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# INCREASING AGRICULTURAL FOOD PRODUCTION THROUGH SELECTED TREE PLANTING TECHNIQUES

A Summary Memorandum

with

Selected References

By

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This memorandum and collation of selected references has been prepared for use by US and other technicians interested in quantifying the contribution which selected tree planting practices can make to the problem of increasing agricultural food crop production in sub-Saharan Africa.

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# INCREASING AGRICULTURAL FOOD PRODUCTION THROUGH SELECTED TREE PLANTING TECHNIQUES

## Background

The low level of agricultural production, per capita and per hectare, remains a primary constraint to overall economic development in sub-Saharan Africa. Increasing agricultural production is the primary goal of the Africa Bureau's Strategic Plan. Declines in cereals production are of particular concern, requiring increasing grain imports to meet urban and rural demand.

Policy reforms, including better prices for domestic food crops and increased incentives for the private sector, will be pursued in support of this goal. However policy reforms alone will not be enough to increase production and productivity unless deteriorating soils can be improved and water availability enhanced.

It is generally agreed that deforestation is a principal cause of deteriorating soil fertility and water loss in sub-Saharan Africa. In turn, the principal cause of deforestation is the clearing of woodlands to increase the area available for food production, with fuelwood collection a large additional but less significant reason. So long as food production and trees are in direct competition for the same scarce land and water, the deforestation--soil/water deterioration spiral is likely to continue and farm systems technical packages intended to remove soil and water constraints will have limited effectiveness.

Given this impasse and the central importance of food production in African and AID development goals, any evidence that selected tree species and tree planting techniques could significantly increase, rather than decrease, net food crop production and productivity on small holder plots deserves close and intensive exploration.

Claims have been made in a few research reports recently brought to the attention of the Office of Technical Resources of the Africa Bureau that some tree planting techniques are doing just that. This memorandum summarizes the information at hand, including summaries and excerpts from some of the reports, and describes the steps we are taking to verify the claims. If the evidence can be substantiated, selected tree planting techniques could provide a useful addition to technical packages already being designed and tested in AID and other donors' research and extension assistance to small holder farming systems in Sub-Saharan Africa.

## The Link Between Tree-Planting and Food Crop Production

Although a substantial body of research has been conducted on the influence of various tree species and planting techniques on temperature, soil fertility, water retention and related soil nutrient phenomena, very few of these studies have attempted to measure the net effect of such techniques on the production of agricultural food crops in real farming situations in sub Saharan-Africa.

A recent quick review of the literature has surfaced six studies in which measurements have been made of production of selected food crops in tree-enhanced plots as compared with control plots without trees. One evaluation reported a net increase of 23% in millet on one site involving windbreaks in Niger. Other studies reported increases in the general range of 10-15%, attributed to Acacia albida interplanting and water conservation techniques, in selected sites in Upper Volta and Senegal. Summaries and selected excerpts are supplied in Annexes I and II.

The techniques involve the use of trees for windbreaks, live fencing and wide-spaced interplanting on farm land. These techniques reportedly increase water availability and improve the quality of adjacent soils by: micro-climate modification; green manuring from leaf litter, soil structuring by root penetration, bringing to the surface, via the long tap roots, nutrients not otherwise retrieved; slowing rain water runoff directly as a diking barrier; and facilitating percolation through increased soil porocity.

The use of Acacia albida is reported in most of the studies. This tree species is notable because of its seemingly agro-forestry tailored characteristics: natural defoliation during the rainy season, allowing uninterrupted crop production under the tree canopy and furnishing nutrient and organic matter at a crucial time. Other species are reportedly able to perform some of the same functions. Microcatchment and contour diking techniques associated with tree planting reinforce water conservation effects. Low technology land preparation, including plowing, is not impeded under these tree planting patterns.

Given the central importance of low agricultural productivity as a constraint to overall economic development in Africa, it seems worthwhile to try to verify as soon as possible whether such increases can in fact be widely achieved; if so, to refine the techniques and add them to technical packages designed to increase small farm holder crop production.

## Actions Proposed

The Office of Technical Resources intends more systematically to explore this link and the claimed direct benefits through the following steps:

1. This report will be forwarded to Agricultural and other concerned officers in selected USAID Missions, together with a request (a) to identify and forward any other existing studies, formal or informal, AID-financed or otherwise, which have attempted measurement of agricultural food crop production in tree-assisted plots as compared with controls; (b) to identify AID-supported or other existing agricultural projects involving farms where tree planting may already have been added, which could be made the subject of comparative crop production tests during the coming cropping season; and (c) provide description of cereals crop mensuration methods already being used in current farm systems research in the field.

References have been found to farm crop/tree planting sites where crop yield tests could be instituted in several countries, including Chad, Camaroon, Kenya, Malawi, Niger, Nigeria, Rwanda, Senegal, Somalia, Tanzania and Upper Volta. A citation to these and persons who could be contacted for additional information is attached as Annex II.

2. Donor representatives on the CDA Agricultural Research and Forestry/Fuelwood Committees, the IBRD, FAO, ICRAF, IITA, ILCA and Peace Corps will also be contacted for similar information.

3. An ad-hoc task force has been set up with representatives from AID agriculture, forestry and PVO programs to continue the literature search, review responses from the field and make recommendations or additional action as seems appropriate.

It should be noted that farm trees can provide incremental benefits other than the cereals crop increases which have been claimed. For example, individual trees planted on farm sites are said to provide twice as much volume in branch and mainstem fuelwood supply as the same species provide when grown in plantations; that leguminous trees provide substantial annual fodder increments in leaves and pods for livestock feeding supplements; that coppicing and pollarding permit harvesting of fuelwood and building poles, often eight to fifteen times during the life of the tree without replanting, after which the final cutting provides timber or major fuelwood supplies; and that fruit and nut trees provide annual food cash income supplements.

These claims can be or have been, tested in other studies. For purposes of this exercise, it is intended only to test the claim that selected tree planting techniques can produce net increases in cereal crops on the same hectare of land.

## ANNEX I

### List of Studies Reporting Quantitative Crop Yields Related to Intercropping With Selected Tree Species

Els Bognetteau-Verlinden, Study on Impact of Windbreaks in Majjia Valley, Niger, February 1980, 77 pp plus annexes. An evaluation of a CARE-Niger Forest Service windbreak project begun in the Majjia Valley in 1974, with first planting of neem (*Azadirachta indica*) in 1975. The report describes the project, the results and the methodology used to measure agricultural yields. Net increases in millet yields of 23% were reported in the study, which was conducted in 1979.

Direction des Eaux et Forets, Republic of Upper Volta, Secteur de Restauration de Sols de Ouahigouya, 1965, 25 pp. Experiments with *Acadia albida* interplanting are reported, with 50% increases in millet yields on land under acacia tree canopy as compared with controls. It does not provide information which would permit average per hectare estimates for a regular farm plot.

Peter Felker, State of the Art: Acacia Albida as a Complementary Permanent Intercrop with annual Crops, April 1978 (Grant No. AID/afr-C-1361) University of California, Riversi..e, California, 133 pp. This overview identifies and summarizes research and measurement methodologies to date, including four assessments on comparative crop yields for mil'et and groundnuts in two sub-Saharan African countries (Sarlin, 1963; IRHO, 1966, Charreau and Vidal, 1965, Dancette and Poulain, 1969). Increased millet yields under *Acacia albida* canopy were reported by Charreau and Vidal as 152% and 104% higher than controls in two tests in Senegal. Dancette reported only 3% increases in one Senegal test. Sarlin reported millet increases for an average of 29 sites in Upper Volta of 50%. The summaries do not indicate average per hectare yields or density of planting. However the fields were reportedly served by mature trees which crown at 10 meter spacing.

Peter Wright, Project Agro Forestier (OXFAM): Rapport de Fin de Campagne 1982 au Yatenga, Haute Volta, March 1983, 24 pp, with tables. In this project, which involved rock lined contour diking techniques and associated tree planting, increased millet and sorgum production averaging 10% in tests comparing 47 enhanced plots with 48 controls are reported, with very wide ranges in the individual plot yields. The project area increased in response to small

holder demands for technical aid in the techniques, from an initial 6.6 hectares to 64 hectares in two years. (It should be emphasized that the cereals crop increases reported in this study were correlated with the contour dikes, not with the tree planting, although other observers report that spontaneous tree growth had taken place reinforcing the rock and soil dikes. The measurement methodology is of interest and could be reviewed in the process of choosing a common research protocol.)

ANNEX II

## Preliminary List Of Possible Sites For Testing Comparative Crop Yields With And Without Selective Tree Planting And Contact References

CHAD — An *Acacia albida* program was begun by CARE, in 1976, to encourage farmers to interplant these trees in their fields in order to increase soil fertility and agricultural production. In 1976, 1,500 hectares of *acacia* were planted, with a survival rate of 40%. In 1977, 2,500 hectares were planted. By October of 1978 the project had expanded to include nine nurseries producing a total of 300,000 seedlings a year being distributed and planted by 2,000 farmers. A preliminary study showed that the presence of *Acacia albida* increased crop yields by 15%. Through-out 1976, 1977 and 1978 there were four or five PCVs involved in the program. (Source: Peace Corps Forestry Projects=Success and Failures December 1980; See also, "Experience en Agro-Foresterie au Tchad," by M. Koumbage Belyo, in vol 2 *Background Papers*. Seminar on Agroforestry in The Sahel, 23 May to June 1983, Niamey, Niger, pp. 118 - 127).

CAMEROON — As of 1980, a six year stand of windbreaks had tested wind erosion control by *Cassia siamea*. (Source: Reported by Carl G. Wenner, Farm Management Branch, Ministry of Agriculture, P. O. Box 20028, Nairobi, in *Proceedings: Kenya National Seminar on Agro-Forestry*, 12-22 November 1980.

KENYA — Interplanting of trees and food crops: is underway in two projects in Machakos and Baringo Districts. (Source: Reported by Mattias O. Were, Chief, Project Manager and Evaluation Division, Ministry of Agriculture, P.O. Box 30028, Nairobi, in *Proceedings: Kenya National Seminar on Agro-Forestry*, 12-22 November 1980, p.25.) ICRAF has undertaken on-farm research in agro-forestry involving use of trees to increase food crops at Kathama, Machakos District. Two small farm holdings are subjects of study. Hedgerow mulch farming with *Leucaen leucocephala* and *Cassia Simea* is being tested. (Source: ICRAF Newsletter, March and May 1982, p.4).

MALAWI — Agroforestry practices where farmers have retained legume trees in farm fields were observed by Gunnar Paulsen during a field visit March 25, 1981, between Kasungu and Lilongwe via Ntchisi and Dowa Districts.

Possible contact: Mr. F.J. Chakoloma, Project Officer, Ntchisi RDP.

It seems possible that comparative crop yield data could be obtained from the monitoring system operating under the Lilongwe Land Development Program (Source: Reported by B. Kinsey, Director Overseas Development Group, University of East Anglea, Norwich, England, in FAO, Monitoring systems for agricultural and rural development projects, Rome 1981, pp. 70-81. The report provides selected recording forms which include crop yields and presence of trees).

It may be noted that Malawi is both forestry coordinator and conservation coordinator for SADCC.

NIGER

A winter vegetable gardening project, sponsored by Luthern World Relief, introduced live fencing (Prosopis and local species) in twelve different sites in Niger beginning in 1979. (Source: Reported in Weber and Hoskins, Agroforestry in the Sahel, Virginia Polytechnic Institute, 1983, p. 31-2.)

An Acacia albida project was begun in early 1974 with Peace Corps support, with the objective of assisting in increasing crop yields. (Source: Peace Corps Forestry Projects, op. cit, 1980).

As part of the Project Development Rural de Dosso, beginning in 1981 an extensive Acacia albida project has been undertaken, with the goal of natural regeneration on 7,500 hectares, and man-made plantations of 200 hectares. (Source: "Une Experience Agro-forestier de Niger, Le Projet Gao de Dosso," by Aboubacer. Isser, in Vol. 2, Background papers, Seminar on Agroforestry in the Sahel; 23 May to June 1983, Niamey Niger. pp. 111-117.)

NIGERIA

The Shelterbelt Research Station, Kano, Kano State acquires, and collates information on shelterbelts in arid and semi arid areas and could be a source of sites for testing. (Source: Reported by Federal Ministry of Agriculture, Nigeria, at African Forestry Commission, Sixth Session, Arusha, Tanzania, Sept. 12-16, 1983.)

The International Institute for Tropical Agriculture, Ibadan, Nigeria is reportedly testing "alley cropping" of leucaena and maize. B.N. Okigobo, R. Lal, A. Getahun, and G. Wilson will be able to supply information on IITA crop yield tests, if available. D. Bowers, of IITA is another expert who is interested in the use of agricultural tree crops as a no-tillage system to improve agricultural productivity.

RWANDA A large scale German (GTZ) sponsored agro-forestry project, started in 1969 in Nyabisindu, began in 1976 to develop a new farming system for small holdings in which integration of trees building on indigenous tree-agricultural crop systems, is a major component. There is wide participation by local farmers in the project area which as of 1981, included 4,000 hectares under erosion control and 3,000 hectares improved to assist in food crop production. A small research unit was established in 1980 and it is possible comparative cereals crop yields may already be available. (Source: "An Example of Agro-Forestry for Tropical Mountain Areas, by F. Behmel and I. Neuman, in Agro-Forestry in the African Humid Tropics Proceedings from Ibadan Workshop 27 April - 1 May 1981. UNU, 1982, pp. 92-98. See also "An Ecological Approach to Farming" by Tim H. Zeuner, Nyabisindu Rwanda Project Director, in Proceedings of Kenya Seminar on Agro-forestry, 12-22 November 1980, Nairobi.)

SENEGAL Since 1964, a program has been underway to protect Acacia Albida seedlings on 11,000 hectares in Kebemer, Mback, and Louga area. A second project to establish a 1,000 hectare plantation near Diourbel has also been started. (Source: M. El Hadji Sene, Director, Eaux de Foret, as reported to Peter Felker during field trip to Senegal, November 1977. Felker also reported that an FAO-financed project undertaken by the Eaux de Foret tree seedling nursery in Kebemer, had planned to plant about 1,000 hectares of Acacia albida in farmers fields per year.)

A German-Senegales forestry project was begun in 1975 in the Ferlo Region in northern Senegal. Recent development has focused on farm or community activities on private farmlands planting Acacia

Senegal (or other species) at 10 X 10 spacing, with interplanting of millet, ground peas and cowpeas. (Source: Agroforestry in the West African Sahel, BOSTID, National Research Council 1983, pp. 37-40, citing H. -J. von Maydell.)

SOMALIA Several areas are available for checking out the impact of selected tree planting techniques in relationship to cereals production in and around refugee camps where agricultural and forestry projects are being supported by USAID and other donors: Belet Uen, the Gedo region, Quorioli and Jalalaqsi.

TANZANIA Dr. E. M. Mnzava, Director of Forestry, reported that the Forestry Department had undertaken comparative tests interplanting trees (species unspecified) in sites adjacent to control sites where no trees were interplanted

A "doubling" of grain in the tree-inter-planted plots was reported. (Source: USAID consultant, (Dwight Swart - Zendruber, personal communication Jan. 24, 1984.) Existing land use practises in the Arusha-Moshi-Lushoto region, are being studied by ICRAF in cooperation with University of Dar-es-Salaam, Monorogro Campus. P.K.R. Nair of ICRAF will have information.

## ANNEX III

## SELECTED REFERENCES

This section provides excerpts from the research reports listed in Annex I, to give readers who may not have access to the originals an indication of the scope and methodology used. The final selection, from a recent ICRAF report, discusses situations in which it is beneficial to add trees to arable crop fields and is included because of its description of the factors contributing to "complementarity", the phenomenon which we believe deserves further investigation.


1. Els Bognetteau-Verlinden, Study on Impact of Windbreaks in Majjia Valley, Niger, February 1980, 77 pp plus annexes. (Excerpts)

2. Peter Felker, State of the Art: Acacia Albida as a Complementary Permanent Intercrop with Annual Crops, April 1978 (Grant No. AID/afr-C-1361) University of California, Riverside, California, 133 pp. (Excerpts)

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# STUDY ON IMPACT OF WINDBREAKS IN MAJJIA VALLEY, NIGER

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## C. MAJJIA VALLEY REFORESTATION PROJECT

### 1. Final goals

- Increase and/or stabilize the agricultural income of rural families in the Vallee de la Majjia, arrondissement Bouza by agricultural land protection schemes against wind-erosion and direct negative influences of wind on crops and the distribution of trees for production.
- Improve the general ecological system of the area, stimulate conservation efforts and improve the general environmental situation through the protection of endangered areas and the provision of tree seedlings for planting in project areas and in private compounds, public areas and private and public woodlots.

### 2. Realisations

#### a. General

The Majjia Valley Reforestation project was begun in 1974 through the combined efforts of the Niger Forestry Service and CARE, after initial complaints of farmers about their crops being damaged by heavy storms during the rainy season.

The first activity was extending the already existing nursery of the Forestry Service in Karayé, so that the additional trees for the program could be produced. Since that time the main activity has been the realisation of the windbreak part of the program.
An intensive extension program is carried out each year before the field activities start, in the villages that will be touched by the program the coming season. The extension work is done by the Forestry Service with assistance of the Extension Service.
The actual lay out of the windbreak system is decided upon by the Forestry Service, who in trying to serve the general interest of the villagers, cannot take into account possible

wishes of individual farmers as far as the windbreaks are concerned. The space needed to plant the windbreaks is claimed by the Forestry Service, who can do so without indemnifying the actual users of the land.

The windbreaks have been planted in the direction NNW - SSE (340°), starting in 1975 from the 'gebi' temporary riverbed with coarse sand load) at Garadoumé (see Map 1), extending 1 km in the direction of the hills. From 1976 on the windbreaks usually had a length of more than 1 km, depending on the extension of the valuable agricultural land.
A windbreak consists of two rows of trees, mostly Neem (Azadirachta indica; see appendix I, species description), placed at 4 x 4 m intervals. The first two years the two rows were planted in rectangular spacing, from 1977 on a triangular spacing. The intervals between the windbreaks are in general 100 m, in some cases up to 125 m, which means that every linear km of windbreaks equals a minimum of 10 ha of protected agricultural land.
In 1975 and 1976 both the rows in the windbreaks consisted of Neem, except in some of the 'bas-fonds' (lowest parts, temporary inundated, heavy clay soils), where Acacia seyal and also, with little success, Prosopis juliflora have been planted with double rows (see appendix I).
In 1977 all windbreaks consisted of two rows of Neem, except for two experimental lines of one row Acacia scorpioides/ A. seyal (windward side) and one row of Neem.
In 1978 a greater number of windbreaks, especially in the lower parts, consisted of one row A. scorpioides and one row of Neem.
In 1979 this tendency was continued and besides that one line was planted with Eucalyptus camaldulensis as an experiment in a temporarily inundated area (see appendix I).

The realisations are given in the following table:

| year | linear km of double row wind-breaks | number of trees planted | | | | | |
|---|---|---|---|---|---|---|---|
| | | total | Azadirachta indica | Acacia scorpi-oides | Acacia seyal | Prosopis juli-flora | Eucalypt. camaldu-lensis |
| 1975 | 13 | 6,500 | 6,000 | - | 250 | 250 | - |
| 1976 | 20 | 10,000 | 10,000 | - | - | - | - |
| 1977 | 20 | 10,000 | 9,500 | 250 | 250 | - | - |
| 1978 | 20 | 10,000 | 7,000 | 3,000 | - | - | - |
| 1979 | 28 | 14,000 | 9,000 | 4,400 | 500 | - | 100 |
| Total | 101 | 50,500 | 41,500 | 7,650 | 1,000 | 250 | 100 |

Roughly 90 % of the trees planted have survived.
There is a difference in the growth and health of the Neem: on the sandy soils growth is good (1975-plantation are now more or less closed and reach a height of 7 meters); on the heavier soils (with stagnant groundwater during the rainy season) there have been more problems: growth is less and the general appearance is sometimes a little yellowish.
The A. scorpioides and A. seyal do well, especially on these heavier soils, though these species will never form tall trees.

The total numbers of trees grown in the Karayé nursery for the different years and activities are listed below:

| year | number of trees produced for | | | |
|---|---|---|---|---|
| | windbreaks | live fencing | free distribution | total |
| 1975 | 6,500 | 7,000 | 6,500 | 20,000 |
| 1976 | 10,000 | 15,000 | 10,000 | 35,000 |
| 1977 | 10,000 | 8,000 | 12,000 | 30,000 |
| 1978 | 10,000 | 4,000 | 9,000 | 23,000 |
| 1979 | 14,000 | - | 28,000 | 42,000 |
| Total | 50,500 | 34,000 | 65,500 | 150,000 |

The other parts of the program are more difficult to analyze than the windbreak-part, as very little is known on what has been planted exactly where and when.

For the live fencing Prosopis juliflora has been used. This part of the program, however, has never been very successfull, first of all because the farmers don't seem to like live fencing. They do need fencing around their dry-season gardens, but these gardens form part of their normal arable land during the rainy season and the borders are not necessarily the same. Also, the farmers don't like Prosopis, as it is invading in their fields too easily and has very painful thorns.
Whatever has been planted as live fencing has never been maintained so it is not effective. This might be due to lack of motivation and technical assistance. Anyway, people still use their traditional fencing, being millet/sorghum stalk fences and fences made from the residue of the cotton plant.

The village woodlots, managed by the forestry service, do very well. The woodlots have a surface of 1-3 ha and usually consist of Neem, sometimes Prosopis juliflora or Acacia scorpioides; the Neem-woodlots are surrounded by two rows of Prosopis as live fencing.

The trees for free distribution are mostly A. indica, some Prosopis and, in 1979, some eucalypts, baobabs (Adansonia digitata) and cashew nuts (Anacardium occidentale).
Most of these trees are planted as shade trees in compounds, market places, school yards, as individual trees in fields or gardens, and more and more for production purposes as small private woodlots.

Little by little we see that the Majjia valley is getting a 'green' appearance by the combined efforts of the project,

f. Harvest

Until now no harvesting has taken place in the windbreaks, nor in the other kind of plantations.

Although almost no production figures are available, it is known from experience with older Neem plantations in the region that harvesting for poles (construction) can take place in a 8 - 10 year rotation, leaving the Neem for 3 to 4 rotations; after coppicing two poles are left growing on each trunk. Growth rates of an 8 year old village woodlot near Taboyé were estimated to be 11 $m^3$/ha/yr, of which 8$m^3$/ha/yr as poles and 3$m^3$/ha/yr as small size wood/fire wood could be harvested.

The system of coppicing might also work very well in the windbreaksystem, though care should be taken that not too much is harvested at once, so that the protective role of the windbreaks will never get lost.

Harvesting in the village woodlots and windbreaks will be done by the Forestry Service, who will sell the poles in the area at reasonable prices. At the same time considerable amounts of fuelwood and other small size wood, by-products like fodder, tannin, fruits etc. are produced, which are very badly needed in the area; these by-products

are free for gathering by the villagers: small size wood after harvesting by the Forestry Service, the rest during the whole rotation.
Though the temptation seems to be great, until now no appreciable illegal cutting of trees by the villagers occurred.

Harvesting for poles, firewood or other purpose-wood of the live fencing and distributed trees is done by the owners, whenever they feel the need for it. In this case no permit from the Forestry Service is needed.

3. Future plans

As farmers in the longest protected area already claim to have higher yields from their fields, most of the villages that are not yet touched by the program are anxious to see the windbreaks being planted in their grounds. The fact that herewith a certain surface is taken out of agricultural production seems to be accepted.
Therefore, for the coming years it is foreseen to extend the windbreak program further down the valley until the villages of Taboyé and Tounfafi, in the same way as has been done until this year.

The total number of linear km of windbreaks to be planted in the coming three years is planned to be 165 km, which equals 1650 ha of protected agricultural land.
The species used will essentially be the same, though greater emphasis is needed on Acacia scorpioides, Eucalyptus camaldulensis or other species. The reason for this is that large parts of the area to be covered now will be in heavier soils, temporarily inundated or at least with a high groundwater table, where Neem certainly is not the best choice.

The live fencing part of the program will gradually be

diminished as farmers are not interested in this part of the program; the trees that are still produced will be used in the first place to fence new woodlot-areas (private or public).

As people are getting more and more interested in growing trees themself for their own wood-supply or as a cash-crop, the production of trees for distribution to interested people will continue at a high rate. Neem and Eucalypt will continue to be distributed as wood-production trees, but also greater numbers of local, useful trees, for which exists a big demand, will be grown in the nursery: for example Adansonia digitata (baobab; kuka; leaves and fruits are very much appreciated food), Acacia scorpioides (bagarua; pods for tanning), Hyphaene thebaica (doum; goriba; leaves for mats, edible fruits), Borassus aethiopum (ronier; gigunya; termite-proof poles for construction), Tamarindus indica (tamarinier; tsamiya; edible fruits) and Moringa pterygosperma (zogala; edible leaves).
A problem with most of these trees is that growth is much slower than Neem and Eucalypt, so that protection is needed longer.

A second nursery is set up this year in Taboyé in order to increase tree production for the program in a decentralized way.

Quantitatively, the plans for the years 1980 - 1982 are given below (CARE, Multi year plan, 1979):

Total production of trees in the nurseries Karayé and Taboyé:

| year | windbreaks | live fencing | other activities | total |
|---|---|---|---|---|
| 1980 | 22,500 | 10,000 | 17,500 | 50,000 |
| 1981 | 30,000 | 10,000 | 17,500 | 57,500 |
| 1982 | 30,000 | 5,000 | 17,500 | 52,500 |
| Total | 82,500 | 25,000 | 52,500 | 160,000 |

# E. STUDY ON IMPACT OF WINDBREAKS IN THE MAJJIA VALLEY

## 1. Introduction

Having the final goals of the project and the supposed effects of windbreaks in mind, the most relevant parameters for evaluation of the effects of the windbreak system were formulated as:

1. Influence of windbreaks on wind velocity: this being the most important factor for changes in the microclimate in the protected area and therefore of great importance for the reduction of wind-erosion and the growth of agricultural crops.
2. Influence of windbreaks on available soil moisture: in a country where soil moisture is often a limiting factor for plant growth, it is obviously important to know the influence of windbreaks on this factor.
3. Influence of windbreaks on crop yields: increase in income of the farmers by increased crop yields being the first short-term goal of the project, information on this factor is very valuable.

To evaluate these influences, measurements were carried out on each of the parameters during the rainy season of 1979; wind measurements continued in the dry season 1979-1980. To carry out the measurements a site was selected within the windbreak lines which were planted in 1975 and are now almost completely closed. A comparable control site was chosen as close to it as possible, but outside the influence of the windbreak system.

## 2. Description of research site

The site within the windbreak system of 1975 is located 1 km Westward of the village of Garadoume. It is between the fourth and fifth windbreak line and from 200 to 400 m North

of the gebi (seasonal river). The control site is located at the same latitude but from 100 to 150 m South of the gebi (see fig. 15 and 16A,B).

Both windbreak lines are homogenous and well developed, with a height of 7 meters, a crown of medium density and a denuded stem of 1.5 m. One windbreak line consists of two rows of neem (Azadirachta indica), planted in rectangular spacing of 4 x 4 m. The total width of one windbreak line is 8 m (= vertical crown-projection). The distance between the two lines concerned is 120 m or 17 times tree height (17h) from inner trunk to inner trunk. The direction of the lines is NNW-SSE. The prevailing wind-direction during the monsoon is West, during the harmattan East.

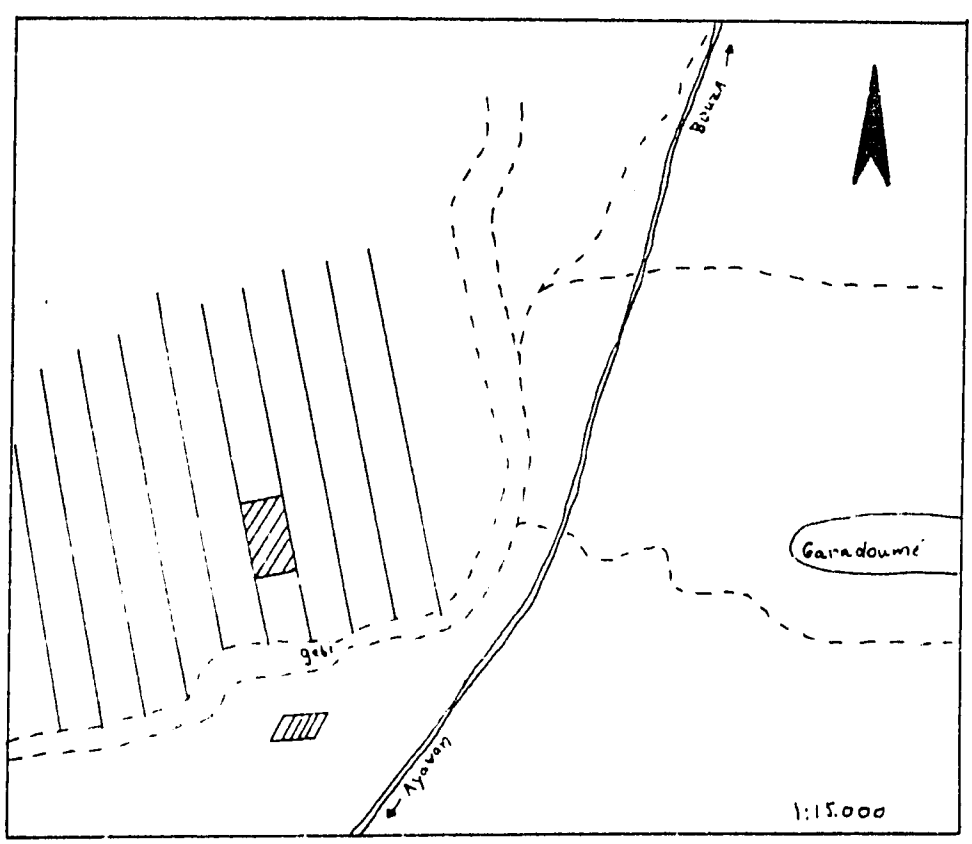
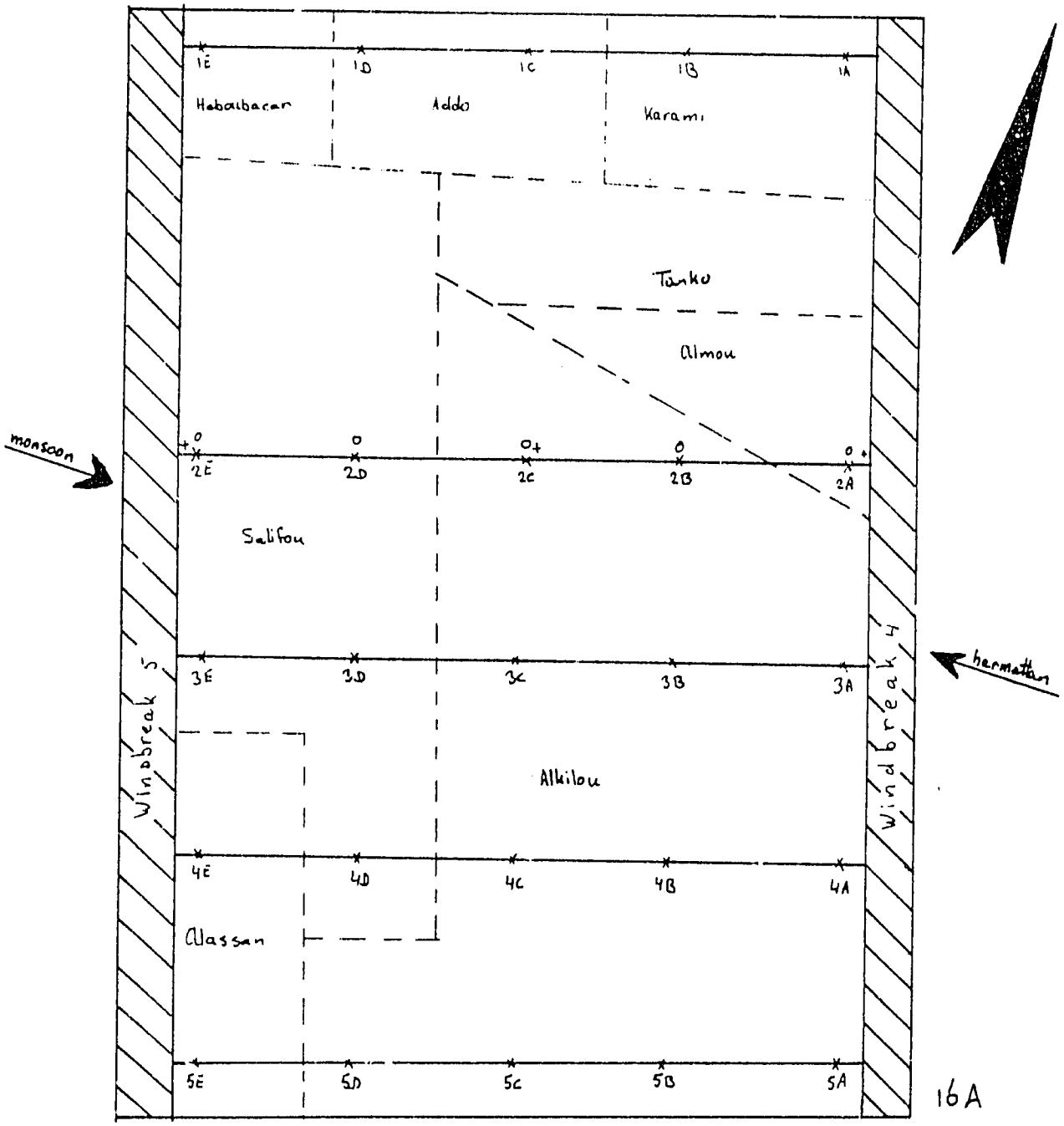



fig.15 Location of research site



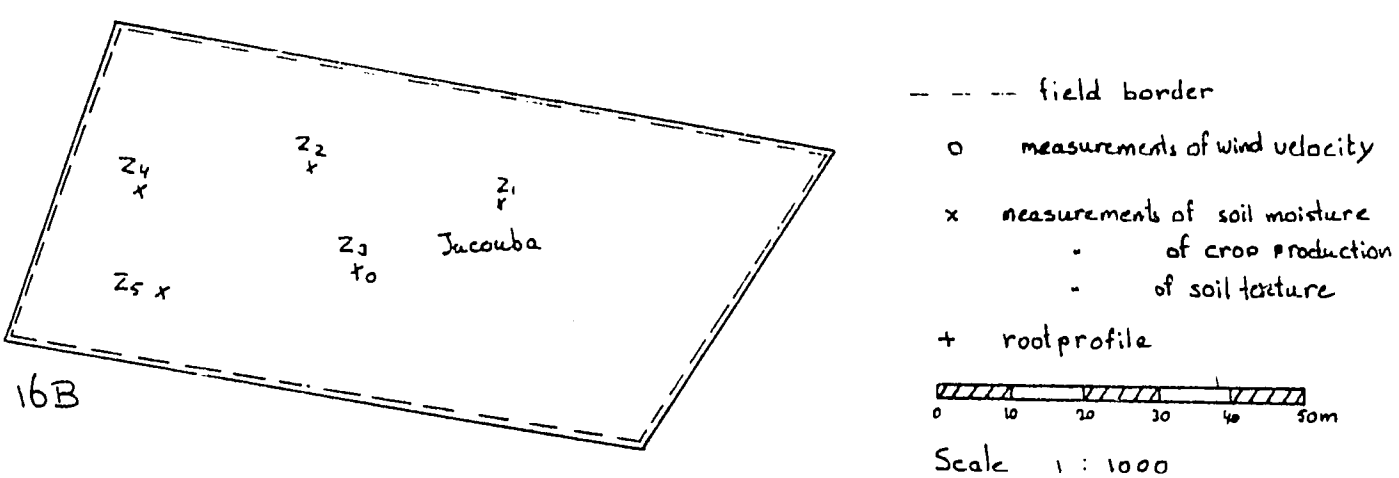




fig. 16 Details of research site (A) within the windbreaaks
(B) control

The soil in the windbreak site, as well as the control site, is an alluvial soil with a loam or clay loam layer in the subsoil. This is covered by various layers of less heavier materials, sandy loam or sandy clay loam mostly (see soil texture profiles, app. II).
Derived from calcareous materials, these brown soils have a pH of 7.5, a high CEC, and are well to moderately well drained. No presence of salt or gypsum was observed. The soil is relatively rich, although nitrogen content is low (see chemical analysis, app. II).
The groundwater table varies between 4 and 9 meters, depending on the season.

The fields within the selected sites belong to eight farmers. All of them use their land for millet production under traditional cropping methods: just before the rainy season the fields are cleaned if necessary; the farmer will seed by hand with seeds out of his own harvest, preferably just before or just after the first heavy rain, at a distance of 75 x 75 cm. The first tillage is done with the hoe about 4 weeks after germination, the second about 3 weeks later. The grain can be harvested 14 weeks after germination. The stalks are left on the field and will be cut afterwards for construction of fences or left for grazing.
No fertilizer or additional manure -except for that of the grazing animals- is used. No fallow and almost no crop rotation exist.

## 3. Methodology

### a. Wind velocity measurements

In the selected site within the windbreaks a line was drawn perpendicular to the windbreaks. Along this line all wind measurements were carried out at 5 points with equal intervals.

During the rainy season (W-winds) measurements were started from 1h leeward of the western windbreak to 1h windward of the eastern windbreak. During the harmattan, due to changing wind direction (E-winds), measurements were taken in the opposite direction:

| windbreak 5 | E | D | C | B | A | windbreak 4 | |
|---|---|---|---|---|---|---|---|
| 0 | 7 | 33 | 60 | 86 | 113 | 120 | meters |
| 0h | 1h | 5h | 8.5h | 12h | 16h | 17h | monsoon |
| 17h | 16h | 12h | 8.5h | 5h | 1h | 0h | harmattan |

(see also fig. 16A). Control measurements were taken in point 3 of the control site Z (see fig. 16B).

Wind measurements were carried out at two different heights:

- at 1 m : During the time that there was no vegetation or only low vegetation (until 50 cm). This height was chosen as it is high enough to disregard any surface roughness factors and low enough to give an indication on the erosive force of the wind.
- at 2.5 m:: With all measurements. This height was chosen to give an indication of the influence of the windbreaks on the wind velocity on the theoretical crop-height of millet, which was expected to be 2 - 2.5 m in the concerned area. However, it appeared that the millet growth within the windbreaks was favoured in such a way that it reached a height of 3 - 3.5 m, which made it impossible to continue measurements at 2.5 m.

The wind measurements were made on days with stable, strong winds (more than 10 mph (= 4.4 m/s) at measuring heights), in a direction more or less perpendicular to the windbreaks.

Wind measurements were carried out with a transportable anemometer of a rotating type, connected to a meter giving momentaneous readings in miles per hour. Every measurement consisted of the mean of 20 successive readings, taken every 15 seconds. All these wind velocities were expressed in % of the wind velocity in the control site at the same height: the relative wind velocity.

Besides these wind measurements, some general observations were done on wind direction and wind velocity during the monsoon winds, during rainstorms and during the harmattan winds. Observations were also done on the threshold-velocity for wind-erosion.

b. Measurements on available soil moisture

In order to get 5 repetitions of soil moisture measurements, 5 lines were drawn perpendicular to the windbreaks in the selected site. Along all of these lines measurements on available soil moisture were carried out at the same distances from the windbreaks as used for the wind velocity measurements during the rainy season, i.e.

| windbreak 5 | E | D | C | B | A | windbreak 4 |
|---|---|---|---|---|---|---|
| | 1h | 5h | 8.5h | 12h | 16 | |

It should be noted that for microclimatic reasons during the rainy season, windbreak 5 was the windward side, though during the rains itself windbreak 4 was the windward side (see also fig. 16A).
Control measurements were taken at 5 points in the control site (see fig. 16B).

In all of the measuring points soil texture of the different layers over a depth of 90 cm was estimated on the basis of samples analysed by the INRAN laboratory of soils

and soil texture profiles of the area were made.(see app. II).

Due to late arrival of the equipment, the measurements could only be effective from the 25th of July, which was already halfway the rainy season. From this time until September 21 (all crops harvested), measurements were taken on available soil moisture at three different depths: 10, 40 and 80 cm.
The zone from 0 - 10 cm was considered to be mostly influenced by evaporation. The zone from 10 - 40 cm was supposed to be the depth at which an indication could be found of the surplus water not used for evaporation and transpiration by the crops. At this same depth (80 cm) possible influences of water consumption by the trees would be noticeable.

Measurements were carried out with a transportable Boyouccus moisture meter, connected with permanently buried gypsum blocks at the indicated depths.
The mean for 5 repetitions at a certain distance from the windbreaks was taken and the resulting values of available soil moisture at the different depths were expressed as percentage of the mean values of available soil moisture in the control site, thus giving the relative amount of available soil moisture.

Rainfall data in the area were collected just outside the windbreaks (see appendix III). Though the total amount of rainfall can be considered normal, the repartition was certainly not normal: August usually has a high rainfall-figure, the rain falling constantly in small amounts. However, during August 1979, when the millet was in its full growth, there was a three week period of drought.

c. Measurements on crop production

At the same points where soil moisture was measured - 5 repetitions at each of the distances 1h, 5h, 8.5h, 12h and 16h of the windbreaks and 5 control points (see fig. 16A, B) - plots were laid out of 10 x 5 m with the long side parallel to the windbreaks. The plots 1h and 16h were laid out in such a way that the side closest to the windbreak was the vertical projection of the crowns. In these plots observations were done on the mean height of the millet during the growing season and yields were measured after harvesting and drying of the grains. A problem in interpretation arose from the fact that some of the plots could not be seeded until the second rain. However, no reasonable reduction factor could be found for height growth and yields and the results were interpreted as such.

Production figures of the millet were found by taking the mean figure of the 5 repetitions and converting them to kg/ha. The yields were compared by statistical analysis of the results. For this purpose the results were ordered in groups of most comparable soils (see appendix II).

Some general observations were done during the growing season on mechanical wind damage of the crops, crop growth in the direct vicinity of the windbreaks and sensitivity to drought.

At the end of the growing season three rootprofiles have been made to get an idea of the root development of the crop. Holes have been dug to a depth of 1m: in plot 2A just windward of windbreak 4 (3m from trunk), in 2E just leeward of windbreak 5 ( 3 m from trunk) and in plot 2C (see fig. 16A). Root development here was evaluated 'at the eye'.

## 4. Results

### a. Influence of windbreaks on wind velocity

The wind direction during the rainy season ranged from SW to WNW, but was predominantly W. Rains were accompanied by NE to SE winds, with predominantly E storms. During the dry season the wind direction ranged from ENE to ESE, but was predominantly E.

The wind measurements during the dry season and the beginning of the rainy season at 1 m height showed the following mean relative wind velocities (see fig. 17 and appendix IV):

| Control | 1h | 5h | 8.5h | 12h | 16h | distance leeward from windbreak |
|---|---|---|---|---|---|---|
| 100 | 78 | 47 | 60 | 72 | 63 | relative wind velocity (% |

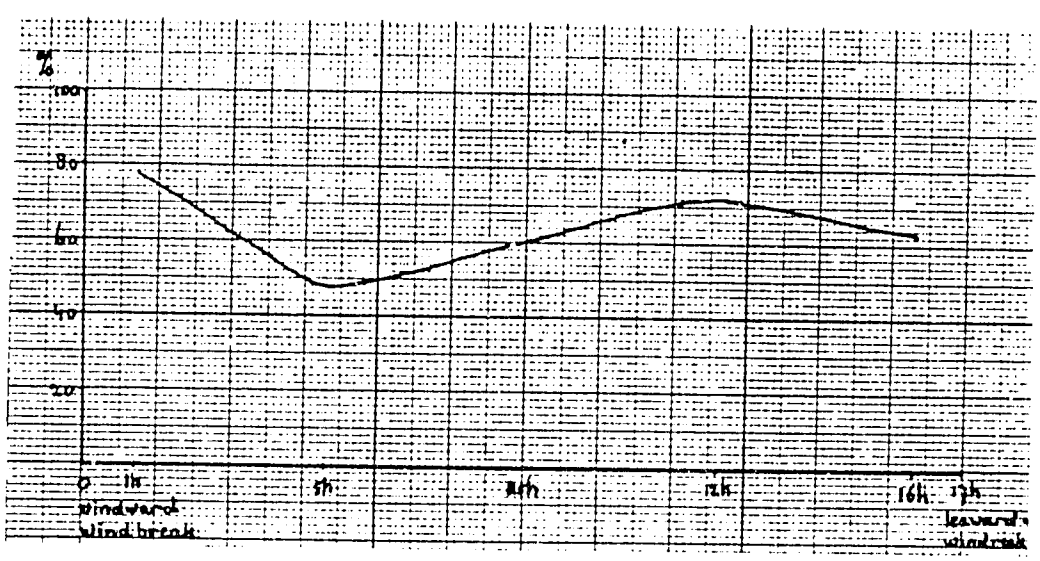



fig. 17 Relative wind velocity at 1 m height

Just leeward of the windbreak a relative high wind velocity occurs, due to jetting through the leafless parts of the stems. The area of minimum wind velocity therefore

is found at a rather great distance behind the windbreak. A gradual increase of wind velocity occurs further leeward of the area with minimum velocity, until the windward effects of the next windbreak start playing a role in again reducing the wind velocity. The free wind velocity will never be reached due to the combinated windward and leeward effects of the successive windbreaks.

The wind measurements at the theoretical crop height of 2.5 m showed the following mean values of relative wind velocity (see fig. 18 and appendix IV):

| Control | 1h | 5h | 8.5h | 12h | 16h | distance leeward from windbreak |
|---|---|---|---|---|---|---|
| 100 | 38 | 46 | 58 | 66 | 67 | relative wind velocity(%) |

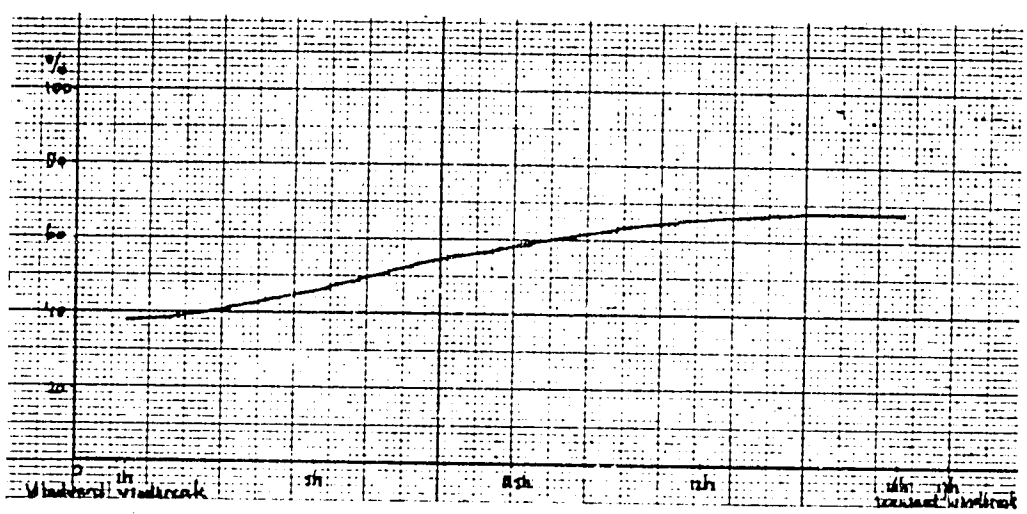


fig. 18 Relative wind velocity at 2.5 m height

At this height wind reduction is maximal just leeward of the windbreak. Further leeward a gradual increase in wind

velocity occurs, until again the windward effects of the next windbreak start plaing a role. Wind reduction just windward of the next windbreak line does not seem to be optimal due to turbulence.

It was observed that during the dry season with the local conditions of soil, vegetative cover and humidity, the threshold velocity for wind erosion in the unprotected area was 10 mph (= 4,4 m/s) at 1 m height.

The harmattan winds usually reach free wind velocities of 10 - 15 mph (= 4,4 - 6,6 m/s) at 1 m height. This wind will be reduced inside the windbreak system to a maximum of 78% at the same height (7,8 - 11,7 mph = 3,4 - 5,1 m/s) and this windspeed only occurs over short distances. Consequently, the threshold velocity for wind erosion will usually not be reached within the windbreak system.
With the highest velocities though, wind erosion in the protected area might still be initiated in the jetting area just leeward of the windbreaks or by the lifting up of soil particles by passing cattle. However, avalanching would only occur to a very limited extent due to decreasing wind velocity after a short distance,and deposition of soil particles will be the result.
This phenomena could easily be observed during the dry season.

It is obvious that the windbreak system already provides an important protection against wind erosion in the dry season, though a definite improvement could be made if jetting was stopped by creating a higher density of the windbreaks near the ground.

In the beginning of the rainy season some wind erosion was still observed in the unprotected area. However, the new

vegetative cover and higher soil humidity soon seemed to provide an adequate protection against wind erosion. Another important factor in this context is that wind velocities generally are lower during the monsoon than during the harmattan, although high momentary velocities may occur with the Eastern winds accompanying the rainstorms (20 - 35 mph = 9 - 15,5 m/s at 2,5 m height). During these storms wind erosion occurs as long as the top-soil is dry and not completely covered by vegetation.
Especially at the end of the growing season these storms cause mechanical damage to the crops by layering.

b. Influence of windbreaks on available soil moisture

The collected data on available soil moisture during the rainy season at the depths of 10, 40 and 80 cm are summarized in appendix V, together with the corresponding values of relative available soil moisture in % of the value in the control zone Z.
A graphical display of the first figures shows the following tendencies (see fig. 19):

- At a depth of 10 cm the changes in available soil moisture during the season are the most noticeable: fast moistening after rain, fast drying out due to evapotranspiration and percolation.
- Large quantities of water are needed before the demands for evapotranspiration are met and surplus water is allowed to a greater depth.

From a graphical display of the values of relative available soil moisture (see fig. 20) some conclusions were drawn about the influence of windbreaks on this factor:

- As long as water-supplies are sufficient, no significant difference in available soil moisture occurs between the

protected and unprotected area up to a depth of 40 cm. However, more surplus water is allowed to percolate to greater depth (80 cm) in the protected zone, or less water is used for evapotranspiration.

- As soon as water-supplies become scarce (from the fifth of August to harvest), the opposite occurs. The available soil moisture within the windbreaks is less than in the unprotected area. However, the water seems to be used for better crop growth (see also 4c).
- The plots A (during the rains at a distance 1h leeward of the windbreaks) are in general less humid than the others due to interception of the rain by the windbreak.
- Water consumption by the windbreaks at a distance of 1h on both sides of the windbreaks (plots A and E) does not seem to influence the amount of available soil moisture in the most important rooting zone of the crop (10 - 40 cm). Even at 80 cm a difference is hardly noticeable. Considering also the fact that at 1h on both sides of the windbreaks only few roots of the neem trees were found (see also 4c) and those deeper than 50 - 60 cm, it can be concluded that the neem windbreaks depend mostly on water-supplies close to the trunk and on the groundwater-table.

## c. Influence on crops

Yields of millet in the studied areas can be summarized as:

| Control Z | 1h E | 5h D | 8.5h C | 12h B | 16h A | mean A - E | |
|---|---|---|---|---|---|---|---|
| 854 | 1106 | 1332 | 1043 | 1070 | 944 | 1099 | (kg/ha) |
| 100 | 130 | 156 | 122 | 125 | 111 | 129 | (%) |

(see also appendix VI, crop yields)

Analysis of variance of these results shows (see appendix VI) that at a significance level of 5 % difference existed between the 'treatments' (= distance to windbreaks), while no difference existed between the 'blocks' (= most comparable soils).
A t-test further showed that at a significance level of 10 % the plots B, C, D and E had higher yields than Z, the control area. D had significantly higher yields than all the other plots, while A, B, C and E did not differ among each other.

Several factors can be held responsable for the fact that in plot A no significantly better results were found than in the control zone:
- During the rains, these plots become 1h leeward of windbreak 4 and receive a reduced amount of water due to interception of rain by the windbreak.
- During the rains, the plants at the edge of the plots get damaged by the strong winds jetting through the leafless lower parts of the windbreak.
- Shadowing during the morning hours by the windbreak.
- As mentioned in 4b, water consumption of the trees does not seem to play an important role next to the crown projection of the windbreak lines.

Although wind protection at the theoretical crop height and vegetative growth are maximal in the plots E, no maximal crop yields are found here, for which the following explanations can be given:
- Reduced yields at the edge of the plots by influences of the Western winds jetting through the leafless lower parts of the windbreak.
- Shadowing during the afternoon hours.
- During the rainstorms, when the plots E become 1h windward of windbreak 5, mechanical damage to the millet occurs due to a strong turbulence in the eddying area just before the windbreaks.

The high yields in the plots D (5h) can be explained by the fact that:

- Windreduction at this distance from the windbreak is high at both 1 m height and at 2.5 m height, or optimal growing conditions are guaranteed during all phases of plant growth.

Yields of millet planted underneath the trees were zero, as no generative growth was possible under these circumstances.

Although no definite answer can be given, it is assumed that the yields in both C and D would have been better if all plots had been seeded after the first big rain.

The mean yield within the windbreaks, being 129 % of the yield in the open, only takes into consideration the yields between the rows of trees. For a more realistic approach, a correction has to be made for the fact that underneath the trees, over a width of 8 m, no millet at all can be produced. In this case, with a distance of 124 m between the windbreaks, the surface lost for agricultural production per 100 m length of windbreak is $\frac{8 \times 100}{124 \times 100} = 0.06 = 6\ \%$.
The total yield in the protected area is therefore 129 % - 6 % = 123 % of the yield in the open.

The mean height of the millet during the growing season is shown in fig. 21 and appendix VI.
It can clearly be seen that the mean height - and with it all vegetative growth - within the windbreaks is much better than in the open. In the field it could be observed that not only the mean height was better within the windbreaks, but also that growth was more equally here.
Wind reduction, and all climatic changes induced by this, favour this better plant growth. This in turn offers a possibility for higher yields. As shown before, water

consumption increases with this higher plant growth, but the water is in this cases used in a more efficient way than in the unprotected zone.

Contrary to expectations, height growth at a distance of 1h at both sides of the windbreaks (A and E) does not seem to be negatively influenced by the windbreaks. Millet planted underneath the trees, however, does not develop at all: several small-sized leaves are formed but no shooting occurs. However, almost directly next to the trees normal height growth could be observed.

The most important zone of root development of the millet (see appendix VI) appeared to be 5 to 40 cm, after this gradually decreasing over the total depth of the profil (1 m). Roots of the neem trees, at a distance of 3 m at both sides of the stems in the windbreak, were found scarcely and almost only deeper than 50 cm.

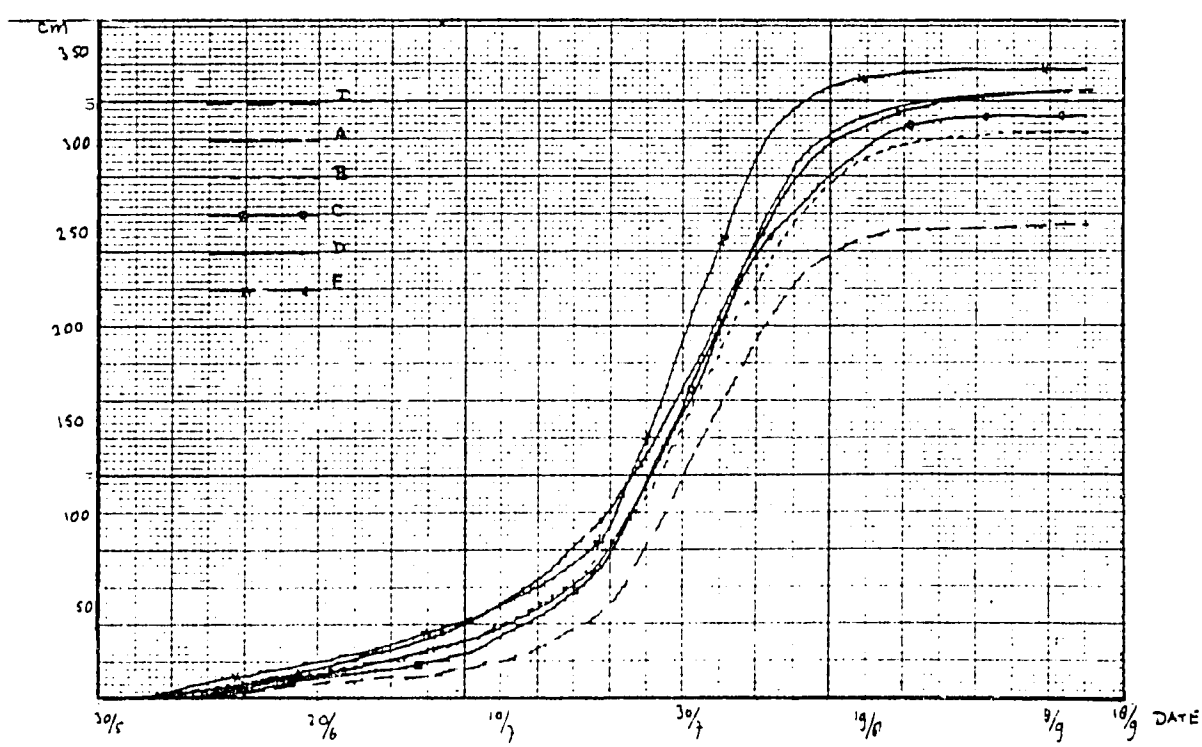



fig. 21 Mean height of millet during the growing season

## 5. Conclusions

The conclusions of the research undertaken in the area protected by two windbreaks, placed at a distance of 17h, can be summarized as follows:

1. Wind velocity inside the windbreak system, measured at 1 m height, is reduced to approximately 45 - 80 % of the free wind velocity, the minimum velocity occurring 5h leeward of the windbreak, the maximum just leeward of the windbreak as a result of jetting; a second maximum occurs at 12h leeward of the windbreak.
2. Wind velocity inside the windbreak system, measured at 2.5 m height, is reduced to approximately 40 - 70 % of the free wind velocity, the minimum velocity occurring just leeward of the windbreak, the maximum from 12h to 16h leeward of it.
3. Wind erosion is reduced considerably by the windbreaks, but an improvement could be made by creating a higher density of the windbreaks near the ground.
4. Soil moisture within the windbreak system is higher than in the open during periods with a high water supply; with a low water supply soil moisture within the windbreak system is lower than in the open, but at the same time a better plant growth is achieved within the windbreak system.
5. Soil moisture is reduced at a distance of 1h leeward of the windbreaks due to interception of the rain.
6. Water consumption by the windbreaks does not seem to influence soil moisture in the most important rooting zone of the crop.
7. Crop yields inside the windbreak system were found to be 129 % of those in the open, rangeing from 111 % at a distance 16h leeward of the first windbreak to 156 % at a distance 5h leeward of it; corrected for the loss of production underneath the trees, the production in the protected area still reaches 123 % of that in the open.

8. Underneath the neem trees no millet growth is possible as soon as the canopy is closed.
9. Height growth of the millet is much better and much more equal at all sites inside the windbreak system than in the open.

## 6. Discussion

When the results found during the research on the influences of the windbreaks in the Majjia Valley are compared with the results found so far by other authors, as decribed in part D, the following can be noticed:

Wind reduction patterns as measured fall in the range of reductions to be expected, considering the fact that it is dealt here with two successive windbreaks of moderate density, open near the ground.
The measurements at 1 m height show a much more unevenly distributed pattern of wind reduction than those at 2.5 m height; the relative high velocities 1h leeward of the windbreaks are caused by the jetting of air through the leafless parts of the stems as mentioned by Caborn (1957, 1960), though in this case no wind velocities were measured higher than the free wind velocity.

As with greater distance leeward of the first windbreak, relative wind velocities do not pass approximately 70 %, it is clear that the successive windbreaks are placed close enough to get an overlap of leeward and windward effects of the successive windbreaks, which could be expected with a distance of 17h in between them (Caborn, 1957; Guyot, 1964; WMO, 1964).
Any possible accumulative effects in the transition zone of a series of shelterbelts (WMO, 1964; Giffard, 1974) are not

considered here, this being too detailed within the scope of this research.

As no measurements were done on wind-erosion, it only can be said from general observations that a considerable reduction of it is realized by the windbreaks. Looking at the wind velocity patterns at 1 m height, an improvement could be made when a higher density of the windbreaks was realized near the ground.

The influence of the windbreaks on available soil moisture appeared to be different depending on the water supplies: during a period with high water supply a positive influence could be noticed, during a period with lower water supply a negative influence was found.
Comparing this with the results found by Guyot (1964), this is understandable as the first case represents humid climatological conditions, when windbreaks influence a reduction of ETR thus leaving more available water untouched in the protected area; the second case represents arid climatological conditions, when windbreaks influence an increase of ETR due to less wilting of the plants, causing at the same time a higher plant production.

Though with the neem windbreaks water consumption of the trees did not seem to influence the amount of available soil moisture adjacent to the windbreaks, this might be different when trees are being used with a more superficial root-system.

It could be concluded that crop yields in all of the protected area were, to a bigger or lesser extent, positively influenced by the windbreaks. Care should be taken that the figures are not generalized too soon. Crop yields may differ considerably from year to year and from place to

place only because of the very unreliable rainfall. Though most probably the influence of the windbreaks on crop yields will remain positive, the relative increase might differ under other rainfall conditions.

## 7. Recommendations

Though the tendencies found from the research undertaken clearly justify continuation of the efforts to plant windbreaks in the Majjia Valley, it should be noted that more detailed research is needed to give any definite conclusions on the impact of these windbreaks.
More sophisticated equipment, especially for wind-measurements, should be installed permanently at different distances from the windbreaks and at different heights above ground-level to obtain more detailed information.
Measurements on soil moisture and crop yields should be repeated during the coming years in order to see the influences of the windbreaks during years with other repartition of the rainfall.
In addition measurements on evaporation and quantitative measurements on soil flow due to wind-erosion might be carried out to provide further valuable information on the influence of the windbreaks.

Yields of millet grains in plots of 5 x 10 $m^2$
Production de grains de mil dans des parcelles de 5 x 10 $m^2$

| Plot no. | Yield/Production | | | |
|---|---|---|---|---|
| | kg/50 $m^2$ | kg/ha | mean/moyenne (kg/ha) | % of contr.Z<br>% de contr.Z |
| Z1 | 5.125 | 1025 | | |
| Z2 | 5.025 | 1005 | | |
| Z3 | 3.650 | 730 | 854 | 100 |
| Z4 | 3.750 | 750 | | |
| Z5 | 3.800 | 760 | | |
| 1A | 5.150 | 1030 | | |
| 2A | 4.550 | 910 | | |
| 3A | 3.950 | 790 | 944 | 111 |
| 4A | 4.850 | 970 | | |
| 5A | 5.100 | 1020 | | |
| 1B | 5.300 | 1060 | | |
| 2B | 5.850 | 1170 | | |
| 3B | 5.300 | 1060 | 1070 | 125 |
| 4B | 5.400 | 1080 | | |
| 5B | 4.900 | 980 | | |
| 1C* | 6.150* | 1230* | | |
| 2C | 5.750 | 1150 | | |
| 3C | 5.325 | 1065 | 1043 | 122 |
| 4C* | 4.350 | 870* | | |
| 5C* | 4.500* | 900* | | |
| 1D* | 5.250* | 1050* | | |
| 2D | 8.100 | 1620 | | |
| 3D | 7.700 | 1540 | 1332 | 156 |
| 4D | 7.300 | 1460 | | |
| 5D* | 4.950* | 990* | | |
| 1E | 4.600 | 920 | | |
| 2E | 5.800 | 1160 | | |
| 3E | 6.900 | 1380 | 1105 | 130 |
| 4E | 4.650 | 930 | | |
| 5E | 5.700 | 1140 | | |

* sown after 2nd rain
semence apres 2me pluie

# STATE OF THE ART: ACACIA ALBIDA
## AS A COMPLEMENTARY PERMANENT INTERCROP WITH ANNUAL CROPS

APRIL 1978

Grant No. AID/afr-C-1361
University of California
Riverside, California

## FOREWORD

Documents reviewed for "*Acacia albida*: State of the Art" were obtained in numerous ways. A few useful citations on *Acacia albida* and on *Acacia* were obtained from computer searches on the following six data bases using facilities provided by the University of California, Riverside (UCR) library.

(1) Biosis Previews (Biological Abstracts and Biological Research Index)

(2) National Technical Information Service

(3) CAIN - U.S. National Agricultural Library

(4) Smithsonian Science Information Exchange, Inc.

(5) SCISEARCH - Science Citation Index

(6) CAB Abstracts - Commonwealth Agricultural Bureau

The holdings of the Moisture Utilization in Semi-arid Tropics (MUSAT: sra) special collection at UCR provided several references. Many useful documents were examined and photocopied at the Centre Techniques Forestier Tropicale (CTFT) and Institute Recherche Agronomique Tropicale (IRAT) in Nogent-sur-Marne, France. Additional materials were located in ORSTOM holdings in Bondy, France and various other locations in Paris. At the following organizations in Senegal, West Africa resource personnel were contacted and/or bibliographic holdings were examined: ORSTOM - Bel Air Dakar; ORSTOM-HANN, Dakar; Laboratoire d'Elevage, Dakar; CNRF, Dakar; Eaux et Foret, Dakar; IFAN, Dakar; FAO, Dakar; ICRISAT, Dakar; SODEVA, Dakar and Thies; and CNRA, Bambey.

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Author: Charreau, C. and P. Vidal (1965)

Title: Influence de l'*Acacia albida* Del sur le sol, nutrition minerale et rendements des mils *Pennisetum* au Senegal.

Source: Agron. Trop. 6-7 pp 660-626

a) The purpose of this paper was to study the effects of *A. albida* average millet yield per hill at the soil sampling site. Seven such determinations were averaged for each of the three categories: millet under the tree, millet at the proximity of tree coverage, and millet outside the tree coverage. The results were then expressed in kg/ha assuming a planting density of 10,000 hills/ha.

2c) A multiple range test run at the University of California, Riverside, on the 7 yields under *A. albida*, the 6 yields in the proximity of coverage, and the 7 yields away from the tree indicated that yields under and away from the tree were significantly different at the 1% level. The yields just under the edge of the foliage were not significantly different from either yields away from the tree or under the tree at the 1% level. These statistical analyses assume the sampling was done either in a representative or random manner but this was not stated in the paper.

3b) The yield of peanuts was also measured under and away from an *Acacia albida* on 100 $m^2$ sized plots. The results were the pod yield of peanuts decreased under *A. albida* (from 2,813 kg/ha to 1,839 kg/ha) while the straw yield of the peanut increased (from 2,587 to 2,761 kg/ha) under *A. albida*.

3c) The yields of peanuts in these experiments are rather high (1,839 and 2,813 kg/ha) both away and under the *A. albida* compared to normal pod yields of peanuts in Senegal (600-800 kg/ha). Because of the high yields of vegetative matter in this experiment and the fact that high N levels can depress the yield of reproductive structure in plants, it appears as if a very high level of fertility under



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the A. albida was the cause of this low yield.[1]

d) There are many facets to this paper but the two main inescapable ones are: 1) under A albida there is a two fold statistically significant increase of soil nitrogen and organic matter[2] which has probably caused the observed increases in cation exchange capacity and water holding capacity, 2) under A. albida there is a 2.5 fold statistically significant increase in millet yields.[3] Since cattle had been excluded from this region for many years, it is unlikely that the increased fertility is due to preferential deposition of fecal material around the trees.

The fact that A. albida lowered the yield of peanuts is probably due to a depressing effect of high fertility on pod yield, caused by a long absence of cultivation beneath the trees. It is important to realize that the depressed peanut yield (1800 kg/ha) is in this instance double or triple what Senegalese farmers normally obtain.

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[1] Dr. Charreau has informed this reviewer that since the publication of this paper he has discovered that peanut yield depression is quite uncommon under A. albida.

[2] Please note that Charreau uses the notation $^{0}/00$ which is parts per thousand not per hundred.

[3] Dr. Charreau has suggested to this reviewer that not all trees appear to have this remarkable fertilizing effect and that a population study of trees having beneficial effects on yields might be of value. (For further discussion of this point see Sarlin, 1963, and Dancette and Poulain, 1969.)

Author: Dançette, C. and J. F. Poulain (1969)

Title: Influence of Acacia albida on pedoclimatic factors and crop yields

Source: African Soils 14, 1-2, 143-184

a) The object of this study was to evaluate the effect of A. albida in a long established traditional Senegalese farming setting on: chemical and physical properties of soils; microclimate of crops; responses of crops to normal fertilizer addition; and yield of crops. The major statistically significant results of the effects of the Acacia albida were: the relative humidity under the Acacia albida is higher than away from the tree; there is a reduction in the absolute maximum temperature and an increase in the absolute minimum temperature under the A. albida; the soil humidity is greater under the tree for the first 120 cm of soil and less for deeper soil layers

(than soils beyond A. albida foliage cover); the quantity of rain intercepted by the soil under the A. albida is greater for rains of intensity greater than 16mm/hr and less for rainfall of less than 16mm/hr than soil without A. albida; there is a 40% increase in soil carbon and a 33% increase in soil nitrogen under the A. albida; and there is an increase in yield of 300 kg/ha of peanuts (37% increase) and an increase of 480 kg/ha of sorghum (105% increase).

b) One of the most important assets of the experimental design of this paper was the inclusion of a large number of trees (12) in a traditional Senegalese setting which had been farmed for many years. Five 3.6 x 9 m plots were made with each tree. Two of the plots (with and without added fertilizer) were located under the cover of the tree and three of the plots (no fertilizer and two levels of fertilizer) were located outside the cover of the tree. For yield determinations the center line of each plot consisting of 9 hills of sorghum were harvested. The sorghum heights were also measured as a function of time and developmental stage. The soil analysis was carried out by techniques which have been reviewed in other papers, e.g., Charreau and Vidal (1966) and Radwanski and Wickens (1969).

The following microclimatological experiments were conducted on a single tree at the limits of the Centre National de Recherche Agronomique (CNRA), Bambey. The humidity analysis was done with sheltered psychrometers during the month of July at various times of the day with paired psychrometers 2 and 15 meters away from the tree trunk. The temperature measurements were made using maximum and minimum thermometers over a three week period at the start of the dry season

(late October) at two distances (one near the trunk and the other outside the foliage limit). The soil moisture measurements were made gravimetrically after sampling with an auger at three distances in four directions from the tree before the rainy season began and 9 days after the end of the rainy season.

The rainfall was measured using vessels buried to one third of their height in 8 directions at 5 distances from the the Acacia albida tree. This rainfall data was correlated with data taken at the meteorological station (both the studied tree and the meterological station were on the grounds of the CNRA, Bambey) on rainfall intensity and wind direction.

c) Due to the extensive experimental replication employed by these authors they were able to obtain a good statistical evaluation of their experiments so that the results they report are valid. Their use of what appears to be a random sample of 12 trees in a heavily farmed area yields results which are more generally applicable than those of other authors using single trees.

d) The major results of this paper are that in a population of A. albida trees, the yields of peanuts increased by a rate of 300 kg/ha and the yields of sorghum increased by a rate of 475 kg/ha. This rate of increase occurs only under the A. albida tree and it would be necessary to have complete canopy cover in order to achieve these increases over a hectare.

Author: Dugain, F. (1960)

Title: Rapport de Mission au Niger

Source: Centre de Pedologie de HANN-Dakar. Mimeo, 22 pages.

a) The main purpose of this document was to report methods for erosion control in Niger. An appendix is attached on the effect of Acacia albida on soil chemical and physical parameters. The soils under A. albida were found to be increased in organic matter by 269% and in nitrogen by 231% as opposed to areas not under Acacia albida cover. The soil water holding capacity was higher under the Acacia albida as well as the plant nutrients, calcium, magnesium, potassium and phosphorus.

b) Dugain's (1960) method employed five Acacia albida trees. Twenty five, 100 g sc amp (0-10 cm) were taken from a site under each Acacia albida and from a site about 10 meters away from the limit of coverage. It was not stated what method was used for soil analysis, but commonly used simple soil analyses methods such as these are little prone to error. The results of the assay are similar to that of Charreau and Vidal (1966) and Dancette and Poulain (1969).

c) Statistical analysis of the data from the five trees was not carried out since in no case was the nitrogen, organic matter, cation exchange capacity, potassium, calcium and magnesium in any of the soils away from the Acacia albida greater than the levels under the Acacia albida. The average values for the preceding chemical analyses under the tree were several fold higher than found away from the tree.

d) While yield measurements under the tree were not carried out it would indeed be surprising if soils under the five Acacia albida trees with several fold higher contents of plant nutrients than away from the

Author: I.R.H.O. Senegal (1966) (probably Gatreau)

Title: Essais sous kads

Source: IRHO Senegal rapport annual memeo. Station de Bambey, 19-29.

a) As Acacia albida was reputed to increase yields of peanuts, the Senegalese government commissioned a research program to study the effect of Acacia albida on the yield of peanuts. In 3 cases out of 5 Acacia albida increased the peanut yield on the test plots an average of 590 kg/ha but in two cases a small decrease in yield (60 kg/ha) was observed under the Acacia albida. The study concluded (in translation) "the effect of the Acacia albida cover was benefi/ial for peanuts. It is not possible to obtain the soil fertility level provided by Acacia albida with mineral fertilizer."

b) The research method used 5 sites in which the yield of peanuts was measured under the trees and outside of the foliage cover. Two of the sites located near Patar were 1 km apart, and each contained two trees with overlapping foliage. Each of these sites had 28, 5.8 $m^2$ plots marked

out in perpendicular directions. Sixteen of these small plots were under the cover of the foliage and 12 plots were exterior to the foliage cover.

Near Marnane three more trees were chosen for study. Two of the trees had 5 or 6 small plots under the tree and 8 small plots exterior to the foliage cover. Under the third tree near Marnane the top 2 cm of soil was removed from a series of plots beneath the foliage cover and placed on plots just at the limit of the foliage cover to examine the relationship between soil fertility and yield under A. albida.

On all 5 experimental sites fertilizer additions were made to determine if mineral fetilizers could replace yield increases produced by A. albida.

c) It is difficult to evaluate these experiments for several reasons. First, it is difficult to gain an idea of an average effect of A. albida trees as three of the five Acacia albida plots produced yield increases of 590 kg/ha while 2 of the plots depressed yield by 60 kg/ha.

Second, no statistical calculations were carried out to evaluate the validity of yield increases even though as many as 13 subplots were used for yield determinations. Third, the significance of the experiment in which soils were moved from sites close to the tree to areas near limit of foliage cover is clouded by the fact that 2 out of 5 Acacia albida sites depressed yield. It would seem that until A. albida yield increases were demonstrated in all cases it would not be appropriate to study causal mechanisms for the yield increase.

Fourth, soils of high fertility have been known to increase plant vegetative growth at the expense of reproductive structures, e.g., pods

or grain. If A. albida's natural capability to increase soil fertility were combined with a fertility restoring long fallow, the soil under A. albida could have a sufficiently high fertility to depress peanut pod yields. In the absence of any description of past farming practices on the involved sites, it would not be possible to know what general fertility level could have been expected under the trees, and thus whether yield depressions were caused by overfertility. The rather high pod yields obtained (1300 kg/ha) indicate the soils were far from infertile (Gillier, 1960).

d) Although the experiments are far from perfect, two useful facts emerge. (1) while A. albida increased the average peanut yield for all trees, in some cases there was an actual yield depression; (2) peanut yield depressions are associated with A. albida on sites where peanut yields are high (approximately 1300 kg/ha) and yield depressions if statistically significant are much smaller (60 kg/ha) than yield increases (590 kg/ha) associated with A. albida on poor sites.

(Note: See Also Selection 3 for Full Report)

Author: Sarlin (1963)

Title: Le Faidherbia albida (Acacia albida Del) a Ouahigouya

Source: Mimeo: Centre Technique Forestier Tropical, 36 pages.

a. This research examined the effect of Acacia albida on millet yields and on soil fertility on numerous sites near Ouahigouya. For an average of 29 sites on various topographies (crests of hills, slopes, and low-lying areas) Acacia albida increased the unthreshed millet head yields from 820 to 1,250 kg/ha.

b. Twenty-nine sites were established close to roads leaving Ouahigouya in all directions. The sites were chosen to represent crests of hills, slopes, and low-lying areas. Measurements were made of Acacia albida's trunk diameter, crown diameter and distance to the nearest Acacia albida. The following soil parameters were also measured: pH; organic matter; nitrogen content; carbon content; exchangeable calcium, magnesium and potassium; and total and assimilable phosphate.

The soil was sampled by staking out a square 10 meters on a side. Each corner and each side were sampled once and the middle of the square was sampled twice. Each of the above places was subsampled 10 times for a total of 100 samplings per square. The yield of millet was also measured in the above described squares. For each square under an Acacia albida there was a control outside the Acacia albida cover. Correlations were attempted between most of the tree and soil parameters. An equation was derived to relate Acacia albida seedling death to number and frequency of cattle steps.

c. The effort used to derive equations relating frequency of cattle steps to A. albida seedling mortality and thus mature stand density would have been better spent designing animal-proof protection devices. Plots of the attempted correlations between tree parameters and soil parameters have a great deal of scatter and in view of the absence of a statistical asessment of their reliability, they are of questionable value.

The extensive number and replication of soil samples taken should be sufficient to find any real differences between the control soil and the soil under Acacia albida. As the type of soil analyses are quite standard and as they were carried out at the CTFT lab near Paris one would imagine they are reliable. Nevertheless, the data for the tree on the crest looks suspicious since the millet yield under A. albida went from 300 kg/ha to 1,125 kg/ha, while the soil organic matter and nitrogen content under A. albida went down when all other soil parameters remained the same. Similarly, in parcel 3 the yield under A. albida went down

by 900 kg/ha when soil analyses showed all soil parameters under the tree to be more favorable. These strong inverse correlations between yield and soil nutrient status are in conflict with data obtained by Dancette and Poulain (1969) and Charreau and Vidal (1965). This reviewer would tend to support the conclusions of the latter workers. It is this reviewer's opinion that the results from the data in this document are overextended.

d. Acacia albida increased the yield in 22 out of 29 cases, it had no effect in 2 cases, and in 5 cases it decreased the yield. While A. albida does not always increase the millet yield there was an average millet yield increase for all 29 trees of 430 kg/ha. Research is needed to determine why the yield is depressed in some cases and what will be required for A. albida to increase the yield in all cases.

## II. SUMMARY

### A. Effect of Acacia albida on crop yields

There are four original papers in which the effect of A. albida on crop yield was studied (Sarlin, 1963, Charreau and Vidal, 1965; IRHO, 1966; and Dancette and Poulain, 1969). In all four cases there was a valid average yield increase reported, but in cases where a large number of trees were included there were a few A. albida trees under which crop yields decreased. Sarlin (1963) reported an average millet increase of 430 kg/ha, Charreau and Vidal (1965) reported a 1,008 kg/ha increase for millet, Dancette and Poulain (1969) reported yield increases of 480 kg/ha for sorghum and 300 kg/ha for peanuts, and IRHO (1966) reported an average 330 kg/ha yield increase for peanuts. For the single case where Charreau and Vidal (1965) measured peanut yields, they found a 974 kg/ha decrease. (Charreau has informed this reviewer that very seldom is such the case in Senegal.) The peanut yields were depressed by the Acacia albida trees to 1300 kg/ha in the IRHO (1966) study and to 1800 kg/ha in the Charreau and Vidal (1965) study, and these "depressed yields" are much higher than typical Senegalese peanut yields. For instance, Gillier (1960) lists the following yields for different soil categories: (a) 320 kg/ha for a completely infertile soil; (b) 620 kg/ha for the soil listed above after three years of fallow and (c) 1535 kg/ha for a soil thoroughly enriched in inorganic and organic nutrients. An example of an average peanut yield would be the 810 kg/ha yield observed by Dancette and Poulain (1969) outside the foliage cover of A. albida trees.

The peanut yield depressions reported by Charreau and Vidal (1965) and IRHO (1966) are most readily explained if one considers that excessive soil fertility can cause excessive vegetative growth at the expense of reproductive growth (grain or pods). In the Charreau and Vidal (1965) study, the peanut vegetative growth under A. albida was higher than away from A. albida even though the grain yields were not. Since the fields in the Charreau and Vidal study had not been in cultivation for many years, it seems probable that the fertility was excessively high under the peanuts. As the past farming history of the IRHO (1966) study was not discussed, it is not possible to ascertain whether a high fertility level there might also have caused a yield decrease.

Yield decreases induced by high fertility are very unlikely to occur on most Senegalese soils because they are farmed continuously without fallow. For example, well-fertilized peanut fields with yields of 1200 kg/ha when placed under continuous peanut culture, without fertilization, have been reported by Gillier (1960) to yield 600 kg/ha three years later. It seems reasonable that land which had been under continuous cultivation for many years would have a low fertility level and its yields would be stimulated by A. albida. Dancette and Poulain's (1969) study which was conducted in a natural farming setting that had been under continuous cultivation for many years supports this point of view. This reviewer would choose the Dancette and Poulain study as the work which was both most representative of typical farming situations and most thorough.

As an average figure, A. albida will increase peanut yields when grown under continuous cultivation by approximately 300 kg/ha but, if

peanut yields approach 1200 kg/ha, A. albida may have a slight yield-depressing effect. Yield depressing effects of A. albida on cereals could also occur by increasing the soil fertility, but this is less likely to occur because millet, unlike peanuts, has no capacity to fix nitrogen. Again, Dancette and Poulain's data for millet yield increases (480 kg/ha) are probably the most accurate and representative of a typical farming situation. Acacia albida can be recommended without reservation in regions where peanut and millet yields are now 500 ± 200 and where 900 ± 200 kg/ha yields are desirable.

B. Effect of Acacia albida on soil properties

While only four articles have described A. albida's effect on yield, several other articles have reported A. albida's effect on the soil chemical, physical, and microbiological characteristics. These additional articles are by Dugain (1960), Wickens (1966), Radwanski and Wickens (19[illegible] and Jung (1966, 1967). For total organic carbon and total nitrogen, the following workers reported the following increases: Dugain (1960) N-231%, C-269%; Dancette and Poulain (1969) N-33%, C-40%; Radwanski and Wickens (1969) N-600%, C-200%; Charreau and Vidal (1965) N-194%, C-192%, and Jung (1966) N-110%, C-91%. Many of the above workers reported increased soil water holding capacity and cation exchange capacity in soils under A. albida, which would be expected as a direct consequence of a higher soil organic matter content under A. albida. A soil with a higher cation exchange capacity is important because cations like $Ca^{++}$ and $Mg^{++}$ (which arise from

decaying leaf litter) are held in greater concentration by the soil where they can be absorbed by the plant. A soil with higher water holding capacity will have more water after a rain available to the plant.

In addition to the study of the chemical and physical soil properties, Jung (1966 and 1967) compared soil microbiological changes under and away from A. albida trees. Under the A. albida he found clear increases in invertase, dehydrogenase, asparaginase, and respiratory $CO_2$. Bacteria counts under and away from the tree were the same but under the A. albida tree there was a marked increase in the fungi and actinomycete population. In general, these latter organisms can degrade lignins and plant cell walls more easily than bacteria so that soil under A. albida could more quickly degrade leaf litter to release plant nutrients. The combination of the higher enzyme activities, and fungi and actinomycete populations were taken by Jung (1966, 1967) to indicate a general higher level of microbial activity. In the past, soils with active microflora have been used to indicate areas of high fertility.

C. Causes for Acacia albida induced soil fertility

The causes for the increased fertility under the A. albida have been a subject of controversy. From the A. albida data available, this reviewer believes there is little alternative but to conclude the higher fertility under A. albida is being driven by nitrogen fixation by the Acacia albida. The reasons for this point of view are as follows:

(1) Both Habish and Khairi (1968) and Jung (1967) have observed

nodules on A. albida seedlings and have shown them to increase the nitrogen content of greenhouse grown pots when supplied a complete nutrient solution minus nitrogen.

(2) Higher soil nitrogen and organic matter contents are not found under the non-leguminous bush Guiera senegalensis (Jung, 1967) or under the non-leguminous tree Balanites aegyptica (Wickens and Radwanski, 1969) indicating that the trees are not scavenging nitrogen from areas deep in the soil profile.

(3) The most compelling reason to believe A. albida is fixing nitrogen results from an analysis of the nitrogen cycle. Assuming the yield of peanuts growing under A. albida to be 800 kg/ha and assuming they contain about 3% nitrogen (18.75% protein), 24 kg/ha/yr of nitrogen will be removed from the fields to be sold in the city. An evaluation of the sources of fixed nitrogen coming into the continuous peanut culture under A. albida reveals: (a) nitrogen cannot arise from weathering of any bedrock or parent material as nitrogen unlike calcium or magnesium does not exist in these forms. If nitrogen were obtained by A. albida deep in the soil profile, that nitrogen cannot be the result of parent material degradation and must have been fixed at some point; (b) while peanuts can fix nitrogen, no nitrogen input is assumed to come from the peanuts since peanuts cannot sustain a high soil nitrogen and organic matter content or a high yield without A. albida; (c) no nitrogen is assumed to come from fertilizers; (d) fixed nitrogen coming from the atmosphere being fixed in electrical storms is about 2 kg N/ha/yr (Paul et al, 1971); (e) estimates of nitrogen fixed by free living nitrogen fixers are assumed to be

less than 1 kg/ha/yr (Paul et al, 1971). Therefore, one is left with a deficit of 24 - 2 kg/ha from electrical storms - 1 kg/ha from free living nitrogen fixers = 21 kg N/ha/yr coming from an as yet unidentified source. This deficit will be even greater if all the peanut roots and leaves are not returned to the soil. Cattle and other animals cannot be considered as a source of nitrogen to the cycle because they do not fix nitrogen but merely redistribute and transform fixed nitrogen from one kind of protein to another (cattle can cause a loss of nitrogen to the cycle if they eat plant products and if the cattle are sold in the city.) Since the soil nitrogen content does not increase under the non-leguminous trees Balanites aegyptica and Guiera senegalensis, while it does under A. albida, the most logical conclusion is that A. albida is the source of the 21 kg N/ha/yr.

(4) The failure to observe nodules on A. albida seedlings in the field can be explained by an adverse effect of soil moisture stress on nodulation. Habish's (1970) study of moisture stress on Acacia nodulation reports that at 7% soil moisture the number of nodules formed and total pot nitrogen was considerably less than at 15% soil moisture. At the end of the dry season, which is the end of A. albida's normal growth period, Dancette and Poulain (1969) reported soil moisture contents lower than 1.4% to a depth of 1.4 meters. Since in these soils 1.4% soil moisture content is the permanent wilting point (-15 bars or pF 4.2) it is apparent that many young seedlings would have difficulty nodulating.

(5) There is a different explanation to account for the failure to observe nodules on mature A. albida trees. Orchard and Darb (1956) when

measuring nitrogen fixation on Acacia mollissima in South Africa (they found 200 ± 45 kg N/ha/yr) reported that when Acacias were first established on the very poor infertile, but moist soils, nodules were abundant. Upon harvesting the Acacia mollissima every 8 years, they noticed that nodules were very abundant in the first 8-year cycle, less abundant in the second 8-year cycle, and even less abundant in the third 8-year cycle when the soil nitrogen and organic matter content was several fold higher. This decreasing nodule abundance with increased soil fertility could have been predicted from behavior in annual crops where either nitrate or ammonia supplied to the plant causes an immediate cessation of nitrogen fixation.

The absence of nodules on mature A. albida trees on soils with high nitrogen and organic matter content is perhaps related to the high accumulated soil nitrogen which causes nodules to stop functioning and being produced. Another possible reason why nodules are seldom observed on mature A. albida trees is that they may be formed at times of the year and at depths in the soil which have not yet been examined.

## D. Concluding remarks for A. albida soil fertility and crop yield

A. albida trees in their present unmanaged natural state can be expected to increase peanut and millet yields in areas where the yields are now 500 ± 200 kg/ha to about 900 ± 200 kg/ha when the trees reach maturity. A concommitant 50-100% increase in soil organic matter and soil nitrogen content, a marked increase in soil microbiological activity, and an increase in soil water holding capacity will also be

found beneath A. albida trees. The most plausible reason for the increase in soil fertility and yields is nitrogen fixation by Acacia albida.

E. Acacia albida pod yields

The maximum pod yields on Acacia albida appear to develop very slowly. Nongonierma (1976) reports that A. albida trees in the University of Dakar gardens first bore pods at eight years of age. Lemaitre (1954) reports "pod production begins when the A. albida trunk is 20 cm (7.8") in diameter, is maximum when the crown is large, and averaged over a period of years there are differences in pod production by various trees." The age of Lemaitre's 20 cm diameter tree can be calculated as Mariaux (1966) has determined A. albida diameter growth rates range from 0.61 to 2.9 cm/year. By using the average figure of 1.75 cm/year, a 20 cm diameter tree would begin pod production at about eleven years of age. For twenty A. albida trees, thirty years of age, Lemaitre reports the average pod productivity to be 6 to 8 kg/tree, but he states an exceptional tree might produce 40 kg. Assuming an average of 100 trees/ha, Lemaitre suggested a hectare should yield from 600 to 800 kg pods/ha.

These tree pod yield values are much lower than the values of 125 kg/tree and 135 kg/tree reported by Jung (1967), and Wickens (1966) respectively. This yield discrepancy is perhaps attributable to the younger age (30 years) of Lemaitre's trees. Using Jung's (1967) lowest pod yield density of 3000 kg/ha and assuming it came from the youngest (30 years old) and smallest tree (surface area of 98 $m^2$) a tree pod yield

of 29 kg can be calculated. Thus Jung's (1966) data from his estimated thirty year old tree (29 kg/tree) is approximately fourfold higher than the 6 to 8 kg/tree average for 20 A. albida trees thirty years of age reported by Lemaitre.

Only Jung's (1967) procedure is described in sufficient detail to permit evaluation of his method, but unfortunately this method appears to have a serious limitation to predict total tree pod yield since only two 2 $m^2$ sampling nets were used per tree, for an average projected canopy cover of 231 $m^2$.

The tree pod yield data is further complicated by calculations and assumptions required to arrive at pod production/hectare. Jung (1967) assumed 43 trees/ha to arrive at a maximum pod yield of 5400 kg/ha. As discussed in the review of Jung's (1967) paper, this tree density is four times higher than naturally occurs in the area (Jung, 1969), but A. albida densities of 43 trees/ha have been reported in the Sudan (Wickens and Radwanski, 1969). The low estimate of A. albida pod yield can be determined using a moderate A. albida density (15 trees/ha) with the low pod yields of Lemaitre (7 kg/30-year old tree) to obtain a yield of 105 kg/ha. Thus A. albida pod yields, from the data presented, can be calculated to range from 105 kg/ha to 5400 kg/ha.

In the absence of any description of Wickens' (1966) procedure to measure pod yield, and in view of the sharply contrasting tree pod yield data of Lemaitre (1954) and Jung (1967), average pod yields per tree and average pod yields per hectare must be considered unknown.

F. A. albida pod feeding value

Proximate analyses of the pods and seeds of A. albida have been reported by Gwynne (1969) to be: 10-13% protein for entire pods, 26-28% protein for seeds only, and 43-59% nitrogen free extract (carbohydrate) and by Wickens (1969) to be in the range: 10.6-15.5% protein for the entire pods, 27% protein for seeds only, and 44 to 58% nitrogen free extract (carbohydrates).

As discussed specifically for that paper Boudet and Riviere (1968) have performed chemical analyses on A. albida pods but it is not clear how these chemical values relate to proximate analyses defined by English and American workers. From the chemical analyses Boudet and Riviere (1968) estimate that A. albida pods have 77% of the available energy of an equal weight of barley. By applying a protein digestability coefficient derived from alfalfa hay to the A. albida pod crude protein percentages, Boudet and Riviere (1968) arrive at a forage unit stated to be applicable to cattle. The use of an alfalfa-derived protein digestability coefficient to assess A. albida pod protein is extremely questionable for the following reasons: (1) Wickens (1966) has demonstrated that if A. albida seeds are fed to a steer 66% of the seeds pass intact and undigested through the animal's rumen; (2) the presence of fiber, sucrose, and unknown plant metabolites could adversely affect the protein digestability. This reviewer believes Boudet and Riviere's (1968) International forage unit concept is at present not applicable to A. albida pods.

A useful breeding tool for the selection of high protein A. albida pods will be the fact that A. albida seed to pod weight ratio varied from

1:2.6 to 1:7.7 (Wickens, 1966). Since the seeds contain 26% protein while the pods alone only contain 13% protein (Wickens, 1969), selection for high protein can be done initially by selecting for pods with high seed contents.

## G. Cultural aspects of *Acacia albida*

### 1. Seed germination techniques

Three basic techniques used to break seed dormancy in *A. albida* are: (1) soaking in acid; (2) mechanical scarification, and (3) boiling water treatments. Lemaitre (1954) obtained the optimum acid-induced germination rate of 77% by soaking in sulfuric acid for 5 minutes. Wickens (1966) compared seven boiling water treatments ranging from 0 to 3 minutes with mechanical seed scarification. Wickens found that boiling the seeds did not enhance germination over the control and it took 85 days to reach 90 percent germination for boiled and control seeds. In contrast the nicked seeds reached 87 to 97 percent germination in 10 days. Thus nicked seeds have better germination than sulfuric acid-treated seeds, which are much better than boiled seeds. Mechanical shaking devices have been used in the past to scarify hard-coated seeds and might profitably be employed with *A. albida*.

### 2. Growth rate

Diameter growth rates are reported by Mariaux to range from 0.61 to 2.9 cm annually, by Wickens to be 1.59 $\pm$ 0.59 cm annually, and by Anon (1966) to range from 0.31 to 2.9 cm annually. With the use of metal dendrometer bands, *A. albida* diameter growth was shown to be fast from

November to July and very slow from August until November (Anon, 1966). Part of the reason for the large range can be attributed to site variability (Mariaux, 1966), but this reviewer believes a major part of this variability can be attributed to genetic differences. It is important to realize that total stem growth is proportional to the square of the diameter growth rate, and therefore a five fold range in diameter growth rate represents a twenty-five fold range in stem volume growth. With the use of good nursery techniques, and with vegetative cuttings from fast-growing trees a 2 cm/year diameter growth rate would be a reasonable goal.

Less work has been reported on A. albida height growth with only Anon (1966) reporting an average annual height growth for 8 trees to be 92 cm with a 50 to 160 cm range. Flowering of A. albida has been reported at seven years of age and pod formation at eight years of age (Nongonierma, 1976).

SELECTION No. 3: Full Report

REPUBLIQUE DE HAUTE VOLTA

MINISTERE DE L'ECONOMIE NATIONALE

Direction des sols et [illegible]
et de la [illegible] des sols

# SECTEUR DE RESTAURATION DES SOLS DE OUAHIGOUYA

## LE FAIDHERBIA ALBIDA

GROUPEMENT EUROPEEN
de
RESTAURATION des SOLS VOLTAIQUES

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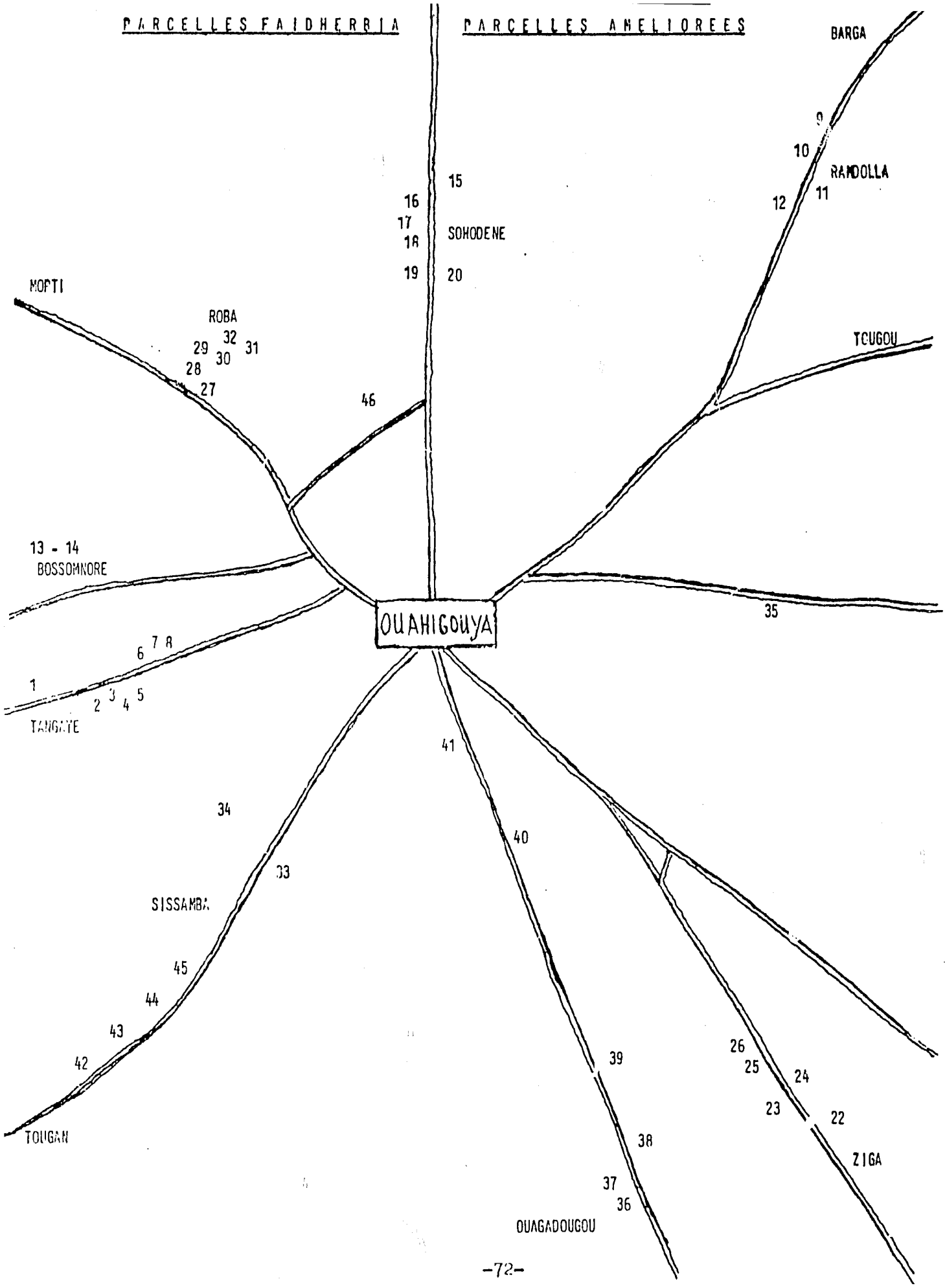
PARCELLES FAIDHERBIA
PARCELLES AMELIOREES
BARGA
9
10
RAMDOLLA
11
12
15
16
17
18
SOHODENE
19
20
MOPTI
ROBA
32
29
30
31
28
27
46
TCUGOU
13 - 14
BOSSOMNORE
OUAHIGOUYA
35
6
7
8
1
2
3
4
5
TANGAYE
41
34
40
33
SISSAMBA
45
44
43
42
TOUGAN
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26
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24
23
22
38
ZIGA
37
36
OUAGADOUGOU

## LE FAIDHERBIA ALBIDA

### Exigeances vis à vis du sol - Généralités

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Il apparaît à première vue que pour le Faidherbia, l'exigeance en eau est primordiale, pour les raisons suivantes :

- La période végétative coincide avec la saison sèche ; L'arbre forme ses feuilles (en partie), ses fleurs et ses fruits en l'absence de toute pluie.
- A cette époque la consommation en eau du végétal est accrue du fait de la température élevée, de la très forte insolation et de l'action desséchante de l'harmattan extrêmement sec.

C'est dans le sol que le Faidherbia doit puiser d'une façon continue l'eau qui lui est nécessaire.

On a peu de renseignements sur l'importance de ces besoins, on peut cependant, penser que seuls les sols retenant de l'eau en quantité abondante pendant toute la saison sèche seront capables d'assurer la végétation du Faidherbia pendant cette période.

Ces conditions seront favorisées par les dispositions naturelles suivantes :

- une protection superficielle garantissant l'économie en eau, protection réalisée par une granulométrie grossière sur plusieurs décimètres
- ensuite, une profondeur de sol assez importante, nous dirons "plusieurs mètres"

- ou bien une nappe phréatique suffisamment proche en saison sèche pour que les racines puissent s'y alimenter

Les observations faites sur le terrain, en Haute-Volta ou ailleurs, semblent confirmer ce point de vue.

Il convient de faire remarquer que si ces conditions favorisent l'alimentation en eau du Faidherbia, elles ne semblent pas favoriser la régénération.

1 - La nappe est très proche de la surface du sol.
Il n'y a généralement pas de Faidherbia sur les sols hydromorphes, sur les argiles des bas fonds.
Par contre, il peut y avoir des peuplements denses de gros sujets et régénération naturelle sur des sols à engorgement temporaire pendant les pluies, la nappe étant à quelques mètres de profondeur en saison sèche (Bossomnore, Haute-Volta)

2 - La nappe est proche ou assez proche de la surface du sol : entre 1 et 10 mètres.
Il semble que cette situation représente la station la plus favorable, le sol étant assez grossier en surface, plus fin en profondeur.
La régénération n'est cependant assez bonne que si la nappe atteint, en saison sèche, les premiers mètres.

3 - La nappe est à une profondeur de plus de 10 mètres.
Les peuplements de Faidherbia peuvent exister, moins denses, moins gros.
La régénération naturelle est de plus, très aléatoire dans ce cas.

4 - La nappe étant très profonde, les peuplements de Faidherbia sont rares ou inexistants, des sujets isolés peuvent persister.

## INFLUENCE DU SOL

Les sols accidentés, en relief, surtout s'ils sont rocheux ou imperméables sont pénétrés par bien moins d'eau que les précipitations pluviales, et n'ont que de rares Faidherbia ou pas du tout.
(Argiles de Filingué, granites de Zinder, grès de Gouré au Niger ; collines latéritiques du Yatenga en Haute-Volta).

Par contre, l'eau rassemblée dans les dépressions, sous des sols sableux profonds, favorise les peuplements de Faidherbia (Route de Filingué à Dosso au Niger ; pays Dogon au Mali).

Sur les sols de dunes fixées, les Faidherbia sont fréquents et gros dans les creux, rares et chétifs sur les pentes et les sommets des dunes.

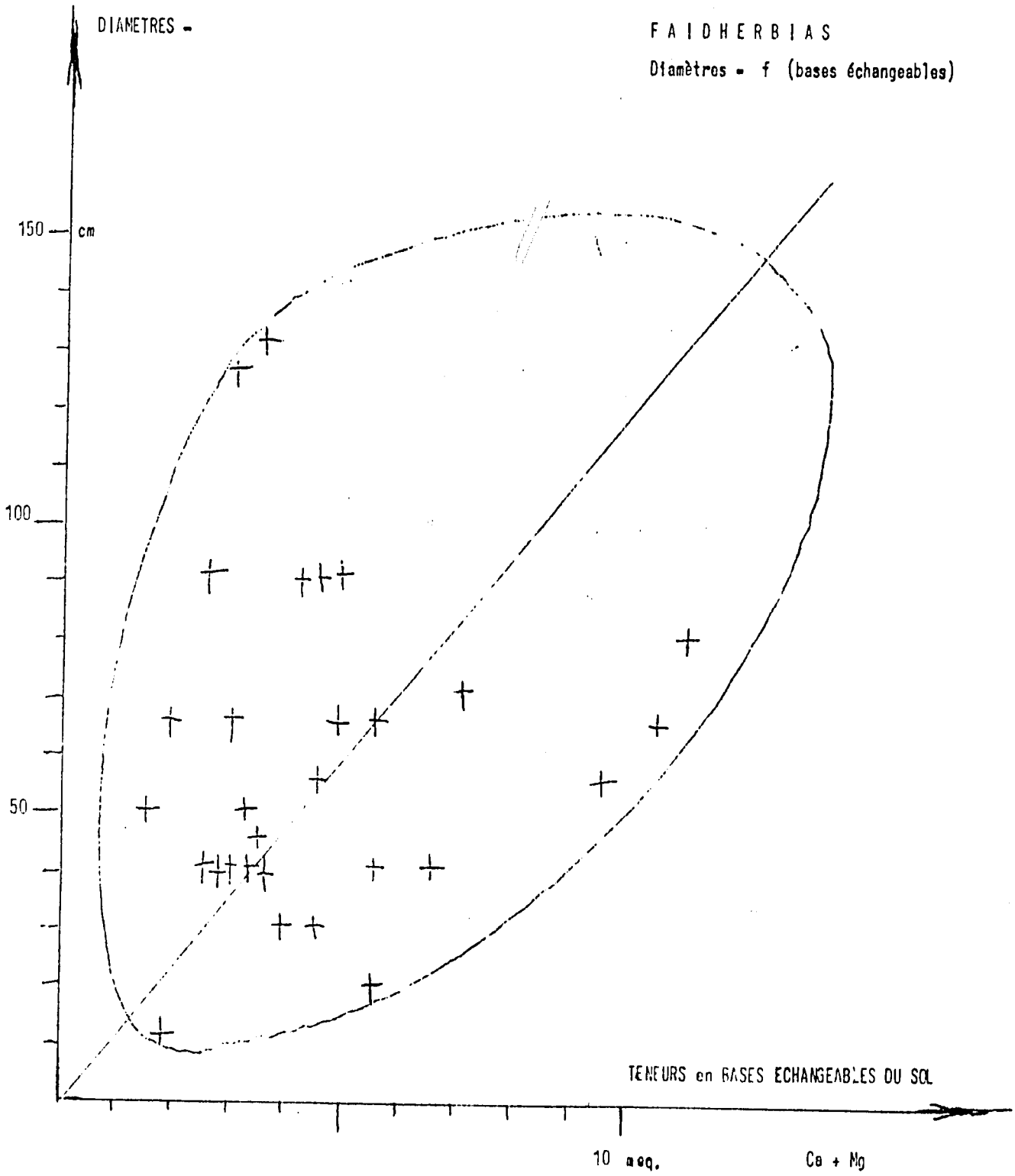
## FERTILITE DU SOL

On peut distinguer :

I - Sols favorables -
- Sols argilo-limoneux des bas fonds du Yatenga ;
- Sols argileux sur roches vertes à Kaya ;
- Sols sableux profonds de Myrriah au Niger ;
- Sols de sables fins des creux de vieilles dunes, au Niger.

II - Sols moyens -
- sables argileux de colluvionnement
- sols gravillonnaires non cuirassés
- carapaces démantelées.

III - Sols défavorables -
- cuirasses latéritiques
- collines ferrugineuses
- sables sur grès ou granites acides
- sables lessivés sur pente
- sommets de dunes à sable grossier lessivé


DIAMETRES -
F A I D H E R B I A S
Diamètres - f (bases échangeables)
150
cm
100
50
TENEURS en BASES ECHANGEABLES DU SOL
10 meq.
Ca + Mg

Pour chacun de ces sols, les plantes indicatrices sont, entre autres, respectivement :

I - Andropogon Gayanus
Panicum maximum

II - Berinicetum pédicillatum
Cenchrus ciliaris
Eragrostis tremula
Shenefeldia gracilis

III - Leptadenia spartium
Aristida Adscensionis
Aristida sp.
Loudetia togoensis

Le meilleur indicateur étant évidemment le Faidherbia lui-même.

Il semble que la fertilité influe, dans l'ordre indiqué, sur :

- la régénération naturelle
- la vitesse de croissance
- la taille maximum atteinte
- la densité des peuplements

On devine une relation entre les diamètres des Faidherbias observés et les bases échangeables Ca, Mg dans le sol, mais la correlation qui doit exister peut difficilement être mise en évidence, de façon sûre, en effet :

- il faudrait rapporter la fertilité à l'accroissement annuel, et non au diamètre d'arbres d'âges très divers, âge inconnu.
  Il n'y a pas de cernes d'accroissement bien visible
  voir figure ci-contre
- il faudrait éliminer l'interférence de l'action de la nappe phréatique.

## ACTIONS HUMAINES

### La culture

La culture est favorable au Faidherbia, surtout si elle est pratiquée plusieurs années. Les plants rescapés sont suffisamment gros pour être épargnés par les façons culturales suivantes.

Par contre, une trop longue jachère augmente la concurrence des autres espèces.
Il y a donc un cycle cultural optimum, dont la durée n'est pas connue.

Il faut également tenir compte de la prise de conscience de l'importance du Faidherbia qui existe, à des degrés très divers, chez les cultivateurs et leur fait quelquefois respecter les jeunes semis.

L'absence de culture, donc l'absence des binages qui supprime l'économie en eau du sol, est défavorable, de même que la culture intensive, qui multiplie les chances de destruction des jeunes semis.

### L'élevage

L'élevage contribue à diffuser les graines, mais aussi, s'il est trop intense, à détruire les semis.

- L'élevage est un facteur favorable,
- L'intensification de l'élevage est un facteur défavorable.

Nous pouvons en donner la preuve par l'exemple suivant.

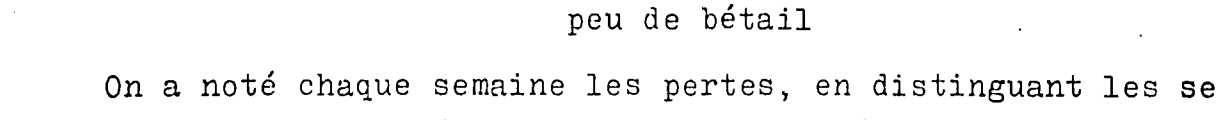
Au début de la saison sèche, deux groupes de 50 semis ou rejets de Faidherbias ont été repérés :

l'un à TANGAYE, sol ferrugineux tropical faiblement lessivé,
profond
culture de mil
bonne terre,
BETAIL abondant

l'autre route de MOPTI, sol de carapace latéritique
inculte
mauvaise terre,
peu de bétail

On a noté chaque semaine les pertes, en distinguant les semis détruits par le bétail, et ceux ayant séché.

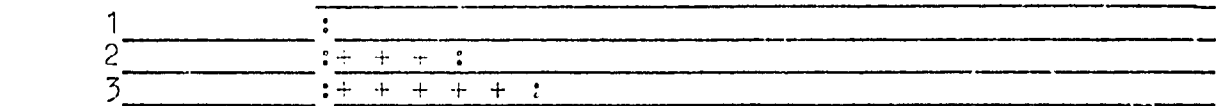
A TANGAYE :



1/ Début décembre : 50 semis (100 à l'ha.) 23,5 cm de haut en moyenne
2/ Début janvier : 12 meurent (bétail) 1 sèche : 17,5 cm
3/ Début février : 24 meurent (bétail) 7 sèchent : 22,5 cm

Restent 6 sujets de 41 centimètres

ROUTE DE MOPTI :



1/ Début décembre : 50 semis (100 à l'Ha.) 28,5 cm de haut en moyenne
2/ Début janvier : 5 meurent (bétail) 1 sèche : 21 cm
3/ Début Février : 3 meurent (bétail) 1 sèche : 19 cm

Restent 40 sujets de 30,5 centimètres

CONCLUSION : La présence du bétail a renversé la situation : En bon sol, en deux mois seulement, 90 % des semis ont disparu alors qu'en mauvais sol il en reste encore 80 %.

# OBSERVATIONS sur une PLANTATION de FAIDHERBIA

Il s'agit de Faidherbias plantés en Juillet 1959 à Ouahigouya, au début de la saison des pluies.

En Février 1960, en pleine saison sèche, la situation est la suivante :

1 - Sur sol graveleux avec, à 20 ou 30 centimètres de profondeur, un horizon concretionné (carapace ou cuirasse)
Végétation : buissons de Guiera, pelouse de Loudetia sol nu par places.

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2 - Sur sol ferrugineux faiblement lessivé, beige, de sable fin, profond, avec nappe phréatique temporaire à plus de 1 mètre.

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. + . + . + . . . . . . . . . . . . . . . . + + + + . + + ++++
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Les plants sont figurés : + existant
. manquant

la proportion de survie, dès la première saison sèche, est donc : 1 - de 3 % sur sol plus ou moins cuirassé
2 - de 40 % sur sol beige profond.

A l'âge de 3 ans, la plantation n'a pas beaucoup changé en ce qui concerne ces proportions.

Sur sol cuirassé, l'élimination est presque totale, alors qu'il y a une forte proportion de plants sur sol beige profond.

A l'âge de 4 ans, on peut distinguer :

1 - sur sol graveleux mince, 20 centimètres de profondeur, reposant sur cuirasse compacte :
sur 2 ou 300 plants au départ, il n'y a qu'un seul survivant :

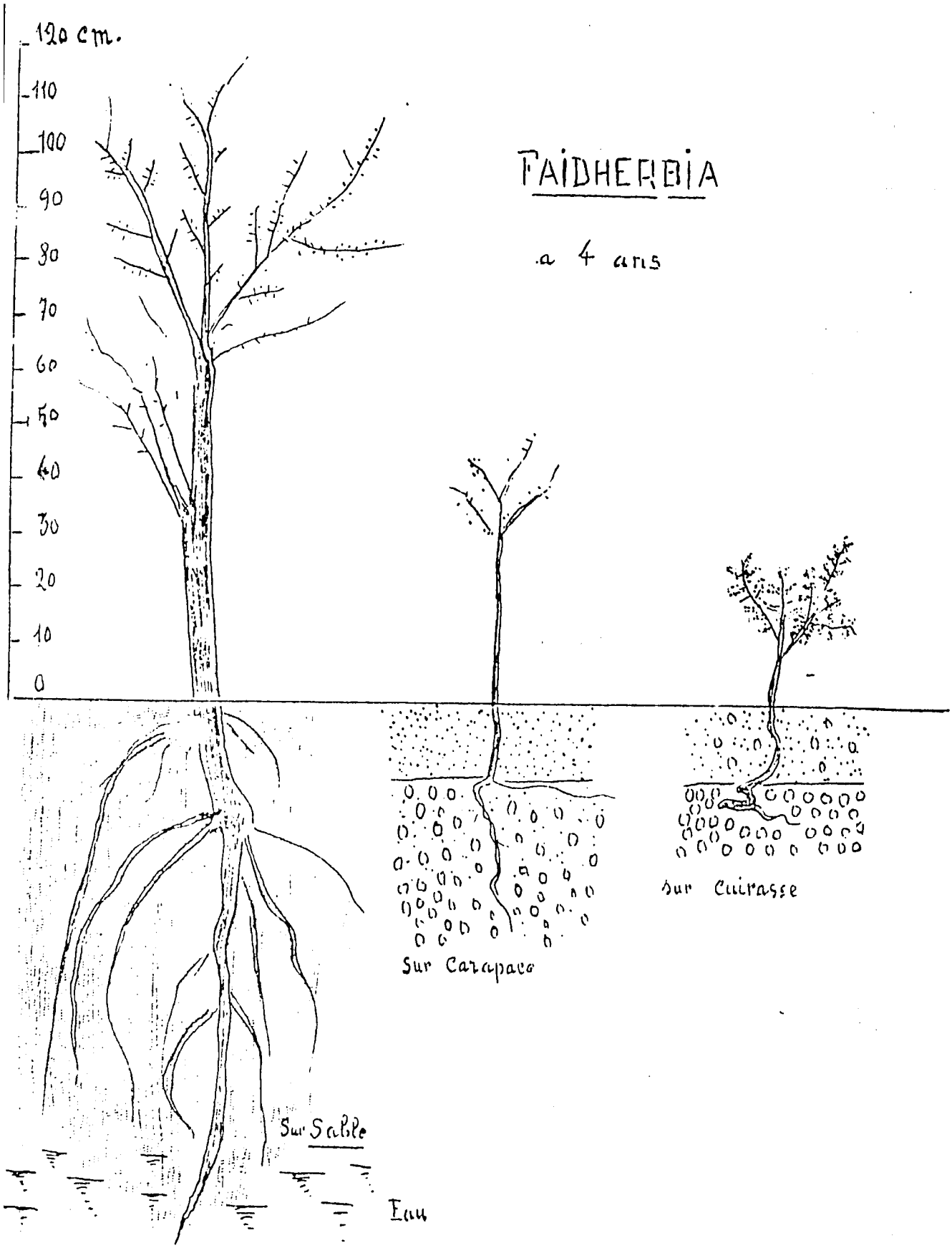
- 20 centimètres de haut
- en feuilles pendant la saison des pluies
- à 10 centimètres de profondeur son pivot tire-bouchonné au niveau de la cuirasse, se continue avec une section très réduite, dans une fissure rencontrée ou créée par la racine
- profondeur de la racine : 20 centimètres plus les radicelles détruites à l'arrachage.

2 - En sol graveleux, de 30 centimètres de profondeur, reposant sur carapace compacte, relativement friable par places :
Il y a quelques rares survivants dont l'un a été examiné :

- 30 centimètres de haut
- en feuilles pendant la saison des pluies
- un pivot vertical, plus vigoureux que le précédent.

3 - En sol sablo-argileux profond.
Les sujets sont nombreux, certaines lignes n'ont presque pas de manquants, d'autres sont très dégarnies.
Un sujet moyen a été examiné :

- un mètre de hauteur
- Défeuillé en saison des pluies
- plusieurs gros pivots descendant directement à plus de 1 mètre de profondeur (jusqu'à la nappe)


120 cm.
110
100
90
80
70
60
50
40
30
20
10
0
FAIDHERBIA
a 4 ans
Sur Sable
Eau
Sur Carapace
Sur Cuirasse

Conclusion :

En raison de son mode de vie particulier, le Faidherbia exige des sols profonds, permettant aux racines une descente facile dans les horizons encore pourvus d'eau, pendant une partie de la longue saison sèche.

Il y a quelques Faidherbia sur carapace et même sur cuirasse. On doit les considérer comme les exceptions d'innombrables échecs de semis naturels, exceptions dues probablement à la présence fortuite d'une fissure au lieu de germination de la graine.

# ETUDE SUR L'INFLUENCE
# du FAIDHERBIA ALBIDA
# sur la fertilité du sol

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Cette étude est le fruit d'observations effectuées, dans la région de OUAHIGOUYA principalement, aux époques suivantes :

- Février (comptages en saison sèche)
- Août (parcelles d'observation en milieu coutumier)
- Septembre (mesures de rendements)

Les analyses ont été exécutées par le laboratoire de pédologie de la SOGREAH à Grenoble, et le rapport établi au Centre Technique Forestier Tropical à Nogent sur Marne (Seine).

Les parcelles d'observation en milieu coutumier, ont été choisies en s'inspirant des principes suivants :

1 - Situation dans le secteur de restauration des sols, aussi dispersées que possible, tout en étant très accessibles (à proximité d'une route).
46 emplacements ont été choisis sur les routes de : MOPTI, SOHODENE, RAMDOLLA, ZIGA, OUAGADOUGOU, SISSAMBA, TOUGAN, BOSSOMNORE, TANGAYE.

2 - Répétition des parcelles en fonction de la variation des types géomorphologiques, choisis comme étant caractéristiques :
Dômes, latérites, bas de pente, bas fonds.

3 - Recherche, au même emplacement, ou dans une proximité de quelques mètres, de modes de cultures différents, à savoir :

- culture traditionnelle sans aucun apport : c'est le témoin
- culture sous Faidherbia
- culture plus évoluée avec fumure, c'est-à-dire...
  a) soit un parcage de troupeau seul
  b) soit une fumure, apportée généralement en poquets, au moment des semis
  c) soit une fumure naturelle, autre,
  d) soit un paillage, généralement sans fumure.

Le matériel d'observation est donc à priori hétérogène au départ, mais c'est celui du secteur.

4 - Notation du maximum d'informations qu'il était possible de recueillir sur la pacelle, avec dans tous les cas, pour le Faidherbia, le relevé de :
- diamètre du tronc
- diamètre du houppier
- distance du sujet au Faidherbia le plus voisin (pour des questions d'abri de bétail en saison sèche).

5 - Fixation précise de la parcelle de 1 are.

6 - Prise d'échantillons en coins, sur les côtés et 2 au centre ; 10 prises par échantillon ; 104 échantillons.

7 - Mesure : du rendement en mil (en épis, puis en grains après pilonnage).

Analyses du sol :
- p H
- Matière organique totale
- Azote (rapport C/N)
- Humidité équivalente
- Calcium et Magnésium échangeables
- Potassium échangeable
- Phosphore assimilable (Truog)
- Phosphore total

Malgré l'extraordinaire hétérogénéité de ce matériel, les résultats sont très positifs sur bien des points, grâce au couplage des observations avec un témoin juxtaposé, et au repérage des objets permettant de rechercher des relations à différents points de vue.

# ANALYSES DE SOLS sous FAIDHERBIA & TEMOINS

| PARCELLE | Rt. | pH | Mo | N | C/N | H u | CaMg | K | Truog | P2O5 |
|---|---|---|---|---|---|---|---|---|---|---|
| DOME | | | | | | | | | | |
| 1 Témoin | 3 | 5,6 | 0,90 | 0,73 | 7 | 16 | 3,0 | 0,15 | 7 | 610 |
| 1 Faidherbia 40 cm. 6 m | 11,250 | 5,6 | 0,77 | 0,66 | 7 | 18 | 3,0 | 0,24 | 7 | 620 |
| LATERITES | | | | | | | | | | |
| 20 Témoin | 4,3 | 5,2 | 1,40 | 0,94 | 9 | 16 | 6,4 | 0,18 | 13 | 410 |
| 20 Faidherbia 90 cm 20 m | 24,5 | 6,4 | 1,10 | 1,01 | 6 | 14 | 4,6 | 0,29 | 37 | 510 |
| 45 Témoin | 5,5 | 5,6 | 0,96 | 0,66 | 8 | 13,5 | 2,6 | 0,20 | 8 | 460 |
| 45 Faidh. 40 cm. 13 m | 11 | 5,7 | 1,20 | 0,63 | 11 | 13,5 | 2,6 | 0,21 | 8 | 400 |
| 15 Témoin | 10,200 | 6,1 | 1,10 | 0,70 | 8 | 11,5 | 6,4 | 0,32 | 13 | 230 |
| 15 Faidh. 30 cm 5m | 15,500 | 6,6 | 1,30 | 0,77 | 10 | 11 | 4,5 | 0,34 | 28 | 280 |
| 40 Témoin | 12 | 6 | 1,00 | 0,77 | 8 | 17 | 3 | 0,32 | 40 | 980 |
| 40 Faidh. 40 cm. 11 m | 15,5 | 6 | 1,70 | 0,91 | 11 | 18 | 3,5 | 0,45 | 28 | 940 |
| 36 Témoin | 12 | 7 | 1,70 | 0,91 | 11 | 20 | 5,6 | 0,47 | 10 | 1520 |
| 36 Faidh. 65 cm. 19 m | 20 | 6,4 | 1,50 | 0,98 | 9 | 19 | 5,3 | 0,46 | 13 | 700 |
| 41 Témoin | 13,500 | 6,7 | 1,10 | 0,87 | 7 | 20 | 9 | 0,46 | 20 | 960 |
| 41 ter Faidherbia | 13,500 | 7 | 0,83 | 0,59 | 8 | 13 | 4,5 | 0,28 | 73 | 980 |
| 8 Témoin | 14,250 | 6 | 0,83 | 0,84 | 6 | 16 | 3,7 | 0,44 | 14 | 450 |
| 8 Faidh. 90 cm. 17 m | 26,125 | 6,4 | 0,95 | 1,05 | 5 | 9 | 4,2 | 0,60 | 16 | 610 |
| BAS DE PENTE | | | | | | | | | | |
| 44 Témoin | 7 | 6,8 | 1,30 | 0,73 | 10 | 12,5 | 5,8 | 0,43 | 130 | 760 |
| 44 Faidh. 70 cm. 16 m | 13,5 | 6,9 | 1,60 | 0,94 | 10 | 15 | 7,0 | 0,60 | 350 | 2150 |
| 23 Témoin | 8,500 | 5,6 | 1,20 | 0,84 | 8 | 12 | 2,4 | 0,20 | 33 | 420 |
| 23 Faidh. 50 cm. 10 m | 19 | 6,5 | 0,85 | 0,52 | 10 | 9,5 | 3,2 | 0,39 | 39 | 315 |
| 19 Témoin | 9,700 | 5,3 | 0,40 | 0,21 | 11 | 7,5 | 2,4 | 0,10 | 3 | 65 |
| 19 Faidh. 40 cm. 6 m | 10,000 | 6,2 | 0,63 | 0,52 | 7 | 8,5 | 3 | 0,15 | 67 | 130 |
| 28 Témoin | 10,500 | 6,1 | 0,47 | 0,31 | 9 | 7 | 1,8 | 0,20 | 5 | 116 |
| 28 Faidh. 65 cm. 20 m | 16,250 | 5,7 | 0,74 | 0,49 | 9 | 6,5 | 1,9 | 0,21 | 15 | 72 |
| 16 Témoin | 10,5 | 5,9 | 1,00 | 0,70 | 9 | 15 | 4,6 | 0,17 | 14 | 130 |
| 16 Faidh. 40 cm. 6 m | 33 | 7,2 | 0,83 | 0,52 | 9 | 9 | 5,4 | 0,36 | 48 | 165 |
| 42 Témoin | 11 | 6,2 | 0,65 | 0,56 | 7 | 11,5 | 1,9 | 0,53 | 5 | 65 |
| 42 Faidh. 65 cm. 15 m | 30 | 6,6 | 1,30 | 1,05 | 12 | 8 | 4,8 | 0,69 | 25 | 233 |
| 6 Témoin | 12 | 5,7 | 0,78 | 0,52 | 9 | 9 | 4,8 | 0,24 | 4 | 480 |
| 6 Faidh. 40 cm. 5 m | 6,200 | 5,8 | 0,80 | 0,56 | 8 | 17 | 6,4 | 0,34 | 8 | 430 |

# ANALYSES DE SOLS sous FAIDHERBIA & TEMOINS

| PARCELLE | Rt. | pH | Mo | N | C/N | Hu | CaMg | K | Truog | P205. |
|---|---|---|---|---|---|---|---|---|---|---|
| Suite. | | | | | | | | | | |
| BAS DE PENTE | | | | | | | | | | |
| 25 Témoin | 12,500 | 6,2 | 1,5 | 0,70 | 13 | 14 | 3,8 | 0,25 | 13 | 470 |
| 25 Faidherbia 45 cm, 10 m | 15 | 6 | 0,[illegible]0 | 0,35 | 13 | 8,5 | 3,3 | 0,29 | 38 | 400 |
| 17 Témoin | 15,300 | 5,9 | 0,44 | 0,31 | 8 | 7,5 | 2,7 | 0,16 | 4 | 120 |
| 17 Faidh. 130 cm, 25 m | 45,100 | 6,6 | 0,89 | 0,56 | 9 | 7,5 | 3,3 | 0,38 | 15 | 192 |
| 31 Témoin | 20,125 | 6,4 | 1,10 | 0,66 | 10 | 11 | 3,7 | 0,48 | 13 | 320 |
| 31 Faidh. 30 cm,6 m | 22,750 | 6,3 | 1,20 | 0,66 | 10 | 11,5 | 3,8 | 0,58 | 28 | 480 |
| 3 Témoin | 20,500 | 5,8 | 0,58 | 0,59 | 7 | 11,5 | 3 | 0,20 | 19 | 560 |
| 3 Faidh. 20 cm, 3 m | 11 | 6,3 | 1,00 | 0,77 | 8 | 12,5 | 5,4 | 0,46 | 49 | 800 |
| BAS FONDS | | | | | | | | | | |
| 39 Témoin | 3,500 | 6 | 0,85 | 0,56 | 9 | 12,5 | 2,6 | 0,27 | 4 | 212 |
| 39 Faidh. 40 cm, 12 m | 12,500 | 6,4 | 0,85 | 0,49 | 10 | 10 | 3 | 0,42 | 8 | 220 |
| 46 Témoin | 9 | 5,6 | 0,33 | 0,28 | 7 | 6 | 1,6 | 0,23 | 2 | 110 |
| 46 Ter Faidherbia | 16,500 | 6 | 0,78 | 0,49 | 9 | 11,5 | 4,2 | 0,48 | 5 | 248 |
| 38 Témoin | 11 | 6 | 0,56 | 0,56 | 6 | 15 | 4 | 0,25 | 3 | 152 |
| 38 Faidherbia | 14 | 6,6 | 1,00 | 0,70 | 8 | 15 | 5 | 0,35 | 7 | 285 |
| 18 Témoin | 11 | 6,1 | 0,73 | 0,42 | 10 | 11 | 2,4 | 0,13 | 5 | 120 |
| 18 Faidh. 50 cm, 6 m | 15,5 | 5,9 | 0,66 | 0,42 | 9 | 9 | 1,3 | 0,18 | 5 | 100 |
| 14 Témoin | 13,200 | 6 | 2,00 | 1,01 | 11 | 25 | 8,8 | 0,29 | 5 | 430 |
| 14 Faidh. 60 cm, 10 m | 18 | 6,2 | 2,60 | 1,29 | 12 | 27 | 10,4 | 0,36 | 7 | 640 |
| 29 Témoin | 14,250 | 6,3 | 0,57 | 0,35 | 9 | 7 | 2,2 | 0,27 | 7 | 95 |
| 29 Faidh. 65 cm, 20 m | 13 | 6,4 | 0,80 | 0,49 | 9 | 8,5 | 3,0 | 0,50 | 15 | 110 |
| 35 Témoin | 14,500 | 6,4 | 1,20 | 0,49 | 14 | 18 | 5,3 | 0,41 | 9 | 268 |
| 35 Faidherbia | 7,500 | 6,8 | 1,00 | 0,70 | 9 | 16 | 4,8 | 0,60 | 12 | 282 |
| 30 Témoin | 14,500 | 6,8 | 0,72 | 0,63 | 7 | 11 | 3,7 | 0,40 | 17 | 148 |
| 30t1 55 cm, 14 m | 14,600 | 6,4 | 1,10 | 0,70 | 9 | 10 | 4,6 | 0,45 | 16 | 200 |
| 30t2 90 cm, 26 m | 16,250 | 6,5 | 0,65 | 0,35 | 11 | 7,5 | 2,6 | 0,40 | 8 | 100 |
| 30t3 125 cm, 30 m | 12,500 | 6,3 | 0,84 | 0,56 | 9 | 11 | 3,0 | 0,47 | 22 | 134 |
| 13 Témoin | 18,500 | 5,9 | 2,00 | 1,01 | 12 | 24 | 9 | 0,28 | 4 | 460 |
| 13 Faidh. 78 cm, 16 m | 15,200 | 6,1 | 2,70 | 1,40 | 11 | 24 | 11,2 | 0,45 | 8 | 590 |
| 5 Témoin | 19,500 | 6,2 | 1,30 | 0,91 | 8 | 18 | 5,4 | 0,37 | 5 | 400 |
| 5 Faidh. 90 cm, 17 m | 26,500 | 6,3 | 1,30 | 1,01 | 8 | 12 | 4,8 | 0,63 | 8 | 365 |

## NOTE EXPLICATIVE

Rt - Rendement de la parcelle, rapporté à une surface de un hectare, et exprimé en quintaux d'épis de mil non battues (un quintal d'épis fournit en moyenne 0,7 quintal de grain, après battage).

pH - Potentiel hydrogène ; réaction du sol en unités pH, la neutralité se situant à pH 7.

Mo - Matière organique totale du sol, pour cent, obtenue par le dosage du Carbone total, et la multiplication par le facteur conventionnel 1,72

N - Azote total du sol, pour mille.

C/N - Rapport carbone/azote.

Hu - Humidité équivalente du sol, mesurée à la centrifugeuse (eau retenue par le sol après centrifugation d'un échantillon de sol saturé d'eau).

CaMg - Calcium et Magnésium échangeables exprimés en milliéquivalents pour 100 grammes de sol.

K - Potassium échangeable, exprimé en milli-équivalents pour 100 grammes de sol.

Truog- Acide phosphorique assimilable déterminé par la méthode du Prof. TRUOG, exprimé en parties de P2 O5 par million.

P2 O5- Acide phosphorique total, exprimé en parties de P2 O5 par million.

# AUGMENTATION des RENDEMENTS en MIL

# Sous le FAIDHERBIA ALBIDA

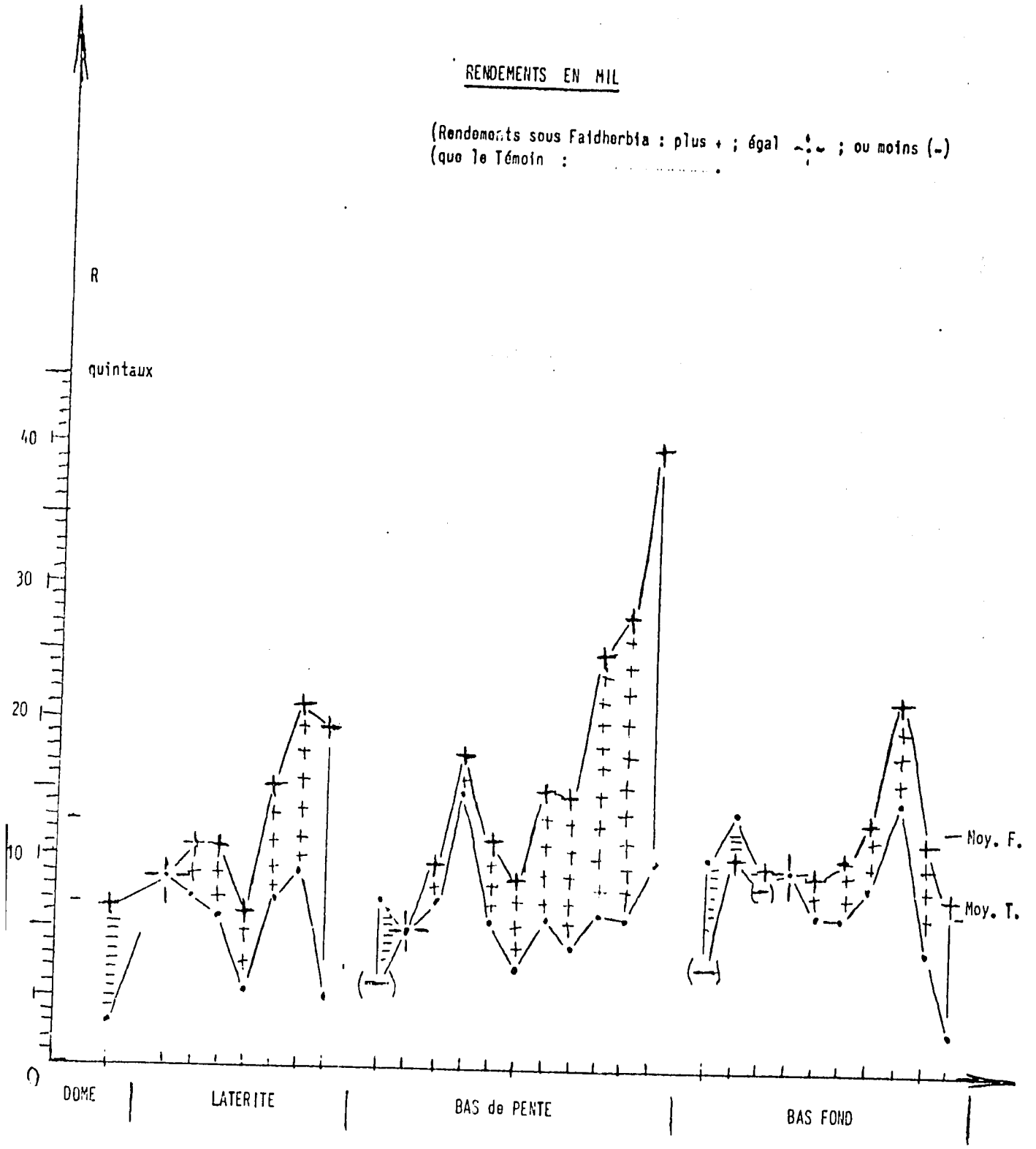
---

INFLUENCE du TYPE de SOL

INFLUENCE du DIAMETRE du FAIDHERBIA

INFLUENCE de L'ESPACEMENT des FAIDHERBIAS

PEUPLEMENTS JEUNES ET ANCIENS


RENDEMENTS EN MIL
(Rendements sous Faidherbia : plus + ; égal ; ou moins (-)
(que le Témoin :
R
quintaux
40
30
20
10
0
Moy. F.
Moy. T.
DOME
LATERITE
BAS de PENTE
BAS FOND

## AUGMENTATION des RENDEMENTS en MIL
## Sous le FAIDHERBIA ALBIDA

### INFLUENCE du TYPE de SOL

Les rendements sont augmentés sensiblement, d'autant plus que le sol est pauvre à l'origine (latérites des hauteurs).

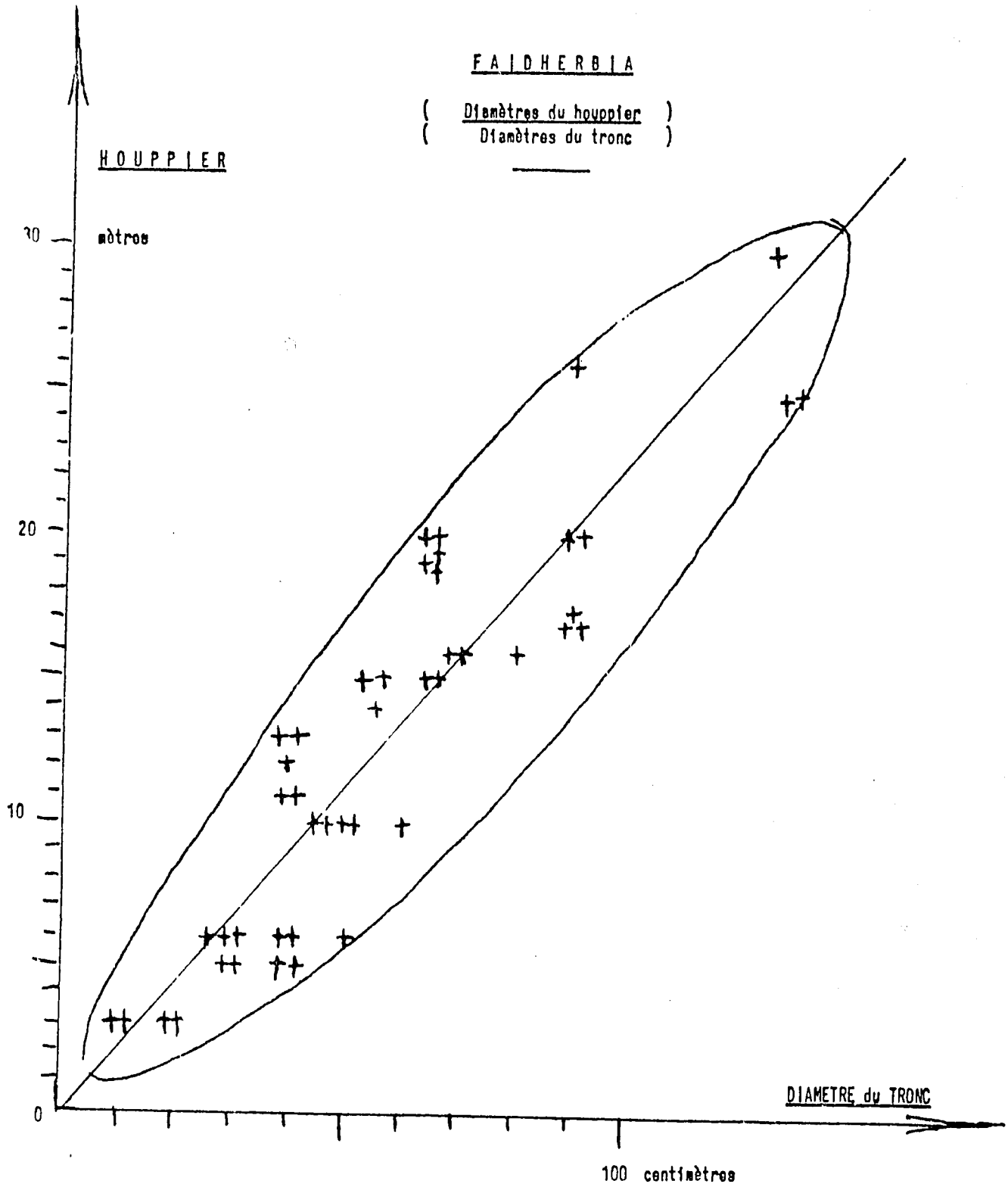
Dans les vallées, ou bas fonds, l'augmentation est moins sensible et ceci peut avoir plusieurs causes :

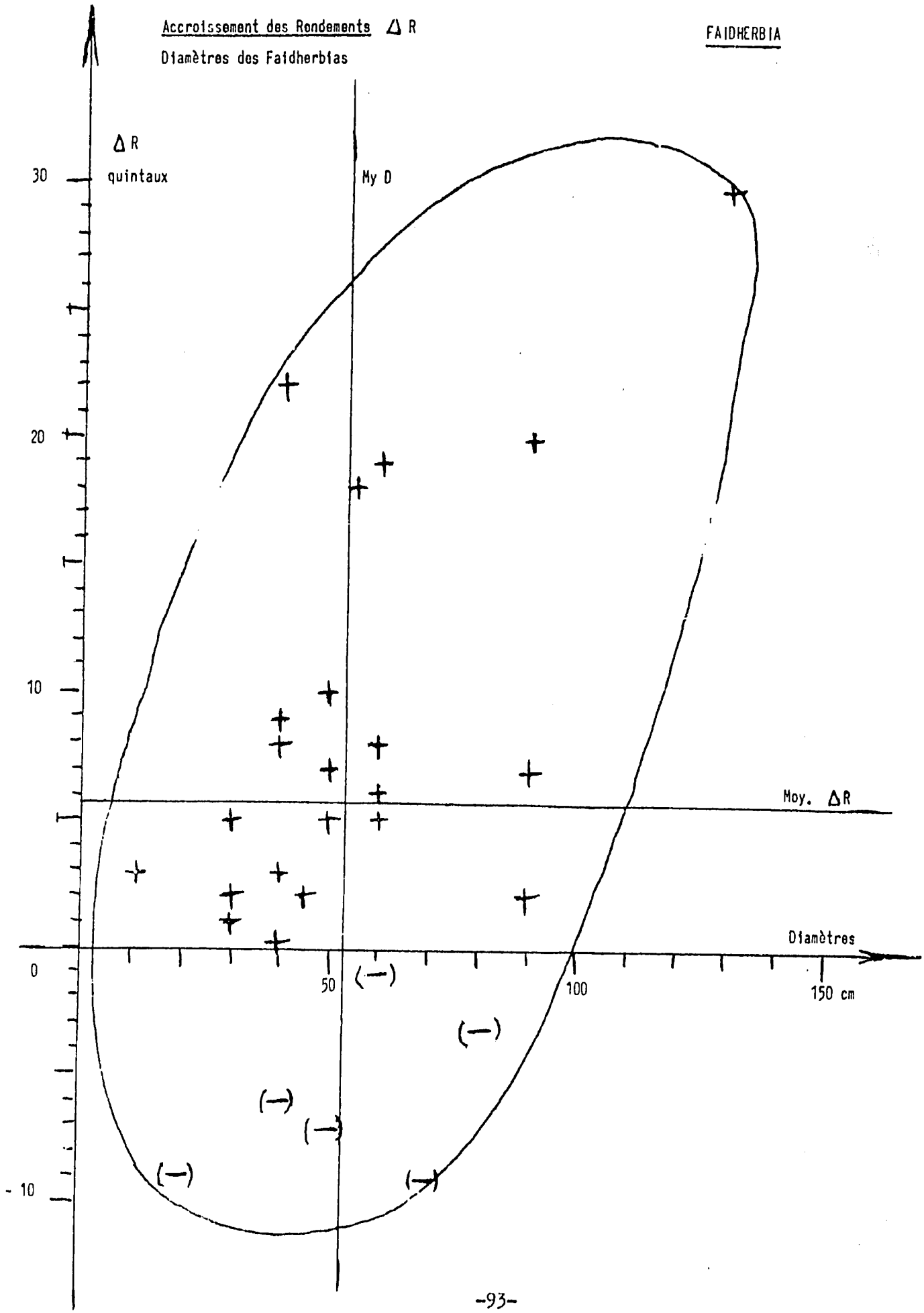
- culture continue, sans jachère, donc épuisement des sols, même sous Faidherbia.
- lessivage par les eaux des nappes qui convergent dans les fonds.

L'augmentation moyenne de rendement par rapport au témoin est de 50 %.

| | Témoin | Sous Faidherbia | Augmentation |
|---|---|---|---|
| Dôme : 1 échantillon | 3 | 11,250 | + |
| Latérite 7 -"- | 10,2 | 18 | + 78 % |
| Bas de pente 11 " | 12,5 | 20,6 | + 64 % |
| Bas fonds 10 " | 12,9 | 15,3 | + 18 % |
| Moyenne 29 échantillons | 11,77 | 17,9 | + 50 % |
| Rendement en grain (qx/ha) | 8,2 | 12,5 | -"- |

Figure ci-contre : (Témoin .
(Sous Faidherbia +


FAIDHERBIA
( Diamètres du houppier )
( Diamètres du tronc )
HOUPPIER
mètres
30
20
10
0
DIAMETRE du TRONC
100 centimètres


Accroissement des Rendements ΔR
Diamètres des Faidherbias
FAIDHERBIA
ΔR
quintaux
30
20
10
0
- 10
My D
Moy. ΔR
Diamètres
50
100
150 cm
(—)

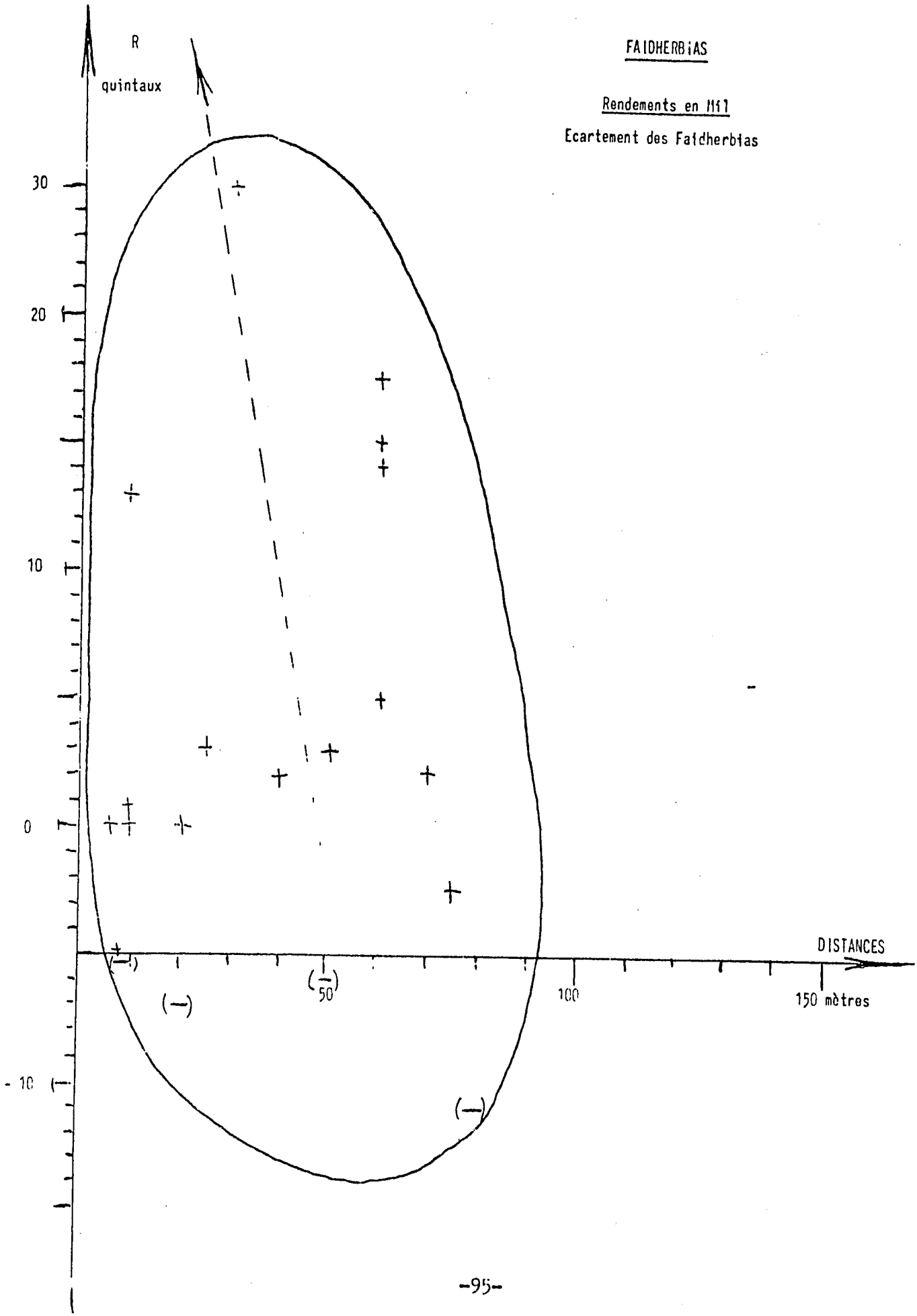
## ACCROISSEMENT des RENDEMENTS en MIL sous les FAIDHERBIAS et DIAMETRE de CEUX-CI

Il y a une assez bonne corrélation entre l'augmentation des rendements mesurés sous Faidherbia, par comparaison avec le rendement du Témoin voisin, hors Faidherbia, d'une part, et le diamètre de l'arbre, d'autre part.

Ceci n'a rien d'étonnant : le Faidherbia enrichit le sol par l'apport de ses feuilles principalement, et celles-ci sont en quantité d'autant plus grande que le Faidherbia est plus développé.

Une relation analogue peut être observée si on remplace le diamètre du tronc par celui du houppier

On observe de fortes variations, mais, en moyenne : les rendements sont accrus d'autant plus que le Faidherbia est plus gros.


FAIDHERBIAS
Rendements en Mil
Ecartement des Faidherbias
R
quintaux
30
20
10
0
- 10
DISTANCES
50
100
150 mètres

## ACCROISSEMENT des RENDEMENTS en Mil sous FAIDHERBIA et ESPACEMENT de CEUX-CI

On a souvent avancé que la fertilité relative observée sous Faidherbia était due à la fumure apportée par le bétail en saison sèche.

A cette époque la chaleur est grande, et presque tous les arbres sont défeuillés, à l'exception du Faidherbia, et le bétail, chèvres surtout, et moutons, se réfugie pendant de longues heures du jour sous cet ombrage.

Si l'augmentation des rendements sous Faidherbia était due principalement au stationnement du bétail en saison sèche, on pourrait observer ceci :

- Faible accroissement de la fertilité, donc des rendements, là ou les Faidherbias sont très rapprochés dans les vallées, par suite de la "dilution" du bétail qui a le choix de l'ombre, le couvert étant souvent presque continu.
- Fort accroissement relatif des rendements pour les Faidherbias isolés qui représentent pour le bétail un pôle d'ombre attractif sans concurrence voisine.

C'est pour cela que les distances au Faidherbia le plus voisin ont été notées.

Il n'y a pas de relation nette, bien que puisse se discerner une tendance à l'alignement avec inclinaison négative faible.

<u>CONCLUSION</u> : Il n'y a pas de relation nette entre l'augmentarion relative de la fertilité sous les Faidherbias,et l'espacement de ceux-ci.

# SOL SOUS FAIDHERBIA
## (COMPARE AU TEMOIN)

| FAIDHERBIA R | pH | | MO | | N | | H | | Ca Mg | | K | | TRUOG | | P TOTAL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | - | + | - | + | - | + | - | + | - | + | - | + | - | + | - | + | |
| 1 - 8,250 | - | + | 0,13 | + | 0,07 | + | - | 2 | - | + | - | 0,09 | - | + | - | 10 | Dôme |
| 20 - 20,2 | - | 1,2 | 0,30 | + | - | 0,07 | 2 | + | 1,8 | + | - | 0,11 | - | 24 | - | 100 | |
| 45 - 5,5 | - | 0,1 | - | 0,24 | 0,03 | + | - | + | - | + | - | 0,01 | - | + | 60 | + | |
| 15 - 5,3 | - | 0,5 | - | 0,20 | - | 0,07 | 0,5 | + | 1,9 | + | - | 0,02 | - | 15 | - | 50 | |
| 40 - 3,5 | - | + | - | 0,70 | - | 0,14 | - | 1 | - | 0,5 | - | 0,12 | 12 | + | 40 | + | |
| 36 - 8 | 0,6 | + | 0,20 | + | - | 0,07 | 1 | + | 0,3 | + | 0,01 | + | - | 3 | 820 | + | |
| 41 - | - | 0,3 | 0,27 | + | 0,28 | + | 7 | + | 4,5 | + | 0,18 | + | - | 53 | - | 20 | |
| 8 - 10 | - | 0,4 | - | 0,12 | - | 0,21 | 7 | + | - | 0,5 | - | 0,16 | - | 32 | - | 160 | Latérite |
| 44 - 6,5 | - | 0,1 | - | 0,30 | - | 0,21 | - | 2,5 | - | 1,2 | - | 0,17 | - | 220 | - | 1390 | |
| 23 - 10,5 | - | 0,9 | 0,35 | + | 0,32 | + | 2,5 | + | - | 0,8 | - | 0,19 | - | 6 | 104 | + | |
| 19 - 0,3 | - | 0,9 | - | 0,23 | - | 0,31 | - | 1 | - | 0,6 | - | 0,05 | - | 64 | - | 65 | |
| 28 - 6,250 | 0,4 | + | - | 0,27 | - | 0,18 | 0,5 | + | - | 0,1 | - | 0,01 | - | 10 | 44 | + | |
| 16 - 22,50 | - | 1,3 | 0,17 | + | 0,18 | + | 6 | + | - | 0,8 | - | 0,19 | - | 34 | - | 55 | |
| 42 - 19 | - | 0,4 | - | 0,65 | - | 0,49 | 3,5 | + | - | 2,9 | - | 0,16 | - | 20 | - | 173 | |
| 6 - 5,8 | - | 0,1 | - | 0,02 | - | 0,02 | - | 8 | - | 1,6 | - | 0,10 | 4 | + | 50 | + | |
| 25 - 2,5 | 0,2 | + | 0,70 | + | 0,35 | + | 5,5 | + | 0,5 | + | - | 0,04 | - | 25 | 70 | + | |
| 17 - 30 | - | 0,7 | - | 0,45 | - | 0,25 | - | + | - | 0,6 | - | 0,22 | - | 11 | - | 72 | |
| 31 - 2,5 | 0,1 | + | - | 0,10 | - | + | - | 0,5 | - | 0,1 | - | 0,10 | - | 15 | - | 160 | Bas de |
| 3 - 9,5 | - | 0,5 | - | 0,32 | - | 0,18 | - | 1 | - | 2,4 | - | 0,26 | - | 30 | - | 240 | pente |
| 39 - 9 | - | 0,4 | - | + | 0,07 | + | 2,5 | + | - | 0,4 | - | 0,15 | - | 4 | - | 8 | |
| 46 - 7,5 | - | 0,4 | - | 0,45 | - | 0,21 | - | 5,5 | - | 2,6 | - | 0,25 | - | 3 | - | 138 | |
| 38 - 3 | - | 0,6 | - | 0,44 | - | 0,14 | - | + | - | 1 | - | 0,10 | - | 4 | - | 133 | |
| 18 - 4,5 | 0,2 | + | 0,07 | + | - | + | 2 | + | 1,1 | + | - | 0,05 | - | + | 20 | + | |
| 14 - 4,8 | - | 0,2 | - | 0,60 | - | 0,28 | - | 2 | | 1,6 | - | 0,07 | - | 2 | - | 210 | |
| 29 - 1 | - | 0,1 | - | 0,23 | - | 0,14 | - | 1,5 | - | 0,8 | - | 0,23 | - | 8 | - | 15 | |
| 35 - 7 | - | 0,4 | 0,20 | + | - | 0,21 | 2 | + | 0,5 | + | - | 0,19 | - | 3 | - | 14 | |
| 30 - | 0,4 | + | - | 0,14 | 0,16 | + | 1 | + | 0,3 | + | - | 0,04 | - | 2 | - | + | |
| 13 - 3,3 | - | 0,2 | - | 0,75 | - | 0,39 | - | + | - | 2,2 | - | 0,17 | - | 4 | - | 130 | Bas |
| 5 - 7 | - | 0,1 | - | + | - | 0,10 | 6 | + | 0,6 | + | - | 0,26 | - | 3 | 35 | + | Fonds |
| 206,00 | 1,9 | 9,8 | 2,39 | 6,16 | 1,40 | 3,57 | 4,9 | 25 | 11,4 | 19,7 | 0,19 | 3,75 | 16 | 595 | 1243 | 3143 | |
| 17 | | | | | -1,40 | | | -25 | | | -0,19 | | -16 | | | | |
| 190 | | +7,9 | | +3,77 | | +2,17 | 24 | | | +8 | | +3,52 | | +579 | | | |
| Moy 6,5qx | 0,27 | | 0,13 | | 0,075 | | - 1 | | 0,30 | | 0,11 | | 13 | | 50 | | |

## VARIATIONS du RENDEMENT
## et des ELEMENTS ETUDIES

En comparant les parcelles sous Faidherbia et la parcelle témoin correspondante en ce qui concerne les rendements et la quantité d'éléments étudiés, on peut observer selon le cas :

- une variation du rendement et de l'élément en accord c'est-à-dire dans le même sens
- une variation en désaccord, c'est-àdire en sens contraire.

Si l'un des termes ne varie pas il y a indifférence

Nous avons ainsi :

Variations du rendement
en fonction des variations de certains éléments
(29 comparaisons)

| ELEMENT | ACCORD | INDIFFERENT | DESACCORD |
|---|---|---|---|
| K échangeable | 21 | 2 | 6 |
| P2O5 assimilable | 19 | 5 | 5 |
| p H | 15 | 4 | 10 |
| matière organique | 15 | 4 | 10 |
| Azote | 15 | 4 | 10 |
| Ca + Mg échangeables | 15 | 4 | 10 |
| P2O5 total | 15 | 2 | 12 |
| Humidité équivalente | 8 | 6 | 15 |
| | 123 | 31 | 78 |

L'accord est assez marqué pour le phosphore assimilable et le potassium échangeable. Il est moins net pour le pH, la matière organique et l'azote, et pour le calcium et magnésium échangeables.

# A N A L Y S E S des S O L S

## des PARCELLES sous FAIDHERBIA

## et des PARCELLES TEMOINS

---

### ETUDE des DIFFERENCES OBSERVEES
### Sous Faidherbia et hors Faidherbia

### En ce qui concerne

| | |
|---|---|
| - Le rendement | R |
| - Le pH | |
| - La matière organique totale du sol | Mo |
| - L'azote total du sol | N |
| - Le rapport | C/N |
| - Les bases échangeables | Ca + Mg |
| - Le potassium échangeable | K |
| - Le phosphore assimilable | (TRUOG) |
| - Le phosphore total | P2 05 Total |

(tableau ci-contre)

Un tel peuplement représente :
- une rente de : (100 kilogs de mil à 25 F.) 2.500 F.CFA
- ou encore un capital, travaillant à 5%, de 50.000 F.CFA
Il faut au moins 20 ans pour constituer un tel peuplement. Pendant ce temps, c'est une somme de 18.000 Frs. qui empruntée à 5 % aura pris une valeur de 50.000 Frs. C'est donc une somme de 18.000 Frs.CFA que l'on pourrait consacrer à un hectare à reboiser en Faidherbia, dans ces hypothèses.

Anticipant sur ces applications, nous pensons qu'il convient de tempérer l'optimisme que pourrait créer cet ensemble d'améliorations en moyenne TOUTES POSITIVES.

En effet, la multiplication du Faidherbia exige une attente de 20 ans au moins, des moyens, un choix judicieux des sols et une protection efficace contre le bétail.

Nous pensons dès à présent que les chances de réussite sont incomparablement supérieures dans les bons sols pourvus de Faidherbia que dans les mauvais qui en ont peu ou pas du tout. Autrement dit :

"Il faut mettre du Faidherbia là où il y en a déjà".

Ce n'est pas un paradoxe ; les parcs couvrent seulement 5 à 30 % du sol, 20 % étant déjà une très bonne moyenne qu'il est possible de dépasser puisque des couverts continus ne sont pas exceptionnels.

Il serait donc plus judicieux d'envisager un passage de 5 à 30 % du couvert en zone très favorable, ce qui conduirait à une rente de 1 quintal de mil par hectare et par an,

## COMPARAISON des

## DIFFERENTS TYPES de SOL

En ce qui concerne : La TENEUR EN QUELQUES ELEMENTS

1 - Sous Faidherbia

2 - Hors Faidherbia

Les analyses de sols ont été groupés par éléments, et par principaux types de positions, à savoir :

| ELEMENTS | TYPES de POSITIONS géomorphologiques |
|---|---|
| - Matière organique totale | Dôme |
| - Azote total | Latérite |
| - Calcium + Magnésium échangeables | Bas de pente |
| - Potassium échangeable | Bas fond |
| - Phosphore assimilable | |

La matière organique totale est exprimée en pour cent.

L'azote est exprimée pour mille

Calcium et Magnésium ; Potassium échangeables sont exprimés en milli-équivalents pour 100 g.

Le Phosphore assimilable est exprimé en parties par million.

| POSITION GEOMORPHOLOGIQUE | ELEMENT | Sous FAIDHERBIA | TEMOIN | DIFFERENCE Absolue | DIFFERENCE Relative |
|---|---|---|---|---|---|
| DOMES (1 échantillon) | pH | 5,6 | 5,6 | 0 | 0 |
| | Matière organique | 0,77 | 0,90 | - 0,13 | - 14 % |
| | Azote | 0,66 | 0,73 | - 0,09 | - 12 % |
| | Ca + Mg éch. | 3 | 3 | 0 | 0 |
| | K éch. | 0,24 | 0,15 | + 0,09 | + 40 % |
| | $P_2O_5$ ass. | 7 | 7 | 0 | 0 |
| LATERITES (7 échantillons) | pH | 6,35 | 6,1 | + 0,25 | |
| | Matière organique | 1,22 | 1,15 | + 0,07 | + 6 % |
| | Azote | 0,85 | 0,81 | + 0,04 | + 5 % |
| | Ca + Mg éch. | 4,2 | 5,2 | - 1 | - 20 % |
| | K éch. | 0,37 | 0,34 | + 0,03 | + 10 % |
| | $P_2O_5$ ass. | 33 | 17 | 16 | - + 90 % |
| BAS de PENTE (11 échantillons) | pH | 6,37 | 6,0 | 0,37 | |
| | Matière organique | 0,94 | 0,87 | + 0,07 | + 8 % |
| | Azote | 0,65 | 0,56 | + 0,07 | + 12 % |
| | Ca + Mg éch. | 4,3 | 3,3 | + 1 | + 30 % |
| | K éch. | 0,40 | 0,27 | + 0,13 | + 50 % |
| | $P_2O_5$ ass. | 69 | 22 | + 40 | + 180 % |
| BAS FONDS (10 échantillons) | pH | 6,3 | 6,1 | 0,18 | |
| | Matière organique | 1,25 | 1,03 | + 0,22 | + 21 % |
| | Azote | 0,75 | 0,62 | + 0,13 | + 20 % |
| | Ca + Mg éch. | 5,1 | 4,5 | + 0,6 | + |
| | K éch. | 0,44 | 0,29 | + 0,15 | + 50 % |
| | $P_2O_5$ ass. | 90 | 61 | 29 | 47 % |

La première position n'est pas à retenir : il y a, sur dôme, un seul échantillon.

Les différences constatées pour les quelques éléments étudiés en comparant leur quantité sous Faidherbia et dans la parcelle témoin, sont d'autant plus nettes que l'on passe des Latérites aux bas de pentes, puis aux bas fonds, c'est-à-dire lorsque l'on passe des situations en relief aux situations de vallées.

Les différences relatives augmentent régulièrement, dans l'ensemble de façon très nette :

| | Laterites | Bas de pente | Bas fonds | Moyenne |
|---|---|---|---|---|
| Pour la matière organique | 6 % | 11 % | 21 % | 13 % |
| Pour l'azote | 5 % | 14 % | 20 % | 11 % |
| Pour le Ca + Mg échangeable | (diminution) | 30 % | 1,3 % | 7 % |
| Pour le K échangeable | 10 % | 50 % | 50 % | 58 % |
| Pour $P_2O_5$ assimilable | 90 % | 200 % | 50 % | 130 % |

Il semble donc que les effets du Faidherbia sur le sol soient plus importants en valeur relative pour les sols de vallée, où ces arbres sont d'ailleurs plus vigoureux et plus répandus que sur les sols cuirassés ou soumis à l'érosion des parties plus hautes.

# CONCLUSION

Nous avons constaté que le Faidherbia :

- Protège le sol par son ombre et le défend contre l'érosion éolienne, en saison sèche, fournit un abri au bétail.
- Augmente les rendements de 50 % sous son couvert. Ce couvert étant en moyenne dans un bon peuplement de 20 % les rendements sont augmentés de 10 % environ.
- Permet de nourrir 1/10e. de tête de gros bétail supplémentaire par hectare, par l'apport de ses gousses et le surplus des tiges de mil paturées en saison sèche.

  Une faible charge de 1 tête sur 10 hectares passe à $\frac{1}{10} + \frac{1}{10} = \frac{1}{5}$ :1 tête sur 5 hectares.

- Contribue au passage du système de la culture itinérante ou avec jachère, à celui de la culture continue.
- Apporte, par son étude comparée, des précisions sur les exigeances de la culture du mil et les facteurs sur lesquels il faudra agir pour augmenter les rendements.
- Une simple indication peut être donnée sur la rentabilité d'une "opération Faidherbia" :
  Les rendements sont augmentés de 8 à 12 quintaux, soit 4 quintaux de mil par hectare sous un couvert continu de Faidherbia, et seulement de 1 quintal si le couvert n'est que de 25 %, ce qui est plus fréquent.

sans travail ni apport supplémentaire, que de multiplier sur des sols latériques des essais voués à un échec presque certain.

Une telle opération exigerait des moyens suffisants, emploi de grillages "ursus", une discipline très stricte de culture et de parcage.

EN CONCLUSION.

Le Faidherbia a droit à toute la sollicitude des cultivateurs et des pouvoirs publics. .

Il pourrait être multiplié avec des moyens et dans le cadre d'une organisation disciplinée.

Dans l'état actuel il ne peut devenir le cheval de bataille du développement de l'agriculture, d'autres procédés étant immédiatement plus efficaces.

# PROJET AGRO - FORESTIER (OXFAM)

## RAPPORT DE FIN DE CAMPAGNE 1982

## AU YATENGA, HAUTE VOLTA

Par : Peter WRIGHT

MARS 1983

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# INTRODUCTION

La campagne de 1982 était la quatrième et dernière année des expériences sur l'utilité des techniques de la récolte et l'exploitat on des eaux d'écoulement à but agricole et forestier dans le milieu rural du Yatenga. Les expériences et observations s'intéressaient surtout au raffinement des techniques directement liées à l'exploitation et à la conservation des eaux, ainsi que des techniques agricoles qui s'y associaient. Un accent était mis sur l'utilité du "niveau à eau" dans la construction des diguettes sur courbe de niveau, qui s'avéraient le plus efficace dans ce domaine.

L'association des arbres à l'exploitation agricole a été renforcée par l'établissement des pépinières villageoises et des observations sur le semis direct des plantes. Des observations sur l'influence des diguettes sur la croissance des arbres ont été faites aussi.

Ce rapport se termine avec des conclusions qui prennent en considération les expériences de cette année dans l'élaboration d'un programme de vulgarisation pour la campagne de 1983.

## PLUVIOMETRIE

La pluviométrie décadaire reçue sur sept localités du Yatenga est présentée sur tableau 1 en annexe. Elle peut être caractérisée comme médiocre à travers la région.

Le début de la saison était marqué par très peu de pluies insuffisantes pour effectuer la semence. Ensuite la fin de la saison voyait des sècheresses marquées : à Ouahigouya dix jours ont passé avec sept millimètres de pluie au mois d'Août, ainsi que six millimètres pour la première décade de Septembre. Durant ces périodes une forte insolation produisait des températures montant jusqu'à 40° C. La saison a sensiblement pris fin avec la pluie du 16 Septembre. Une légère reprise en Octobre était trop tard.

La pluviométrie totale de la saison a été classée par rapport à 34 années de données de l'ASECNA de Ouahigouya. Cette analyse indique qu'une pluviométrie saisonière de moins de 450 mm arriverait moins de trois fois tous les cent ans. Cinq sur nos sept stations pluviométriques ont eu en dessous de 450 mm cette année.

## AMENAGEMENT DES CHAMPS

### OBJECTIFS

L'objectif principal était de subir le niveau à eau à une utilisation extensive pour évaluer son utilité dans la construction des diguettes sur courbe de niveau lorsque cela est entrepris par un paysan. Une réflexion sur les méthodes appropriées pour l'extension de son utilisation était maintenue le long de la saison. D'autre part on a continué des observations sur le fonctionnement des diguettes ainsi que les techniques culturelles qui s'associent à l'exploitation des eaux de ruissellement.

### SITES

Le projet a eu des interventions dans les trois secteurs de Séguénéga, Gourcy et Ouahigouya. A Séguénéga on travaillait sur les champs accidentés de Kalsaka, sur un sol latéritique gravillonneux et peu profond. Aux Secteurs de Ouahigouya et Gourcy on se trouvait sur des clairières (anciens champs abandonnés) et sur des champs ayant subit une érosion hydrique. Ils se situaient habituellement entre les sommets gravillonneux des collines (source d'écoulement) et les champs de bas de pente. Un recensement des sites au secteur de Ouahigouya indiquait que sur 37 champs, environ 60 % étaient sur des clairières, et 40 % sur des jachères ou champs cultivés.

Vu l'intérêt porté aux clairières de la part des exploitants, il est clair que leur valeur agricole n'échappe pas au paysan, malgré l'aspect visuel d'une clairière. Pour mieux comprendre ces sols, une analyse est présentée au tableau 6 en annexe.

Etant de texture limono-argileuse, ils présentent une capacité de rétention en eau assez élevée ; à condition d'améliorer l'infiltration. Un paysan affirme qu'une culture sur ce sol peut passer les périodes de sècheresse plus facilement que sur d'autres sols.

METHODES

L'intervention du projet, en forme de conseil technique, avait lieu des fois sur le champ commun d'un groupement, mais le plus souvent il s'agissait d'un champ individuel. Les propriétaires étaient néanmoins des membres d'un groupement dans la plupart des cas.

Durant la période de Janvier à Mai le personnel du projet ainsi que les agents de l'O.R.D. essayaient de passer une fois par semaine ou tous les deux semaines dans le champ de chacun jusqu'à ce que le travail soit achevé. Ce rythme était difficile à maintenir sur tous les sites. On se retrouvait ainsi à Kalsaka tous les deux mois.

Lors des rencontres on faisait d'abord des démonstrations avec le niveau à eau et ensuite observait l'utilisation du niveau aux mains des paysans. On encourageait les paysans à garder le niveau chez eux et de l'utiliser sans notre présence.

On a porté des conseils sur la construction des diguettes, dont deux points étaient à souligner : une diguette en cailloux, pour exploiter les eaux d'écoulement, doit être renforcée avec de la terre pour mieux retenir l'eau ; une diguette ainsi construite doit prévoir un réseau de passages d'eau. Ces passages peuvent être ouverts (ailes), ou fermés (déversoir en cailloux).

La pierre était de loin le matériau de préférence pour la construction des diguettes. A défaut de cela certains faisaient recours à d'autres matériaux traditionnels (pailles et tiges) ; d'autres faisaient en terre. Ces derniers sont plus fragiles, surtout quand on s'attend à exploiter les eaux d'écoulement.

On conseillait un labour avant de semer, mais cela était rarement fait, soit par manque de matériel, soit par la difficulté du sol (clairière).

Sur les clairières, si un labour n'était pas possible, il fallait d'autres traitements avant de semer pour s'attendre à une récolte. Sans traitement deux problèmes se posaient :

.../...

soit la densité du sol empêchait le développement du système racinaire, soit l'infiltration se limitait au long des diguettes (surtout lorsque les diguettes étaient en tiges ou en pailles, ou n'étaient pas très hautes).

Alors, soit on effectuait une trouaison sur le champ représentant un trou de 15 à 40 cm de large et 5 à 15 cm de profondeur à la place de chaque poquet, soit on mettait de la matière organique (paille ou fumier) sur la surface du sol. Tous les deux traitements diminuent l'écoulement de surface, mais la matière organique a l'avantage de fertiliser le sol ainsi que d'augmenter la porosité grâce à l'activité des termites qui y sont attirés. Ce dernier peut être très important pour la réclamation d'un terrain dégradé.

RESULTATS

A notre avis l'utilité du niveau à eau dans les mains des paysans est sans question. Bien sûr il y a des gens qui apprennent moins vite que d'autres, ou qui sont moins motivés d'entreprendre un travail sans assistance, mais la plupart des participants ont compris comment l'utiliser. Environ un quart ont pu travailler sans assistance après quelques sessions de pratique.

Les superficies aménagées par les divers participants dans les secteurs de Ouahigouya et Gourcy sont présentées au tableau 2 en annexe. Elles représentent en tout environ 64 Ha. sur les deux secteurs.

Au tableau 3 de l'annexe on trouve une estimation des récoltes en céréales d'un certain nombre de sites. Les récoltes ont été mesurées sur des carrés de rendement de 100 $m^2$. Le rendement moyen sur le champ aménagé était 495Kg/Ha. Le témoin avait 450 Kg/Ha, pour mil-sorgho.

A Kalsaka on n'y a pas placé de carré, mais les participants ont affirmé que les diguettes sur courbe de niveau sont supérieures aux anciennes du type traditionnel. Ils citent une meilleure distribution de l'eau dans le champ avec les nouvelles diguettes.

DISCUSSION

Lors des observations sur l'utilisation du niveau à eau, on a constaté qu'une compréhension du "comment l'utiliser" n'implique pas une compréhension du "pourquoi l'utiliser". Cette hypothèse était sugéré par des paysans qui, après avoir appris comment l'utiliser, sont retournés au champ et ont continué à travailler sans le niveau. Si c'est ainsi il faut suggérer une meilleure pédagogie pour démontrer la différence entre les diguettes traditionnelles et les diguettes sur courbe de niveau.

La prépondérence des interventions sur champs individuels n'était ni arbitraire ni calculée, mais le résultat de certaines réalités que présentait le milieu d'intervention. L'I.P.D., dans une étude de milieu au Yatenga 1/ remarque que "l'extrême hétérogénité du milieu, tant physique que socio-économique, confirme la non-validité des solutions 'passe partout'...". Alors, lorsqu'on recherche une unité physique et sociale suffisamment uniforme pour entreprendre un aménagement on se retrouve très vite devant l'exploitant et sa parcelle. En fait, il semble que le milieu social est de loin le plus hétérogène lorsqu'il s'agit de se réunir pour une activité de groupe ; surtout parce que tout le monde ne peut pas bénéficier de la même manière. On avance l'hypothèse, qu'avec la désintégration de la famille (l'unité de production et consommation) en des parties de plus en plus petites, il deviendra de plus en plus difficile de réunir les gens autour d'un travail. En ce qui concerne l'aménagement du territoire on voit trois possibilités de réunir les gens : surtout sur les champs communs (par exemple des groupements), et pour la formation.

.../...

1/ I.P.D./AOS, 1982. Developpement - Société rurale et auto-promotion paysanne en zone Soudano-sahélienne - Le cas du Yatenga.

Pour réunir un groupe qui peut travailler sur un terrain qui dépasse une parcelle, il faut que chaque participant ait sa parcelle dans les limites du terrain choisi, et que chaque parcelle comprise soit aménagée dans une même opération. L'organisation nécessaire pour ce dernier, si elle ne dépasse pas la capacité d'un paysan, dépasse largement la capacité du projet. Lorsque le moment du travail coïncide au moment des travaux champêtres, ce qui est le cas pour l'entretien, les problèmes d'équité et d'organisation deviennent autant plus aigus pour un travail de groupe.

Le rendement en céréale, sur témoin et parcelle aménagée, a été influencé par plusieurs facteurs. Ceux-ci étaient principalement : la position relative du témoin par rapport à la parcelle, la date de semence, l'utilisation de la matière organique, et la préparation du sol.

Pour le secteur de Ouahigouya, où environ 60 % des parcelles recensées se situaient sur des clairières, le témoin se trouvait toujours sur un sol supérieur à la parcelle. L'explication est que la clairière est un sol squelettique, et ne peut pas être cultivé sans un aménagement. Alors, le témoin placé aux mêmes conditions que la parcelle aménagée n'aura pas de récolte dans ces circonstances. On a préféré mettre les témoins dans un champ valable, même si les conditions pour un vrai témoin n'étaient pas respectées.

La dépendance du rendement sur la date de semence était quantifiée par une analyse de régression. L'analyse porte sur les résultats de 18 carrés de rendement pour lesquels on retenait la date de semence et qui étaient entretenus correctement. Cet échantillonnage comprenait 14 parcelles aménagées et 4 témoins.

L'analyse, présentée sur page à l'annexe montre qu'un retard de 10 jours sur la date de semence représentait une baisse de 100 Kg/Ha sur la récolte. Le coefficient de corrélation (r) était important : -0,76. Cela veut dire que malgré tous les autres facteurs limitants sur la récolte, une très grande partie du succès ou échec peut être attribuée tout simplement à la date de semence.

.../...

Alors, l'amélioration de la récolte qui peut être entraînée par l'utilisation d'un système de récolte des eaux de ruissellement ne se basera peut-être pas sur un meilleur régime d'eau au sein de la saison, mais plutôt sur son potentiel de prolonger la saison de culture. Une étude ée sur ordinateur par l'auteur a indiqué que la saison peut être prolongée par 10 à 15 jours en exploitant les eaux d'écoulement. L'expérience indique que cela peut être encore très conservateur: à Gourga on a semé un champ, aménagé sur une clairière, durant la première décade de Mai en '81 et '82. Les champs avoisinants étaient semés au mois de Juin. Ce cas est cité pour démontrer le potentiel, car la plupart des paysans qui ont fait des aménagements n'ont pas, jusqu'à présent, reconnu ou exploité ce potentiel.

L'importance de la matière organique et la préparation du sol était remarqué sur certains sites en particulier. On parlera de cela plus loin dans les études de cas.

.../...

## ETUDES DE CAS

S'il est vrai qu'une association des thèmes techniques est impératif pour escompter une bonne récolte sur un champ quelconque, il est encore plus impératif sur un champ aménagé. Il faut un certain minimum d'effort d'abord pour l'aménagement, et encore pour le mettre en valeur. Pour illustrer ce fait, et souligner des points qui ne doivent pas être négligés, on présentera trois études de cas. Ils porteront sur l'importance de la matière organique, l'entretien, le choix des cultures et la qualité des diguettes.

1. Loubre

Ce site se situe sur une clairière tout juste aux bords d'un bas-fond. Lors des grandes crues il subit des inondations sur la partie près du marigot. La pente est environ 1 %.

L'aménagement était fait en cailloux par un groupement. Par manque de pluie la semence ~~s'est~~ fait tard en Juillet, sans application d'engrais ou fumier. Avec l'exception d'une petite partie du champ, la levée du sorgho était un échec, et les quelques plantes qui restaient ne dépassaient pas 30 cm de hauteur en moyenne. L'exception était le lieu où étaient entreposées des tiges de mil, en cas de besoin pour la construction des diguettes. Lors de la semence elles ont été éparpillées sur le sol. Sur cette partie la densité du sorgho ainsi que son hauteur et la formation des épis étaient très respectables. Un carré de rendement n'y était pas placé.

Une analyse des sols sur la partie paillée et hors site est présentée au tableau 6 de l'annexe. On constate que la teneur en matière organique a bien sûr augmenté sur la partie paillée de 75 %. Mais plus important est le changement du pH que la matière organique a entrainé. A travers le tableau on constate que le pH est très bas sur tous les sols de clairière : 4,9 en moyenne. Une telle acidité assure que le peu de nutriments contenus dans le sol ne seront pas disponibles aux plantes. Le rapport azote/pH, étant un indice de la fertilité, était évalué en rapport avec des résultats de l'ORSTOM. L'amélioration du pH de 4,8 hors site, à 6,6 sous paillage entraînera une amélioration de deux classes sur la fertilité : de "très bas" à

En conclusion alors on avance l'hypothèse que le sol d'une clairière est souvent trop acide pour rendre ses éléments disponibles aux cultures. Dans ce cas un apport de matière organique semble avoir une contribution très importante en dehors de ses autres vertues telles que l'apport de fertilité directe et l'amélioration de la structure du sol.

2. Gourga

Ce site, aménagé par un individu, se situe sur la partie avale d'une très grande clairière. L'analyse du sol est présentée au tableau 6. L'aménagement était fait avec des tiges de mil placées en quadrillage contre l'écoulement. Dans l'espace de trois ans les tiges ont cédé leur place en faveur des bandes de végétations qui maintiennent le sol et diminue l'écoulement.

La saison de '81 a démontré le potentiel du site, avec un rendement atteingnant 700 Kg/Ha sur le carré de rendement. Par contre la récolte de cette campagne a baissé de 50 % ; dû partiellement à une pluviométrie médiocre, mais aussi par un manque d'entretien. Le champ a été envahi par les mauvaises herbes dès la première pluie. Pourtant cette condition aurait pu être évitée, car les mauvaises herbes provenaient des bandes enherbées dans le champ. Il lui aurait fallu tout simplement couper les herbes avant qu'elles montent en graine l'année précédente. Il a tenté plutôt les brûler en saison sèche, ce qui détruisait ses bandes de végétation (qui ancraient son champ contre l'eau) mais qui a eu trop peu d'effet sur les graines, déjà éparpillées.

3. Kao

Ce site se situe également sur une clairière dont l'analyse du sol figure dans le tableau 6 de l'annexe. L'aménagement était fait en cailloux par un groupement et a vu deux saisons de culture. La première année a démontré le potentiel de ce site et type d'aménagement. En effet, des rendements de 1250 Kg/Ha en riz paddy et sorgho dépassaient toute expectation. Cette année rien n'a été récolté, en dehors de quelques leçons.



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La raison se trouve dans deux fautes de la stratégie de la campagne. Premièrement, en voulant agrandir le site on ajoute une nouvelle diguette du côté amont du champ. Cette diguette était mal orientée, alors, au lieu de capturer les eaux d'écoulement, elle les versait à côté du champ. Cette situation a été découverte et corrigée en mi-juillet. La deuxième faute restait dans le choix des cultures. On a décidé de semer du riz pluvial en espérant répéter la réussite de l'an passé. Mais avec la date de semence déjà en retard à cause de la nouvelle diguette mal placée, et la rupture de la pluie en début Septembre, on voit en revanche que le choix du sorgho était indiqué.

L'expérience de ce site résume alors la valeur d'un aménagement qui vise sur l'exploitation des écoulements de l'eau,l'importance de bien orienter les diguettes sur courbe de niveau, ainsi que de bien choisir les cultures.
Plus généralement, ces trois études de cas démontrent que la tâche n'est pas finie avec la construction des diguettes : il faut un ensemble des stratégies et pratiques culturelles pour obtenir le rendement maximum.

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## PEPINIERES VILLAGEOISES

L'objectif des pépinières villageoises était de décentraliser la production des plantes forestières en établissant des pépinières au sein des villages ; auto-gérées et auto-financées. Cela aurait servi surtout à sensibiliser et responsabiliser le paysan, et ensuite de produire les espèces désirées où et quand elles sont en besoin.

Le projet a eu des interventions dans sept villages dans les secteurs de Gourcy et Ouahigouya. Le fait qu'on utilise le mot "intervention" indique qu'elles ne sont pas encore ni auto-gérées ni auto-financées. Dans ce sens le projet a fourni gratuitement des pots plastiques à tous les villages. Des arrosoirs ont été fournis dans la plupart des cas, ainsi que deux barriques dans deux villages où le problème de l'eau se posait. Pour rendre l'opération plus indépendante d'une subvention, certains villages ont vendu des plantes de surplus au projet "Bois de villages", qui servaient pour des plantations dans d'autres villages.

Les sept pépinières ont produit environ 4000 plantes en neuf espèces, des neems et nérés étant environ la moitié de la production. Celle-là est détaillée au tableau 4 de l'annexe.

Une toxité apparamment due à l'utilisation d'un fumier mal-décomposé a rendu la levée des plantes dans les pots difficile pour trois villages. Une tenacité de la part du paysan a repété la semence jusqu'à ce que ce problème soit passé. La réussité en général a été très proportionnelle à l'enthousiasme de chaque groupe.

La possibilité de rendre ces opérations indépendantes est contrainte surtout par les frais et la disponibilité des pots plastiques. Autrement les responsabilités semblent complètement au niveau du paysan. On citera l'existence de quelques individus qui produisent des neems et nérés à racine nue pour leur propres besoins, sans assistance.

## EXPERIENCES SUR PLANTATION

L'hypothèse que des diguettes en forme de croissant de lune pourraient améliorer la productivité de plantations a été testée par des obserservations sur la croissance des arbres dans la plantation villageoise de Rikou. Cette plantation a reçu un aménagement avec des diguettes en juin '81.

Le site est sur une pente de 2 à 5 %. Le sol est gravillonneux et dénué à l'exception de quelques arbustes. Le sol est de 30 à 50 cm de profondeur et l'infiltration est de l'ordre de quelques centimètres à l'heure.

La plantation, faite avec des neems en 1980, était divisée selon le protocole en quatre parties : trois traitements avec différentes dimensions de diguettes, et un témoin. Les diguettes en forme de demi-cercles, entouraient le côté aval des pieds d'arbres. Le rayon de la diguette ainsi que l'écart entre l'arbre et la diguette ont été variés selon le traitement. Les plus grandes diguettes avaient un rayon de 1,5 m ainsi qu'un écart de 1,5m. Les plus petites étaient de 0,75m de rayon et d'écart. Les traitements et leurs résultats sont détaillés au tableau 5 de l'annexe.

Une année d'observations (Juin '81 à Juin '82) démontre que la croissance est liée plutôt à l'écart entre la diguette et l'arbre qu'aux dimensions de la diguette elle-même. Les arbres se situant à grand écart de la diguette n'ont vu aucun avantage en croissance bien que leurs diguettes retenaient le plus d'eau. Les diguettes plus serrées à l'arbre ont doublé la croissance de leurs arbres par rapport au témoin.

Il est très intéressant de remarquer que la croissance était sensiblement égale sur témoin et traité pendant la saison des pluies. Mais d'Octobre à Juin les traités continuaient à pousser, plus même qu'en saison des pluies !. Ceci peut être dû à deux causes. Peut-être les traités avaient un plus grand stock d'eau en réserve durant cette période, ou plus probablement ils gagnaient leur avantage en exploitant mieux l'écoulement occasionné par les petites pluies au début de la saison. Toutefois, la plupart de leur croissance se faisait au mois de Mai et Juin, le moment des petites pluies violentes, capables de faire un bon écoulement.

Finalement, la mortalité des arbres semble à avoir baissé de 14 % sur témoir à 3 % sur deux des trois traitements. Le traitement à grand écart n'a vu aucun avantage sur ce point non plus.

Il faut néanmoins interpreter ces résultats avec prudence, car d'autres conditions de sols et espaces pourraient changer tous les rapports.

## REVEGETATION PAR SEMIS-DIRECT

Des observations sur le semis direct des arbres et arbustes étaient menées sur quelques champs. L'avantage de ces voies serait de diminuer la main d'oeuvre nécessaire pour l'établissement des arbres et arbustes dans les champs ou ailleurs. Il sera plus important pour les espèces qui ont moins de valeur directe, mais qui servent à maintenir et enrichir le sol, i.e. les arbustes.

La revégétation naturelle, telle qu'on observe au long des diguettes un peu partout, indique que le Sclerocarya birrea, Lannea acida et Combretum sp. sont tous très facile à établir de cette manière. Des densités qui s'approchent à une haie vive ont été observées sur des anciennes diguettes à Kalsaka, composées surtout de ces espèces.

En ce qui concerne le semis artificiel des arbres, on ne connait que deux individus qui le pratiquent pour le moment.
Ils se trouvent à Gourga et Touya, tous les deux ayant semé des nérés avec succès dans leurs champs. Le nombre d'arbres est encore petit, mais il pourrait s'augmenter dans le temps.

## CONCLUSIONS

Les points signifiants relevés de cette campagne étaient les suivants :

1. L'exploitation des eaux d'écoulement, qui a donné une récolte en mil/sorgho de 495 kg/Ha 1/ sur une saison sinistre et sur des sols souvent "incultivables", semble donner une certaine assurance contre la sècheresse ainsi que des possibilités de réclamer des sols.
2. Cela semblerait dû, au moins partiellement, au potentiel de semer jusqu'à un mois plus tôt sur les champs aménagés. Cet avantage peut être analogue pour la croissance des arbres.
3. La matière organique est très importante pour la réclamation des terres dégradées.
4. La prépondérance des initiatives individuelles doit être prises en considération dans la vulgarisation.
5. Le niveau à eau est approprié aux conditions du milieu rural, mais les avantages des diguettes sur courbe de niveau doivent être démontrés visiblement pour que le paysan comprenne son utilité.
6. L'association de la végétation vivace (arbres et arbustes) à l'exploitation agricole doit être renforcée par la sensibilisation et des démonstrations.

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1/ Rendement moyen sur 47 carres de rendement.

## PERSPECTIVES D'AVENIR

En Septembre 1982 une deuxième phase d'activités a été démarrée avec, comme objectif, la définition d'un schéma pédagogique pour l'auto-promotion des techniques acquises sur les années passées.

La nécessité de cette phase était déduit de l'enthousiasme des nombreux paysans qui commençaient à aménager leurs champs avec ou sans notre collaboration. La nécessité d'une auto-promotion ressortait du fait que les animateurs, toujours d'un nombre limité, seront un goulot d'étranglement tant que le paysan n'est pas amené à se responsabiliser de ses problèmes et de la nécessité de sa participation à toute solution y compris sa formation.

Dans la lumière de quatre ans d'expériences, on propose de commencer d'abord avec une formation à l'intention de tout paysan déjà concerné par le projet, pour améliorer et harmoniser leur connaissance. Ces paysans serviront éventuellement comme des noyaux pour aider les animateurs dans la formation des nouveaux. Le but final pourrait être la formation de plusieurs personnes dans chaque groupement, voire chaque quartier de chaque village intéressé.

La formation continuera de mettre un accent sur des techniques qui permettent une exploitation des eaux d'écoulement là où c'est possible.

La formation sera mieux faite dans un temps concentré (2 à 3 jours). Cela permettra l'utilisation des méthodes pédagogiques qui nécessitent des groupes et alors donnera des avantages déchelle sur le nombre de personnes qu'on peut former dans un délai donné.

La formation encouragera et même nécessitera l'entre-aide en forme de petits groupes (3 à 6 personnes), qui semble raisonnable en terme d'entre-aide au niveau des exploitations.

L'utilisation des images pédagogiques sera faite pour démontrer la nécessité d'associer les arbres à l'exploitation

Chaque session de formation se terminera avec une auto-critique. A la fin de la saison une évaluation des résultats permettra un raffinement du schéma pédagogique à poursuivre par le projet et/ou d'autres organismes ainsi que les paysans eux-mêmes.

## /=) N N E X E S

1. Tableau 1. Pluviométrie décadaire 1982.
2. Tableau 2. Inventaire des aménagements.
3. Tableau 3. Rendement sur sites et témoins.
4. Analyse de Regression.
5. Tableau 4. Production d'arbres en pépinière villageoise
6. Tableau 5. Influence des diguettes en forme de croissant de lune sur la croissance des neems en plantation.
7. Tableau 6. Analyse des sols sur trois sites de clairière.

TABLEAU 1

PLUVIOMETRIE DECADAIRE 1982 (MM.)

| DECADE | LIEU | | | | | | |
|---|---|---|---|---|---|---|---|
| | KAO | WAGANDE | ZIICA | SISSAMBA | TOUYA | GOULAGOU | OUAHIGOUYA (CER) |
| MAI | | | | | | | |
| 1 | 0 | 34 | 13 | 9 | 0 | 4 | 4 |
| 2 | 4 | 0 | 4 | 6 | 0 | 3 | 5 |
| 3 | 44 | 40 | 13 | 35 | 8 | 17 | 5 |
| TOTAL | (48) | (74) | (30) | (50) | (8) | (24) | (29) |
| JUIN | | | | | | | |
| 1 | 17 | 14 | 7 | 0 | 0 | 0 | 0 |
| 2 | 10 | 23 | 18 | 13 | 19 | 6 | 13 |
| 3 | 51 | 51 | 60 | 74 | 11 | 58 | 53 |
| TOTAL | (78) | (88) | (85) | (87) | (30) | (64) | (66) |
| JUILLET | | | | | | | |
| 1 | 19 | 16 | 53 | 11 | 11 | 47 | 28 |
| 2 | 20 | 21 | 11 | 20 | 24 | 30 | 27 |
| 3 | 59 | 33 | 35 | 30 | 12 | 32 | 28 |
| TOTAL | (98) | (70) | (99) | (61) | (47) | (109) | (83) |
| AOUT | | | | | | | |
| 1 | 63 | 57 | 42 | 77 | 59 | 85 | 67 |
| 2 | 50 | 16 | 10 | 8 | 34 | 80 | 25 |
| 3 | 60 | 49 | 20 | 47 | 97 | 45 | 50 |
| TOTAL | (173) | (122) | (72) | (132) | (190) | (210) | (142) |
| SEPTEMBRE | | | | | | | |
| 1 | 13 | 54 | 22 | 26 | 114 | 28 | 6 |
| 2 | 12 | 2 | 33 | 10 | 8 | 17 | 31 |
| 3 | 1 | 0 | 4 | 0 | 0 | 2 | 2 |
| TOTAL | (26) | (56) | (59) | (36) | (122) | (47) | (39) |
| OCTOBRE | | | | | | | |
| 1 | 3 | 37 | 33 | 36 | 6 | 22 | 6 |
| 2 | 0 | 10 | 3 | 1 | 22 | 5 | 7 |
| 3 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| TOTAL | (3) | (47) | (41) | (37) | (28) | (27) | (13) |
| TOTAL SAISON | 426 | 457 | 386 | 403 | 425 | 481 | 372 |

TABLEAU 2

INVENTAIRE DES AMENAGEMENTS

| VILLAGE | SUPERFICIE AMENAGEE (Ha.) | | |
|---|---|---|---|
| | ANTERIEURE A 1982 | 1982 | TOTAL |
| KAO | 0,6 | 1,2 | 1,8 |
| WAGANDE | 0 | 0,9 | 0,9 |
| LOUGOURI | 0,5 | 0,9 | 1,4 |
| GOURGA | 1,9 | 4,2 | 6,1 |
| LOUBRE | 0 | 0,5 | 0,5 |
| TOUYA | 0 | 1,9 | 1,9 |
| NAMSIGUIA | 0 | 0,6 | 0,6 |
| ZIIGA | 0 | 2,4 | 2,4 |
| GOULAGOU | 0,6 | 0,6 | 1,2 |
| SISSAMBA | 1,0 | 0,9 | 1,9 |
| BOULOULOU | 0 | 7,3 | 7,3 |
| BOURI | 0 | 11,0 | 11,0 |
| SAN | 0 | 4,5 | 4,5 |
| BASCI | 1,0 | 7,0 | 8,0 |
| LINTEBA | 0 | 3,0 | 3,0 |
| SAYE | 0 | 4,0 | 4,0 |
| KOENEBA | 1,0 | 4,0 | 5,0 |
| KELYEM | 0 | 2,0 | 2,0 |
| KINOIBA | 0 | 4,0 | 4,0 |
| KIBILO | 0 | 1,5 | 1,5 |
| TOTAL | 6,6 | 62,4 | 69,0 |

TABLEAU 3 RENDEMENT SUR SITES ET TEMOINS

| LIEU | CHAMPS AMENAGES | | | TEMOINS | | |
|---|---|---|---|---|---|---|
| - OUAHIGOUYA - | Culture | N° Carrés | Rendement Kg/100m² | Culture | N° Echantillon | Rendement Kg/100m2 |
| ZIIGA | SORGHO | 6 | 4,15 | SORGHO | 3 | 3,80 |
| GOULAGOU | SORGHO | 4 | 2;70 | SORGHO | 2 | 3,20 |
| SI SAMBA | SORGHO | 2 | 3,40 | | | |
| GOURGA | SORGHO | 5 | 4,05 | SORGHO<br>MIL | 3<br>2 | 6,50<br>3,25 |
| TOUYA | SORGHO<br>MIL | 1<br>4 | 3,05<br>4,90 | MIL | 2 | 6,70 |
| - GOURCY - | | | | | | |
| BOURI | MIL<br>SORGHO | 4<br>3 | 5,60<br>5,60 | MIL<br>SORGHO | 7<br>3 | 4,60<br>3,00 |
| BOULOULOU | SORGHO<br>MIL | 3<br>2 | 4,70<br>3,45 | SORGHO<br>MIL | 6<br>4 | 4,50<br>2,80 |
| SAN | MIL<br>SORGHO | 2<br>1 | 3,65<br>1,80 | MIL<br>SORGHO | 3<br>4 | 2,75<br>3,70 |
| BASSI | SORGHO | 3 | 6,30 | SORGHO | 2 | 5,90 |
| KOENEBA | SOR.-MIL | 4 | 7,95 | SOR.-MIL | 4 | 6,25 |
| GOURCY | SORGHO | 3 | 9,00 | SORGHO | 3 | 7,05 |
| | | 47 | 4,95 | | 48 | 4,50 |

TABLEAU 4

PRODUCTION D'ARBRES EN PEPINIERE VILLAGEOISE

| VILLAGE | ESPECES | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | N | PB | PJ | CP | Mo | Ad | Ec | SB | LL | |
| KOUDOUMBO | | 100 | 100 | | | | | | | 200 |
| RAT-YIRI | | 100 | 200 | | | 60 | 100 | 30 | | 490 |
| KIRPALOGO | | 100 | 200 | | | 50 | | | 100 | 450 |
| LOUBRE | | 140 | | | | | | | | 140 |
| TOUTA | | 190 | | | | | 190 | | | 380 |
| WAGANDE | 560 | 200 | 60 | 50 | 20 | | | | | 890 |
| KAO | 450 | 150 | 85 | 70 | 90 | | | | | 845 |
| LOUGOURI | 400 | 120 | 70 | 60 | 50 | | | | | 700 |
| TOTAL | 1410 | 1100 | 715 | 180 | 160 | 110 | 290 | 30 | 100 | 4095 |

N - NEEM
PB - PARKIA BIGLOBOSA
PJ - PROSOPIS JULIFLORA
CP - CEIBA PENTANDRA
Mo - MORINGA OLEIFERA
Ad - ADANSONIA DIGITATA
Ec - EUCALYPTUS CAMALDULENSIS
SB - SCLEROCARYA BIRREA
LL - LEUCAENA LEUCOCEPHALA

Cette analyse de regression sert à chercher une corrélation entre la date de semence et le rendement obtenu sur 18 carrés de rendement placés sur 16 exploitations dans le secteur de Cushigouya.

| $i$ | $X_i$ | $Y_i$ |
|---|---|---|
| 1 | 5 | 11,0 |
| 2 | 38 | 6,7 |
| 3 | 45 | 5,9 |
| 4 | 46 | 3,5 |
| 5 | 46 | 6,0 |
| 6 | 46 | 5,2 |
| 7 | 48 | 1,8 |
| 8 | 49 | 5,5 |
| 9 | 52 | 1,0 |
| 10 | 60 | 3,8 |
| 11 | 60 | 2,6 |
| 12 | 65 | 6,7 |
| 13 | 69 | 3,6 |
| 14 | 72 | 6,3 |
| 15 | 75 | 1,6 |
| 16 | 77 | 2,4 |
| 17 | 82 | 2,8 |
| 18 | 91 | 0 |

(i) numéro d'échantillon

($X_i$) date de semence où 1= 1 Mai, 31= 1 Juin, etc.

($Y_i$) rendement en céréale (kg./100M$^2$)

$Y = 10-0,1X$

$r = -0,76$

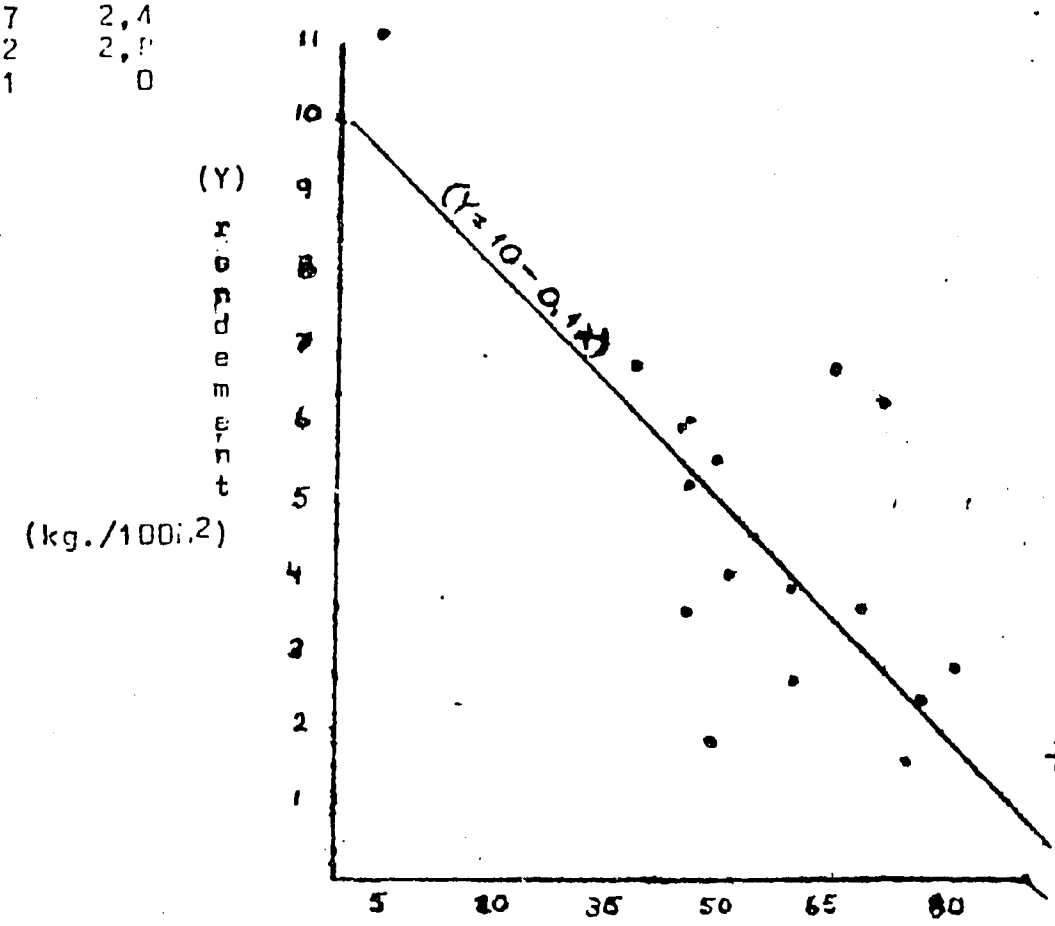


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TABLEAU 5

INFLUENCE DES DIGUETTES EN FORME DE CROISSANT DE LUNE SUR LA CROISSANCE DES NEEM EN PLANTATION

| DIMENSIONS DE LA DIGUETTE | DATE DE RECENSEMENT | NOMBRES D'ARBRES VIVANTS | HAUTEUR MOYENNE (cm.) | CROISSANCE (cm.) |
|---|---|---|---|---|
| TEMOIN, SANS DIGUETTES | 6.81 | 43 | 85 | |
| | 10.81 | 42 | 104 | 19 |
| | 6.82 | 37 | 109 | 5 |
| | | | | TOTAL= 24 |
| RAYON= 0,75m. ECART= 0,75m. | 6.81 | 31 | 71 | |
| | 10.81 | 30 | 95 | 24 |
| | 6.82 | 30 | 132 | 37 |
| | | | | TOTAL= 61 |
| RAYON= 1,5m. ECART= 1,0m. | 6.81 | 36 | 94 | |
| | 10.81 | 36 | 115 | 21 |
| | 6.82 | 35 | 153 | 38 |
| | | | | TOTAL= 59 |
| RAYON= 1,5m. ECART= 1,5m. | 6.81 | 37 | 86 | |
| | 10.81 | 37 | 94 | 8 |
| | 6.82 | 1 | 106 | 12 |
| | | | | TOTAL= 20 |

# BIOECONOMIC CONSIDERATIONS IN THE DESIGN OF AGROFORESTRY INTERCROPPING SYSTEMS

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International Council for Research in Agroforestry

## SUMMARY

The productivity of multipurpose agroforestry systems cannot be assessed on the basis of conventional measures of productivity in monocultural fields. Indices such as Land Equivalent Ratio, developed for arable intercropping systems, will prove useful in the development of improved agroforestry-based land use systems, but the ultimate unit of evaluation in agroforestry is the enterprise, not the field. Even the most sophisticated index of yield per unit of land will be the most relevant index of productivity only where land is the limiting production factor. The relationship between trees and their understorey intercrops can be competitive, complementary, supplementary or some composite of these relationships; which of these predominates in a given intercropping system depends not only on the genotype, number and espacement of components, but also on which growth factors are limiting for the respective components under realistic field conditions. An analysis of interactional effects indicates that certain highly promising agroforestry complementarities are significant only under low-input production conditions. This suggests that a number of synergistic intercropping potentials in agroforestry will remain seriously underdeveloped if agroforestry research retains the traditional experiment station orientation to production conditions characteristic of "high access" farmers, rather than concentrating on the low-input conditions typical of the majority of farmers and potential agroforestry technology adopters in developing countries. Following a discussion of bioeconomic considerations involved in deciding when it is advantageous to add trees to arable crop fields, the main bioeconomic principles for a decision on the optimum number of trees are presented. Bugeting techniques are discussed and an illustration is given of the use of linear programming as a practical bioeconomic design tool in agroforestry.

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# BIOECONOMIC CONSIDERATIONS IN THE DESIGN OF AGROFORESTRY INTERCROPPING SYSTEMS

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ICRAF

Bioeconomics, that branch of the dismal science which deals most directly with biological processes, has an important role to play in the design of research on agroforestry intercropping systems. In order to understand the nature of this role it is important to distinguish between bioeconomic and socioeconomic aims and methods. For purposes of this paper, they may be differentiated most simply on epistemological grounds: if socioeconomic dimensions of agroforestry intercropping systems are not taken into account, researchers will have no way of knowing whether the technologies they develop will have any relevance to the resource endowments, production constraints, and end-use requirements of potential users. On the other hand, if bioeconomic considerations are ignored, agroforestry researchers will have no way of assessing the economic significance of interesting plant combinations, interactions, and cultural manipulations. Concerned with the middle ground between determinants of technical feasibility and determinants of socioeconomic adoptability, bioeconomic considerations impinge directly on the conduct of plant aspects research in agroforestry.

The elementary bioeconomic thought is that the figure of merit, when evaluating the productivity of agroforestry systems, is not the per hectare biological yield *per se*, but *some transform* of that figure which takes account of its net value to the producer. A full and adequate discussion of all of the considerations involved in defining the precise nature of that value-accounting function for even a simple real-world production situation is beyond the scope of this brief contribution. This paper will only scratch the surface of bioeconomic concerns in agroforestry, but it will attempt to make some headway toward a bioeconomic perspective on the evaluation of competitive, complementary, and supplementary relationships among potential agroforestry intercrops, particularly as they affect assessment of optimum productivity under realistic field conditions. Although, we will not progress very far toward the goal in this paper, the ultimate aim is to develop practical bioeconomic measures and procedures which will eventually contribute to our ability to give reasonably optimal answers to the basic agroforestry design questions: "What trees?" "How many?" and "What arrangements?" (Huxley, 1981).



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## RETURNS TO LAND

In agroforestry, production and conservation are two sides of the same coin. The concept of sustainable land-use systems is basic to almost every definition of agroforestry. Consequently, the development of objective indicators of "sustainability" is high on the agenda of research needed to develop adequate evaluation and design methods for agroforestry systems. Bioeconomic methods will play an important role in operationalizing this concept, but at the moment there is little to report. One bioeconomically significant factor, however, is that conservation benefits in themselves are seldom viewed as sufficient incentives for adoption of new technology. Farmers the world over respond favourably to innovations in conservation technology only if they entail additional short-run economic incentives. In advanced economies this often takes the form of government subsidies on designated land-use practices. In agroforestry systems for developing countries, adoption incentives will probably take the form of economic "byproducts" (Raintree, 1980). If this is so, then it becomes imperative for agroforestry researchers to identify and develop multi-product components and intercropping systems.

One immediate consequence of the multi-product nature of agroforestry production systems is that their productivity cannot be assessed by conventional measures of the per ha yields of the separate crops taken individually. This is true for the simple reason that, although the yields of the individual intercrops may be depressed relative to their yields in monocultures, the total production of the field may be higher than what is obtainable when the individual crops are grown side by side as sole crops on the same amount of land.

### Land Equivalent Ratio

The concept of Land Equivalent Ratio (LER) has been developed to deal with this aspect of non-agroforestry intercropping (IRRI 1974, 1975; Trenbath 1976; Wiley 1979) and is equally applicable to agroforestry systems. Assuming equivalent levels of management, LER may be defined as the relative land area under sole crops that is required to produce the yields achieved by intercropping (Willey, 1979). When LER is experimentally assessed on the basis of uniform planting density of both intercrop and sole crops, the resulting LER figure is equivalent to the Relative Yield Total (RYT) of de Wit and van den Bergh (1965).

When intercropping gives a yield advantage, however, the total optimum intercrop density may be higher than that of either sole crop optimum (Willey, 1979). It has been suggested, therefore, that calculations of LER and other indices of yield advantage should be made on the basis of optimum, rather than constant, density in order not to distort the true practical potential of intercropping (Huxley and Maingu, 1978). In any case, the practice of intercropping is assumed to be beneficial when LER > 1, of neutral value when LER = 1, and detrimental to yields when LER < 1. LERs of as much as 1.6 have been reported for traditional farmers' fields (Norman, 1973) and up to 2.0 for experimental plots (Andrews and Kassam, 1976). The measure should prove useful in agroforestry applications, providing some additional means is used to assess differences in duration of the production period.

WHEN IS IT BENEFICIAL TO ADD TREES TO ARABLE CROP FIELDS?

It is often tacitly assumed, even by proponents of agroforestry, that the addition of a tree component to a field crop situation will almost always decrease the yield of the field crop, although the additional tree crop production may offset this decrease to give an overall LER > 1. The assumption that understorey arable crop components in mixed agroforestry systems will suffer from association with trees is usually based on the notion that the trees, being the dominant partner in the association, will compete with understorey crops, particularly for light, and that as a result of this competition the arable crop yields will be depressed. There is little doubt that evolution has conferred a competitive advantage on trees in the form of their greater stature, but whether, in the contexts of particular agroforestry production systems, they are always competitive with understorey crops and whether, being competitive, they always reduce net yields, are questions which require closer analysis.

This type of problem has been given a general treatment in economics by means of Production Possibility Curves. Under the assumption of fixed resources (the isoresource condition), production possibility curves show what happens to the quantity of each of two products when resources are transfered from one to the other. In this case the resource in question is land. Conventional economic analysis is usually content to deal with land as a unitary quantity on a par with the other main production factors, labour and capital. For purposes of bioeconomic analysis, however, it is

necessary to disaggregate this production factor and recognize that "land" implies access to variable amounts of a whole set of associated plant growth factors, including light, $CO_2$, nutrients and moisture.

As shown in Figure 1, there are three general relationships possible between two products under isoresource conditions: *competition, complementarity* and *supplementarity*. Which of the three relationships obtain between products or components in an agroforestry association depends upon a number of complex interactional factors discussed in greater depth in other contributions to this conference. I would like to suggest, however, that among the most important factors are: 1) the genotypes involved, 2) the proportion and arrangement of trees in the mixture, and 3) which plant growth factors are limiting for the respective components under field conditions. Actual production possibility curves for specific combinations will often be some composite of the three general relationships (Figure 2).

Supplementarity

Two products are supplementary if the production of one can be increased with neither an increase or decrease in the other, i.e. the outputs are essentially independent within the range of supplementarity. An example in agroforestry is multistorey intercropping with coconuts (Nair, 1979). Providing that light is not normally the limiting factor for the understorey crops when grown as sole crops on farmers' fields, the presence of tall, well-spaced, mature coconuts will have little effect on crop yield. Nutrients or moisture will normally be more limiting than light under smallholder conditions outside of the continuously humid tropics, and coconut palms offer only localized competition for these growth factors.

Another possible example of supplementarity in agroforestry is that of sorghum under *Parkia clappertoniana* in farmed parkland of the guinea savanna in Nigeria (Pullan, 1974). Farmers in this zone say that the sorghum yield under naturally occurring locust bean trees is no different from that of the surrounding fields. They report that the plants grow taller in the shaded, more fertile environment under the tree, but no change in grain yield is observed. If the observation is valid, perhaps the reported supplementarity is the net result of mixed competitive and complementary interactions which cancel each other out on balance. But even though the light intensity of the savanna environment is high, it is reasonable to suppose that at some density of *Parkia* trees light would

become limiting and sorghum yields would be noticeably depressed. Considering the economic value of the locust beans themselves, which local farmers collect and sell for more than three times the price of soybeans, it would be interesting to have some exact data on these interactions. Perhaps other contributions to this conference will shed light on the subject.

Complementarity

Two products are complementary if increasing the production of one results in a corresponding increase in the other. The by now nearly classic example of complementarity in agroforestry is that of *Acacia albida* with millet, sorghum, or groundnuts. Due to the peculiar reverse leaf habit of this unusual tree legume, the shading effects are conveniently withdrawn during the rainy season when the grain crops are in the field, leaving only the beneficial effects of improved soil fertility and moisture regime. Consequently, the tree stands in a net complementary relationship to the understorey arable crop.

The benefits of *A. albida* are fairly well documented (Felker, 1978) and more research is under way, but how representative is this unique tree of the potential for complementary agroforestry associations? I suggest that our awareness of complementarity in agroforestry is just beginning, although we already have quite a few examples from among the tree legumes. It has been fairly well established that what *A. albida* does automatically for the fertility status of associated soils can also be achieved, with appropriate inputs of labour and management, by other tree legumes such as *Leucaena leucocephala, Cajanus cajan, Gliricidia sepium* and *Tephrosia candida* (CIAT, 1977, 1978; IITA, 1979, 1980; Benge, 1979; Wilson and Kang, 1980; Rachie, 1981; Wilson and Raintree, 1981). Several other tree legumes have been suggested for trial (Raintree, 1980; Rachie, 1981) in "mixed" or "zonal" agroforestry systems (Huxley, 1981).

Lest it be thought that complementarity in mixed agroforestry systems can only be achieved in the absence of canopy prunning by *Acacia albida*, one hastens to add the example from Western Rajasthan of increased yields of arable crops and range grasses under *Prosopis cineraria* (Mann and Shankarnarayan, 1980). Also, lest it be assumed that yield improving fertility increases are only achieved by leguminous or other nitrogen fixing trees such as *Alnus*, one must cite the practices of farmers in population-pressured areas of Eastern Nigeria of planting and managing

*Acioa barteri* for its value as a "nutrient pump" amidst shallow-rooted crops on leached soils (Okigbo and Lal, 1979).

A search for examples of complementary relationships among agroforestry intercrops quickly leads one to the conclusion that interactional effects are important in determining which growth factors are limiting and, therefore, which plants are complementary in a given environment. Of particular bioeconomic significance are the interactions between soil fertility and other growth factors. I will try to illustrate the nature of the bioeconomic concerns with two examples.

Felker *et. al.* (1980) have recently reviewed the literature on the effects of soil fertility status on water-use efficiency and drawn some interesting conclusions on agroforestry potentials in semi-arid ecosystems. The basic effect was established by Hanks and Tanner (1952) in their experiments on water-use efficiency of field crops on fertilized and unfertilized Wisconsin soils. These experiments showed that, while water might be limiting crop yields, the biomass increase per unit of water is lower at lower fertility levels. In their two-year field trial, water-use efficiencies for maize and oats on fertilized plots averaged 143% and 175% higher, respectively, than on the unfertilized control plots. In a later range fertilization study in Montana Wight and Black, (1979) discovered a yield plateau of 1250 kg/ha for the unfertilized plots which was present in both the wettest and driest years, suggesting that water was not limiting plant productivity above this level. The fertilized plots showed an average 10 year increase of 120% over unfertilized rangeland. Felker *et. al.* (1980) estimated natural nitrogen inputs to semi-arid ecosystems and compared them with data on water use efficiency. Their analysis indicates that plant productivity in the semi-arid zone may be 10 times more limited by nitrogen than by available moisture.

The second example relates to the effects of shade in mixed intercropping systems at different levels of fertility. All of the examples considered so far of complementarity between trees and their understorey intercrops refer to situations in which the tree canopies are either light, seasonal, or heavily prunned. These examples do little to question the common assumption that shading *per se* is always in some measure detrimental to understorey crops. The tendency in recent years to remove the traditional shade trees from coffee, cocoa, and tea plantations has lent credence to

the general impression that shade is never, in itself, beneficial.

In a more critical light, however, it becomes obvious that the issue is dependent on a number of factors that can be quite complex in their interaction (Willey, 1975). From their investigations on the effects of artificial shade on cocoa yields in Trinidad, Murray and Nichols (1966) reported that in plantations fertilized with adequate amounts of NPK the highest yields were obtained in full sunlight, but that unfertilized plantations of low nutrient status gave their highest yields under shade. Comparable experiments with tea in north-east India, showed a similar interaction between light and nitrogen level (Wight, 1958). In the case of coffee, workers have concluded that where soil fertility is low and adequate fertilizer cannot be added, shading may be desirable in order to prevent periodic over-bearing and die-back (Hardy, 1962; Huxley, 1970; Fernie, 1970). The function of shading in this case is to regulate yield to a level which is sustainable on the basis of inherent soil fertility (Willey, 1975).

These two examples are bioeconomically significant because they relate to two of the most limiting and ubiquitous constraints on smallholder production in the tropics, low soil fertility and inadequate supplies of mineral fertilizer. In both examples the conventional wisdom, i.e. that moisture is the most limiting factor in dry regions and that shade is always detrimental to understorey crops, is overturned in situations where soil fertility is low and adequate amounts of mineral fertilizer cannot be added. *But these are precisely the conditions which characterise smallholder production in most developing countries.* The assumption that moisture is most limiting or that shade always reduces yields of understorey crops could only be made in the context of the production conditions enjoyed by research stations and a select group of "high-access" farmers (Roling, 1980) wherein all otherwise more limiting production factors are routinely topped up to optimal levels by inputs from outside the system. The assumption is that the "best" farmers will do the same.

Ah, but there is the rub. In the strange world outside the agricultural laboratory, the inputs are not always available, at least not in sufficient quantity to reach the majority of farmers. In many cases the economics of fertilizer use are questionable (Raintree and Turay, 1980), but even where government subsidies have reduced farmgate fertilizer costs to

economic levels, the infrastructure to deliver them in adequate supply is often simply not there. The supply situation in Nigeria, a country which has an exceptionally good foreign exchange balance and which maintains fertilizer subsidies of more than 80% (Knipscheer, 1979; Menz, 1980), is perhaps more typical than we like to admit. An analysis (Raintree, 1980b) of data from the British Overseas Development Ministry's Central Nigeria Project Farming Systems Survey (Cosden, 1978) shows 100% of the survey villages reporting *lack of inputs generally* and 95% reporting *lack of fertilizer specifically* as major production constraints.

The general conclusion to be drawn from these examples is that, while the potential for complementarity between components of well designed agroforestry systems would appear to be quite promising, unless agroforestry research is designed with realistic field conditions in mind, this potential is likely to remain seriously underdeveloped.

Competition

Two products are competitive if increasing the production of one results in a decrease in the production of the other, given a fixed level of resources. The products of trees and associate arable crops which are limited by the same factors, which draw these factors from the same pools, and which have no compensating interactions, will stand in a relationship of net competition. Does this mean that intercropping would be uneconomic? Not necessarily, since the total productivity of the association might still be higher in terms of LER or GM/ha than the monocultural alternative. The only competitive situation which can be ruled out immediately on biological grounds is one in which the components are *mutually inhibiting*, or amensalistic. As long as one component is benefitted by the association, there is the economic possibility that a higher LER may be achieved by intercropping.

It is an economic truism that the rational, profit-maximizing producer will always operate in the region of diminishing returns. In the present context this means in the region of competition on the production possibilities curve. As explained in the next section, the level of competition which is appropriate and desirable depends upon the relative prices of the products and the rate at which they substitute for each other in the production process. Examples of competitive relationships among agro-

forestry components are too numerous to mention. Even complementary products become competitive at high production densities (Figure 2).

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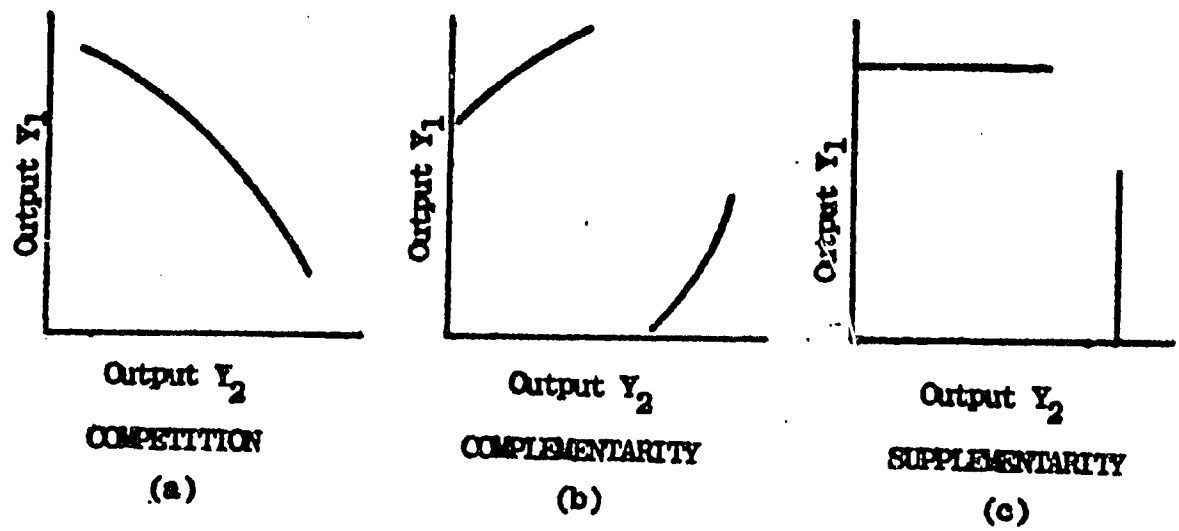


Fig. 1 Production possibility curves under isoresource conditions

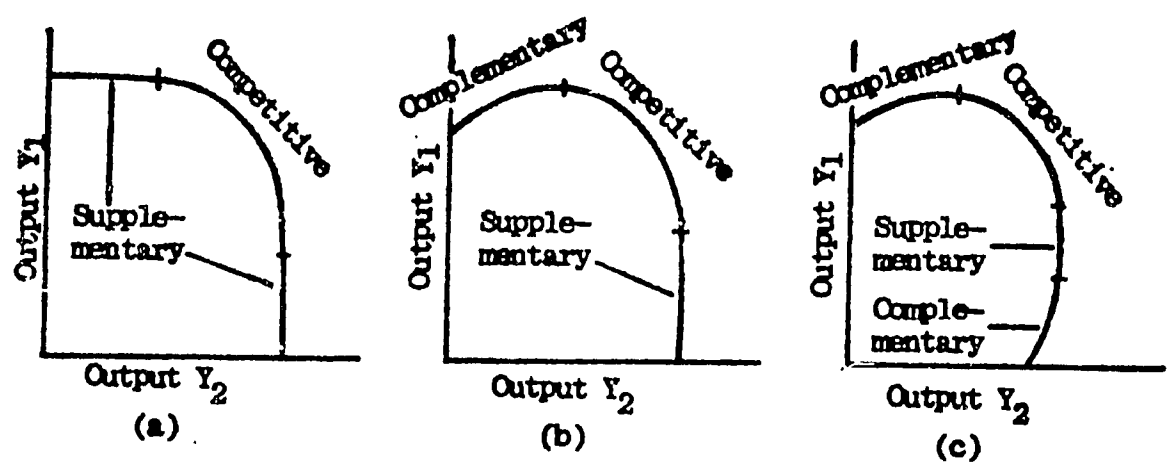


Fig. 2 Some examples of composite production possibility curves