaye and Sanders). During the catastrophic seasons, farmers need support, as is the case in developed countries. The best way to help them without harming their dignity is to initiate public works such as road maintenance, the construction of bridges, or environmental activities such as regeneration of degraded lands or tree planting. Such works may be remunerated either in cash (money for work) or in kind with cheques /food coupons (food for work).

11. CONCLUSION

There are many opportunities to improve agriculture in the Sahel. The choice of different technologies and approaches depends on socio-economic conditions and household conditions. There is no technology that fits everywhere. Farmers, who do not have the necessary financial means, cannot take big risks and are not in a position to make heavy investments. The role of development agencies is to facilitate farmers' work, and to identify and remove bottlenecks associated with access to innovations, inputs, infrastructures, institutions or incentives. There is a great potential for agricultural development in the Sahel. It is important to identify and seize the opportunities when they arise.

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