The Sahelian Eco-Farm

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Abstract

The Sahelian Eco-Farm (SEF) is an integrated agriculture production system that provides simultaneous solutions to the main constraints of Africa's rain-fed agriculture. These are: soil erosion, low soil fertility, low water use efficiency, droughts, insufficient supply of animal feed, low income, and inefficient distribution of the labor force.

The SEF is an alley cropping system in which trees and/or shrubs are intercropped with annual crops. The first SEF model under development is composed of Acacia colei trees, domesticated Ziziphus mauritiana called Pomme du Sahel (PDS) and three annual crops (millet, cowpeas and Roselle).

Soil erosion by water is prevented by the construction of earth bunds combined with micro-catchments every thirty meters down the slope. PDS trees are planted inside each micro-catchment. Erosion by wind is prevented by the wind breaking effect of the Acacia colei trees and by mulch produced from the Acacia branches and phyllodes.

Acacia colei trees play a major role in soil fertility enhancement. The trees are pruned once a year and their branches are spread over the field adding organic matter to the soil. Tree roots add organic matter and fix atmospheric nitrogen. Soil fertility is also enhanced by crop rotation.

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Water use efficiency (WUE) is increased due to the reduction of water run-off resulting from higher rates of water infiltration induced by mulching, the improved soil porosity, and through the reduction run-off water by the combined earth bunds and micro-catchments structures. Trees that utilize residual moisture and water from depths beyond the reach of annual crops roots, and the higher biomass production by the annuals and perennials further improves WUE.

The SEF provides a greater amount of animal feed, than the conventional systems, deriving from the greater biomass produced by the annual crops, the incorporation of dual purpose (grain/forage) cowpeas varieties, the Roselle leaves, PDS leaves and A. colei seeds.

The incorporation of fruit and edible seeds-producing drought tolerant trees mitigate the effect of droughts. Trees are less sensitive to the advent of dry spells and lower water availability than annual crops.

It is estimated that the combined profit per ha from all the SEF components is ten times higher than the profit derived from a millet field.

The SEF model under study utilizes farm-labor eleven months of the year as compared with traditional systems that provide labor for only four months of the year.

The SEF is still at an experimental stage. This paper presents the rationale for the development of the SEF and reports the results of a few diverse studies that were carried out to support the SEF system.

Introduction

The Sudano-Sahelian zone is a strip of land about 600 km wide and more then 6,000 km in length stretching south of the Sahara desert from the Atlantic to the Indian Ocean (Le Houerou 1989). The borders of the Sudano-Sahelian zone are defined by the 300 mm rain isohyets in the north and the 800 mm rain isohyets in the south. The climate of this region is typified by a monomodal precipitation pattern with a short rainy season of 3-5 months and a dry season of 7-9 months (Bationo and Buekert 2001).

The agropastoral system of this region is based on two main coarse grains; millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) intercropped many times with cowpeas (*Vigna unguiculata* L. Walp). Ruminants are raised on pasturelands (normally degraded agricultural lands) and on crop residues.

The Sudano-Sahelian agropastoral system is characterized by a very low level of productivity that results from an inherent poor soil and from a severe, human induced land degradation process. Frequent droughts also contribute to low productivity. Average grain yields are very low. For example average sorghum yield in Niger is 300 kg ha^{-1} compared with 4,000 kg ha^{-1} in the USA (Lal 1988).

Soil erosion is the main reason for land degradation. Land clearing for agricultural use combined with overgrazing and utilization of all crop residues leave the land bare and susceptible to erosion inducing elements. Water erosion is more common in the Sudano region where alfisols dominate the landscape whereas wind erosion is the dominant factor in the Sahelian region where entisols are more common. The very strong monsoonal storms, typical to the region, result in considerable run off and soil erosion (Kowal and Kassam 1978). The strong impact of the rain drops on the soil results in soil surface crusting, reducing infiltration rates and further accelerating run off and soil erosion (Morin 1993). Soil loss ranging between 10-40 t ha^{-1} $year^{-1}$ due to water erosion are common on cropped lands of the Sudano region (Lal 1988; Bationo et al. 1996).

Soil erosion by wind can be even greater than soil erosion by water. Buerkert et al. (1996a) measured absolute soil loss of 190 t ha^{-1} in one year on bare plots as opposed to soil deposition of 270 t ha^{-1} on plots with 2 t ha^{-1} millet stover mulch. Sterk et al. (1996) calculated that 45.9 t ha^{-1} of soil was lost at Sadore, Niger during four storms in 1993. The corresponding loss of N was 18.3 kg ha^{-1}, of P it was 6.1 kg ha^{-1} and 57.1 kg ha^{-1} for K. Reduction of soil erosion can be more effective in reducing nutrient losses than additions of costly fertilizers, compost or manure.

Africa's soils are derived from old, highly weathered landscapes that are inherently poor in nutrients which is expressed in low levels of organic carbon (generally less than 0.3 %), low total and available phosphorus and nitrogen, and low effective cation exchange capacity (Bationo and Mokwunye 1991). In the Sudano-Sahelian region farmers do not fertilize the soil and the result is soil "nutrient mining" at a serious scale. Stoorvogel and Smaling (1990) reported average negative annual budgets of 22 kg ha^{-1} of N, 7 kg ha^{-1} of P and 18 kg ha^{-1} of K in Burkina Faso. Sandy soils lose their carbon and nitrogen contents within the first two years after beginning of cultivation. Thus a continuous supply of nitrogen and carbon to these soils is a prerequisite for the maintenance of soil fertility.

A major constraint for crop production in the Sudano-Sahel is inadequate water supply. In many instances however, rains provide adequate quantity of water for optimal crop production but this water is lost through runoff, evaporation from bare soils, and deep percolation beyond the rooting zone of the annual crops (Fox and Rockström 2003). The low dry matter yields resulting from poor soil fertility and water insufficiency markedly reduce crop water use efficiency.

Droughts are a permanent feature of the Sudano Sahelian climate (Sivakumar 1991). The coefficient of variation of monthly rainfall is very high in the beginning of the rainy season, in May – June, and at the end of the season, in September and October. Crop failures due to dry spells can be as severe as crop failures from lower total annual rainfall.

Livestock population in Africa increased from 295 animal units in 1950 to 515 million in 1983 (Brown and Wolf 1985). In the Sahel, animal feed is available during seven months of the year but it is severely limited between the months of February and July (Abouda 2001). The lack of animal feed results in significant animal weight loss towards the end of the dry season negating all the gains during the July-February period.

The price of grains, the main product of present day systems, is about US$0.1 kg^{-1}. An average farmer can cultivate a maximum of 4 hectares giving a gross income worth US$120. According to an IFPRI report (Pinstrap-Andersen et al. 1999), these low international prices for grains will persist until the year 2020 and beyond. The prices of cowpea grains are higher than the prices of cereal grains; however in general, cowpea yields are only 10 % of potential due to the fact that farmers do not spray against cowpeas insects (Franks et al. 1987).

In the Sahel, human labor is the most underutilized resource. Farm work is available only during the 100-120 days of sorghum and millet production and even during this short period of activity, the return per work is very low because of the low current prices of grains. In many places farmers migrate to cities during the dry season in search of seasonal labor. Others just wait idly until the advent of the following rainy season.

The problems of the rain-fed Sahelian systems can be solved only through an integrated approach in which all the limiting factors are simultaneously addressed. Solutions of single problems without addressing other existing constraints are doomed to fail. For example, farmers will be able to purchase farm inputs such as chemical sprays and fertilizers or to address soil erosion problems only after the net income from the land will increase significantly. The use of high yielding varieties cannot be materialized under low soil fertility conditions. The use of chemical fertilizers without addressing the problem of soil erosion will eventually result in total soil degradation.

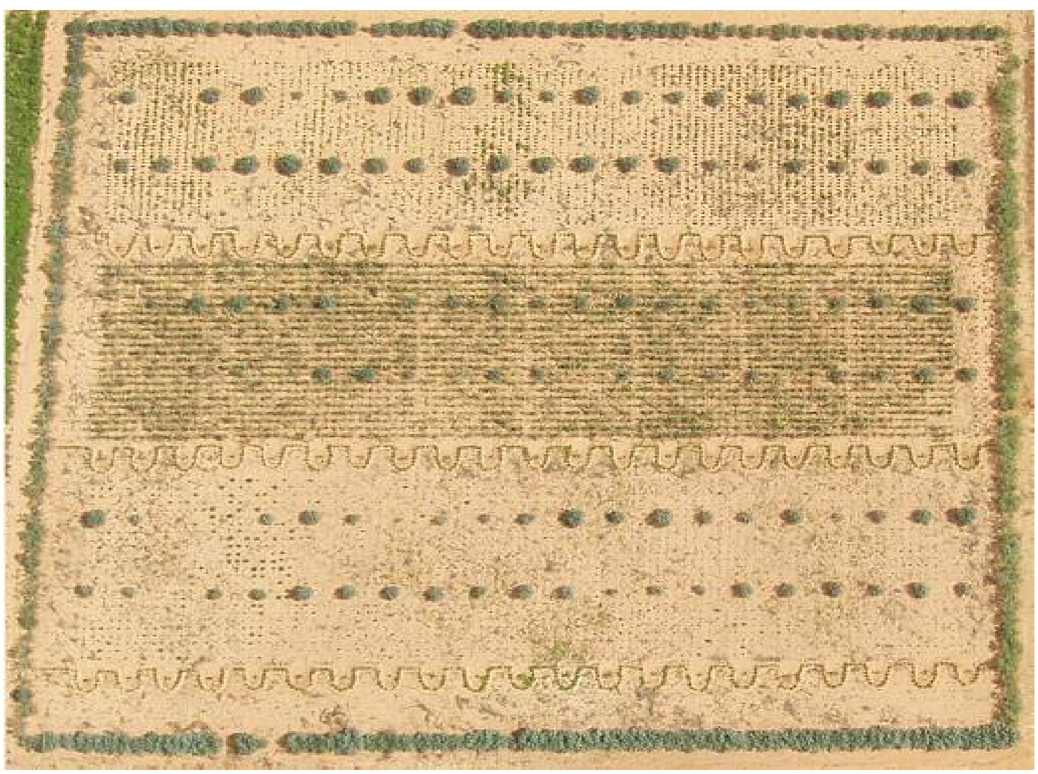
Description of the Sahelian Eco-Farm

The Sahelian Eco-Farm is a rain-fed production system that provides simultaneous solutions to the major constraints of the rain-fed system. The model under investigation is comprised of the following components (Plate1),

- A hedge of *Acacia colei*, planted at 2 meters spacing surrounding the field.
- Trees are planted down the slope in units of three rows; two rows of *A.colei*, followed by a row of the domesticated *Ziziphus mauritiana* called Pomme du Sahel (PDS). Spacing is 10 m between rows and 5 m between trees in a row.
- Pomme du Sahel (PDS) trees are planted inside 3m wide and 3m long micro-catchments connected by 2m wide earth bunds.
- Three annual crops are planted among the trees. Millet, dual-purpose (grain and forage) cowpeas and Roselle. The annual crops are rotated annually.

Plate1. An aerial photograph of the SEF.

Note: A.colei fence and sets of two rows of A.colei followed by a row of Pomme du Sahel planted inside micro-catchments. Top one-third planted with cowpeas, center with millet and bottom one-third with Roselle.



Global services of the SEF components

- The *A.colei* hedge can become impermeable to farm animals by reinforcing it with dry spiny branches from PDS.
- *A.colei* trees are pruned once a year (at a height of 1.0m) before the rainy season to produce firewood and mulch (phyllodes and small branches). Mulch provides the following services, (a) Prevention of crust formation thus increasing rainwater infiltration, (b) Impediment of soil erosion by wind and water, (c) Addition of organic matter to the soil and (d) Prevention of soil surface heating during annual crops germination and establishment. Large *A.colei* branches can be later collected to provide firewood. Pruning of Acacia trees just before the rainy season eliminates potential competition for water and light between the trees and the annuals, which are planted between the trees. Top pruning results in root death thus providing organic matter to the soil. Acacia phyllodes are not palatable to animals and are therefore not collected by farmers or eaten by animals (as is the case of crop residues) during the dry season. Labor requirement for carrying the mulch is minimized by the fact that the mulch is spread in a 5-10 m circle around each tree. *A.colei* seeds are rich in crude protein (24 %) and are therefore a valuable feed source for chicken and other fowl. *A.colei* roots fix atmospheric nitrogen.
- The micro-catchments reduce water and soil loss from the field while harvesting water for the PDS trees.
- The PDS trees provide nourishing fruit, forage, spiny branches for fencing and firewood.
- Roselle provides income from the sale of dry calices and seeds, forage from its leaves, and raw material for ropes, firewood, and mulch from the dry branches.
- Double purpose cowpeas provide valuable protein for the farmer's family, forage for his animals, and income from sales. Cowpeas also fix atmospheric nitrogen.

- Millet provides carbohydrate, protein and animal forage.

Rotation among the three annual components ensures maintenance of high soil fertility and reduction in the population of parasites such as striga and of soil nematodes and pathogens.

Economic and socioeconomic services

- Simultaneous planting of five income-generating crops in a single field mitigates risks of crop failures as compared with mono-cropping systems.
- Mitigation of drought effects - Perennial crops (trees and shrubs) are less sensitive to droughts (imposed by dry spells or by a general low rainfall year) as compared with annual crops.
- The higher yields that result from improved soil fertility and higher water use efficiency result in higher income as compared with the conventional systems.
- The incorporation of income generating crops increases profits (Figure 1).
- A higher biomass production coupled with the addition of feed crops results in higher animal feed production.
- Labor and income distribution - The SEF provides employment for 11 months and income during 8 months of the year. The SEF yearly work calendar is as follows: Annuals are sown in June and weeding and spraying are carried out till September. Millet is harvested in September, cowpeas in October, Roselle in November, PDS from December to March, *A.colei* seeds are harvested in March and pruning of *A.colei* and PDS is carried out in May.

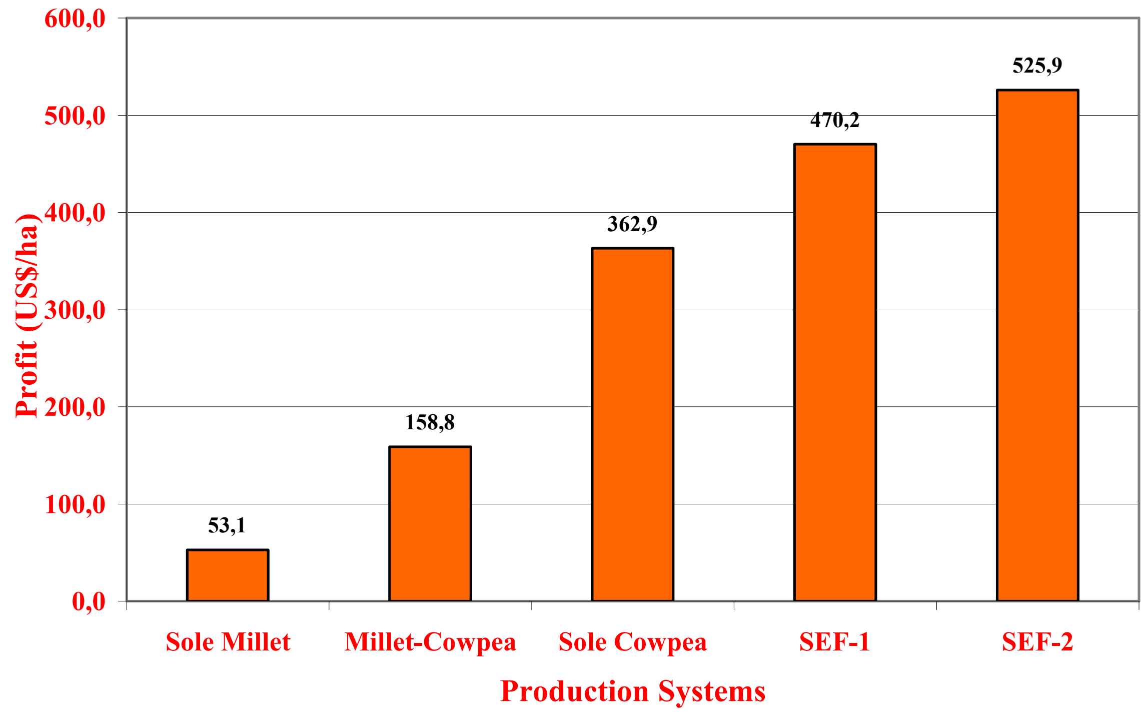


Figure1. Profits per ha of three production systems in the Sahel. Millet only, cowpeas only and the SEF. Data obtained from on-station research.

Environmental services

- Arresting soil erosion.
- Build up of soil fertility.
- Provision of firewood thus reducing pressure on natural resources.
- Diversification of micro-fauna due to increased number of trees and enriched soil organic material.
- Reduced use of chemical fertilizers and chemical sprays.

Results and discussions

First research results

On station research of the SEF started in the 2002 rainy season. On farm research with eight pilot farmers started in 2003. This is a long-term study that will require a minimum of five years to complete.

The development of integrated systems starts with the study and the perfection of each of the subsystems involved and continues with their integration into the SEF.

We are reporting here the first results of four studies of individual subsystems of the SEF. They are as follows,

1. Substitution of conventional protein sources by *A.colei* seeds in the diet of broilers.
2. Jatropha oil - an effective insecticide against cowpea pests.
3. Agro-management of Roselle.
4. Effect of termites on the rate of disappearance of *A.colei* mulch.

1. Substitution of conventional protein sources by *Acacia colei* seeds in the diet of broilers.

Sahelian countries normally use two sources of protein in chicken rations: groundnut cake (10 %) and fish meal (10 %). A broiler feeding trial was conducted to verify whether *A.colei* seeds that contain about 24 % crude protein could substitute part of the protein sources in the diet of broilers. Treatments were:

- Control-commercial broiler feed.
- Substitution of 50 % of fish meal by *A.colei* seeds.
- Substitution of 75 % of fish meal with *A. colei* seeds.

- Substitution of 50 % of groundnut cake by *A. colei* seeds.
- Substitution of 75 % of groundnut cake by *A. colei* seeds.

Broilers weight gains over a 70-day period are given in Figure 2. *A.colei* seeds could substitute 50 % of either fish meal or groundnut cake without affecting broiler weight gain. The price of fish meal in Niger is about US$2.0/kg. *A.colei* seeds can be sold at 10 % of this price. Sale of *A.colei* seeds to chicken feed producers can introduce a new source of income for farmers practicing the SEF.

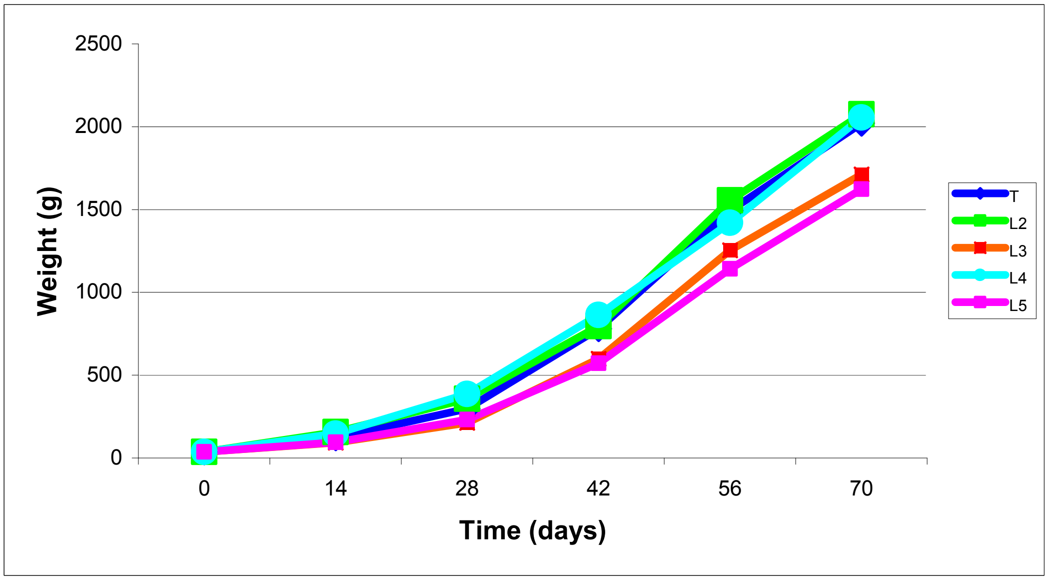


Fig. 2. Weight gain with time of broilers fed with various rations containing different sources of protein.

T= Control : 10% groundnut cake + 10% fish meal

L2 : 5% groundnut cake + 5% *A.colei* seeds

L3 : 3% groundnut cake + 7% *A.colei* seeds

L4 : 5% fish meal + 5% *A.colei* seeds

L5 : 3% fish meal + 7% *A.colei* seeds

2. Jatropha oil - an effective insecticide against cowpea pests.

In West Africa cowpea grain yield is around 300 kg ha^{-1}. This is in marked contrast to yields over 2000 kg ha^{-1} that are obtained on research stations (Ntare 1989; Reddy et al. 1992). A major reason for these low yields lies in the fact that farmers normally do not spray the cowpeas against insect pests that attack this species. The damaging effects of insects during grain storage are no less severe than insect damage caused during plant growth. Caswell (1984) demonstrated that under traditional grain storage practices and after eight months of storage the proportion of grains with one or more holes was as high as 82%.

Jatropha curcas Linnaeus is a shrub belonging to the Euphorbiaceae family. It has its origins is Central America. It is cultivated in the tropics of most continents (Gübitz et al. 1999). *J.curcas* is a succulent drought tolerant species that sheds its leaves in the dry season. Solsoloy and Solsoloy (1997) have conducted the most comprehensive study on the action of *J.curcas* oil as a multi-purpose insecticide. The formulated crude oil had contact toxicity to corn weevil and bean weevil and deterred their oviposition on corn and sprayed mungbean seeds. The oil extract was able to effectively control cotton bollworm and the cotton flower weevil.

Figure 3 shows the effect of Jatropha oil concentration on grain yield of cowpeas. A 7.5% concentration of *Jatropha* oil was as effective against cowpea pests as a commercial insecticide.

The results of the above study indicate that the incorporation of *Jatropha curcas* shrubs in the SEF could provide low cost, effective and affordable insecticide for the control of cowpea pests.

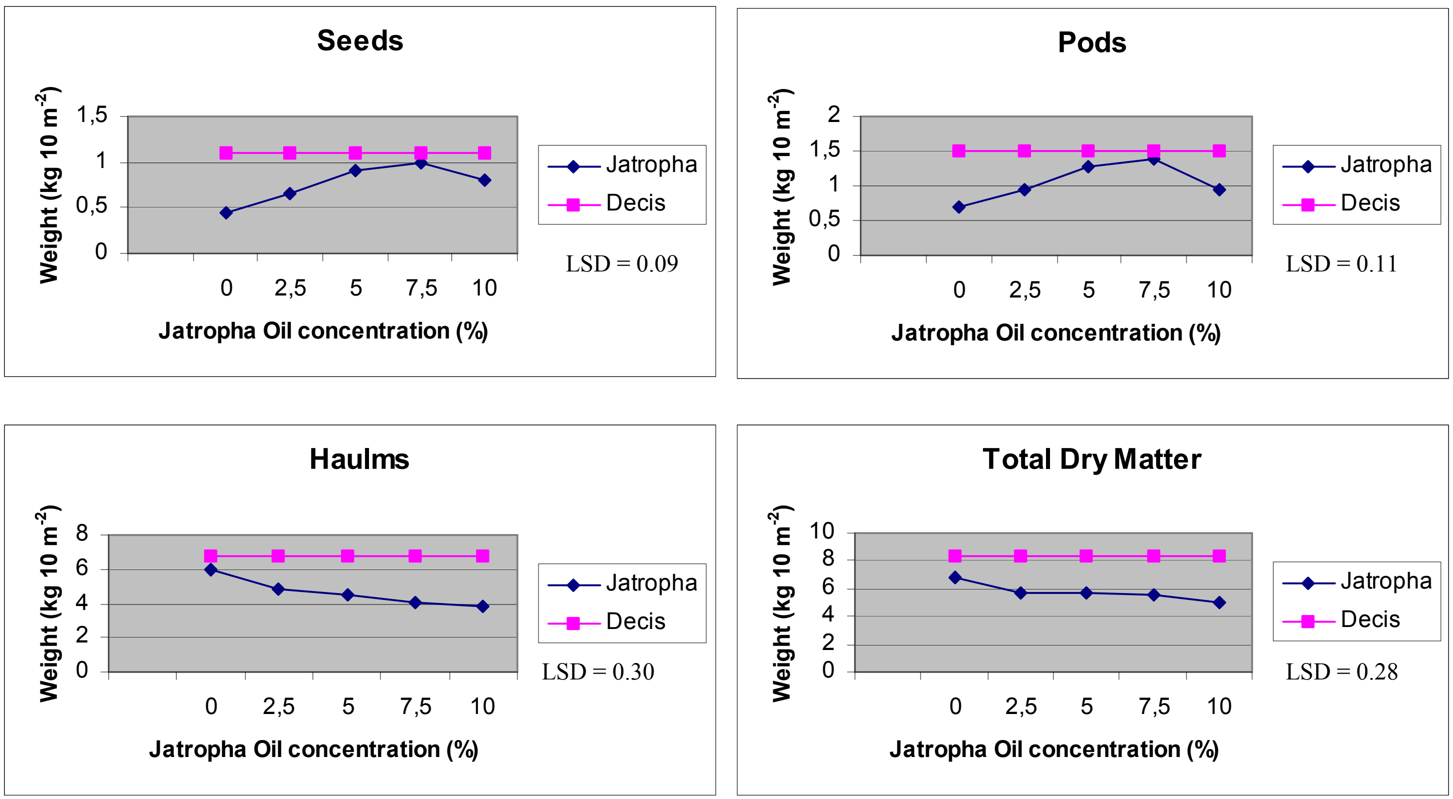


Figure 3. Effect of six concentrations of Jatropha oil spray on cowpeas grain yield. Horizontal line gives yields of cowpeas sprayed with a commercial chemical insecticide (Decis).

3. Agro-management of Roselle.

Roselle (*Hibiscus sabdariffa*) is an annual herbaceous plant widely grown in the Sahel. Farmers normally plant Roselle in small plots in the periphery of their millet fields. The dried succulent calices of this plant are used to produce a drink called *Bissap*. In many countries Roselle calices are used in herbal teas and as a natural food colorant. A recent USAID-Mali market survey showed that the international market for dried Roselle calices is worth more then US$120 million per year. Roselle calices produced in the Sudano-Sahelian country receive double the prices than Roselle produced in tropical countries. Seeds are used to make sauces. Roselle leaves are highly nutritious for ruminants. Stems are used for production of ropes and as firewood.

A series of trials were conducted in order to evaluate yield potential of Roselle under good management conditions. In this study we compared the effect of planting density on the performance of three varieties. Results are given in Table1. Dry calices yields were as high as 500 kg ha^{-1}. There were no significant differences in calyx yield between the three tested varieties but the Tanout variety, an early maturing variety, produced higher grain yields as compared with the two other varieties.

Table1. Yield Parameters (in kg ha^{-1}). and Days to Harvest for Three Roselle Varieties. Means of 3 densities (0.5x0.5; 0.5x1.0;1.0x1.0m).

Yield parameters	Roselle Variety		
	Niamey	Senegal	Tanout
Days to harvest	118	124	103
Calices	451	499	487
Grain	444	343	614
Significance (p = 0.05)	S	NS	S

NS =Not Significant, S = Significant

4. Effect of termites on the rate of disappearance of *Acacia colei* mulch.

Termites are effective decomposers of dry organic matter (Mando and Stroosnijder 1999).

A trial was conducted to appraise the effect of termites on the decomposition of *A.colei* mulch. The following treatments were imposed,

1. *Acacia colei* mulch. No pesticide.
2. Millet mulch. No pesticide.
3. *Acacia colei* mulch with furadan pesticide.
4. Millet mulch with furadan pesticide.

Results are expressed in Figure 4 as the rate of mulch disappearance. The effect of the pesticide furadan lasted about 100 days. During this period the difference in mulch disappearance between the plots with and without pesticide was attributed to the action of termites. It can be seen that termites acted on both *A.colei* and on millet mulch but the rate of decomposition by termites of millet mulch was much higher than the rate of *A.colei* decomposition. The relatively slower rate of decomposition of *A.colei* mulch might be an advantage because it allows covering of the ground for a longer period of time as compared with millet mulch and the production of stable humic acids.

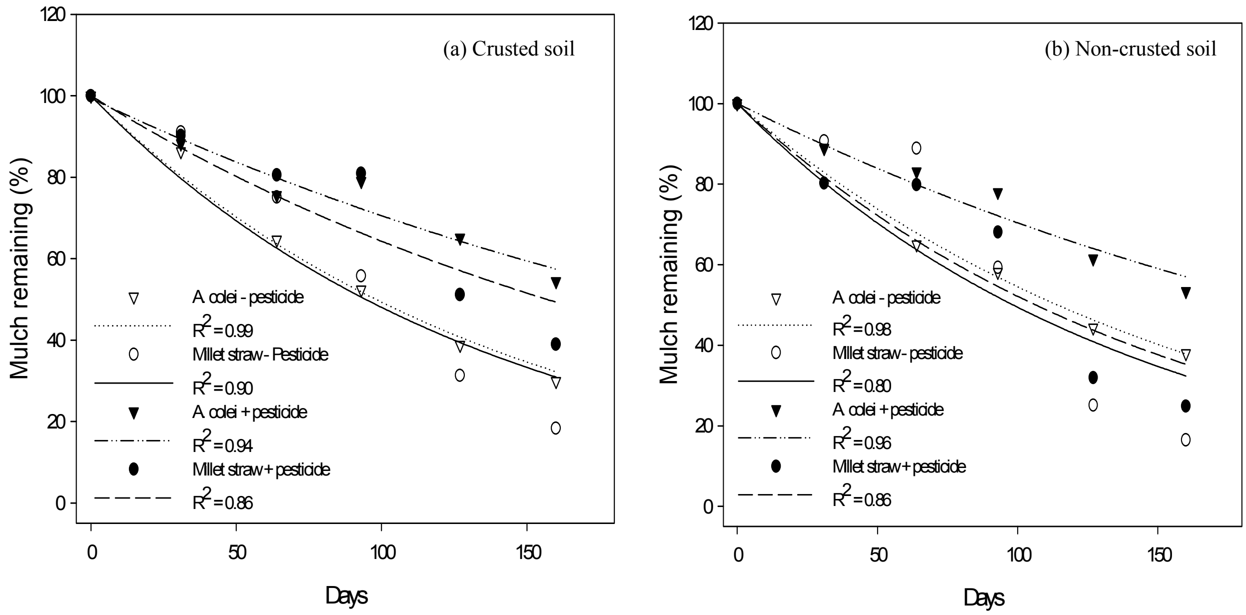


Figure 4. Rate of disappearance of insecticide treated and untreated Acacia colei and millet mulch with time.

Conclusions

Results of the four diverse studies reported in this paper should markedly contribute to the performance of the SEF system. The finding that seeds of *A.colei* can replace 50 % of the protein source of chicken rations should produce a market for the seeds, adding to the farmer's revenue from the SEF, thus encouraging tree maintenance by farmers. The finding that *J.curcas* oil is an effective insecticide against both plant pests and grain storage pests should result in marked increases in cowpea yields planted in the SEF once farmers start using this low cost and readily available bio-pesticide. The Roselle trial shows that high calyx and seed yields can be obtained with 550 mm of rain under proper agronomic management and the results of the fourth study demonstrate that *A.colei* phyllodes are consumed by termites that decompose the lignin rich phyllodes making the nutrients stored in them available for the plants and enriching the soil with organic carbon.

The Sahelian Eco-Farm is a new integrated approach to rain-fed agriculture in the semi arid tropics of Africa. The development of the SEF is being carried out with the help of a series of long-term studies during which the performance of the whole system is evaluated using both on-station and on-farm studies.

So far the results of research of the individual sub-systems and their integrated performances indicate that a solution for the many constraints of present day Sahelian rain-fed systems is in the making.

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