Plant Research and Development

A Biannual Collection
of Recent German Contributions Concerning
Development through Plant Research

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PLANT RESEARCH AND DEVELOPMENT
A Biannual Collection
of Recent German Contributions

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NATURAL FOREST MANAGEMENT IN THE ATLANTIC COASTAL RAIN FOREST OF BRAZIL

by

KLAUS G. HERING
Florestal RH Ltda, Blumenau SC, Brazil

"Natural Forest Management" is a system developed by Florestal RH Ltda., a private company, for sustainable multi-purpose management of the Mata Atlântica in the southern Brazilian state, Santa Catarina. Its outstanding features enable the bio-diversity of tropical primary forests and the basal area ditribution of more than 80 tree species to be maintained. If 25% of the basal area is extracted, the forest reverts to its original basal area after 12 years. The allowable cut of 2.56 m^3/ha/yr was obtained from sample plots and an inventory of the entire area: 2208 ha. The production of lumber, palmetto hearts and honey guarantees a positive income of $ US 58/ha. This value is very sensitive to interest rate fluctuations. Thus the Brazilian Monetary Policy, and the constant reduction in the property rights of the forest owner, accelerate forest destruction and restrict the development and application of sustainable managment methods such as "Natural Forest Management".

The Atlantic coastal rain forest of Brazil is one of the most endangered terrestrial ecosystems on this planet. Nowadays, the rain forest region has shrunk to only about one thenth of its original extent (see Fig. 1) (Fundação 1990). Most of the still forested area is covered with secondary forests and highly degraded primary forests. Only very small fragments of primary forests, containing a rich stock of trees, still exist intact. The federal state of Santa Catarina still possesses a relatively large percentage of this forest formation, namely a continuous evergreen humid forest of the submontane to montane type, containing very few deciduous species of tree. It has all the characteristics of a tropical rain forest and, because of the warm and rainy maritime climate, it constitutes an extrazonal form of vegetation which is situated far outside the equatorial rain forest zone. Veloso and Klein (1959) classified this forest as "Floresta Ombrófila Densa da Encosta Atlântica" (dense rain forest on the Atlantic mountain slopes). The most frequent species of tree encountered belong to the families of the Lauraceae, Myrtaceae, Leguminosae, Meliaceae, Melastomataceae, Apocynaceae and Euphorbiaceae. The commercially most important species of tree in the southern part of this type of forest is the *Ocotea catharinensis* (Lauraceae).

The climate of the region is subtropical, i. e. humid without any dry season, and the annual precipitation of 1600 mm is uniformly distributed; the annual

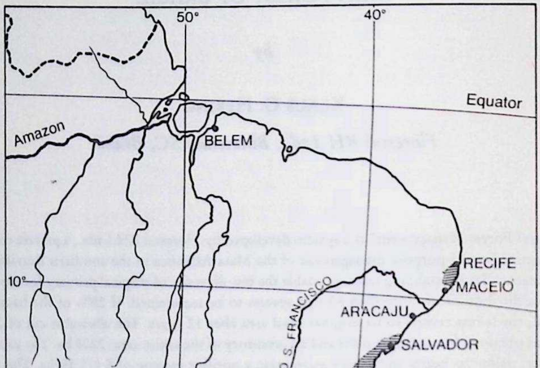

Fig. 1 – *Original distribution area of the Atlantic coastal rain forest in Brazil.*

average temperature is 19 °C, with mean temperatures of 26 °C and 15 °C occurring in the warmest and coldest months respectively. The average relative atmospheric humidity is 85 %. The soils are deeply weathered, mostly podzolized latosols or cambisols formed on crystalline basement rock.

For 18 years, the firm Florestal BH Ltda has been managing an area of 2208 ha of the coastal rain forest (most of it primary forest), using an approach with principles aimed at combining sustainable commercial exploitation of several forest products with the goal of preserving the biodiversity, the genetic reserves, and the complex and sensitive ecological balance of this forest formation. At present, this is the only research project of its kind in the Atlantic coastal rain forest which has been approved by the environmental protection agency IBAMA.

In the course of a long process of adaptation to the natural conditions, the ecosystem of the coastal rain forest has attained a state of equilibrium which may be described as the ecological optimum or climax state. Since the interactions between climate, soil, flora, fauna and human intervention are largely unknown, the management of the forest seeks to avoid as far as possible creating any major disruptions in the exosystem. Accordingly, the fundamental principle guiding those who manage the forest is to maintain as much as possible of the structure of the primary forest, namely its stock of species and their relative proportions in the stand. At present, commercial exploitation involves the production of timber, palmetto hearts and honey. The difficulty of managing such a forest is to reconcile the ecological desirability of guaranteeing the sustainable yield of these raw materials, on the one hand, with commercial activity within a free market economy, on the other. The project is based on the concept of long-term exploitation, in contrast to the desire to make a quick profit, which is a feature of the traditional exploitation of primeval tropical forests. We have called this form of forest management "Manejo Natural", and in German we use the term "naturnahe Waldbewirtschaftung" (natural forest management).

The purpose of this paper is to describe the silvicultural methods applied, to present the provisional data on stand dynamics which have so far been collected in the field, and to demonstrate the economic feasibility of this method which preserves the natural resources.

Description of the silvicultural method

Treatment of the middle and upper layers of trees in the stand

The trees to be felled are selected and marked by compartment, after an inventory has first been established, taking into account the individual properties of the trees and their role in the structure of the forest. The purpose of the selection is to improve the quality of the stand. Vital, straight-stemmed upwards-growing and qualitatively high-grade trees in the middle and upper layers are carefully tended, and poor-growth specimens with weak crowns and low-quality stems are removed.

The selection process also seeks to avoid creating any major gaps in the stand, thus permitting the subsequent colonization by pioneer species of tree. The valuable climax species and gap-filling opportunists can only be cultivated in small clearings under the protective canopy of the stand. This is an additional reason for sparing giant trees with strongly developed crowns; they are essential for preserving the wide range of niches and for insuring the sustained growth of the tropical forest. Most of the trees removed from the stand in this first cutting are poorly formed specimens or specimens with weak crowns, which are not likely to grow or reproduce very well.

The degree to which any intervention is made into the forest is restricted by the need to maintain the original stock of trees in terms of the species spectrum and the relative abundances. In addition, once the intervention has been carried out, the stand should be able to return by itself as nearly as possible to its original state. Excessive exploitation creates large gaps in the stand. On the other hand, excessively cautious exploitation endangers the economic viability of the operation, in view of the high fixed costs for the construction of forest roads and for procuring forestry machinery. Thus, when deciding on the intensity of the cuts to be made, it is necessary to tread a fine line between what is maximally acceptable in ecological and silvicultural terms, on the one hand, and minimum economic requirements on the other.

Management of the palmetto stand

Euterpe edulis (palmiteira, Palmae), a palm growing in the middle tree layer, supplies what is known as a "palmito" (palmetto heart), namely the edible apical meristem of the tree, a product which is very much sought after by the canning industry. *E. edulis* plays an important role in the maintenance and restoration of the microclimate in the forest because its crown reacts very quickly to the increased availability of light following any felling operation. The low basal area per individual (at a DBH [diameter at breast height] of between 10 and 15 cm, *E. edulis* attains the maximum diameter of the meristem), the intensive rate of natural rejuvenation, its rapid growth when the stand is thinned, without impairing the growth of other species in the middle tree layer, make this species an ecologically and economically ideal "gap filler".

For example, at Florestal RH, the mean number of seedlings and small plants up to a height of one metre was increased from 3000 in the year 1982 to

6000 per hectare by the present date. This reservoir of plants is available to react to the changed light conditions following removal of timber or palmetto palms.

The forest is managed by making a positive selection of products and by maintaining an adequate quantity of seed trees, which results in rapid restoration of the formerly lush but later totally degraded palmetto stands.

The palmetto stand is cultivated by regulating the competition between the older palms. This is done either by removing a younger tree growing under the protection of an excellent seed tree, or a dominant fully grown palm is removed, thereby accelerating the growth of younger plants. An adequate number of seed trees must be retained in order to achieve dense natural rejuvenation and to provide a source of food for the species of birds, bats and rodents which are important vectors for spreading the seeds.

Veloso and Klein (1959), in their phytosociological studies of the same region, had already noted the high abundance of *E. edulis* in the middle tree layer; they had discovered up to 150 fully grown palm trees per hectare on sloping sites in the primary forest. From our own observations, we have concluded that a well-developed palmetto stand contains approximately 200 adult and adolescent palms per hectare. If 50 of these palms per hectare are retained as seed trees, 150 specimens may be harvested in a period of approximately 3 years, while the younger individuals grow at the same rate into these size categories. Given an average production of 0.705 kg palmetto heart per plant, a well-maintained palmetto stand can produce 35 kg of palmetto hearts per annum and hectare.

Honey production

So far, it has been discovered that 31 of the species of tree are capable of supplying nectar for the Africanized honey bee *(Apis melifera)*. In addition, there are many species of lianas, shrubs and epiphytic cacti growing on trees. The honey-bearing plants blossom from August to January.

The area so far given over to honey production comprises approximately 60 % of the total area of forest. The harvest during the 1991/1992 season, when climatic conditions were extraordinarily favourable, amounted to 6.7 tonnes, which is an average production of 40 kg per hive. If the entire forested area is used, it will be possible to produce on average 6 tonnes per annum, which would be equivalent to a yield of 2.72 kg per hectare. In the long term, it is likely that this yield will be increased, because the management of the forest will improve the vitality of the crowns and the intensity of flowering in the dominant tree layer.

Stand dynamics – development of forest growth under the influence of management techniques

Inventory method

The Florestal RH company uses an inventory system which records the diameter distributions, basal areas and timber reserves for each individual species. Because of the highly heterogeneous composition of the forest and the site-related differences in the stand structures, it is necessary to proceed compartment by compartment when planning and carrying out forestry measures. Mean values for abundance, dominance and frequency throughout the entire area are thus not really useable when marking individual trees in the stand, because the site-related variations result in completely different species compositions and competitive conditions.

The forest compartments are about one hectare in size and are reached by roadways. All the trees having a DBH of 10 cm and more are numbered with tags. The useable height of the stem (up to the start of the crown or the first branches, possibly up to the point where a stem becomes very crooked) is estimated, and the shape and vitality of the crown are classified into three categories (Hosokawa 1992). Given the species-specific variations in the crown types, this approach requires a great deal of experience if reliable results are to be achieved.

In order to describe the effects of management on forest growth and to obtain well-founded reference points for determining the yield, we use data taken over two growing seasons from a managed area measuring 0.45 ha. It is located on a North-facing slope at a height of 700 meters above sea level; it carries 62 species of tree and reflects the heterogeneous composition of the coastal rain forest. The palmetto stand, which originally possessed the greatest abundance, was totally devastated 18 years ago and is currently reestablishing itself, although this process is hampered by the increase in the numbers of competitive species in the lower and middle forest layers.

The difficulties in determining the volume of timber and the changes which it undergoes are well enough known and usually lead to relatively unreliable results. Therefore, the yardstick for determining forest growth used here is the current annual increment in basal area, given in square meters or in percent of the initial basal area.

An inventory of the compartment was taken in May 1990. At that time, all the trees having a DBH of 10 cm and more were tagged and calipered. Then the selected trees were felled. In May 1991 and 1992, follow-up inventories were taken and all the stems of the remaining stand were calipered.

Results

Table 1 shows that in the primary forest 10 species account for 52.1 % of the number of stems and 60.8 % of the basal area. The highest grade timber is supplied by *Ocotea catharinensis,* which has the highest values for abundance and dominance in the stand. The high-grade timber trees also include *Ocotea* sp. (canela prego) and *Ocotea odorifera* (sassafrás), the latter is also the source of the valuable safrole oil. All the other trees are species of hardwoods and softwoods. Six species (*O. odorifera, O. sp., Crytocaria sp., O. acyphilla, Aparisthmium cordatum and Nectandra rigida)* rejuvenate spontaneously by putting out shoots from the stem as soon as the vitality of the parent stem declines – this is something to which Hering (1990) had drawn attention.

The number of stems was reduced from 851 to 645 and the basal area from 48.5 to 29.2 m^2. Thus, 24 % of the number of stems or 40 % of the basal area were removed by felling, including the trees damaged by the felling procedures. Fig. 2 shows the absolute abundance values per diameter stage before and after the selective logging action, depicted separately according to the planned and actually remaining number of stems. The largest number of stems taken by planned logging came from the classes of tree having a DBH of 20-29 and 30-39 cm. The collateral cutting damage caused in the lower DBH level, or the difference between the planned and executed felling, was partially compensated for by a reduction in the planned number of stems taken from the 20-29 cm class.

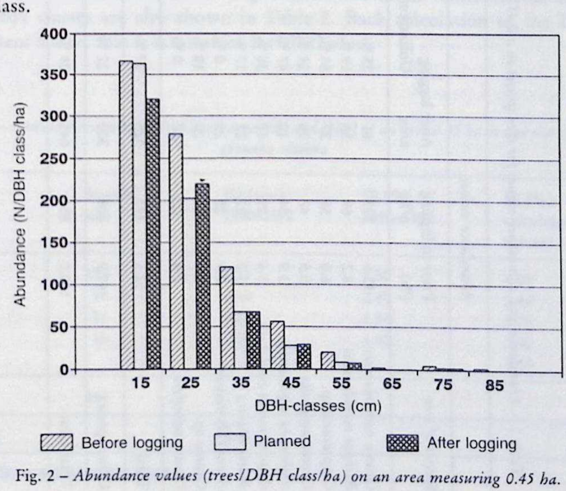

Fig. 2 – *Abundance values (trees/DBH class/ha) on an area measuring 0.45 ha.*

Table 1 – *Abundance and dominance values for tree species in a 0.45 ha sample area, using natural forest management techniques (DBH > 10 cm)*

	Abundance values					Dominance values			
Species of tree	Prior to logging (%)	Prior to logging n/ha	After logging n/ha	After logging Utilization	*Species of tree*	Prior to logging (%)	Prior to logging m^2/ha	After logging m^2/ha	After logging Utilization
Ocotea catharinensis	12.6	107	81	25 %	*Ocotea catharinensis*	18.0	8.72	5.6	36 %
Bathysa meridionalis	8.2	69	56	19 %	*Alchornea triplinervea*	11.3	5.49	2.0	64 %
Cryptocaria sp.	6.8	58	27	54 %	*Cryptocaria* sp.	7.6	3.69	1.1	70 %
Ocotea acyphilla	5.5	47	36	24 %	*Bathysa meridionalis*	5.2	2.50	1.9	25 %
Alchornea triplinervea	3.9	34	18	47 %	*Maria Faceira*	4.0	1.95	1.40	28 %
Aparisthmium cordatum	3.4	29	18	38 %	*Nectandra rigida*	3.3	1.59	0.93	42 %
Maria Faceira	3.2	27	22	17 %	*Ocotea acyphilla*	3.2	1.57	1.01	36 %
Araca (Myrtaceae)	2.9	25	25	0 %	*Mataybya guianensis*	2.9	1.38	0.99	28 %
Ocotea sp.	2.9	25	20	18 %	*Ocotea kuhlmannii*	2.8	1.35	0.85	37 %
Ocotea odorifera	2.6	22	22	0 %	*Ocotea odorifera*	2.5	1.23	1.23	0 %
Total	52.1	443	325	27 %	Total	60.8	29.5	17.0	43 %
Other species	47.9	408	320	22 %	Other species	39.2	19.0	12.2	36 %
Total value	100.0	851	645	24 %	Total value	100.0	48.5	29.2	40 %

The number of species was reduced from 62 to 59 as a result of damage sustained by the less abundant species during the cutting operations, with the exception of the planned felling of one senile tree of a rather infrequent species.

The goal of natural management is to remove trees with weak crowns and thus to increase the number of trees with normal and above-average crowns. In order to determine the increment in basal area in the course of a cutting cycle, the increment data of trees with normal and above-average crowns are used. Some data had to be eliminated because of obvious measurement errors; therefore, according to the follow up inventories, increment data on basal areas are available for 244 individual trees. Because of the small size of the sample, all the trees having a DBH of more than 40 cm were included in the "50 cm" class. Table 2 shows the measured increment in basal area in percent.

Since the relative species composition of the forest is retained, the different rates of increment of the species do not affect the mean value of the grouped data, from which the growth function of the forest is calculated. Using the method of least squares, the following function was derived fro the relationship between the grouped data of the increment in basal area (IB) and the diameter class (DBH):

$$LN\ (IB) = 4.038 - 09.72\ LN\ (DBH)$$

This function has a highly significant correlation coefficient ($r = 0.97$) and therefore fits in well with the average values. The mean values calculated for the DBH classes are also shown in Table 2. Back calculation to the DBH increment shows that it is constant for all classes.

Table 2 – *Annual increments (ID) in basal area (IB) and DBH of an area 0.45 ha in size during two growing seasons*

DBH stage	Sample size	ID (cm/a) 1990–1992	IB (%) 1990–1992	IB (%) calculated values*
15	123	0.32	4.30	4.08
25	94	0.30	2.40	2.48
35	11	0.27	1.54	1.79
45	16	0.36	1.60	1.40
55				1.15
Total	244			
Average		0.31		

* LN (IB) = 4.038 – 0.972 (DBH)

On the other hand, the weak-crowned trees exhibited a mean increment in basal area of 0.89 %. After the selective logging, they still constitute about 30 % of the total stand.

In the following, it is assumed that the crown quality does not change, i. e. 30 % of the trees continue to have weak and 70 % normal and above-average crowns, although the concentration on the increment of the most vital trees leads one to hope that the increment values will increase from cycle to cycle. Therefore, the increment function is written as follows:

$(IB \times 0.7) + (0.89 \times 0.3)$ for $(IB > 0.89)$ and

$IB\ (= e^{LN(IB)})$ for $(IB \leq 0.89)$

in order to exclude the possibility of overestimating the DBH classes with lower rates of increment.

No data are available on natural losses. During the course of a cutting cycle they were estimated at 5 % of the basal area in the diameter classes from 30 cm upwards. Consequently, the basal area of a tree in the final year of the cutting cycle, B(j), is equal to the basal area in the year (j - 1) plus the growth of the corresponding diameter class, reduced by a 5 % loss rate, which is written as follows

$IB(j) = B(j - 1) \times (1 + 0.01 \times IB) \times 0.95.$

Based on these date, the increment in basal area for the trees remaining in the stand was iteratively calculated up to attainment of the original basal area in the year 2016. Table 3 presents the corresponding values per hectare. The basal area of the palm trees in the 10 - 14 cm DBH class is also included.

The stand inventories taken in the year 91/92 revealed an increase in the palm tree stand from 78 to 101 per hectare in the 10 - 14 DBH class. Because of the ongoing intensive natural rejuvenation, it is likely that already by 1995, the optimum abundance for the 200 palms in the stated DBH class will have been achieved with a basal area of 2.6 m^2.

The populations in the tree diameter classes gradually shift in the course of iteration towards the next higher class, which results in a reduction of the values in the lowermost class. By maintaining the natural rejuvenation, the value of the initial basal area in this first diameter class prior to felling was used for the projection up to the year 2016.

This yields an annual increment in the stand basal area of 1.8 %. After 26 years, the stand will once more reach its initial basal area of 49 m^2 (wood species 46.4 m^2 and palms 2.6 m^2). A shift takes place in the basal area values towards the DBH classes between 20 - 40 cm.

Experience has shown that removing up to 25 % of the basal area (Hering 1994), while respecting the selection criteria mentioned above, preserves the rejuvenation of the primary forest species. If the logs are felled and skidded

Table 3 – *Increase in the basal area and the timber volume per hectare using natural management techniques*

	1990								2016			
DBH classes	Before logging				After logging				Calculated*			
	n	B m^2	V m^3	NV m^3	n	B m^2	V m^3	NV m^3	n	B m^2	V m^3	NV m^3
15	367	6.6	27.7		320	5.8	25.0		367	6.6	27.7	
25	278	13.4	60.9		219	10.3	49.8		271	13.4	59.6	
35	121	11.3	50.7	50.7	67	6.1	30.6	30.6	145	12.9	61.2	61.2
45	56	8.7	46.4	46.4	29	4.4	25.3	25.3	40	7.6	41.0	41.0
55	20	4.6	28.2	28.2	7	1.6	11.3	11.3	15	3.5	22.9	22.9
65	2	0.8	2.2	2.2				0.0	4	1.4	7.9	7.9
75	4	2.0	9.2	9.2	2	0.9	3.8	3.8	2	1.1	4.5	4.5
85	2	1.2	9.7	9.7				0.0				0.0
Total	851	48.5	235.0	146.5	645	29.2	145.9	71.0	844	46.4	224.8	137.5
Annual increment (%)										1.80 %		
Average increment (m^3/ha)												2.56
Palms (DBH) 12.5	49	0.6			49	0.6			200	2.6		
Trees and palms	900	49.1			694	29.8			1044	49.0		

* Assuming a natural loss of 5 % and 30 % of weak-crowned trees
B = basal area V = timber volume NV = usable timber volume

carefully, very little harvesting damage is caused. Fig. 2 shows that such damage only occurs in the first DBH stage, while in the rest of the stand the actual cutting, including collateral damage, corresponds approximately to the target figures. In the case of an annual growth rate of 1.8 %, it is anticipated that the removal of one quarter of the basal area will be compensated for by the growth increment over the course of 12 years and thus represents a sustainable rate of exploitation. Removing 40 % of the basal area must therefore be regarded as clearly excessive.

The sustainable production of timber will now be calculated on the basis of the percentage values obtained for basal area increments in the test area. This area according to a random sample inventory of the overall area can be regarded as representative. Timber having a DBH of more than 30 cm is regarded as removable.

The volume function

$$Vol = (-0.00422525 + 0.00005278 \times DBH^2) \times HT$$

(HT = height of timber) was used to calculate the reserves of timber (excluding firewood) per hectare. Assuming a natural mortality of 5 %, a stand with 30 % weak-crowned and 70 % normal and strongly crowned trees, and given a constant timber height, the annual sustainable cut amounts to 2.56 m^3/ha (see Table 3). This careful estimate ignores the increment in the two lowest DBH categories, because this increment does not provide any useable timber in the true sense of the term.

Feasibility analysis

Starting data

In the following investigation we have based our calculations on the currently achievable market prices for timber, palmetto hearts and honey, as well as on the annual costs incurred for a cut of 1400 m^3 of timber and a honey harvest of 6000 kg. The palmetto stand was partially harvested in 1990 and the next harvest will begin in 1993.

The first column in Table 4 contains the economic data relating to the current exploitation of the forest. All the species of trees can be sold, with the exception of the old and misshapen *Sloana sp.* The three different types of wood (high-grade and special woods, good quality hardwoods, soft, i.e. peelable, woods) account for 40 %, 32 % and 16 % respectively of the trees that are logged. The average revenue per cubic meter of skidded timber is US $ 47.68.

The annual honey production of 2.72 kg per hectare corresponds to 12,766 jars, each containing 470 g, which are sold for US $ 1.59 apiece, including value added tax (ICMS).

Table 4 – *Actual and simulated operating income and expenditures (in US$/year) using natural management techniques and clear felling of a 2208 ha forest area*

		Production of timber and honey 1992*	Production of timber and honey according to the allowable cut	Production of timber, honey and palmetto hearts according to the allowable cut		Clear felling
A operating income	US$	87,053	247,317	387,177	100 %	13,534,385
Logging	US$	66,745	227,009	227,009	59 %	12,290,385
	m^3	1,400	4,762	4,762		257,796
	ha	1,860	1,860	1,860		1,860
Palmetto harvest	US$			139,860	36 %	252,000
	Palm.			55,500		100,000
	ha	1,110	1,110	1,110		1,110
Honey harvest	US$	20,309	20,309	20,309	5 %	
	kg	6,000	6,000	6,000		
	ha	2,208	2,208	2,208		2,208
Fuelwood	US$					620,000
	Estere					4,133
Land value	US$					372,000
B. Operating expenditures	US$	75,067	160,780	187,165		4,948,344
B1. General expenditures	US$	31,807	50,053	54,945		566,447
Forest manager	US$	11,346	11,346	11,346		11,346
Foreman	US$	4,255	4,255	4,255		4,255
Catering	US$	715	715	715		715
Forestry engineer	US$	1,080	1,080	1,080		1,080
Accomm. and transp.	US$	1,442	2,227	2,493		22,509
Bookkeep./payroll serv.	US$	873	2,165	2,603		35,549
Materials	US$	579	1,435	1,725		23,560
Property tax	US$	1,754	1,754	1,754		1,754
Data processing	US$	402	402	402		
Telephone/fax	US$	771	1,913	2,300		31,414
All-terrain vehicles	US$	8,589	22,760	26,272		434,265
Number	n	1	3	3		21
Fuels and lubricants	US$	1,584	5,387	5,387		291,637
Servicing incl. spares	US$	3,229	8,009	9,628		65,751
Investment reserves	US$	2,537	6,291	7,563		51,649
Insurance, taxes	US$	1,239	3,073	3,694		25,229
B2. Logging	US$	31,708	99,175	99,175		4,351,802
Forestry worker	US$	14,244	48,446	48,446		914,429
Number	n	5	17	17		322
Catering	US$	1,794	6,102	6,102		115,171
Road-building	US$	2,901	9,866	9,866		2,409,977
	km	2	5	5		62

sFriday, the Table shows the costs for accommodation, catering and transportation.

The forest manager, in this case the author, is responsible for the general management of the operation as well as for deciding which trees to mark, and also for the data processing procedures. In addition, Brazilian legislation requires that the company must employ a responsible forestry engineer in order for the logging permit to be awarded. In the company described here, the foreman is at the same time the beekeeper and the driver of the all-terrain vehicle.

The roads are constructed by subcontractors who are paid per hour of machine operation. The investments consist largely of reserves set aside for the purchase of forestry machinery. In the administrative sector, the financial bookkeeping and payroll operations are services which are contracted out to appropriate offices.

Column 2 in Table 4 lists the adjusted operating data based on the allowable cut. For reasons of environmental protection, the logging is restricted to an area of 1860 ha. Given a permissible cut of 2.56 m^3 per hectare and annum, this results in the annual removal of 4,762 m^3 of timber and an operating result of US $ 56,249.

In the third column of the Table, all the data resulting from the production of palmetto hearts are added to the adjusted operating data based on the allowable cut (see column 2); this is done assuming full productivity, and also four additional forest workers and one armed forest guard were employed. Fully manageable palmetto stands are located at altitudes of up to 700 m and are thus restricted to an area of 1100 ha. Given an average production of 35 kg of palmetto heart per annum and hectare, the total production is 55,550 palmetto hearts. The average yield is US $ 2.52/palmetto.

The fourth column shows the simulated result of clear felling, which assumes that all the reserves of logs, firewood and palmetto products, covering 80 % of the total surface area (20 % are environmentally protected in this case), are sold along with the land. A total of 100 stacked cubic meters of fuelwood and a soil value of US $ 150 per hectare are assumed.

Results

The comparison of income and expenditures reveals, from left to right, an increasing cash surplus, starting with the current production of timber and honey (US $ 7,791), then progressing to a simulated intensive, sustainable production of timber and honey (US $ 56,249), and finally an anticipated sustainable palmetto heart harvest is added (US $ 130,008).

In the last case, the logging activity brings in 59 % of the operating earnings, the palmetto harvest 36 % and the honey harvest 5 %. Given natural forest mamanagement, the earnings per hectare are US $ 175 for timber, US $ 126 for palmettos and US $ 9.20 for honey.

If the tax-free profit is regarded as a permanent annuity and capitalized, then, assuming constant revenues and factor-costs and 6 % interest in the case of intensive timber and honey production, the capitalized value of the forest stand can be calculated as:

56,249/0.006 = US $ 937,487.

If intensive palmetto heart production is added, the capitalized value rises to US $ 2.2 million.

The value of simply clear-cutting the forest (to yield logs, fuelwood and palmetto hearts), i.e. the value of traditional exploitation, using up the resources, was calculated to be US $ 5.6 million, including the revenue from the sale of the land.

The discrepancy between the clear-cutting value of US $ 5.6 million and the capitalized value of US $ 2.2 million calculated for the sustainable exploitation of the forest means that no private company would voluntarily use the sustainable yield method. Instead, any entrepreneur would cut down all the useable timber reserves in one go, according to the usual pattern of exploitation: next, he would open up the area for the collection of fuelwood, and then he would sell the land.

Because of the long-term investments involved, the sustainable yield method of management is particularly sensitive to fluctuations in interest rates. Given a real interest charge of 15 %, the capitalized value for example is only US $ 0.9 million.

Assuming a possible tax exemption and a (hypothetical) price increase of 15 % on products from naturally managed, sustainable-yield forests, the difference (at 6 % interest) between the value of such forests and the clear-cutting value would be reduced (US $ 3.9 million compared with US $ 5.6 million). If a tax exemption and a price increase were granted, the ecological advantages of natural forest management and the retention of the protective properties of the forest, on which currently no financial value is placed in the free market economy, could be paid for by society. However, if an interest rate of 15 % is assumed, the capitalized value will remain at US $ 1.6 million.

Conclusions

The provisional data submitted by Florestal RH Ltda. show that the sustainable exploitation of a tropical rain forest, using natural and environmentally compatible management of several forest products, is possible and at the same time species diversity can be preserved.

However, in a free market economy, the prices paid for forest products obtained by the traditional and destructive methods of exploitation mean that sustainable yield management of the forest is not a competitive option.

The higher costs incurred by logging and production methods which protect both the environment and resources would not easily be compensated for by a tax exemption and a 15 % price advantage for "sustainable-yield products".

Public expenditures on research and development (R&D) projects could be seen as compensation for the protective and beneficial effects of the forest which the owner has so far provided free of charge to the population at large.

The greatest pressure on the forest owner comes from the high interest rate policy pursued by the Brazilian government to combat inflation and to cover the budgetary deficit. A rational entrepreneur, even someone who has the techniques of sustainable management at his disposal, would almost certainly choose the option of clear felling, i.e. the route which leads to a rapid and certain profit. The uncertainty with regard to changes in forestry ownership rights and rights of disposal, the constant threat of a total ban on logging (establishment of protected forests), invasions by landless members of the population, or in effect expropriation without compensation, all create a climate of uncertainty which accelerates the destruction of the forest as a short-term cash-flow business, instead of encouraging its preservation through reliable long-term exploitation and guaranteed property rights.

Thus, interest rates which are in line with international practice, and legal guarantees to the forest owner that he can go on using the forest, are essential means of promoting the spread and application of environmentally protective silvicultural procedures. Only these can replace the present highly damaging overexploitation which has destroyed almost all of the Atlantic coastal rain forest and is threatening large areas of the Amazonian rain forest.

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IN-VITRO MULTIPLICATION OF WHITE YAM (*DIOSCOREA ROTUNDATA* POIR.) AND TARO (*COLOCASIA ESCULENTA* L.) FOR THE PRODUCTION OF VEGETATIVE PROPAGATION STOCK

by

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The studies on in-vitro regeneration were performed with two tuber-bearing, starch-containing species of plant, namely the white yam (*Dioscorea rotundata* Poir.) and taro (*Colocasia esculenta* L.).

Dioscorea rotundata Poir. Plants with a well-developed root system were regenerated from the axilarry buds and shoot tips. The highest regeneration rates were observed on the nutrient media containing 6-benzylaminopurine (BAP) and 1-naphthyl acetic acid (NAA). Using rock wool as a support substrate always led to an increase in shoot formation in all the nutrient solutions, which additionally had a low pH value. Adding chlorocholine chloride (CCC) to the nutrient solution resulted in multiple shoot formation, with up to 15 shoots per plant.

Colocasia esculenta L. Plants were regenerated from tubers which had been separated into various tissue zones. The maximum shoot regeneration in all tissue zones was obtained on nutrient media containing BAP and NAA. If, however, auxin was removed from the nutrient medium, the meristematic cell layer (cambium) could not be induced to form shoots.

The plants of both species developed well, and after a hardening phase they were transferred to a greenhouse. The present results revealed clearly that in-vitro propagation of *Dioscorea rotundata* Poir. and *Colocasia esculenta* L. is possible and thus there is good potential for regenerating planting material from these two species.

Of the plants whose underground storage organs contain mainly starch as the stored food material, only four species or genera have any major importance on a worldwide basis as sources of human food or animal feedstuffs. These are: potatoes (*Solanum* spp.), manioc (*Manihot esculentia* L), sweet potato (*Ipomoea batata* L.) and yam (*Dioscorea*).

Other tuber-bearing plant species, such as *Colocasia esculenta* (taro) and *Maranta arundinacea* (arrowroot) are widespread in the tropics, but economically they are of local importance only if they are the sole food plants available.

The tuber-bearing plant species yam (*Dioscorea rotundata* Poir.) and taro (*Colocasia esculenta* L.) are propagated mainly by vegetative means. They have been cultivated for centuries so that there are numerous varieties which differ from each other in shape, colour, taste and cooking properties.

Up to now, these species have not been systematically bred in order, for example, to achieve better yield or improved resistance to disease.

A first step in this direction would be to produce and make available planting material vegetatively propagated with specific characteristics so that pre-selected and healthy material could be cultivated. To do this, it is also necessary to separate the production of planting material from the cultivation of the consumer product – the growth period is up to 10 months long. The use of in-vitro propagation would be a major help in building up a system for the production of planting material and also for maintenance breeding.

This paper describes the results of studies conducted on the in-vitro propagation of yam (*Dioscorea rotundata* Poir.) and taro (*Colocasia esculenta* L.)

Brief description of yam plants and the in-vitro work so far conducted with this group of species

The species of *Dioscorea* (yams) are monocotyledonous climbing plants. Of the approximately 600 species which are distributed throughout the tropical and subtropical zones of the earth, about 10 are cultivated on a large scale in Africa. Most of the cultivated species of yam generate root tubers which arise from adventitious roots at the base of the stem. However, stem tubers and rhizomes also occur.

The white yam (*Dioscorea rotundata* Poir.) is the staple food in some countries of tropical West Africa. The many available selected genotypes have a growth period of 6 to 10 months. Cultivating yams requires a great deal of manual labour, which also includes providing the necessary planting material. Propagation is carried out vegetatively as follows: The tops separated from large harvested tubers (weighing up to 20 kg) are left in the ground and after 6-8 weeks they produce daughter tubers which are then themselves harvested (Franke, 1989; Rehm et al., 1976).

In some species of *Dioscorea*, such as *D. alata and D. bulbifera*, in-vitro techniques have been developed and already successfully applied (Brinks, 1992). In the case of *D. rotundata* Poir., on the other hand, only very slight success has so far been achieved. In 1978, Mantell and coworkers gave a report on the first tests conducted with an in-vitro propagation method for *D. rotundata* Poir. However, only the occasional stem tuber and microtuber could be induced from nodal segments when the length of the day and the saccharose content in the nutrient medium were optimally adjusted to each other (Ng, 1988).

Dioscorea rotundata Poir.

Material and methods

The plants were bred from a provenience which was supplied by the 'Nyankpala Agricultural Experiment Station' (Ghana). Each tuber was placed in a 12-litre plastic bucket filled with soil. The developing shrubs grew over the summer inside the greenhouse where the temperature during the day was about 30°C and at night 22°C.

The nodes with axillary buds and only the shoot tips which had not formed any inflorescences were cultivated.

Prior to cultivating the nodes and shoot tips, the surface of the plant tissue was disinfected for 15 minutes in a 2 % calcium hypochloride solution. Next, the tissue was rinsed several times with a citric acid solution (100 mg/litre) and, in order to avoid browning of the cut surfaces, the tissue parts were left in this solution until they were placed on the nutrient media.

The tissue parts taken from the donor plants were always larger than those actually required for cultivation so that the tissue (cut surfaces) damaged by the calcium hypochloride could be removed.

The nutrient media used for cultivating the nodes and shoot tips were based on the stock nutrient media developed by Murashige and Skoog (1962). The compositions of the nutrient media tested are listed in Table 1 (D1-6). Unless otherwise described, saccharose in various concentrations and 7.5 g/litre agar was added to all the nutrient media. Prior to being autoclaved, the nutrient media were adjusted to different pH values (Table 1). The nodes or shoot tips were cultured at 25°C over a 12-hour day at a light intensity of 4-6 klx. These conditions were maintained for the duration of the in-vitro cultivation.

Once the plants had developed with 3-4 leaves from the axillary buds, the respective explants were removed and the shoots were set out on the nutrient media D6-8 (Table 1).

Either agar (7.5 g/litre) or rock wool was used as the stabilizing substrate in the cultivation containers (9 cm high and 5 cm in diameter). Each pot contained two layers (2 cm thick) of rock wool and 60 ml of nutrient solution (D6-8). The rock wool must be soaked with, but not covered by, the nutrient solution.

Table 1 – *Composition of the nutrient media and their pH values*

Nutrient medium	BAP**	Kin	NAA**	CCC*	Thiamine** H Cl	L-cysteine**	my-o-** inositol	Sugar*	pH value
D1					1		100	20	5.8
D2	0.01		0.1	1			100	20	5.8
D3		0.5				20		20	5.7
D4		0.5				20		50	5.7
D5		0.5				20		50	6.2
D6		0.5				20		50	5.4
D7	2		2	100				80	5.0
D8	2			100				80	5.0

BAP – 6-benzylaminopurine * g/l
Kin – 6-furfurylaminopurine ** mg/l
NAA – 1-naphthyl acetic acid
CCC – chlorocholine chloride

There was no difficulty in transferring the in-vitro plants to the soil, provided that the plants were kept in an environment with high atmospheric humidity during the first few days.

Results and discussion

Plants with well-developed root systems were regenerated from the axillary buds and shoot tips. In addition to this vegetative propagation of the material, the nutrient media described for *Dioscorea rotundata* were also tested (Ng, 1990).

Altogether 50 nodes or shoot tips were placed on each of the four nutrient media (Table 1, D1-4). The composition of the nutrient medium D1 was based on the experience gained with the media used for propagating potatoes (Mix, 1984). However, it was found that on a nutrient medium that contained no hormones, shoot regeneration from axillary buds was very poor (9 %) in monocotyledons such as yams, compared with in dicotyledonous potatoes (95 %). When 6-benzylaminopurine (BAP) ans 1-naphthalene acetic acid (NAA) were added to the nutrient medium (D2), the rate of regeneration was increased by 71 % to 80 %. Multiple shoot formation was promoted by increasing the concentration of BAP and NAA in the nutrient medium (D7, D8). The nutrient media D3 and D4, having the composition described by Ng (1990) for yam, were also included to determine their suitability in connection with the genotypes to be tested. However, in the tests described here, the D3 nutrient medium, which had demonstrated the ability to promote a high rate of shoot formation from nodes, managed to promote only 12 % shoot formation from nodes or shoot tips on agar, or 20 % shoot formation on rock wool. By increasing the saccharose concentration from 20 g/litre to 50 g/litre and extending the length of the day to 12 hours, Ng (1990) was able to induce microtubers on 62.5 % of the yam shoots. This result was not confirmed by the present tests on nutrient medium D4. In the case of D4 the shoot formation rate (10 % on agar, 21 % on rock wool) was similar to that achieved on D3, but the shoot took significantly longer to form and did not once result in the formation of microtubers.

The nutrient media D5 and D6 had the same composition as nutrient medium D4. However, medium D5 was adjusted to a pH of 6.2 and D6 to a pH of 5.4. The results are summarized in Table 2.

The shoot formation was significantly influenced by the pH value on both nutrient media. The high pH value (D5) had a negative effect on the shoot formation rate. On the nutrient medium to which agar had been added, the shoot formation rate was 5 % and on rock wool it was 82 %. On the nutrient medium with the low pH value of 5.4, 62 % of the nodes or shoot tips were able to form shoots on rock wool and 28 % on agar; the shoots which formed on the rock wool were characterized by particularly strong growth.

After 6 to 8 weeks, the shoots were separated from the respective explants. They were then transferred to three nutrient media (Table 1, D6-8), contained in the large pots (9 cm high, 5 cm in diameter).

The reason for placing part of the shoot once more on the D6 nutrient medium was to check again whether, as is possible in the case of the potato (Abbot et al., 1986), a microtuber could be induced to form in the presence of an elevated saccharose concentration and over a longer day.

After 3 months of culturing, microtuber-like structures were detected at the base of the root on three out of 35 shoots; however, these did not develop any further and therefore they cannot be regarded as microtubers.

Table 2 – *Influence of the support substrate on the regeneration rate of shoots*

Nutrient medium	Substrate	Regeneration rate %	Ø Average number of shoots/plant
D5	Agar	5	1
	Rock wool	82	1
D6	Agar	28	1
	Rock wool	62	2
D7	Agar	51	8
	Rock wool	85	15
D8	Agar	3	2
	Rock wool	10	3

1-naphthyl acetic acid was added to nutrient medium D7 and, as was done with the D8 medium, 6-benzylaminopurine, chlorocholine chloride (CCC) and 80 g/litre saccharose were also added and prior to being autoclaved the medium was adjusted to a pH of 5 (Table 1).

Chlorocholine chloride (CCC) was added to the nutrient medium because Hussey et al. (1984) had described this substance as being decisively important for the in-vitro formation of tubers in potatoes. Lentine et al. (1991) also reported the importance of CCC in the formation of tubers. The results obtained here for yams did not confirm the influence of CCC on microtuber formation.

In the case of the yam nodes or the shoot tips, the CCC, acting in combination with NAA, had a strong influence both on single shoot development and also on multiple shoot development; this was proved by the fact that on nutrient medium D 7 with rock wool a plant formed on average 15 shoots at a shoot formation rate of on average 85 %.

On the D7 agrar nutrient medium, the shoot formation rate fell back to 51 % and the multiple shoot formation rate to 8 % per plant. Once the auxin had been removed (nutrient medium D8) significant inhibition of single- and multiple shoot formation was observed. The regeneration results obtained with the rock wool culture were slightly higher than on the nutrient medium to which agar had been added.

The use of rock wool as a stabilizing substrate consistently led to an increase in shoot formation in all the nutrient solutions (Table 2).

Multiple shoot formation was increased still further by using larger cultivation containers. A similar phenomenon was observed in the case of chicory, namely that in larger pots new shoots formed at the base of the root on the in-vitro plants (Mix et al., 1988).

The results obtained with the formation of single and multiple shoots permit us to conclude that the nodes and shoot tips of *Dioscorea rotundata* Poir. prefer a nutrient medium with a low pH value for the in-vitro regeneration of entire plants.

Brief description of Taro (Colocasia esculenta L.) and previous in-vitro work performed on this species

Among the species of plant whose rhizomes are a source of starch, *Colocasia esculenta* L. is the most important food plant and has about 1000 selected genotypes. It is indigenous to the Sunda archipelago, but it also occurs in all tropical regions where suitable conditions are found for the perennial swamp form of the plant. Taro is an interesting plant in cultivational terms because it tolerates very high levels of salt in the soil.

Several thick, heart-shaped leaves, whose stalks can be up to 2 m long, grow from the short, tuberous rhizomes (corms).

Colocasia esculenta L. is an aroid, namely a plant of the family Araceae, and as such it develops a spadix-shaped inflorescence without forming any seeds. During the 6-15 month growth period the rhizome increases in size and the daughter tubers formed on the stolons are used as the planting material (Franke, 1989; Rehm et al., 1976).

The first plants were regenerated in vitro from *Colocasia* shoot-tip (meristem) cultures (Mapes et al. 1972; Cendeño-Maldonado et al., 1988). Other explants such as axillary buds an pieces of stalk were also used for the regeneration of plants (Jackson et al., 1977; Yam et al., 1990 b). In a review article, Morishita (1988) reports on the results which have so far been achieved in vitro.

Since the tuber is usually available as the starting material, it would be advantageous to regenerate plants directly from tuber tissue. Esenowa (1986) succeeded in inducing calluses to form on tuber segments by using a combination of kinetin and various auxins in different concentrations, and also by adding coconut milk to the nutrient medium.

Colocasia esculenta L.

Material and methods

The test to regenerate plants from pieces of tuber were conducted with a *Colocasia* genotype from Asia. The tubers were divided up into ring-shaped pieces by cutting slices (about 1 cm thick) across the width of the tuber; the slices were then divided up into two rings (the width of the ring varied with the size of the tuber) and a centre piece (Figure 1).

The round centre piece was discarded because it consists of primary tissue and as such does not contain any meristematic zones but merely large cells and large intercellular spaces filled with a viscous, opaque fluid. Ring I consisted of cortical cells and leaf primordia, and ring II consisted of vascular tissue and cambium. The tubers were cut up while immersed in solution A (400 mg/l each of citric acid and ascorbic acid) in order to prevent the tissue from turning brown. Then the pieces (separated into ring sections) were placed for one hour in an ash-fungicide solution (B). Solution B contained 100 g of ash and 5.3 g of fungicide (Benomyl/Du Pont) per litre. While this treatment was being carried out, the solution containing the pieces of tuber was stirred several times. Next, the pieces of tuber were disinfected for 20 minutes in a 3 % calcium hypochloride solution (C). After that, the pieces of tuber were rinsed several times with the sterile solution A. They were then left in solution A so that browning

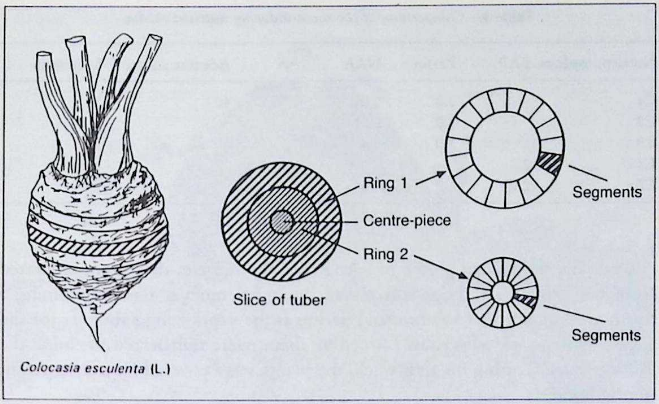

Fig. 1 – *Diagram of the segmentation of the tuber.*

of the tissue would be avoided also while the pieces of tuber were producing shoots.

Rings I and II were cut into pieces about 2 cm wide. From the ring material I and II in each case 200 pieces were placed on 5 different nutrient media (40 pieces per medium). Since the rings were arbitrarily cut into pieces, it is not possible to assume that each piece contained at least one bud or meristematic tissue (cambium). On the other hand, it is possible that one piece contained several zones capable of regeneration.

The pieces were cultured three at a time in an Erlenmeyer flask (100 ml) at 25° C over a day of 16 hours at 4-6 klx. The Erlenmeyer flasks contained either solid nutrient medium (6 g/l agar) or nutrient solution with 4.5 g perlite/glass as the supporting substrate.

All the nutrient media used, on which the pieces of tuber exhibited a reaction, contained a 50 % concentration of the same macro and micronutrients employed by Murashige and Skoog (1962), and also 20 g/l saccharose. The five most successful nutrient media were made up as follows (Table 3): Cytokinins: 6 benzylaminopurine (BAP), zeatin (Z); auxins: indolyl acetic acid (IAA), 1-naphthyl acetic acid (NAA); adenine sulfate (AS) and L-cysteine (CY). 1 mg/l thiamine HCl, 0.5 mg/l nicotinic acid and 0.5 mg/l pyridoxine HCl were added to all the nutrient solutions. The pH of all the solutions was adjusted to 5.7.

Table 3 – *Composition of the shoot-inducing nutrient media*

Nutrient medium	BAP	Zeatin	NAA	IAA	Adenine sulfate	L-cysteine
C1		3.0	0.01		40	30
C2		3.0	0.01			
C3		3.0	0.1			
C4	2.0					
C5	2.0		1.0	0.1		

Once the shoots had grown to a length of about 5 cm, they were separated from the explant. A shoot was placed in an Erlenmeyer flask containing a hormone-free nutrient solution and perlite as the supporting substrate for the shoot. The shoots, with roots formed on them, were transferred to soil at the 2-3 leaf stage. During the first week, the plants were covered by a transparent plastic hood.

A cryomicrotome was used for the microscopic studies. The microscopic sections were stained using a 0.05 % toluidine blue solution.

Results and discussion

It had been discovered in preliminary tests that, while the tubers were being sliced, the tissue gradually turned brown. However, if the tubers were cut while in a solution containing ascorbic acid and citric acid (solution A) the brown discoloration could be reduced by 97.5 % compared with the controls, in which 80 % of the tuber pieces were brown.

A further problem was posed by the disinfection of the pieces of tuber. If the latter were sterilized only in solution C (3% calcium hypochloride solution), 80 % of the pieces of tuber still became contaminated and had to be discarded after a few days. Combined disinfection carried out in solution B (fungicide/ash) and C (calcium hypochloride) reduced the rate of contamination by 50 %.

In order to avoid oxidation of the tissue while being cultured, 30 mg/l L-cysteine was added to the C1 nutrient medium, a procedure which has also been described by other authors (Ng, 1988).

In the present tests, the addition of L-cysteine to the nutrient medium did not yield any additional effect, because rinsing the tissue parts with ascorbic and citric acid (solution A) had a lasting effect on the tissue.

Dividing up the tuber tissue into two rings was intended to demonstrate to what extent the existing cambium zone in monocotyledons is capable of regenerating shoots, and thus of increasing the regeneration rate of a tuber. Up to now only isolated buds have been described as the starting material for

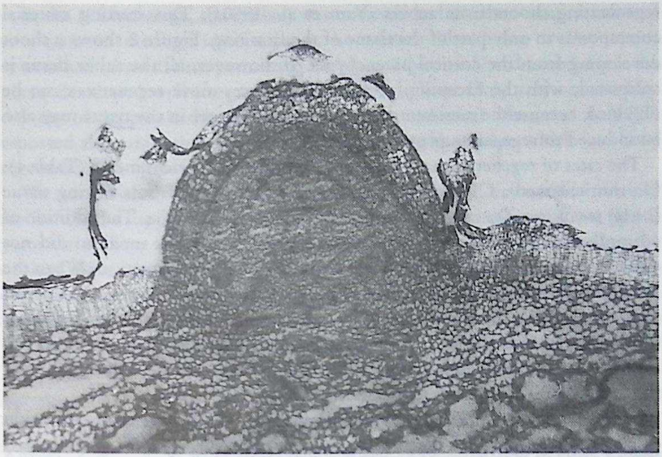

Fig. 2 – *A shoot developing from the cortical layer.*

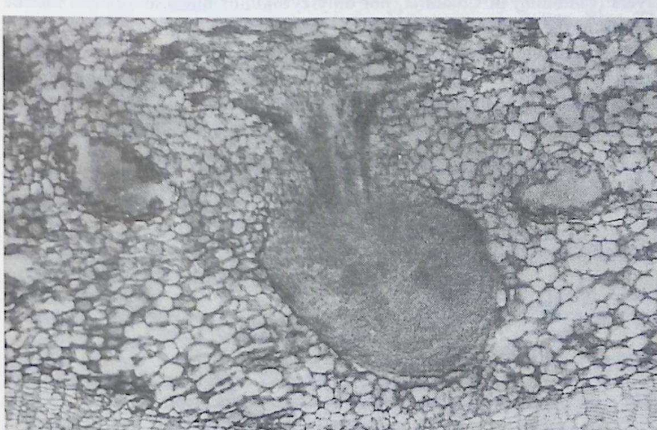

Fig. 3 – *Development of a shoot from a bud embedded in the tissue (Ring II).*

regenerating shoots from tubers (Yam et al., 1990a). This starting material corresponds to only part of the tissue of the first ring. Figure 2 shows a shoot developing from the cortical parenchyma. If, however, all the tuber tissue is cultivated, with the exception of the centre piece, more regenerates can be obtained, because the meristematic zones located deeper in the tissue may also be induced to regenerate plants (Figure 3).

The rates of regeneration varied greatly on the five nutrient media (Table 4): On nutrient media C1 and C2 shoot formation from both sets of ring tissue (I+II) was lower than on the remaining three nutrient media. The addition of 40 mg/l adenine sulfate and L-cysteine to the C1 nutrient medium did not yield any detectable influence on the induction of shoot formation. When the 1-naphthyl acetic acid (NAA) content was increased from 0.01 mg/l (C1 + C2) to 0.1 mg/l (C3), the tissue reacted by exhibiting a significantly higher shoot formation rate in both rings. Similar observations were described by Yam et al. (1990a). In fact, these authors quote 0.1 mg/l NAA in the nutrient medium as the lowest limit for shoot regeneration.

When zeatin was replaced by benzylaminopurin (C4), only the first section of ring tissue displayed a high regenerative capacity on nutrient medium C4. All the visible leaf primordia (buds) formed a shoot, whereas only the occasional shoot was formed from the tissue of the second ring. It would seem to be the case that in order for shoots to regenerate from meristametic cell layers (cambium) in *Colocasia*, not only cytokinins but also auxins must be present in the nutrient medium.

The maximum shoot regeneration from pieces of tissue was attained on nutrient medium C5. Gómez et al. (1989) were also able to report that indolyl acetic acid had a positive effect on shoot formation.

Table 4 – *Number of shoots regenerated from two layers of tuber tissue*

	Nutrient medium	Absolute quantity of regenerated shoots	Regeneration rate
	C1	21	52.5
	C2	19	47.5
Ring I	C3	41	102.5
	C4	38	95
	C5	44	110
	C1	14	35
	C2	12	30
Ring II	C3	34	85
	C4	8	20
	C5	32	80

In the 1-2 leaf stage, the explant was removed and the shoot was transferred to a nutrient medium containing no hormones. After a few weeks, a root system had formed, thus permitting the plant to be transferred to soil. Here the plants developed well after a short adaptational phase. Only very occasionally did any of the plants die off when transferred to the soil. Monge et al. (1987) reported the same observations when cultivating the plants which had been regenerated in vitro.

We can conclude from the results presented here that, if a suitable nutrient medium and a supporting substrate are used, the axillary buds and shoot tips of yams can achieve a high level of shoot formation. If taro tubers are used as the explant material, the regeneration rate can be increased because not only the cortical layer but also the underlying layer containing the cambium can be included in the regenerating tissue.

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REAFFORESTATION AND OTHER FORESTRY CO_2 STRATEGIES

by

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It is not only vegetation cover and the normally much greater biomass in the soil that constitute forestry CO_2 sinks but also the stock of carbon stored in forestry products. The effect of such sinks is increased when the products replace fossil sources of energy.

Factors limiting the realisation of forestry CO_2 sinks are not so much the availability of land or production techniques as organisation, management, funding and processing techniques, plus the selfsame general conditions that foster the present destruction of forests.

Forestry CO_2 strategies should contribute not only to CO_2 absorption but also to regional development. They should be sustainable and socio-culturally acceptable. By these criteria, in such strategies forest protection and the rehabilitation of degraded forest rank highest in terms of priority, while timber plantations rank lowest.

Afforestation is sometimes seen as a cheap, simple solution to the problem of CO_2 accumulation in the atmosphere. In this paper, it is shown that, although forestry CO_2 strategies can make an important, perhaps even indispensible contribution, they cannot possibly solve the CO_2 problem by themselves.

In a forest, CO_2 is continuously absorbed from the air and stored as organically absorbed carbon, but it is also constantly being released during metabolism and as dead biomass decays. The total supply of carbon stored in a forest can increase up to a upper limit that varies considerably according to the location and type of vegetation. Once this upper limit is reached, as much CO_2 is released as is absorbed. The upper limit of carbon stocks may be imagined as a vessel; once the vessel is full, the amount in equals the amount out.

A model for forestry CO_2 sinks

In order to make the CO_2-sink function of forests clearer, the stocks and flows of carbon are shown separately in Figure 1. If the forest is worked for products, the carbon storage capacity of the ecosystem can be increased by the amount of carbon stored in the products. Just as with the carbon storage in the forest, the storage capacity of the products is likewise not expandable ad infinitum but limited. If however the forest products replace or reduce the consumption of carbon fossils (oil, natural gas or coal), this increases the CO_2-sink function of the forest. The carbon cycle of forest, product and atmosphere can in theory replace the linear flow of carbon from the bed via the consumption of energy to the atmosphere an unlimited number of times, i.e. in this case the CO_2-reduction function of the forest would continually expand.

In assessing the effectiveness of a forest in reducing CO_2-accumulation in the atmosphere, it also matters whether this forest and its use contribute to another forest's being preserved rather than burnt to CO_2.

The ideal CO_2 strategy would be to preserve existing forests and plant on barren land forests with high growth and end-supply characteristics and organic material that decays as slowly as possible; forests that can be worked for as many products as possible have a long lifespan and/or replace many carbon fossils; forests whose use represents an effective protection for other forests.

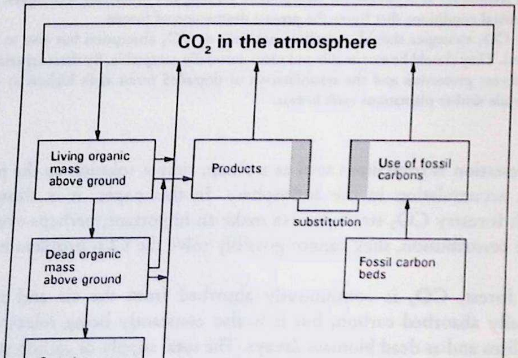

Fig. 1 – *Carbon stocks and flows relevant to forest CO_2 strategies.*

Order of magnitude of forestry CO_2 sinks

Varying climate, soil, type of vegetation and treatment make for a very great variety of forestry CO_2 sinks. The reductions have been quantified very inadequately in the past and on the basis of very different methods scarcely permitting comparisons. We have of course forestry inventories aplenty, but these generally only quantify the volume of trunk wood. For very rough estimates, it can be assumed that 2.5 m^3 of trunk wood corresponds to the vegetation above ground of a tonne of carbon. The estimates in Table 1 will serve just to give an idea of the order of magnitude of forest carbon stocks. According to Sombroek et al. (1993), the stock of carbon in the ground amounts globally to half as much again as that in vegetation; in tropical rainforests, the stocks correspond, while in other ecosystems two to ten times as much carbon is stored in the ground as in vegetation. The quantities of carbon absorbed annually in forests (t C/ha/a) can be estimated for the boreal zone (GTZ, 1993, p. 12) at one, for the temperate latitudes at two to seven and the tropics at seven to ten. Admittedly, the US Environmental Protection Agency puts possible peak values of 26 tonnes C/yr/ha for the tropics (euclyptus hybrids) and 15 tonnes C/yr/ha for temperate zones (Douglas firs) (quoted from Trexler, 1993, p. 21).

Clearing of primary and secondary forest: According to Andrasko, the following quantities of carbon were released in 1990 as a result of burning forests: tropical rain forests 0.57 bn tonnes, savannahs 1.66 bn tonnes, temperate and boreal forests 0.13 bn tonnes (quoted from Howlett and Sargent, 1993, p. 29). Not only is the total biomass above ground converted into CO_2 but 20-50 % of the organic matter in the topsoil is also broken down; though if the land is laid out to certain kinds of pasture immediately after the clearance, the carbon content of the ground can reach the pre-clearance level or possibly even surpass it, without of course compensating for the above-ground loss of carbon (Sombroek at al. 1993). Often, very little of the wood is used in a clearance.

Table 1 – *Estimate of carbon stocks in forest vegetation – (tC/ha)*

Tropics		Temperate		Boreal	
Dry	15– 40	Primary forest	135–160	Primary forest	90
Seasonal	66– 90	Secondary forest	100–120	Secondary forest	65
Humid	70–140				

Source: Houghton et al. 1987, quoted by Trexler 1993, p. 27

Protection of primary forest: Where climax forest is concerned, protecting it has no effect on the CO_2 balance of the atmosphere because just as much CO_2 is released as is absorbed, and the same applies to oxygen. The notion of tropical forests as 'green lungs' is – at least for climax forests – misguided. However, compared with the alternative of clearance, protecting primary forest has very positive effects on the CO_2 balance.

In the protection of secondary forests, moreover, the stocks of carbon in the living and dead above-ground biomass are increased, and in young secondary forests so is the carbon in the soil.

Cultivating primary forest brings about a marked reduction of the above-ground biomass: part of the living biomass is harvested and leads to an increase in product-based storage, while another part – the remaining timber plus the non-usable species also cut as part of the cultivation – initially increase the stock of dead organic matter, which is of course rapidly broken down by the stronger ingression of sunlight. The effects on other carbon reserves are on the one hand negative because of the use of foreign energy (fuel, machinery), on the other hand positive if cultivation reduces the pressure to work other forests.

Cultivating secondary forests brings about a growth in the stocks of organic matter both above and below ground as well as in the supply of products. With regard to the effect on the CO_2 balance of the atmosphere, cultivating the large tracts of secondary forest available seems particularly interesting. Trexler estimates (1993, p. 28) that the rehabilitation of secondary forest up to 2050 could absorb more than twice as much CO_2 (nine to 23bn tonnes) as plantations (nine million tonnes).

Among reafforestations, tropical plantations have the highest potential for CO_2 absorption per hectare, although admittedly certain pre-conditions are required that can be guaranteed only over relatively small areas. Large plantations can increase the pressure to exploit other forests and possibly even cause their destruction.

Small afforestations for timber production or protection purposes often effect little CO_2 absorption; however, success and sustainability are easier to guarantee than with plantations.

Agroforestry systems store even smaller quantities of CO_2 in the above-ground biomass, as the surfaces are only partly stocked with trees. However, they can generate a marked increase in the carbon supply in the ground. In a GTZ project in agroforestry systems in the eastern Amazon area and in very poor soil, within 24 weeks six to nine tonnes of mulch (about 3-4.5 tonnes of carbon) was produced per hectare, depending on the type of trees used, and supplied to the soil (Burger and Brasil, 1991). Even more important than the carbon store itself is however the effect of agroforestry systems on the protection of primary and secondary forests: the tree components and preservation of soil fertility enable a lasting alternative use of cultivated areas compared with the traditional way of abandoning them after 2-3 years and clearing new areas.

Urban tree stocks represent very minor carbon reserves in themselves, but have a great regulatory effect on the climate of a town and can replace to a considerable extent the energy consumption of air-conditioning equipment. Trexler reports (1993) that, although in the USA 100 million trees represents a carbon reserve of only six to ten million tonnes of carbon, they annually replace the consumption of 17 million tonnes of fossil carbons; this means that six trees can effect the replacement of one tonne of fossil carbon, or as much as a whole hectar of boreal forest.

The comparative assessment of the CO_2 relevance of various forestry options is rendered difficult by three unknown factors:

- the possible "fertiliser effect" of the higher CO_2 content of the air;
- a possible rapid breakdown of dead organic matter because of higher temperatures;
- a possible displacement of vegetation zones, as a result of which boreal forests could shrink by 30 %, subtropical forests by 22 % and tropical forests expand by 28 % (Trexler, 1993, p. 91). This would make the large afforested areas unstable despite protection and cultivation, and eventually kill them.

The feasibility of forestry CO_2 sinks

One might assume that forestry CO_2 sinks, expecially reafforestations, could be realised relatively easily. Experience so far testifies quite the opposite. In the tropics, only two per cent of forest areas are reafforestations; in the past decade, ten times as large an area was cleared annually as was reafforested. Were this current imbalance to continue, then in 117 years there would be no forests in the tropics at all. As Table 2 shows, the few tropical reafforestations were moreover carried out chiefly with pioneer tree species, which deliver relatively short-lived products. Only teak is represented in any significant quantity as a valuable timber species in tropical reafforestations.

A very high proportion of the attempts at reafforestation have been unsuccessful. The loss ratio of tropical reafforestations hitherto must be (GTZ, 1993, p. 46) 65% in semi-arid areas, 45% in humid areas and 30% in temperate and boreal areas.

The reasons why reafforestations fail are, besides deficient protection and care, the choice of the wrong types of tree due to inadequate site investigation.

Table 2 – *Forestry resources in the tropics, destruction and renewal 1990, according to FAO 1992**, Dembner 1991***, D. Pandey 1993*****

Region	No. of countries investigated **	Area in m km² **	Forest area m km² **	Forest lost p.a. m ha ***	Reaff. area m ha **	Reaff. area p.a. m ha **	Share of tree species in reaff. projs. in % ****				
							A	B	C	D	E*
Africa	40	22.4	5.3	4.8	2.1	0.09	26	20	5	8	41
America	33	16.5	9.2	7.3	6.0	0.26	47	32	0.2	1.2	20
Asia/Pacific	17	8.9	3.1	4.7	22.6	1.45	16	4	6	10	64
Total	90	47.8	17.6	16.8	30.7	1.80					

* A = eucalyptus, B = pine, C = teak, D = acacia, E = other

Availability of land

The reafforestation programme recommended by the Nordweik conference in 1989 would require an area of 12 million hectares a year, or 600 million hectares altogether. In the tropics, more than a billion hectares of forest have been cleared; a large part of this land is degraded and apparently scarcely used. Grainger (1988, quoted from Trexler, 1993, p. 3) estimates that in the tropics 2.08 billion hectares of land are degraded in various forms and in theory would be available for reafforestation. On the basis of ecological and economic criteria he proposes reafforesting 621 million hectares, 36% of it in Asia, 36% in Latin America and 28% in Africa.

It is of course very often a mistake to assume that no-one lays claim to land that appears abandoned. Often, such land is vital for certain groups of population, even if for the larger part of the year it appears unused, for example pasture areas for nomadic shepherds. On closer examination, far more ecological and economic restrictions are revealed than are apparent at first sight. On the basis of detailed investigations in more than 50 tropical countries, Trexler estimates (1993, p. 8) that in the tropics 67 million hectares are really suitable for timber plantations, 216 million hectares are suitable to secondary forest rehabilitation and 63 million hectares are suitable for agroforestry systems, i.e. in all, 348 million hectares are actually suitable and realistically available.

Large reafforestation and forest rehabilitation programmes should not therefore fail for want of land availability. Even if the whole CO_2 surplus of industrial countries is not to be stored in tropical reafforestations, there are still areas available that would permit an increase in the existing reafforestation and forest rehabilitation activities many times over.

Finance

The costs for the various forestry CO_2 options depend so strongly on the specific local situation that global estimates can ultimately provide no evidence on which to base how much finance is needed; finance can be determined only for programmes specific in content and location. The cost estimates set out in Table 3 represent only ranges of estimated values. The US Environmental Protection Agency (EPA, 1991, as quoted by Trexler, 1993, p. 66) estimates that, for the various forestry options, on average US$ 5 per tonne of carbon would be needed, i.e. substantially less than for other strategies, for example $ 95/tonne for wind energy and $ 535/tonne for nuclear energy (Myers, as quoted by Trexler, 1993, p. 67).

The total forestry development aid of all donor countries amounted to US$ 1 billion in 1989; this represents a fivefold increase compared with 1983, but is still only a fraction of the sums that would be needed to support forestry protection and forest exploitation in the forestry sector of developing countries, such as would be required - among other things - for an efficient CO_2 strategy. According to the FAO, public development aid and private investment in the order of $ 13-17bn would be needed every year for the developing countries in the 1990s. The World Resources Institute puts the figure even higher, at US$ 20-50 billion (cf. Trexler, 1993, p. 64).

Table 3 – *Cost estimates for forestry CO_2 strategies*

Author	Region	Forest protection US$/ha (US$/tC)	Forest rehabilitation US$/ha (US$/tC)	Agroforestry US$/ha (US$/tC)	Timber plantation US$/ha (US$/tC)
EPA 1991	tropics		100–300 (0.54–2)	300–2500 (2–11)	100–4300 (3–26)
Graham 1990	Africa	25–115 (3–15)		50–150 (2–10)	560–1060 (1–22)
Myers 1991	tropics			200–500	2000 (10–16)
EPA 1991	temprte latitds		5800 (0.01–0.43)		5–4500 (0.20–29)
EPA 1991	boreal		75–300 (4–11)		50–575 (3–27)

Source: data publ. by Trexler, 1993, p. 67 ff.

Management and organisation

Successful plantation businesses are generally integrated with the processing industry, and have as tight a management and organisation as the latter. This is necessary, because they involve highly different but interdependent tasks such as obtaining land possibly with purchase or exploitation contracts, establishing a site, running a nursery, recruiting and training a workforce etc.

If the need for management and organisation in the case of the other forestry options is not as high as with plantations, it is still likely to constitute one of the biggest hurdles. This is why attempts worldwide to rehabilitate secondary forest by enrichment plantation have failed after making a very promising start because the management and organisation to provide ongoing care for the area treated were inadequate. Even in the case of agroforestry systems, it can be safely stated that, after the development and spread of promising types of product, management and organisation become critical factors for the success of the systems: in relatively complex systems, the work must be broken down into discrete tasks, particularly the first stages of processing and marketing the products. These are tasks which in many countries neither the producers nor the research and advisory institutions are adequately prepared.

Technology

The technology for all the above-mentioned forestry options are relatively well-known in outline but must of course be adapted and developed for the specific conditions in each application; this is ensured by adequate organisation and management; production technology is hardly likely to become a bottleneck in putting forestry CO_2 strategies into practice.

Processing technology in contrast must be considered a much more critical matter. It was explained above that the effectiveness of forestry CO_2 strategies must remain limited if the attempt is unsuccessful to use substantially more wood product either in the very long term or (and this is the nub of the matter) as a substitution for the application of fossil raw materials. For this, however, the processing technology of wood products, especially that of energy application, must be developed a lot further.

The environment for success

All expansion of forestry activity must remain in doubt in developing countries as long as the socio-economic environment persists that favours the current process of destruction. In its forestry sector paper (World Bank, 1991), the World Bank sets out four core conditions that need to be fulfilled to slow the present destruction of forests:

- strategies for reducing poverty, which particularly include stepping up agricultural productivity and income generation in the non-agricultural realm;
- zoning and regulating forests, i.e. establishing realistic priorities for forest areas of varying function within a land-use framework;
- correcting economic incentives and subsidies such as fixing an appropriate level of concession charges and periods, removing tax, land ownership and other incentives encouraging clearance while at the same time formalising land ownership by settlers as a prior condition for lasting management;
- public investment in favour of controlled development based on environmental impact assessment and forestry institutions for administration, research, training and counselling.

If forestry CO_2 sinks are to be not only preserved but considerably extended, including the increased application of forest products in place of fossil energy sources, it is critical moreover that the economic framework be modified so that the environmental sustainability of the origination and application of products be expressed in their costs, whether by means of price changes or of additional duty or tax. As long as the price for crude oil remains far below the real total economic cost, even the most environmentally sound application of wood cannot compete.

Development criteria for forestry CO_2 strategies

From a developmental policy point of view, strategies focusing exclusively on absorbing or reducing CO_2 appear not very sensible. As the unwanted CO_2 is produced primarily in industrial countries, such strategies would mean developing countries providing 'CO_2-problem rubbish tips' for industrial countries and also being compensated for them in certain circumstances. One can hardly envisage huge tracts of land such as are necessary for forestry CO_2 strategies being reserved exclusively for the benefit of other regions without the region concerned and its inhabitants deriving some direct benefit from it. Forestry CO_2 strategies must be introduced regionally, and this is only possible if they are integrated in regional development planning and are of benefit to it.

Forestry CO_2 strategies must in particular not be carried out at the expense of improved agricultural productivity, for example as a result of competition for fertile agricultural land or ground water. Without drastic productivity improvements in agriculture, the pressure on forests will become so strong that CO_2 strategies will become impossible to introduce. Among the development policy criteria required of forestry CO_2 strategies are:

A contribution to regional development, especially in adding to the region's net product, alleviating poverty and protecting resources; reafforestation has often failed to fulfil these expectations; the job-creation effects of reafforestation and consequent reduction in poverty are often relatively minor. In a study in Thailand, it was established that planned plantations would mean 500 000 families losing their cultivable land and in the best case only 150 families getting an income (Trexler, 1993, p. 96)). Often, plantations lead to an intensified demand to exploit other agricultural and forestry areas, which is detrimental to the protection of the productive resources of a region.

Sustainability, in particular by conserving the fertility of the soil and stability of the stands in the face of disturbances of climatic, biotic or human origin; this requirement is often not adequately met by large-area plantations, particularly when – as has been normal hitherto – they are laid out as monocultures.

Socio-cultural acceptability, above all by constructing new forms of exploitation on already existing exploitation systems and also respecting traditional roles (headmen, the elderly, women) and customs (e.g. sacred sites).

Bearing in mind these development policy criteria, the following priorities for the various forestry CO_2 strategies can be established at present:

- protection of existing forests;
- rehabilitation of degraded forests;
- protective planting;
- agroforestry systems;
- small-area reafforestations;
- management of intact forests;
- timber plantations.

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DETECTING CHANGES IN THE VEGETATION OF THE SAHEL BY MEANS OF MULTITEMPORAL COMPARISON OF SATELLITE DATA

by

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The multitemporal processing of Landsat image data from a test area in the Republic of Niger yielded results which will make it easier and very much cheaper in future to compile vegetation and land use inventories. With the method presented here, it is possible to detect and record desertification processes as a function of time and space. In addition, the method can make an important contribution to estimating (and possibly also forecasting) harvests of rainfed crops, because the areas under cultivation can be identified and the development of the vegetation cover can be monitored.

In addition to spectral characteristics, the method makes use of an additional classification parameter, namely vegetation dynamics, thus considerably increasing the accuracy with which the various vegetation and surface units are identified and delineated. This applies in particular to bush vegetation, grassland, grassland with trees, rainfed crops, and areas without any vegetation cover. Other units such as lateritic crusts, vegetation at the edges of temporary lakes ("mares"), and dried-up watercourses as well as open water can also be identified with sufficient accuracy using monotemporal classification methods.

The results yielded by this method were checked and their high degree of accuracy was verified by carrying out on-the-ground inspection and by comparing them with the data from aerial photo interpretation (scale approx. 1:64 000).

The results of the studies described here are part of the project for the "Evaluation of Satellite Images for a Long-Term Aid Programme in the Sahel

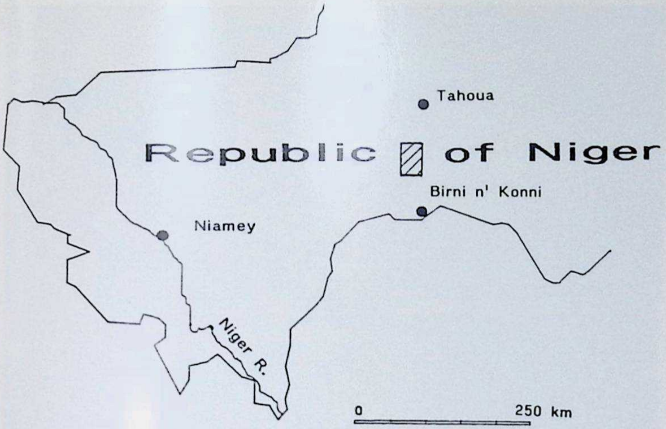

Fig. 1 – *Position of the area of investigation.*

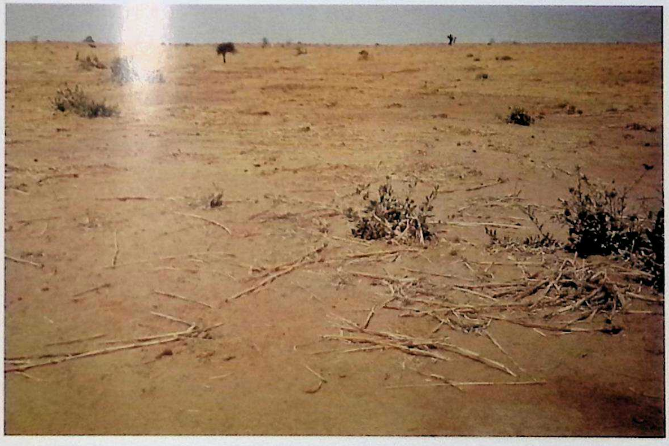

Fig. 2 – *Stationary dune; millet cultivation area after the harvest (photo: Kantor).*

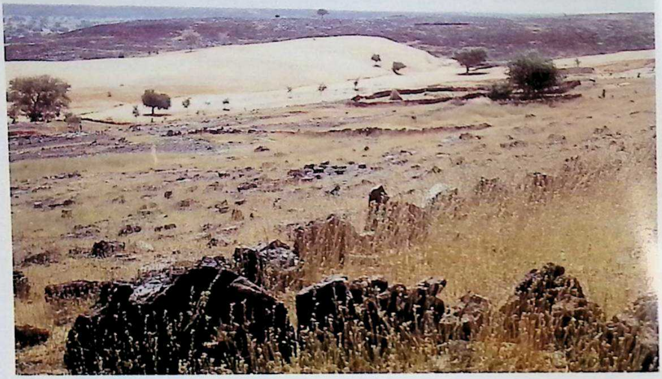

Fig. 3 – *Vegetation-free wandering dune in the centre of the picture (photo: Schwonke).*

Fig. 4 – *Tree stand at the edge of one of the temporary lakes (photo: Kantor).*

40 km

30 km

Fig. 1
Colour image/04. 08. 1975
(vegetation in red)

Fig. 2
Colour image/15. 10. 1975
(vegetation in red)

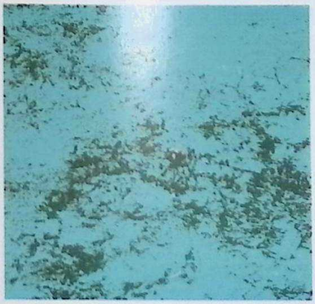

Fig. 3
Distribution of vegetation
(dark areas)
on 04. 08. 1975
Ratio B5/B7 August

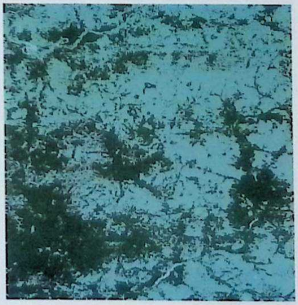

Fig. 4
Distribution of vegetation
(dark areas)
on 15. 10. 1975
Ratio B5/B7 October

Plate 1

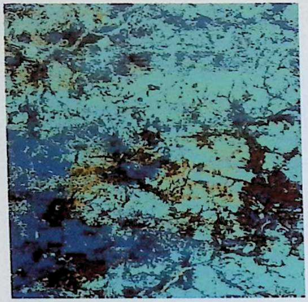

Fig. 1
Change in the vegetation
Difference between the ratios for October and for August 1975
(with gating)

Fig. 2
Change in the vegetation
Difference between the ratios for October and for August 1975
(without gating)

Primary colours: Blue = B5/B7 August; Green = B5/B7 October
Red = B5/B7 October – B5/B7 August

Plate 2

Fig. 1
Change in the vegetation
Difference between the ratios for October and August 1975

Primary colours: Red = B5/B7 August;
Green = B5/B7 October

Explanations for

Plate 2/Fig. 2	Plate 3/Fig. 1
Light blue:	Yellow:

Regions with little or no vegetation which have undergone *very little change* between August and October.

Dark blue:	Red:

Regions in which the vegetation has *increased* between August and October. The stronger the colour, the greater the increase.

Brown:	Brown:

Regions in which a thick vegetation cover has become even *denser* from August to October. Moderate coloration corresponds to moderate vegetation cover.

Yellow:	Green:

Regions in which the vegetation has *declined* between August and October. The stronger the colour, the greater the decrease in vegetation cover.

Plate 3

Region of the Republic of Niger" which was carried out by the Federal Institute for Geosciences and Natural Resources at the request of the Federal Ministry of Economic Cooperation (FRG). The concept was based on the use of Landsat data to draw up regional inventories of soils and land use, as well as geological and hydrogeological conditions.

This present paper contains the results of laboratory experiments which were published as early as 1983 by W. Kirchhof et al. The results were confirmed by follow-up examinations in the field and new information has been added.

Aim of investigation

One important application of satellite remote sensing is the computer-assisted processing of satellite data for the production of thematic maps. With this method, the features of interest on the earth's surface are located, identified and arranged in groups, by recording specific spectral properties and/or characteristic forms.

As part of the present project, the intention is to determine whether computer-based classification in the Tahoua – Birni n'Konni region can be used to produce vegetation and land use maps of sufficient accuracy and at reasonable cost.

Difficulties were encountered when the current monotemporal methods of classification were used. It was found that it was not possible to distinguish accurately enough between certain units of interest, or it would have been unacceptably expensive to attain such accuracy. Therefore, the classification process had to be re-examined and a new approach found to solve this problem.

Vegetation dynamics as a classification feature

The distinction between certain important vegetation units in the study area is made difficult by the fact that at certain periods of time the differences in their spectral reflectance are not large enough. For example, harvested millet fields have characteristics similar to vegetation-free areas, and sometimes grassland looks like bush. In order to solve these problems, a multitemporal method of data linkage was used for the classification. In addition to the spectral characteristics at a certain point in time, this method also takes account of the changes in those characteristics, i.e. the dynamics of the various vegetation units are used as a further identification criterion. Images taken at the start of and soon after the end of the rainy season were selected for the study project, because this combination of data is likely to yield the greatest differences in the vegetation dynamics. The spectral characteristics as determined by the Landsat Multispectral Scanner (Landsat-MSS) are based on areas measuring approximately 80 m x 80 m on the ground.

Selection and position of the study area

The study area measures 28.6 km x 40.4 km and is located about 80 km SSW of Tahoua/Niger (Fig. 1). The section of the image data recorded on 04. 08. 75 and 15. 10. 75 were selected in such a way that as many different surface and land use forms as possible were covered, in order to obtain an optimal impression of the vegetation dynamics.

The area is part of the arid belt south of the Sahara with average precipitation in the order of 350–450 mm/annum and potential evaporation values of around 2300 mm/annum. The rainfall data from Tahoua give a rough impression of the precipitation conditions in that region for the year 1975. According to these data, the first significant rainfall (66 mm) occurred in June. In July 115 mm of rain fell, in August 174 mm and in September 59 mm. No significant precipitation was recorded in any of the other months.

In geological terms, the study area is part of the "Bassin de Jullemeden". The surface is built up by Tertiary lateritic crusts which are locally overlain by aeolian sand. Frequently the sand forms approximately E-W-striking, distinctly delineated chains of dunes.

Land use and vegetation

Rainfed agriculture is practised widely throughout the mainly flat study area; the principal crop grown is pearl millet (*Pennisetum spicatum*). The growing season is 3 months long and the cultivated areas remain almost devoid of vegetation from about October until May (Fig. 2).

Areas of lateritic crust, or the crests of dunes and places where aeolian sand deposits have built up are frequently free of vegetation all the year round (Fig. 3). The same applies to the immediate vicinity of watering holes where, in many cases, the vegetation has been destroyed by overgrazing.

Longer-lasting plant growth can be found on areas covered with grasses, and also where "brousse tigré" is found. The latter is a type of bush vegetation characteristic of the Sahel which occurs in strips and patches. It is made up mainly of *Guiera senegaliensis* and *Calotropus procera* as well as grasses of the species *Cenchrus biflorus*. In addition, trees of the species *Balanites aegyptica* and grasses such as *Phylostigma roticulata* also occur.

The most intensive vegetative growth in the study area is concentrated on the banks around temporary lakes, the so-called "mares" (Fig. 4). In this case, the tree stand consists for the most part of *Nitragyna inermis* and *Piliostigma reticulatum*. Vegetables are also frequently grown in an intensive manner on these areas.

In the vicinity of towns and villages, evergreen trees such as *Azadirachta indica* (Neem) and *Parkia biglobosa* (Nere) are found.

Analysis of Landsat Multispectral Scanner (MSS) data

A good quality multispectral image is absolutely essential if changes are to be detected on the basis of various Landsat MSS image data.

The spectral reflectance properties of an image element are measured in 4 spectral bands and presented as a shade of grey. The individual elements are defined by their coordinates on the image. In the case of two images taken at different times, a set of 8 spectral measurements exist for the image element. By carrying out statistical analyses of these multitemporal data, it is possible to determine features which identify changes in the radiation characteristics of the examined objects on the ground.

Processing and preliminary evaluation

Preprocessing of the data

Two Landsat MSS scenes of comparable quality, recorded on 4 August and 15 September 1975 respectively, were used in digital form as "computer compatible tapes (CCT)".

The selected section of the scene covers an area measuring 40.4 km (N-S) by 28.6 km (E-W) on the ground and corresponds to 512 x 512 image elements which have not been geometrically corrected.

The image elements of the test area recorded on 15 October were geometrically fitted to the scene recorded on 4 August.

Colour images and their interpretation

In the next processing step, colour images were produced from three contrast-enhanced spectral bands.

They provide an overview of the distribution of vegetation on both image-recording days and make it possible to identify certain surface units. On the colour images the vegetation appears red, while all other surface units are shown in approximately their own natural colours. When the August image is compared with the October image, a strong difference in the distribution of the vegetation is apparent; generally speaking, the growth is more intense in October (Plate 1; Figs. 1 and 2).

The following surface units can be directly identified.

- "Mares" (sedimentary pans containing lush vegetation) show up as red spots.
- Areas without vegetation show up yellow.
- Lateritic "buttes" without any vegetation cover show up as light yellow to dirty yellow in colour.
- Open water appears dark to light blue to dirty yellow.
- Dry watercourses with intensive plant growth exhibit a red, dendritic pattern.

Detection of changes on the earth's surface

A number of tried and proven methods exist for recording and quantifying different types of surface and vegetation cover.

A simple method for distinguishing between areas having various degrees of plant cover is to form the ratio of the spectral bands b5 and b7 of the multispectral Landsat scanner; this gives good results.

Band 5 is in the red range of the visible solar spectrum. Because of the high degree of absorption by chlorophyll, healthy vegetation exhibits minimum reflectance in this band. Soil has relatively high reflectance values.

Band 7 measures in the infrared range. The reflectance of the vegetation is very pronounced in this case. The amount of reflectance is determined by the species of plant and by the activity of the biomass. This makes it possible to differentiate according to species of plant and density of vegetation, and also to distinguish between areas with and without vegetation cover.

When forming the b5/b7 ratio, high values must be assigned to surfaces with a large proportion of bare soil and sparse vegetation cover. Declining values indicate higher densities of healthy vegetation. Individual surface or vegetation classes can be defined in the study area by gating, i.e. by setting upper and lower threshold to the ratio b5/b7.

Using the images recorded on 4 August and 15 October 1975, a contrast-enhanced ratio image was produced for bands 5 and 7 respectively. The following steps were selected when establishing the limits:

$b5/b7 < 1$	grey scale step	0
$2 > b5/b7 \geq 1$	grey scale step	100
$3\ b5/b7 \geq 1$	grey scale step	200
$b5/b7 \geq 3$	grey scale step	255

The results of this method of processing the data are presented in Plate 1 and Figs. 3 and 4. Dark image areas indicate dense vegetation (grey scale level 0).

Less dense vegetation and exposed areas of sand and laterite are assigned to grey scale step 200, and open water to step 255.

When a similar method of processing is employed without gating, the transitions between the types of surface cover stand out clearly and permit an additional evaluation of the situation to be made.

A "colour composite" (gated initial images) was produced to depict the change in vegetation. The ratio (b5/b7) for August was assigned the colour blue, the ratio (b5/b7) for October the colour green and the difference between the two was assigned the colour red (Plate 2, Fig. 1). The same procedure was conducted using ungated initial ratios. The coloured display makes it easy to detect the units, and the method of using ungated ratios in turn gave rise to further gradations (Plate 2, Fig. 2). The final outcome of the experiment was that a more attractive colour coding was selected (Plate 3, Fig. 1).

In this method, the ratio b5/b7 for August was assigned the colour red, and the ratio b5/b7 for October was assigned the colour green. The various tones are derived from the additive colour mixing.

The ratio images are referred to as "dynamic images", i.e. the colour units are no longer codes for certain reflectance values but instead denote the temporal change in the reflectance values at the surface of the earth.

Results

Identification of vegetation units

The results of the experiments with the Landsat data were verified in the terrain and also by means of aerial photo interpretation. It can be shown that the differential ratio images permit vegetation units or vegetation communities to be assigned and delimited with great accuracy. Processing the data without setting upper and lower thresholds offers the best chances of success.

Using the specific dynamics, as seen in the different reflectance characteristics for the images recorded on 4 August and 15 October 1978 respectively, the following vegetation units can be identified (Plate 3, Fig. 1):

Yellow Unit: = Areas without vegetation. Poor ground conditions, thin covering of sand.
Vegetation-free sandy areas – millet fields in their fallow phase.

Red Unit: = Grassland with *Ctenium newtonii, Aristida spp.* and *Cenchrus biflorus* (Cram cram).
Red associated with "mares" and watercourses:
Guiera senegaliensis, Mitragyna inermis, Phylostigma roticulata, occasionally Acacia albida.
Fields under millet.

Brown Unit: = Mixed vegetation: Trees (Neem), *Acacia albida*, sometimes on grassland or with millet fields.

Green Unit: = Bush vegetation with: *Guiera senegaliensis, Calotropus procera, Acacia senegaliensis.*

In the areas with green and yellow portions it is in turn possible to distinguish between two further units: Areas with a strong green coloration are relatively densely covered with bush vegetation. These are areas in which a high-density, close-meshed drainage network has been formed due to large amounts of drifting sand. The banks of the intersecting streams have been taken over by bush vegetation. Areas showing up with a large proportion of yellow in the images contain a low-density, wide-meshed drainage network.

Development of the landscape

Interpretation of the aerial photographs and satellite images, together with the results of terrain reconnaissance, permit some important conclusions to be drawn about the development of the landscape, such as the interrelationships between drifting sand, the drainage network and vegetation.

The original drainage network in the study area was considerably disrupted by drifting sand, which now covers parts of the area under stationary plains of wind-borne sand or dunes. Three units can be distinguished, depending on the thickness of the sand cover:

Areas in which the sand cover has *completely smothered the drainage network*: They are generally covered with grass vegetation and in parts used for the cultivation of millet.

Areas in which the sand cover is incomplete but the *drainage network has been considerably disrupted*: Here, the diversion of the watercourses by the irregular sand cover has led to the formation of a fine-meshed drainage network, which may be locally completely buried, or may still be barely visible in the form of the occasional damp spot. The rudimentary drainage network is as a rule covered by bush vegetation and individual trees.

Areas with little or no sand cover where the *drainage network is relatively undisturbed* and wide-meshed: again, mainly bush vegetation and individual trees are linked with the watercourses. The interlying areas are without vegetation due to the unfavourable soil conditions (frequently lateritic crust).

Spectral characteristics of arable land (for rainfed crops)

Arable land for rainfed crops (mainly millet) is prepared for cultivation at the start of the rainy season and secondary vegetation is removed. This gives the fields the spectral characteristics of vegetation-free surfaces on the section of satellite image recorded on 4 August 1975. In the image recorded on 15 October 1975 they display other values.

An evaluation of 10 cultivation areas located on the basis of aerial photographs yielded the following results: Despite the wide ranges of scatter within the spectral intensities, it is noticeable that the values in spectral band 5 are slightly lower in October than in August, while the band 7 values for both months fluctuate with the same interval. When the quotient of band 5/band 7 is formed, a clear difference is seen; in August the quotient is greater than 1.03 and in October it is smaller than 1.03. This finding shows that a slight amount of vegetation can be measured in October. This is presumably ripe cereals or a slight growth of secondary vegetation following the harvest.

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WATER TREATMENT BY FLOCCULANT COMPOUNDS OF HIGHER PLANTS

by

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In rural areas of developing countries supply of potable water of perfect taste and hygiene may present problems. Surface waters can be clarified by compounds of vegetable origin, for instance, seeds *of Moringa oleifera Lam.* and *Moringa stenopetala Cufod.*, small basic proteins of which are responsible for the flocculant effect. Bark of *Boscia senegalensis (Pers.) Lam. ex Poir.* and several legumen also contain flocculant proteins. Following isolation, characterization and sequential analysis of these proteins the flocculating mechanism is explored and nucleotide sequences are derived which may be cloned in *Escherichia coli* by plasmides for the biotechnical production of the proteins.

Traditional water treatment

Methods of traditional water treatment include simple filtration, use of vegetable coagulants or of clarifying clay; they may be used exclusively or in combination. Regional specialities used to clarify water are fish slime or soil of termitaries.

In rural areas, mainly surface water is used. In rivers functioning as a water source pollution by suspended particles depends on the season. In Sudan, for example, there is a tremendous increase during the flood season of the Nile (July – September), and in Indian rivers in the monsoon period (July – October). Nile water may contain up to 8 g suspended matter per l, in extreme cases even more than 50 g per l, compared to less than 100 mg/l during the dry season.

Clay is mainly responsible for the turbidity of river water during the rainy season, but also organic matter and metal or heavy-metal ions as well as faeces of humans and animals limit its use as drinking water. Water from natural or artifical rainwater ponds may also be very turbid and contain up to 8 g suspended matter per l.

Purification is difficult because of the great differences in water pollution. In the regions concerned, natural raw materials, mainly coagulants of mineral or vegetable origin, have been used for this purpose for millennia. To achieve an optimal purification effect it is necessary to employ the coagulants at proper concentration in suitable vessels and, in consideration of the physico-chemical characteristics of the flocculation process, at the proper stirring rate. The bacteriological quality of surface waters varies considerably as well. Contamination by animal faeces in particular is a high potential risk. Salmonella, streptococci, coliform and faecal coliform bacteria are frequently present. Treatment of the water by coagulants may improve its bacteriological status considerably.

According to S.A.A. Jahn (1981, 1986) who provides in two monographs a survey on "Traditional water purification in tropical developing countries" and "Proper use of African natural coagulants for rural water supplies", seeds of *Moringa oleifera Lam. and Moringa stenopetala Cufod.*, and the bark of *Boscia senegalensis (Pers). Lam ex. Poir.* are the best sources of natural flocculants of plant origin. In North Africa, where the flocculant properties of these materials were probably discovered, 3 seeds per 4 l of water are employed. This optimal concentration of 0.7 g of seeds per l clarifies even faint turbidities. The seeds, after removal of coats, are disintegrated in a mortar, filled into a cloth bag and placed into the vessel where they are agitated for 20 to 30 minutes. Clarification depends on the quality of the water and on the proper concentration of seed powder according to the degree of water turbidity. After two further hours the water is ready for use, clear and neutral in taste.

Tuaregs in Niger lay 7 – 10 cm long, thin slices of bark from *Boscia senegalensis* on the surface of turbid water to be consumed the following day; the water is not agitated during treatment. In the Western Sudan muddy water is treated by the leaves or twigs of this tree.

In South Egypt and Northern Sudan water is purified by seeds of *Vicia faba L.* at a concentration of 30 seeds per 40 l water. The seeds, after removal of coats, are powderized. Another traditional means of water purification in Sudan is seeds of *Pisum sativum L.*

Vegetable material

Seeds of *M. oleifera* and *M. stenopetala*, and bark of *B. senegalensis* were sent to us by Dr. S.A.A. Jahn and Mr. S. Uhlig, Sudan. Seeds of *V. faba* and *P. sativum* were obtained from the commercial houses Saatzucht Littmann and Dom, Germany. Seeds of other species of *Vicia, Lathyrus, Phaseolus, Lupinus, Lens* and *Cicer* were collected at the Botanical Garden of Karlsruhe University. The seeds, after removal of coats, and the bark of *B. senegalensis* were powderized by grinding.

Characterization of flocculant activity

Turbidities of surface waters are due to anorganic colloids. At corresponding pH of the water, the colloids are negatively charged and repel each other. Flocculants or flocculant agents as, e.g., iron- or aluminium salts, or water soluble synthetic high molecular polymers, because of their positive charges, interfere with these electric layers, allowing the colloids to aggregate in flocs (Burkert, 1976). Flocculants can be detected by a test developed by Tauscher et al. (1986) on a microscale. Suspensions of glass powder or clay (0.1 mg/ml) served as turbid water. Extracts of the defatted seeds or bark were desalted (Amicon Cell) , lyophilized (Lyovac GT2) and dissolved in 50 mM $NaHCO_3$ (pH 7.9). The protein content of the solution was determined according to Bradford (1976). The solution was pipetted into test tubes and 1 ml of the model solution was added. After sealing of the tubes with parafilm and shaking for 3 seconds, flocculation was visually compared to a control.

Light transmission was measured by spectralphotometer (Beckmann, DU 6) at different intervals of time to follow the kinetics of floc sedimentation. The cuvette was equipped with a minipaddle stirrer. Changes in particle numbers during flocculation were measured by a CIS-Particle Analyzer (L.O.T.). For this, 10 – 500 µl of the protein solution were added to 4 ml of the suspension of model powder. The number of particles was measured for 65 minutes at room temperature under constant stirring at 44 rpm.

All methods yield qualitative or quantitative information about the flocculation process and allow to screen vegetable material for flocculant activity even under most simple conditions. The results of several materials we investigated (Reinecke, 1993; Herlt et al., 1993) are listed in Table 1.

Preparation of protein extracts and chromatography

After size reduction seeds and bark were extracted in a Soxhlet apparatus with trichlorofluoromethan (Frigen 11) for 4 – 5 days at 4°C. The defatted material, after drying, was available as powder which could be stored at 4°C.

Table 1 – *Flocculation activity of plant materials, pure proteins and polymers*

Sample	Protein concentration (µg/ml)	Flocculating activity
Moringa oleifera Lam., seeds	15/30/90/170	+/+/+/–
Moringa stenopetala Lam. ex (Poir.), seeds	0.4/20/100	–/+/+
Moringa stenopetala Lam., seed shell	1.8/20/100	–/–/–
Moringa stenopetala Cufod., leaves	1/5/10	–/–/–
Moringa stenopetala Cufod., pods	1.8/18/27	–/–/–
Moringa stenopetala Cufod., pod shell	1.2/12/24	–/–/–
Moringa stenopetala Cufod., parenchyma	0.8/26/78	–/–/–
Moringa stenopetala Cufod., bark	0.4/11.4/76	–/–/–
Boscia senegalensis (Pers.) Lam. ex Poir, bark	15/30/60/150	+/+/+/+
Boscia senegalensis (Pers.) Lam. ex Poir, leaves	12/72/120	+/+/+
Boscia senegalensis (Pers.) Lam. ex Poir, flowers	23/84/112	–/–/–
Boscia senegalensis (Pers.) Lam. ex Poir, seeds	1/26/130	–/–/–
Balanites aegyptica L. Del., seeds	1/21/108	–/+/+
Vicia villosa Roth., seeds	10/20/100/200	–/+/+/+
Vicia sativa L., seeds	5/20/40/200	–/+/+/+
Vicia ervilia (L.) Willd., seeds	10/20/40/90	–/+/+/+
Vicia faba L. (synta), seeds	20/100/200	+/+/+
Vicia faba L. (farina), seeds	10/20/100/200	+/+/+/+
Lathyrus odoratus L., seeds	15/70/140	+/+/+
Lathyrus aphaca L., seeds	15/30/150/300	+/+/+/+
Lathyrus sativus L., seeds	10/20/110/220	+/+/+/+
Lathyrus latifolius L., seeds	5/10/40/70	–/–/+/+
Phaseolus lunatus L., seeds	10/15/40/70	–/–/+/+
Phaseolus ssp. vulgaris L., seeds	15/30/70/140	+/+/+/+
Phaseolus ssp. nanus (L.) Asch., seeds	10/20/60/120	+/+/+/+
Pisum sativum L., seeds	15/30/80/160	+/+/+/+
Lupinus albus L., seeds	15/30/150	+/+/+
Lens culinaris Medik., seeds	15/25/50	+/+/+
Cicer arietinum L., seeds	5/25/50/250	–/+/+/+
Triticum aestivum L., seeds	12/60/180	–/+/+
Secale cereale L., seeds	12/48/168	+/+/+
Hordeum vulgare L., seeds	12/82/164	–/–/–
Oryza sativa L., seeds	9/54/180	–/+/+
Zea mays L., seeds	4/38/150	–/+/+
Poly – L-arginine	1/30/100	–/+/+
Poly – L-ornithine	1/30/100	–/+/+
Zein	0.5/20/100	–/–/–
650 BC (cation. polymer)	5/10/50/100	+/+/+/+
2530 TR (anion. polymer)	5/10/50/100	+/+/+/+

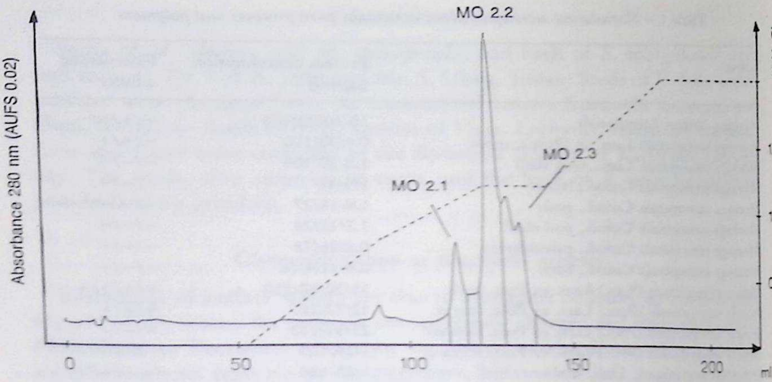

Fig. 1 – *Separation of MO 2 on Fractogel EMD SO_3 (650) S (150 x 10 mm).*

Solvent: A:	50 mM phosphate buffer (pH 7.5) containing 0.02 % NaN_3.
B:	2 M NaCl in A.
Gradient:	0 – 40 % B from 52 – 92 min; 40 – 60 % B from 92 – 122 min, 60 – 100 % B from 142 – 182 min.
Flow rate:	1 ml/min.
Detection:	280 nm.

10 g of the powder were extracted in 100 ml of 0.1 M phosphate buffer Soerensen) (pH 7.5) or 20 mM ammonium hydrogen carbonate (pH 7.9), respectively, at 4°C for 2 hours under occasional stirring. The mixture was centrifuged and desalted, if necessary, in a membrane filter.

At pH 7 to 8 the flocculant proteins are of cationic nature (Fink, 1984). By cation exchange chromatography (Biorex 70) flocculant proteins were largely separated from non-flocculant ones. Of the proteins of *M. oleifera* three flocculant fractions, MO 1, MO 2, and MO 3, were obtained. The Biorex 70 column (260 x 26 mm) was equilibrated first by 0.1 M phosphate buffer, pH 7.5, containing 0.02 % NaN_3. 50 ml of sample were injected and eluted with 0.1 M phosphate buffer. In this range the non-flocculant proteins appeared. A gradient of 0 to 2 M sodium chloride in 0.1 M phosphate buffer was applied to elute the three flocculant protein zones at a flow rate of 3 ml/min.

In a second purifying step, a fractogel ion exchanger was used for chromatography (Fig. 1) . Fraction MO 2 was further separated into three other flocculant protein zones, MO 2.1, MO 2.2, and MO 2.3. Fraction MO 1 yielded a very similar result. Of the proteins of M. stenopetala which may be separated in the same way similar elution diagrams were obtained.

Characterization of the proteins of Moringa seeds

Fractions MO 2.1, MO 2.2, and MO 2.3, and the corresponding fractions of *M. stenopetala*, were studied by polyacrylamide-gel electrophoresis under denaturating and under native conditions. Basic proteins were separated under native conditions according to Reisfeld (1962). The proteins of fractions MO 2.1 and MO 2.2 have been found to be uniform and comparable in their properties, while MO 2.3 shows two additional bands. After separation of MO 2.1, MO 2.2 and MO 2.3 under denaturating conditions according to Lämmli (1970) two bands appeared side by side; it may be that in the case of strongly basic proteins no uniform polyanionic proteins form under the influence of the denaturating reagent during electrophoresis. The basic proteins of *M. stenopetala* responded in a similar manner.

Uniformity of the fractions MO 2.1 and MO 2.2 was checked by dansylation and sequencing. Dansylation revealed no freely admissible N-terminal amino acids in either protein. N-terminal histidine and arginine may escape identification by dansylation, however. Sequencing according to Edman confirmed the absence of histidine and arginine in the N-termini. Edman degradation failed; obviously the N-termini were blocked.

The molecular masses of the two proteins of *M. oleifera* determined by different methods were 6.5 kDa. The isoelectric point of the two proteins estimated by isoelectric focussing was above pH 10.5; this is in confirmation of the result of Fink (1984). A precise determination of the isoelectric points, which is quite laborious, was not made.

Amino acid analysis provides information about protein composition. 20 µg of the proteins of *M. oleifera*, and of the protein MS 2.2 of *M. stenopetala* were hydrolyzed by HCl at 108°C for 24 – 96 hours. Calculations were based on a molecular weight of 6.5 kDa. MO 2.1 and MO 2.2 showed high conformity. Both contain much glutamin/glutamic acid, arginine and proline, but no lysine, while MS 2.2 contained much glutamin/glutamic acid and proline residues. The high isoelectric points of the proteins suggest that glutamic acid and aspartic acid detected after acid hydrolyis are glutamine and asparagine in the intact protein (Table 2).

Tryptophan was not detected by Ehrlich's reagent. As amino acid analysis had shown the *Moringa* proteins to contain several cystein residues, we tested for free SH groups by Ellman's reagent. As the test was negative in all cases disulfide bridges could be assumed to exist.

To determine the primary structure of the *Moringa* proteins, sequenceable peptides were microprepared by chemical and enzymatic fragmentation employing HPL chromatography on reversed phase columns.

As the *Moringa* proteins contained methionine, fragmentation by BrCN

Table 2 – *Amino acid analysis of MO 2.1, MO 2.2 and MS 2.2*

The calculation is based on a molecular mass of 6500 da for each protein.
The obtained amino acid compositions are mean values after acid hydrolysis for 24, 48, 72 and 96 h.

Amino acid	MO 2.1	MO 2.2	MS 2.2
Asx	3.2 (3)	2.2 (2)	1.7 (2)
Thr	1.6 (2)	1.6 (2)	2.7 (3)
Ser	2.4 (2)	2.2 (2)	2.2 (2)
Glx	17.4 (17)	16.3 (16)	11.3 (11)
Pro	6.4 (6)	6.9 (7)	8.3 (8)
Gly	3.8 (4)	3.4 (3)	5.7 (6)
Ala	2.1 (2)	2.4 (2)	4.2 (4)
Cys	1.5 (2)	1.9 (2)	2.7 (3)
Val	1.9 (2)	1.9 (2)	2.9 (3)
Met	0.9 (1)	1.0 (1)	2.2 (2)
Ile	1.4 (1)	1.4 (1)	3.4 (3)
Leu	2.7 (3)	2.7 (3)	4.7 (5)
Phe	2.8 (3)	2.2 (2)	2.8 (3)
His	1.0 (1)	1.0 (1)	1.4 (1)
Arg	7.7 (8)	7.9 (8)	3.1 (3)
Tyr	0.3 (0–1)	0.3 (0–1)	0.5 (1)

seemed advisable. However, in view of the assumed disulfide bridges, reduction by ß-mercaptoethanol and subsequent reaction of the free SH groups with iodoacetic acid was required first, before the stabile S-carboxymethyl derivatives could be exposed to BrCN. MO 2.1 yielded two fragments, CN 1 and CN 2. CN 1 contained the aminoterminal, CN 2 the carboxyterminal range. CN 2 was completely sequenced; while CN 1 had to be further fragmented by trypsin.

Besides the CN 1 fragment, thermally denaturated protein MO 2.1 was also digested by trypsin for 90 minutes. Figure 2 shows fragmentation of the trypsin digested CN 1 fragment of MO 2.1. The fractions were lyophilized and dansylated. Fractions containing only one peptide were sequenced. In this way the sequences of 5 individual peptides totally were isolated. From the intact protein, 4 peptides were sequenced after digestion with trypsin.

Chymotrypsin acts preferably on the carboxyl side, effecting separation from aromatic and other bulky unpolar residues. Peptides obtained by chymotryptic and by tryptic digestion overlap and are well comparable. So complete amino-acid sequences of the polypeptide chain may be analyzed.

We sequenced the peptides of the chymotryptically digested proteins MO 2.1 and MO 2.2, of carboxymethylated MO 2.1 and of the BrCN fragments CN 1 and CN 2 of MO 2.1, i.e. eleven peptides totally.

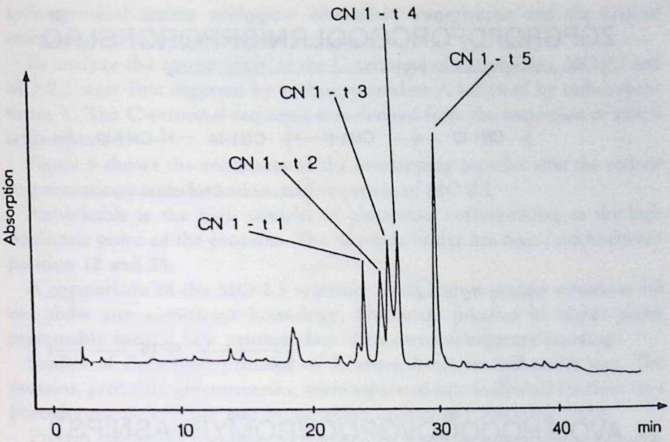

Fig. 2 – *Separation of the CN 1 fragment digested with trypsin on HD-Sil-18-5s-80 (250 x 4 mm).*

Solvent: A:	0.1 % TFA in H_2O (pH 2.0)
B:	0.08 % TFA in 80 % CH_3CH (pH 1.8)
Gradient:	0 – 30 % in 0 – 30 min; 30 – 80 % B in 30 – 50 min.
Flow rate:	0.8 ml/min.
Detection:	220 nm.

To characterize the amino-acid sequence in greater detail, we applied astacus protease which preferably acts upon N-terminals of short-chain aliphatic amino acids. The carboxymethylated proteins MO 2.1 and MO 2.2 were exposed to astacus protease for 8 hours at room temperature. Seven peptides, four of MO 2.1 and three of MO 2.2, were obtained and sequenced.

MO 2.1 and CN 1 were treated by proteinase K which digests preferably hydrophobic aliphatic and aromatic amino acids. As MO 2.1 was not fully digested, a sequence of one single peptide only was shown over four residues. Two fragments obtained from CN 1 failed to yield sequential data.

As mentioned above, direct sequencing of the proteins was not possible. As the proteins contained high levels of glutamin and glutamic acid respectively, cyclic terminal glutamic acid may be assumed to be present. We tried highly specific pyroglutamate aminopeptidase free from any other protease activity which separates terminal pyroglutamic acid selectively. Of MO 2.1 and MO 2.2 which were treated by the enzyme two sequences each were isolated consisting of 18 steps for MO 2.1 and 10 for MO 2.2. In both proteins, the

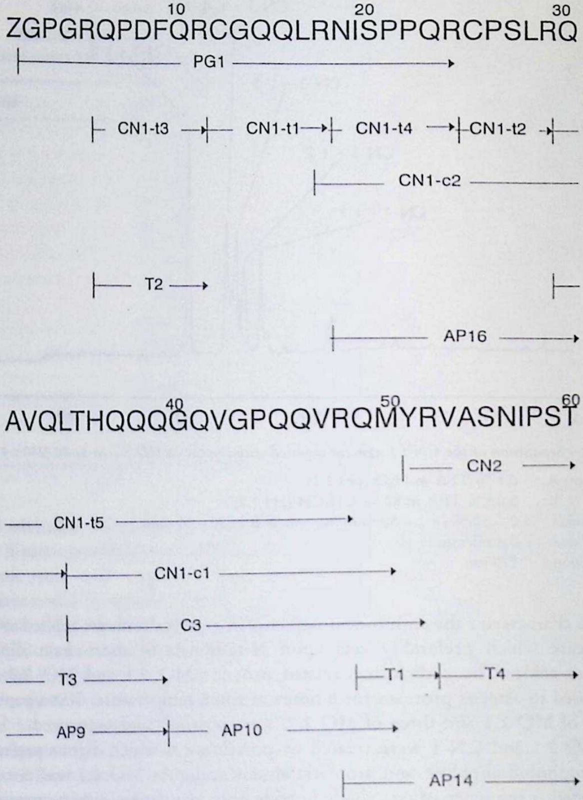

Fig. 3 – *Sequences of the isolated, overlapping peptides to determine the primary structure of MO 2.1.*

Cleavages: CN: BrCN; T,t: trypsin; C,t: chymotrypsin; AP: Astacus protease; PG: pyroglutaminase.

aminoterminal amino acid now admissible was glycine, and the original aminoterminus a pyroglutamine residue.

To analyze the amino acids of the C-terminal of the proteins, MO 2.1 and MO 2.2 were first digested by carboxypeptidase A followed by carboxypeptidase Y. The C-terminal sequence was derived from the succession of amino acids released.

Figure 3 shows the sequences of the overlapping peptides after the various fragmentations and the amino-acid sequence of MO 2.1.

Remarkable is the high content of glutamine, corresponding to the high isoelectric point of the proteins. The disulfide bridge has been found between position 12 and 25.

A comparison of the MO 2.1 sequence to all known protein structures did not show any significant homology. Flocculant proteins of higher plants presumably form a new protein class of its own evolutionary standing.

Studies of flocculant proteins of *B. senegalensis* are still under way. The proteins, probably glycoproteins, were separated into individual fractions on a phenylboronate column and by an anion exchanger (Quickdisk 2500).

Protein extracts of legumen were tested for lectin activity in a hemagglutination assay. The extracts and fractions responding positively were not investigated any further (Reinecke, 1993). Fractions of extracts of *P. sativum* and *V. faba* have been found to be highly flocculant. SDS gel electrophoresis revealed a major and several minor proteins without glycoprotein and agglutination characteristics. The immunoblot assay did not reveal structural resemblance to the protein of *M. oleifera* (Gassenschmidt, 1992). Purification and structural exploration of this protein class remain to be completed.

Molecular biology

From the primary structure of a flocculant protein a nucleotide sequence may be derived which encodes the protein. The DNA sequence encoding the MO 2.1 protein was synthetized in cooperation with the Federal Research Centre for Animal Virus Disease in Tübingen (Gassenschmidt, 1992). The DNA fragment was synthesized in such a way that the N-terminus of the protein also contained methionine and lysine. Methionine was inserted as transcription startpoint and to provide a splitting site for cyanogen bromide in an expressed fusion protein. Lysine was inserted near the N-terminus of the *Moringa* protein as splitting site for lys-C-endoproteinase, to allow separation of the bacterial part of the fusion protein from the actual *Moringa* protein. The *Moringa* protein which does not contain lysine will not be affected in the expressed fusion protein by the lys-C-endoproteinase. Treatment by bromine cyanide is supposed to yield a *Moringa* protein reduced by ten amino acids.

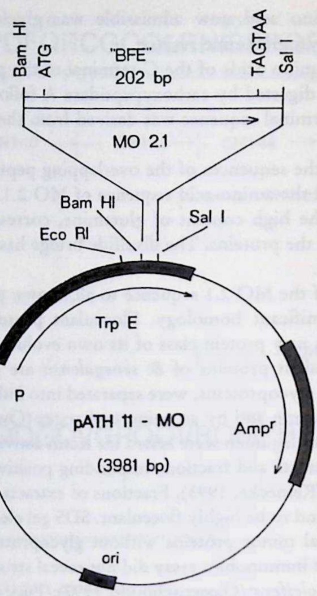

Fig. 4 – *Plasmid map of pATH 11 – MO.*

We succeeded in inserting the encoded DNA sequence into several plasmids in the proper reading frame and orientation. Figure 4 shows the plasmid map of the pATH II MO expression vector. The corresponding fusion protein of about 43 kDA was expressed by means of the construct cloned in *E. coli*. It consists of the bacterial share of about 37 kDA and the vegetable protein share of about 6 kDA. After digestion of *E. coli* the expressed protein share was found to be about 60 % of the total protein. The purified fusion protein was used for rabbit immunization. The antiserum obtained was specific against native flocculant proteins of *Moringa oleifera* and *Moringa stenopetala* and against a protein produced by *in-vitro* translation and cloning of the DNA sequence encoding MO 2.1 in plasmid pSP 65. The antiserum may be used to identify proteins whose structure is similar to that of proteins of *Moringa oleifera*.

To express the *Moringa* protein directly, attempts at cloning into plasmids pQE 4 and pET 3b were made. Unfortunately, however, the expression products were either toxic against the host organism *E. coli* (pET 3b) or expression of the protein failed (pQE 4). The failure of direct expression of the flocculant protein in *E. coli* reduces the feasibility of its biotechnical production by molecular cloning. Cloning in pET 3b was further extended with the aim of expressing a fusion protein of an N-terminal bacterial share of only 10 amino acids. Successful cloning did not yield an expression product of a molecular weight of 7.5 kDA, but one of about 150 kDA which, according to the immunoblot assay, did not show any immunological characteristics similar to those of the *Moringa* protein.

So far the flocculant protein has been expressed as fusion protein only. This means its bacterial share must be large enough to prevent contact between the microorganism and the strongly basic protein share of the *Moringa* protein. Attempts to separate the bacterial from the vegetable protein share at the inserted splitting sites of the fusion protein after purification failed. Further pertinent investigations are required.

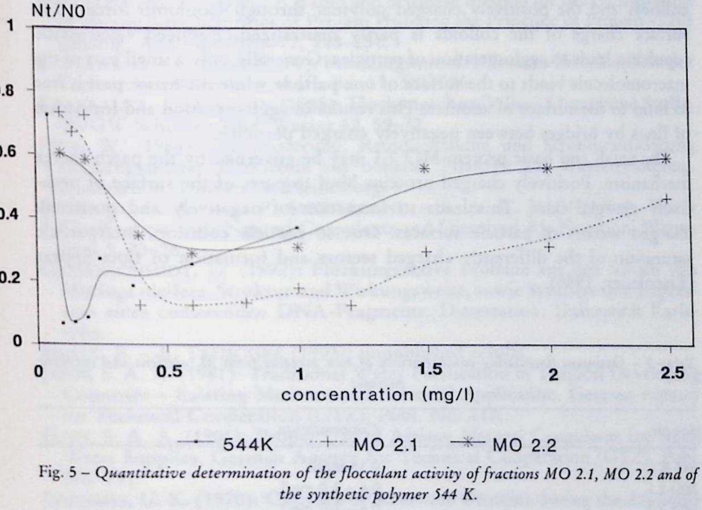

Fig. 5 – *Quantitative determination of the flocculant activity of fractions MO 2.1, MO 2.2 and of the synthetic polymer 544 K.*

N_t: number of particies after 65 min. N_0: number of particies after 0 min.

Flocculant activities

Three tests were applied to learn about the flocculant activities, of which the semi-quantitative assay in glass tubes presents least problems. Flocculant activity was quantitatively determined in the proteins MO 2.1 and MO 2.2 by the ratio of particle numbers at time T = 0 and T = 65 minutes, which is a measure of the flocculant efficiency of the substance quantity applied. Figure 5 shows the flocculant activity of the two proteins and of a synthetic polymer on polyacrylamide basis (544 K, MG > 2 x 10^6), whose flocculant activity and mechanism are known. Maximum flocculant activity appears at the minima of the curves. Optimal active-substance concentrations are shown in Table 3. Over a wide range of concentrations flocculant activity of the natural compounds is superior to that of artificial ones. This makes natural compounds eligible for practical use without the need of precise determination of optimal doses. Although the efficiency of natural compounds is comparable to that of synthetic agents, flocculation mechanisms may be different as the natural compounds have low molecular weight and certainly a high charge density. Flocculation by the standard preparation 544 K is explained by bridge formation; the high molecular weight and the relatively low charge density of the polymer at water pH lead to a bridge-shaped linkage of the negatively charged colloids and the positively charged polymer through Coulomb forces. The surface charge of the colloids is partly neutralized. Reduced electrostatic repulsion leads to agglomeration of particles. Generally only a small part of the macromolecule binds to the surface of one particle while the major part is free to bind to the surface of another. This results in agglomeration and formation of flocs by bridges between negatively charged particles.

The small and basic protein MO 2.1 may be governed by the patch charge mechanism. Positively charged proteins bind to parts of the surface of negatively charged ones. This leads to formation of negatively and positively charged sectors of particle surfaces. Due to particle collision, interparticle saturation of the differently charged sectors and formation of flocs appear (Eisenlauer, 1985).

Table 3 – *Optimum flocculating concentrations of two proteins from M. oleifera and synthetic polymer*

Sample	Concentration
544 K	0.15 mg/l
MO 2.1	0.4 – 1.0 mg/l
MO 2.2	0.4 – 1.0 mg/l

Prospects and application

For treatment of surface and of wastewater for agricultural reuse size-reduced defatted seeds or high protein extracts, but also pure proteins may be used to substitute for chemical coagulants, e.g. aluminium sulfate. For use in practice practicable treatments will have to be developed (Folkhard et al., 1986).

This includes model wastewater treatment plants on the spot also in developing countries, and parameters of cultivation for optimal yields of seeds. Oil extracted from the seeds is another valuable produce. The seed proteins should be produced in a biotechnical manner. Research will be necessary to isolate the gene encoding the flocculant proteins from *Moringa oleifera* or to synthetize the gene for the protein MO 2.1. The synthetic DNA fragment may then be inserted into and expressed in *Escherichia coli.*

A biotechnical protein would open up new possibilities of water treatment and reduce or substitute for conventional flocculants.

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QUALITY SEED PRODUCTION OF SELECTED TROPICAL PASTURE LEGUMES IN SUBHUMID WEST AFRICA

by

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If legumes are used for improved pastures, seeds need to be available in sufficient quantities and quality and at adequate and affordable prices for small scale farmers. Selected pasture legumes like *Stylosanthes hamata* cv Verano, *Chamaecrista rotundifolia* cv Wynn and *Centrosema pascuorum* cv Cavalcade have been successfully tested at the International Livestock Centre for Africa (ILCA), Kaduna, Nigeria for their use in improved pastures for subhumid West Africa. High yields of good quality seeds can only be obtained when appropriate seed production management techniques are applied. Results from field experiments with diverse manual and chemical weed control methods as well as the effect of harvest time and method under different crop management are discussed.

Legumes can be used to overcome limitations in availability and quality of fodder for grazing animals in tropical West Africa. Evaluation of various legume species have shown promising results for their use in improved pastures of supplementary feeding. *Stylosanthes hamata* cv Verano is currently used in legume based pastures in Northern Nigeria. *Chamaecrista rotundifolia* cv Wynn and *Centrosema pascuorum* cv Cavalcade are under evaluation in ILCA and are likely to replace or supplement *Stylosanthes hamata* (Tarawali et al. 1989; Tarawali 1991).

If the concept of fodder banks or improved pastures is to be adopted by a wide range of farmers and agro-pasturalists, the demand for quality seeds of improved pasture legumes will increase (fodder banks are legume-based pastures used for supplementary feeding of grazing cattle during the dry season – or for small ruminants during the rainy season when free grazing is restricted). Determinants for increasing seed supply and demand are given by Ferguson & Sauma (1993). Although these species are commercially available (e. g. from Australia) there is a shortage of quality seeds in the country and they are expensive to import. The problems involved with herbage seed production in Subsaharan Africa are described by Griffiths (1993). The seeds can be supplied according to the demand in two different ways

– in smaller quantities by local producers and/or the farmers, or
– in larger amounts grown by commercial producers in respective areas.

Seeds need to be available in sufficient quantities and good quality. To ensure high yields and good quality of seeds

– weed control

is a crucial factor with special importance as "seed cleaning in the field". The seed yield is also determined by other factors like

– site characteristics
– cropping technique
– age of the crop (established from seeds, ratoon cropping)
– method and time of harvest.

These factors and their effects on seed production of *Stylosanthes hamata*, *Chamaecrista rotundifolia* and *Centrosema pascuorum* will be discussed on the basis of three years (1990 to 1992) of experience in the subhumid zone of Nigeria. Summarized and exemplary results of field experiments from two sites with manual or chemical weed control will be shown here. More details can be found in Kachelriess (1993a), special reference to *Chamaecrista* is given in Kachelriess (1993b) and to *Stylosanthes* in Kachelriess et al. (1992).

General information

The two sites "Kurmin Biri" and "Abuja Road" are located in the subhumid zone of Nigeria in the vicinity of Kaduna (10° 10' N; 7° 25' E; 600 m asl) with an average rainfall of approx. 1300 mm per year during the rainy season from April to October. Kurmin Biri is characterised by a comparatively poor soil

Table 1– *Important weeds at Kurmin Biri and Abuja Road*

Kurmin Biri	Abuja Road
Dicotyledons (without native legumes)	
Borreria spp.	*Celosia trigyna*
Ipomoea eriocarpa	*Coreopsis sp.*
Leucas martinicensis	*Ageratum conyzoides*
Sida rhombifolia	*Ipomoea spp.*
Hyptis suaveolens	*Leucas martinicensis*
Aspilia africana	*Ethulia conyzoides*
Becium obovata	*Amaranthus sp.*
Monocotyledons	
Cyperaceae	*Commelina spp.*
Setaria pallide-fusca	*Eleusine indica*
Brachiaria stigmatisata	*Pennisetum pedicellata*
Eleusine indica	
Digitaria ciliaris	
Dactyloctenium aegyptium	
Paspalum orbiculare	
Native Legumes	
Desmodium hirtum	*Desmodium tortuosum*
Vigna spp.	
Desmodium tortuosum	
Indigofera spp.	

fertility and Abuja Road can be described as more "fertile" especially with regard to available P. Both sites also had a distinguishable botanical compostion of the weed flora (Table 1).

Methods

Purity, germination capacity, sowing rate and sowing depth were 98.8%, 82.7%, 8 kg/ha and 1.5-2.5 cm for *Centrosema pascuorum*, 87.0%, 72.2%, 10 kg/ha and 0.5-1 cm for *Stylosanthes hamata* and 94.0%, 75.3%, 6 kg/ha and 0.5-1 cm for *Chamaecrista rotundifolia* respectively. Seeds were sown in rows 50 cm apart at the end of May and beginning of June. Manually weeded plots of *Chamaecrista* and *Stylosanthes* at Kurmin Biri could be evaluated for three years without replanting since both legumes re-established seeds or plants which survived the dry season. *Centrosema* plots were resown in 1992 since re-establishment from fallen seeds in 1991 was poor. All other experiments were established yearly from sown seeds. The plot size was 2 m x 4 m and the experimental layout was a randomized block design. Land was first disc-

Table 2 – *Manual weed control treatments at Kurmin Biri and Abuja Road*

Kurmin Biri		Abuja Road	
NW	not weeded	NW	not weeded
WF	'weed free'	WF	'weed free'
3 & 6	3 & 6 WAS	4 & 6	4 & 6 WAS
6 & 9	6 & 9 WAS	4, 6 & 8	4, 6 & 8 WAS
9 & 12	9 & 12 WAS	4 & 8	4 & 8 WAS
12	12 WAS	4, 8 & 12	4, 8 & 12 WAS

'Weed free': weekly weeding; WAS: time of weeding in weeks after sowing in the establishment year; WAR: time of weeding in weeks after the beginning of the rainy season in re-growing plots 1991 and 1992.

ploughed and seed bed preparation was done with hand hoes followed by manual harrowing. 150 kg of single super phosphate fertilizer was applied each year along the rows.

Manual weed control was done by pulling the weeds by hand and removal from the plots. At Kurmin Biri 1 to 2 weedings with intervals of 3 weeks in between were applied. At Abuja Road 2 or 3 weedings with intervals of 2 and 4 weeks between the weedings have been scheduled (Table 2).

The herbicides (Table 3) were applied with a knapsack sprayer and a spray bar of 2 m width with 4 spraying nozzles 45 cm above ground level. 300 litres of water per hectare and a spraying pressure of 2 bar were used. Untreated plots without any weed control and with continuous manual weeding were also included.

Table 3 – *Common names of herbicides, their application rates and time of application*

Trifluralin	720 – 1440 g ai/ha	pre sowing, incorporated in the soil (PrS)
Pendimethalin	960 – 1920 g ai/ha	post sowing (PoS)
Diuron	3000 g ai/ha	pre emergence (PrE)
Imazethapyr	80 g ai/ha	pre sowing, incorporated in the soil (PrS)
Imazethapyr	40 – 80 g ai/ha	pre emergence (PrE)
Imazethapyr	40 – 80 g ai/ha	early post emergence (ePoE)
Bentazon	720 – 1440 g ai/ha	post emergence (PoE)
Cycloxidim	200 – 400 g ai/ha	post emergence (PoE)
Fenoxaprop-p-ethyl	60 – 120 g ai/ha	post emergence (PoE)
Bentazon 2160* g ai/ha + Cycloxidim 400 g ai/ha		post emergence (PoE)
Bentazon 2160* g ai/ha + Aciflurfen 160 g ai/ha		post emergence (PoE)
Bentazon 2160* g ai/ha + Fenoxaprop-p-ethyl 60 g ai/ha		post emergence (PoE)

ai/ha: active ingredient/ha; * split application 2 x 1080 g ai/ha

Weed control

Manual weeding and development of legumes

Manual weeding has been proved as an efficient mean to control weeds in tropical pasture legumes. Looking at the soil cover of legume and weeds it could be seen that two manual weedings ensured good growth of the legume and reduced weed infestation in the field (shown for *Stylosanthes* in Fig. 1). If not weeded, soil cover of legume at 12 WAS in the establishment year (1990) was approx. 40%. In subsequent years (1991-1992) the soil cover of legume decreased if not weeded and the plots were almost entirely covered by weeds 15 WAR. If weeded twice 6 & 9 WAS (WAR), the soil cover of weeds was reduced significantly and legume cover was as high as in weed free plots.

At Abuja Road manual weeding was also effective in raising the soil cover of the legume to approx. 80% at 12 WAS as compared to only 20% in the unweeded treatment (Fig. 2). While weeding twice raised the legume cover to approx. 30% at 8 WAS, the legume covered more than 60% of the soil if manual weeding was done three times (4, 6 & 8 WAS).

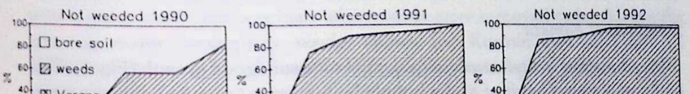

Fig. 1 – *Percent soil cover of Stylosanthes hamata cv Verano and weeds during the years 1990 to 1992 at Kurmin Biri. WAS: weeks after sowing; WAR: weeks after re-establishment; Veg. B.: beginning of vegetation period.*

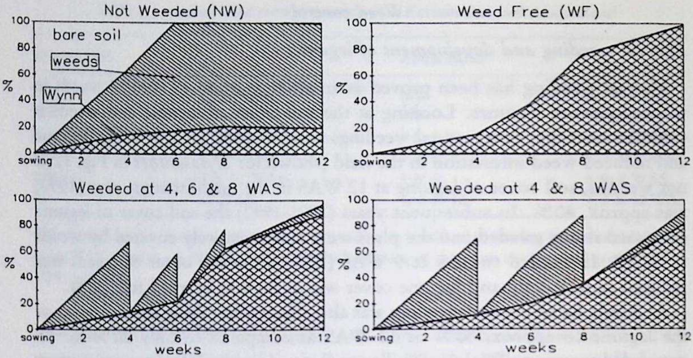

Fig. 2 – *Percent soil cover of Chamaecrista rotundifolia cv Wynn and weeds at Abuja Road. WAS: weeks after sowing.*

Stylosanthes hamata

Weed control in *Stylosanthes* is essential to ensure good growth (Fig. 1). Due to the more erect habit of *Stylosanthes* plants weeding may be necessary up to 12 WAS before *Stylosanthes* forms a closed canopy in the establishment year. Narrowing the width between the rows may help to reduce this problem. Surviving plants of *Stylosanthes* and re-growth from seeds after the dry season ensured good plant stands in the second and third year of production. Plant density per m^2 may already be too high (above 200 young seedlings per m^2) and cause competition between *Stylosanthes* plants, and thinning may be necessary. Early grazing can be advantageous but there is a risk of introducing weed seeds via dung (Humphreys & Riveros 1986). Several years of cropping are possible with efficient manual weed control.

Chamaecrista rotundifolia

Chamaecrista can be regarded as relatively competitive against a number of weeds if growing conditions are favourable. Competition of weeds can be a problem if the germination and/or the emergence of young seedlings of *Chamaecrista* is hampered. Weeds can then establish between and within the sown rows. E.g., heavy rains after the sowing of *Chamaecrista* in 1991 at Abuja Road caused a hard top surface layer of the soil and emergence of

Chamaecrista seedlings was delayed while weeds started growing. The potential ability of *Chamaecrista* to survive the dry season and regenerate quickly after the onset of the rainy season gives an advantage to the legume against weeds establishing from seeds and makes weed control not as necessary as in the establishment year.

Centrosema pascuorum

Emergence of *Centrosema* seedlings is slow, due to the higher requirements for soil moisture for the initialisation of the germination of the sown seeds. With sufficient rainfall and good soil fertility *Centrosema* seedlings pick up quickly and weed control will only be necessary during the early growing period. At Abuja Road the soil cover of *Centrosema* was close to 100 percent at 8 WAS. *Centrosema* cannot persist into the 2nd growing season since re-establishment in the field was poor.

Manual weeding and seed yields of legumes

Seed yields of the legumes generally correspond to percent soil cover and pure legume seed yield was high when weeds were removed twice during the growing season (exemplary results shown for Kurmin Biri in Table 4). Differences between the different weeding treatments were mostly low, indicating that the time of weeding is flexible and can be adjusted according to the weed infestation found in the field at a particular time. This is also important for farmers who may have labour constraints at various times in the growing season. Generally, it was seen that weeding should not be done too early, so that weeds emerging after the second weeding can be suppressed by the

Table 4 – *Seed yields (kg/ha) in manually weeded plots at Kurmin Biri during 3 years of production (direct harvesting)*

	Centrosema			*Stylosanthes*			*Chamaecrista*		
Tmt.	1990	1991	1992*	1990	1991	1992	1990	1991	1992
NW	966	9	2	178	39	98	337	146	138
WF	1387	428	409	285	325	455	473	239	221
3 & 6	1262	109	178	235	255	341	447	144	238
6 & 9	1502	237	37	269	291	397	445	296	220
9 w 12	1237	66	36	263	272	363	344	261	226
12	1026	23	6	284	228	284	371	240	171

resown

legume. Weeding too late should also be avoided since weeding in more dense plant stands is more difficult (e. g. removal of twining species like *Ipomoea*) and weeds with a similar appearance as the particular legume can be overseen during weeding. Weeds with similar appearance to *Chamaecrista* are, e. g., *Desmodium spp.* In *Stylosanthes* there are *Oldenlandia herbacea, Sida spp.* and *Borreria spp.* and in *Centrosema, Borreria spp.* and various grass weeds look similar. Late weeding was also more labour intensive. The total time needed for the manual weeding in the field was similar for all treatments and legumes; only the share of time needed for the first, second or third weeding varied between treatments, but late weeding was more labour intensive (Kachelriess et al. 1992). Between 600 and 1000 man hours are needed for one ha. The labour capacity of one family household in the area of the study is approx. 750 man hours per month (C. Antonza, ILCA-Kaduna, 1992 pers. comm.). The maximum area grown for seed production will therefore be limited by the availability of labour for the weeding.

Seed yields of the legumes correspond to seed yields reported by other authors. *Centrosema pascuorum* cv. Cavalcade seed yields are expected within a range of 600 to 1000 kg/ha with advanced production techniques (herbicide and the use of harvestors) in Australia (Norton 1990). *Stylosanthes hamata* seed yield can be highly variable and yields of 300 kg/ha can be regarded as satisfactory (English & Hopkinson 1985). Hand harvested seed yields for *Chamaecrista rotundifolia* cv. Wynn range between 165 and 721 kg/ha (Strickland et al. 1985). Commercial direct harvesting has yielded up to 260 kg/ha (Cook 1988). The differences between seed yields of different years will be discussed later in this paper.

The purity of harvested seed material of all three legumes was satisfactory and contamination with weed seeds was low. *Stylosanthes* seed material currently available in Nigeria is often highly contaminated with weed seeds and purity is low (<50%) The seed material harvested from manually weeded *Stylosanthes* contained generally more than 80% pure legume seeds and showed a low contamination with weed seeds. Special care should be taken to eliminate *Sida rhombifolia* and *Hyptis suaveolens* in the field since their seeds are difficult to remove by seed cleaning. Moreover these are weeds in pastures; therefore the early removal of *Ipomoea sp.* and *Commelina spp.* is also important in *Centrosema*. *Desmodium spp.* in *Chamaecrista* are less of a problem.

Chemical weed control

The use of herbicides has been proven as one possible method to control weeds in tropical pasture legumes. The seed yields were significantly enhanced as compared to the untreated plots. Although seed yields were not as high as in weed free plots in some cases, the purity of harvested legume seed material was generally lower than in manually weeded treatments. The results were satisfactory and the folowing applications can be recommended (see Table 5).

Imazethapyr was well tolerated by all legumes and gave efficient control of most weeds at both sites. More herbicides have been tested (compare Table 3) but their use may vary from site to site and be limited by the following factors.

- the legume species and
- the weed population

Furthermore, the experience of the seed producer and the available technical equipment (also in terms of precision of time and rate of application) may be considerable constraints on chemical weed control. The availability of herbicides and their impact on the environment and their hazard to the operator need to be taken into consideration.

Site and effect of herbicides on the different legume species

The tolerance of the legume to the herbicide was influenced by the site. The higher application rates of Pendimethalin and Trifluralin caused severe damage to young seedlings of *Stylosanthes* and *Chamaecrista* and also harmed *Centrosema* to some extent. At Abuja Road the damage was much more than at

Table 5 – *Possible use of herbicides, their application rates and time of application recommended for the seed production of tropical pasture legumes*

Stylosanthes hamata		
Imazethapyr	40 – 80 g ai/ha	pre to early post emergence (PrE-ePoE)
Bentazon	720 – 1440 g ai/ha	post emergence (PoE)*
Trifluralin	720 ai/ha	pre sowing, incorporated in the soil (PrS)
Chamaecrista rotundifolia		
Imazethapyr	40 – 80 g ai/ha	pre to early post emergence (PrE-ePoE)
Centrosema pascuorum		
Imazethapyr	40 – 80 g ai/ha	early post emergence (ePoE)
Bentazon	720 – 1440 g ai/ha	post emergence (PoE)*
Trifluralin	1440 ai/ha	pre sowing, incorporated in the soil (PrS)
Pendimethalin	960 – 1920 g ai/ha	post sowing (PoS)[1]

[1] application rate according to soil type and depth of sowing; * according to weed population in combination with a herbicide effective against grass weeds and/or a split application

Kurmin and caused an almost complete loss of seed yield of *Stylosanthes* and a significant reduction of the seed yield of *Chamaecrista* in 1990. The more sandy soils and heavy rains after the application of the herbicides at Abuja Road can be regarded as the main cause. Both herbicides affect the germination and growth of young seedlings and their damaging effect on the germinating legumes increased under these circumstances. Pendimethalin, which is succesfully used as a standard application for the seed production of *Chamaecrista* in Australia (D. Loch, Queensland Department of Primary Industries, 1993 pers. comm.), is washed deeper into the soil and reaches the layer where the seedlings of the more shallow sown species *Chamaecrista* and *Stylosanthes* germinate. The seeds of *Centrosema* which are sown at greater depths into the soil are less affected, therefore even higher application rates of Pendimethalin caused none or less damage, which was then only temporal. Trifluralin is not translocated with water but on soils with low contents of organic matter (like Abuja Road) the effectivness is higher and only lower application rates can be recommended.

Diuron damaged all three legume species to such an extent that it cannot be recommended. Aciflurfen caused only temporal damage to *Centrosema* in greenhouse experiments, while under field conditions the damage to *Centrosema* was such that it cannot be recommended. All other herbicides Cycloxidim, Fenoxaprop-p-ethyl and Imazethapyr did not show harmful direct effects on the three legumes.

Site and weed population

The effectivness of the herbicide application was related to the botanical composition of the weed flora at each site. After the exclusive control of either monocotyledonous or dicotyledonous weed species at Kurmin Biri the plots were overgrown with weeds not affected by the specific herbicide. At sites where the proportion of grasses on the weed population is low (e. g. Abuja Road) the specific control of Dicotyledons was effective.

Efficient control of weeds can either be achieved with combinations of herbicides or herbicides with a wide range of weeds controlled. The combination of Bentazon with a herbicice effective against grasses or the application of Imazethapyr was successful. Bentazon can be sprayed in a single application but with regard to the different periods of time of the emergence of weeds a split application with lower rates each is recommended. Then, the tolerance of the sown legume to the herbicide is also enhanced. The herbicide for the control of grasses can be added at either application in regard of the development of the grasses. At the experiments the mixture was sprayed at the second application of Bentazon. Generally Bentazon should not be applied before the sown legume has developed the third leaflet. Imazethapyr could be applied from pre-sowing to post-emergence of weeds and was effective against a wide range of weed species at both sites.

The comparatively low application rates required for Imazethapyr were remarkable. For the application of such low rates a certain standard in the application technique will be required. This is specially important since it is not documented when hazardous effects on the legume and the environment will occur.

From the above it is obvious that chemical weed control will be limited to a smaller group of specialised seed producers. The necessary technical equipment (e. g. sprayer) for the adequate application of herbicides is currently only found in some few Nigerian (and West African) farm enterprises. The use of herbicides requires good knowledge about the site (e. g. soil characteristics, botanical composition of the weed flora), the expected infestation with weeds and timely spraying. Therefore chemical weed control may only be feasible for specialised commercial seed production on larger areas.

Cropping and harvest

Fields of *Stylosanthes* and *Chamaecrista* can be use for more than one season for the production of seeds due to the ability of these species to survive the dry season and regenerate easily from seeds. The regeneration of *Centrosema* is limited and only one year of cropping without replanting is possible. Efficient manual weed control ensured high seed yields of *Chamaecrista* and *Stylosanthes* (Table 4) in the 2nd and 3rd year of production. Replanted *Centrosema* seed yields in 1992 were not as high as in the first year of production and this can be attributed to disease symptoms that were observed, included yellowing and bleaching of leaves in defined areas of the experimental plots with higher plant densities and black necrotic spots mostly on the leaves that caused light to severe damage to *Centrosema*. The causal pathogenes could not be clearly identified, but from plant material showing symptoms of *Alternaria* sp., *Phoma sorghina* and *Fusarium* spp. have been isolated (A. A. Adeoti, Crop Protection Department, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria). Anthracnose *(Colletotrichum gloeosporioides)* symptoms were found on the cotolydons of young *Stylosanthes* seedlings in 1991. It could be assumed that the seeds were already infected (Burt et al. 1983, Davis et al. 1987). The growth was retarded by approx. 2 weeks, after which the seedlings recovered and plants developed normally by with no further visible symptoms.

The application of herbicides "pre-sowing" or "pre-emergence" will be restricted. The need for incorporating Trifluralin into the soil restricts its use in resown crops. The application of Pendimethalin will only be reasonable if weeds establishing from seeds are the main problem. "Post-emergence" applications of Imazethapyr and Bentazon and combinations of Bentazon with Fenoxaprop-p-ethyl and Cycloxidim may be feasible in the 2nd and 3rd years of cropping. Chemical together with manual weed control will help to reduce time constraints on the manual weeding and the possibility to remove weeds which are difficult to control by herbicides (e. g. *Hyptis* spp.).

For less intensive systems of seed production (e. g. on established pastures) weeds can be controlled by grazing animals. Young grasses are more attractive to grazing animals and are therefore selectively grazed.

The quantity of seeds harvested will not only be dependent on effective weed control but the appropriate time of harvest is also an important factor. The optimum period of harvest will also depend on the method used for harvesting. All three legumes tend to shatter their ripe seeds easily. If seeds should be directly harvested it is important to harvest early but not before the peak of production. The flowering period of the legumes may extend over weeks; this was notable in the 2nd and 3rd years of production for *Chamaecrista* when surviving plants start flowering a few weeks after the onset of the rains and will continue as long as there is sufficient soil moisture. Therefore the determination of the optimum period for harvest requires a lot of experience. Already the choice of location is important. Thus, the harvest time should coincide with the beginning of the dry season. Ripening of seeds will then also be more synchronised.

A single direct harvest is most appropriate for *Centrosema*. Within 1-2 weeks almost all pods ripen and seeds will shatter quickly as the plants dry out. High seed yields of more than 1 t/ha are then possible. During the experiments it was not possible to recover such quantities of fallen seeds from the soil surface. The time period for direct harvesting of *Stylosanthes* is longer (2-4 weeks). At all times of harvest some unripe seeds will be found in the harvested seed material while others have already shattered. Harvesting should commence if ripe seeds are visible and the falling of seeds gets audible if the plants are shaken (Hopkinson & Loch 1977). The indeterminate growth habit of *Chamaecrista* makes it difficult to judge the optimum time for the seed harvest. A periodicity of ripening is proposed and was observed during the experimental phase. Higher proportions of ripe (black) pods were counted every 3-6 weeks (Fig. 3).

Direct harvesting can either be done with sickles followed by drying (if possible on a smooth surface where shattered seeds can be swept off easily) and manual threshing. The use of mowers (E. Agishi, National Animal Production

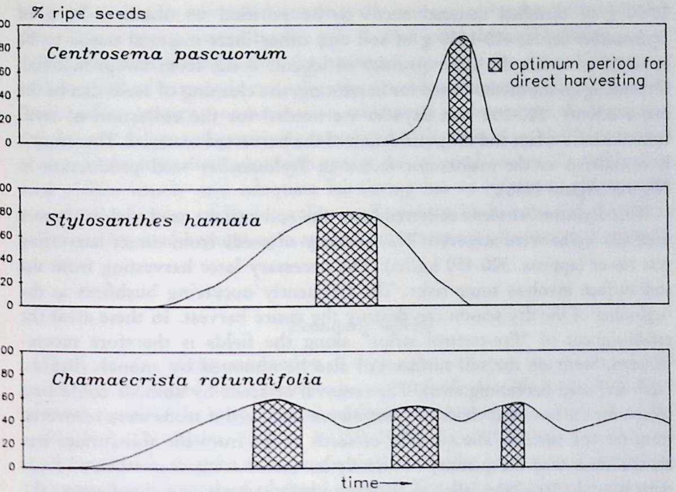

Fig. 3 – *Percentage of ripe seeds of the total quantity of harvestable seeds and optimum periods for direct harvesting of seeds of three tropical pasture legumes.*

Research Institute, Ahmadu Bello University, Zaria, Nigeria, 1993, pers. comm.) or combine harvesting is also possible (English & Hopkinson 1985; Norton 1990) but is of minor importance as Griffiths (1993) recorded only 1 % of herbage seed farmers using combine harvestors in Subsaharan Africa. In *Centrosema*, harvesting of fallen seeds could be done shortly after the legume dried. For the other species harvesting of fallen seeds should be done later. If seeds are to be harvested from the soil surface the simplest way is to use local brooms and shovels. In intensive production systems a suction harvester can be used. This device requires powerful tractor machinery to process the large quantities of soil passing the machine during the process of separating seeds from soil (J. Hopkinson, Queensland Department of Primary Industries, Australia, 1993, pers. comm.). This technique can only be used on lighter soils and under dry conditions. Under Nigerian conditions only manual or partly mechanised techniques are of importance. Seed cleaning can be done with locally produced sieves (chicken-fence, constructing materials, mosquito net) and winnowing is done very effectively by experienced women. While, e. g., 10-50 g of threshed material needs to be purified to obtain 3-50 g of *Stylosanthes* seeds, 400-1200 g of soil and other inert material needs to be removed to obtain the same quantity of legume seeds from swept material. Depending on the method used for harvesting, the cleaning of seeds can be the major activity. 100-200 man days/ha are needed for the collection of seeds from the soil surface and the purification of the harvested material. Therefore it is considered as the major cost factor in *Stylosanthes* seed production in Nigeria (Agishi 1986).

With *Stylosanthes* seeds collected from the soil surface seed yields of more than 600 kg/ha were achieved. The quantity of seeds from direct harvesting was lower (approx. 300-450 kg/ha). The necessary later harvesting from the soil surface involves some risks. The frequently occurring bushfires at the beginning of the dry season can destroy the entire harvest. In these areas the establishment of "fire-control strips" along the fields is therefore recommended. Seeds on the soil surface can also be removed by animals (lizards, birds and seed harvesting ants). The removal of seeds by animals could be a reason for the low seed yields of *Centrosema* observed if seeds were recovered from the soil surface. The quantity of seeds swept from the soil surface was always lower than the quantity of directly harvested seeds even when all seeds must have shattered and fallen to the ground. Otherwise one could expect the comparatively large *Centrosema* seeds should facilitate seed collection from the soil surface. If seeds of *Chamaecrista* are to be harvested from the soil surface the weather conditions must be favourable. *Chamaecrista* seeds form a mucous coat if wet and will stick to each other and to soil particles. Late rainfall or dew can then reduce the quantity of recoverable seeds from soil. Even under dry conditions the seed cleaning of swept material was almost impossible as seeds were of similar size and weight to that of soil particles. With available and cheap labour the collection of ripe pods several times can be profitable. The need for labour is enormous but the effort for the seed cleaning is greatly reduced.

The cultivation of *Chamaecrista* for more than one year offers the chance to have more than one seed harvest per growing season in the 2nd and 3rd year of production. In 1991 seeds of *Chamaecrista* could first be harvested in July (10 WAR) and a second harvest of seeds from the ratoon crop could be taken after 14 weeks in late October. 594 kg/ha (246 and 348 kg/ha respectively) of seeds were then obtained in the weed free treatment compared to 239 kg/ha of a single harvest (Table 4). The first cut during the growing period also has a weed controlling effect. Moreover the plants develop more uniformly after the cut. Due to the climbing habit of *Centrosema*, trellises can be used, resulting in seed yield increases of up to 36 %. The costs for trellising are high. Tall growing weeds like *Hyptis sp.*, *Coreopsis sp.* or *Ethulia sp.* can act as "natural trellises" and with low weed densities the loss caused by the competion with the weeds is compensated by the gain in seed yield through trellising.

It must be emphasised that the optimum choice of the time of harvest for each method of harvest is crucially important to obtain maximum seed yields. Seed quality (purity, contamination with weed seeds and the thousand seed weight) was in general positively correlated with the seed yield. Efficient weed control is the foundation for high seed yields of good quality. To realise these seed yields, timely and adequate harvesting has to be done, otherwise the maximum quantity of high quality seeds cannot be harvested if the wrong technique for seed harvesting is applied or harvesting is done at an inappropriate time.

Economic aspects

The economy of the production of these selected forage legume seeds could be roughly estimated but it seems to be economically feasible for both methods of weed control. The costs for soil cultivation, fertilizer, etc. are between 2000 - 4000 N/ha (N: Naira; 10 N ~ 1 US$, 1991) (Agishi 1986 and data collected by the authors). For the seed production on smaller areas manual weeding is the most feasible method of weed control. The costs for hired labour range between 1200-2100 N/ha. The cost for chemical weed control are up to 1000 N/ha for the herbicide. The herbicide application costs 50 - 100 N/ha. The relatively low costs for the application are only valid on larger areas and if the machinery is also be used for other purposes. Manual seed harvesting and cleaning may incur costs of 1500 - 3000 N/ha. Since no market prices for *Centrosema* and *Chamaecrista* exist the profit can only be estimated for *Stylosanthes*. 1992 the price for *Stylosanthes* seeds was 25 N/kg. With seed yields of 300 - 600 kg/ha revenues of 7500 - 14000 N/ha can be obtained. As a comparison, the prices (1991) of seeds from overseas (Australia) are for *Stylosanthes hamata* cv Verano: 6 AUS$, *Chamaecrista rotundifolia* cv Wynn: 14 AUS$, *Centrosema pascuorum* cv Cavalcade: 10 AUS$, plus 10 to 15 US$ for shipping and insurance. Furthermore, plant quarantine requirements need to be fulfilled, which can be time-consuming and costly. Therefore all efforts should be made to be self-sufficient with pasture legume seeds.

Implications and outlook

Which of the described methods of weed control, harvesting or more general cropping techniques can be used will largely be determined by the expected demand for improved pasture legumes seeds. Several aspects will need to be considered.

- Will the improvement of pastures by the use of legumes be attractive to animal farmers? This will be in close relation to the expected benefit for the animal farmer and in the end determined by the demand for animal products and the purchasing power of consumers.
- What is the ratio between costs and benefits of improved pastures for animal production, or are there other alternatives (e. g. salt licks, improvement of animal health through better veterinary services) which are more cost effective?
- Furthermore, the acceptance of improved pastures is also correlated with the supply of good quality seeds. Only if good quality seeds are supplied already from the start to interested farmers and the resulting pastures are a significant improvement through their high content of sown legumes can a higher future demand be expected.

The seed production of tropical pasture legumes is just beginning in Nigeria. With further acceptance and the integration of improved pastures in crop-livestock farming systems (Tarawali & Pamo 1992) the demand for quality seeds will improve. The production technique can then be adjusted according to the expected demand. The information here provides a basis for choices under different circumstances of production. Recent discussions indicate that the forward way for producing seeds is to train state extension officers who will then train small scale farmers in their respective states to produce seeds, possibly under contract. Currently it seems that Nigerian commercial farmers are not too interested in forage seed production because small scale farmers tend to start producing their own seeds.

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MULTIPURPOSE TREES AND ASPECTS OF THEIR YIELD EVALUATION FOR AGROFORESTRY

by

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"Multipurpose trees and shrubs (MPTS)" are trees and shrubs that are cultivated and managed in such a way, that they may foster sustainable land use with more than one product and/or function. These woody perennials are particularly significant in agroforestry systems, as they not only yield numerous products such as timber and fuelwood, fruits, animal fodder, medicines and poisons, fibres, rubber, tannin agents and mulch, but may also perform specific protective and soil melioration functions. In spite of this, research on MPTS is still only in its initial stages. Over 2000 tree and shrub varieties need to be scientifically evaluated with regard to their potential suitability as MPTS in agroforestry systems.

There is still a dearth of methodological approaches and guidelines based on which the applicability of agroforestry interventions proposed to farmers may be assessed, due to the relatively short history of agroforestry and the use of MPTS in development. On the other hand, the continued adoption of such practices by farmers makes it more urgent than ever to disseminate methods and data that help to evaluate the economic and ecological effects of MPTS. This paper summarizes parts of research work, the aim of which was to contribute to the objective evaluation of product-specific MPTS yields in the context of locally used agroforestry practices.

Multipurpose trees in the agroforestry context

Population growth, demographic change and the resulting modifications in the social and economic environments of farmers are familiar scenarios for most developing countries. Because of the ensuing pressures on the environmental resource base, new or adjusted forms of land use are required to accommodate these developments. However, accelerated and uncontrolled change in the availability, quality and quantity of the resource base also reduces the time available for acquiring empirical evidence of the consequences of new and alternative management strategies (De Haen 1992, Kimmins 1985). Consequently, there is a growing deficit of empirical data regarding the effectiveness of new or modified land-use practices.

The trend towards intensification on smaller agricultural areas, combined with the necessity of sustainable production will, in the future, demand a growing share of labour, external inputs and technical expertise. However, there are limits to this process of intensification in the long term if it is to be economically sustainable. A trade-off emerges between intensifying production on less land and accepting limitations in favour of sustainability. Increased labour and technological inputs are accompanied by the necessary application of higher levels of skill.

Multipurpose trees (MPTS) in agroforestry are one possible solution. Marginal lands can be made productive. The utilization of good sites can be diversified. However, managing trees on short rotations and in combination with field crops requires inputs ranging from adequate site preparation to post-planting care, genetic selection, and multiproduct management through skilful horticultural manipulations, etc. This means that considerable expenditure is required to do so. Thus, the notion that agroforestry cultivation techniques are "low input" systems is often misunderstood. It is true that the use of external inputs, for instance artificial fertilizers, may often be reduced by recycling organic matter within the system. It is equally correct that the dependency on markets is being reduced as a result of the diversification of cultivated areas. But this also means that the farming system's internal expenditures increase.

Only objective and qualitatively acceptable yield data can provide a sound basis for deciding whether agroforestry pathways offer alternatives and acceptable solutions. Accurate, concise, and clear information facilitates the choice between alternatives and to optimize resource use. This information, however is lacking. Indeed, reliable quantitative data on the growth and yield of MPTS is scarce and their economic contribution to agroforestry-based land use is often a matter of speculation. In cases where information about individual MPTS yield potential exists, information regarding their behaviour in temporal and spatial association with crops is scarce. Consequently, farmers, scientists, and policy-makers are compelled to guess and/or estimate the economic and ecological contributions of MPTS to agriculture. This is inadequate at a time when the adoption of lesser-known MPTS is promoted as part of an improved agricultural land use concept in many rural development projects. This paper attempts to show some possible approaches that might help to overcome the current information deficits on MPTS and their possible contribution to intensified and sustainable forms of agroforestry-based land use.

Multipurpose trees

The term multipurpose trees (MPTS) aims to distinguish trees and shrubs from woody perennials commonly grown in plantations for one single (mono) purpose such as pines, which are planted for the production of saw timber. MPTS are woody perennials that are purposely grown to provide more than one significant contribution to the production and/or service function of the land-use system they occupy. In this article, the term MPTS also includes palm trees, rattan and bamboo. The multiple purposes referred to are sub-divided into the production of primary products such as food, fodder, energy and wood; and secondary products such as nitrogen, mulch, and others. Additional roles are the provision of service functions and benefits (Burley and von Carlowitz 1984).

Timber production is usually the principal objective in traditional forestry. All remaining non-timber products are classified as secondary products, despite their increasing importance and economic potential. The various other forestry functions (e.g. regulation of the hydrological balance, effects on the climate, etc.) are associated with the forest ecosystem as a whole and not with the individual tree. In contrast, MPTS are frequently cultivated as individuals where they may be just one component of an intricate agroforestry system. In this context, it is important to note that, *although virtually every tree can play the role of an MPTS, not every tree is an MPTS*. Whether a tree is truly multipurpose depends on the nature of its management and utilization, and the role it is expected to play in a land-use strategy.

MPTS do more than "produce" specified products when integrated into agroforestry-based production systems. They interact positively or negatively with associated crops and the growing site. Outputs like services and benefits influence a farm's production strategy in terms of resource allocation and system organization. The effects of these interactions are rarely replicable on-station and cannot be fully anticipated by researchers. The existence of these effects and their impact, therefore, often remains neglected.

Forms of multiple use

The different forms of multiple-use management in agroforestry may be divided into sub-groups based on multiproduct objectives that are achieved through different management approaches. Wolf (1990) construed sub-groups in an attempt to classify existing yield data on MPTS. Special care was taken to avoid confusion between the multiple utilization of one product (e.g. the "coconut": meat for copra and oils, husks for fibres and fuel) with the multiple utilization of a tree's different products (here, the coconut *tree* (*Cocos nucif-*

era): food from nuts, thatching material from leaves, fibres from bark, boards from the stem, etc.). The most distinct categories are:

- *Multi-use management of the woody perennial*: where the woody perennial occupies a defined space in relation to the agricultural crop, like in most agroforestry technologies, and is consciously managed for several products. The products and service functions are deliberately obtained from one species through:
  a) The *simultaneous* harvesting of more than one product. For instance, palm trees like *Borassus aethiopium* Mart. or *Orbignya martiana* Barb. Rodr.: leaves for basketwork and roofing material, bark for fibres, fruit for oils and toddies, roots for medicinal purposes. An alternative example would be woodlots or hedges (using leguminous species like *Leucaena* or *Calliandra* spp.) that are used for erosion control and are harvested for fodder and fuel at the same time.
  b) The *successive* harvesting of more than one product. For instance, trees that are planted to demarcate a field and are utilized first as tannin agents and/or fodder and are later cut down for timber (e.g.: *Acacia seyal* Del.).
- *Mixed cropping of trees*: the woody perennial is conserved or planted in random mixtures in pasture or cropland. The individual trees are harvested for different products (fruit, fuelwood) and have meliorative functions in addition. Special silvicultural treatments or horticultural manipulations that would promote the growth of any one product are not being applied.
- *Multi-layer systems*: e.g. home gardens where several different species used for specialized products are kept in complementary, vertically integrated associations. Each tree yields a specialized product and has a defined service function. Strictly speaking, this is the highly intensified multiple land use of small units rather than multiproduct management. However, it is classified with the other types of multiproduct management, as the outcome is the same for the farmer in terms of a diversified product flow.

In the aforementioned literature analysis on MPTS yield data, it was observed in virtually all cases that one product constitutes the primary management objective, while the other product(s) were frequently referred to as "fringe" benefits. These are typically not quantified. This suggests that most management practices attempt to maximize the yield of one product, while the harvesting of secondary or tertiary products occurs coincidentally, without special management inputs to optimize them. Only very few cases referred to the fact that more than one product was sought deliberately and that the species was managed for this aim. In this category of true multiproduct management, one must further distinguish whether a multiple-product objective is attained through simultaneous or sequential management/harvesting practices and if it involves one or several species, like in home garden systems for instance.

Multipurpose trees in agroforestry systems

Agroforestry systems are characterized by their diversity and heterogeneity. Here, MPTS are only one of the system's many components. As in any system, the interrelations between the various components may be competitive, spatially and temporally complementary, or be expressed in mutual dependencies (Hoekstra 1985). The compatibility of MPTS with other system components is therefore an important area of research in agroforestry. For instance, competition may be desirable if it is depriving weeds effectively of light, for example. On the other hand, this very competition for light, water and nutrients may provoke unintended yield reductions in the agricultural crop.

An MPTS' interactive relationship within an agricultural system depends on species, variety, associated crops and the prevailing biophysical conditions. The crop management strategy that is based on the farmer's production objectives is equally influential. These objectives are in turn influenced by his skills and capability to add external inputs. None of the aforementioned factors is static: some or all will change over time. This may result in qualitative and quantitative yield increases or decreases. The magnitude of these effects is again a function of plant material, site variability, management skill and the farmer's production objectives. These effects differ for the countless possible tree/crop combinations, not only within a given agroforestry practice, but also for one single agroforestry technology that is applied between farms. The evaluation of these effects is of primary concern when assessing the biological and economic efficiency of MPTS in agroforestry. Given the relative deficiency of reliable yield data that are based on empirical work, farmers must assume significant risks when introducing MPTS in their farming systems. This fact may help explain the still modest success experienced thus far in rural areas with the extension of the agroforestry concept and its range of technology packages.

Performance and yield of MPTS

Multipurpose tree yield may be defined as the quantity of specified products or plant components harvested over time, including the level of utility derived from any of the service functions and benefits. In the context of agroforestry, MPTS yield occurs as a stream of outputs, obtained simultaneously, or in sequence, as a result of introducing woody perennials into the farm production system.

The yield of MPTS in terms of specific products (production) may be quantified objectively. Productivity measures the efficiency that relates output to the use of one or more resources, including time. Measuring biological yields assists in evaluating species and management recommendations. The production relates to a multitude of biological and technical influences, of which the net possible harvest share is ultimately of importance to the farmer (Figure 1). It depends on the:

- species and quality of its genetic material,
- specific site (natural and socioeconomic),
- specific cultivation or management method (input, skills), and
- any promoting or retarding exogenous influences.

It is more difficult to evaluate yield in monetary terms. In fact, it can often only be partly assessed, as a significant share of MPTS products is utilized in the subsistence context. The aspects of product availability during the agricultural cycle and the level of the product's quality are as important as obtaining high yields. In the subsistence context, the quantity of a product alone is meaningless. For instance, in environments where trees are maintained for the supply of dry-season fodder supplements, the relevant measure of fodder production is not necessarily the average annual production of foliage or pods, but rather the fodder available at the time it is required most, namely during the dry season. Availability at the right moment is therefore of as much concern as the quantity that a tree might produce. In this context, the multiproduct attribute of MPTS is a practical advantage in a production strategy, especially in subsistence economies. Multiple products, which may be harvested in small quantities at relatively flexible points in the cropping cycle, conform as well to a marketing strategy that takes advantage of short-term price fluctuations, as they are suited for on-farm consumption needs.

In contrast to an MPTS' physical yield, service functions are generally assessed by indirect means. The protective and meliorative functions may become tangible in the form of erosion protection, nutrient cycling, nitrogen fixation or improvement of the micro-climate. It is even more difficult to evaluate the benefits and welfare functions. These cannot be measured objectively because each individual experiences them subjectively, thus differently, and attaches a different value to them. Examples of benefits are for instance functions regarding property or ownership regulations and cultivation rights. The reduction of risk, which is achieved through species and product diversification, is similarly important. Although benefits alone are generally insufficient for inducing farmers to plant trees, once known they become important factors in the adoption of tree planting and agroforestry.

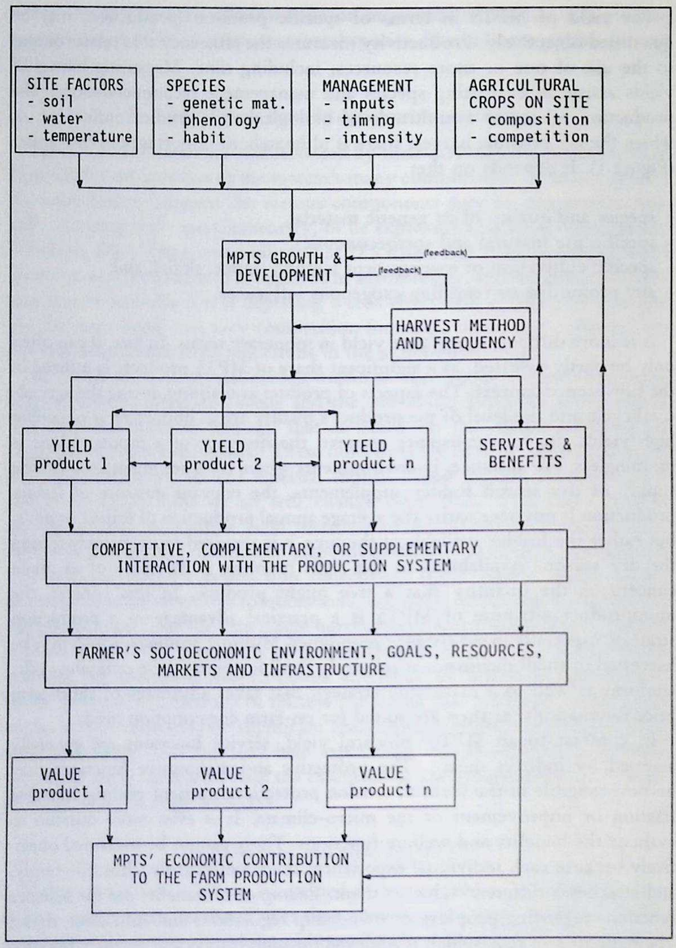

Fig. 1 – *Schematic representation of factors influencing MPTS yield and economic contribution (adapted from Robinson and Thompson 1988).*

Multiple production, product-specific yield data and biomass productivity

When a farmer manages for multiple objectives, he may forgo the maximization of any one tree product, in order to optimize several outputs. Indeed, he may accept an overall reduction in potential tree product yields in order to minimize potentially negative tree/crop interactions or maximize the 'environmental benefits' of trees, e.g. service functions like nitrogen fixation and erosion control. He may also decide to utilize a lower yielding tree species or provenance instead of a higher yielding one if the former proves to be less competitive with companion crops due to its morphology, rooting pattern or other traits.

Another aspect that may influence a farmer's choice of species is that of management flexibility, i.e. the option to switch between products. Management flexibility (depending on the scenario, substitution or compensation) is important for subsistence economies, where cash is scarce and disbursements may be avoided by modifying an agroforestry practice to obtain by-products normally purchased or sold in time of need.

In an attempt to verify the validity of this concept, Wolf (1990) analyzed the data on MPTS utilization practices that was reported by field informants to ICRAF's MPTS-Database project. Data was analyzed for selected species which had been observed in a wide range of different environments because of their tolerance for extreme growing conditions. In this context it was possible to show that although the role of MPTS as a source of fuel surpasses that of fodder in the humid and sub-humid tropics, fodder is more important as a tree product in the semi-arid and arid zones.

A comparison of the frequency of utilization of fodder and fuel showed that neither use strongly dominates the other in any of the ecological zones. However, an increasing number of species is managed for both products (simultaneously or alternatively) in the semi-arid and arid zones, as opposed to the humid and sub-humid zones, where the products are sought from specialized trees (i.e. a 'fodder tree' or a 'fuelwood tree'). Indeed, the two uses appeared to compete, as either utilization is valued highly in the farm household. Any preferences expressed are therefore likely to be subject to external influences, such as climatic fluctuations, shifts in feed or fuel prices, or the market value of cattle, which makes it more efficient to substitute one product with another. The importance of management flexibility, which enables either of the latter two products to be chosen, is thus emphasized and should be considered when choosing MPTS for farm production systems.

Approaches to yield evaluation

Due to the complexity of the subject, the information required to evaluate MPTS for a multitude of biophysical and socioeconomic scenarios will not be available any time soon. Scientists must consequently allocate resources to priority subjects that are most likely to address the most urgent questions on MPTS in agricultural land use.

Yield tables for woody perennials that estimate yields when the species are indeed managed for several products hardly exist. One reason for this may be the observation that the applicability of structured models, such as forestry yield tables for instance, are limited to the environmental conditions under which they are developed (Brünig 1974, Pretsch and Bossel 1988, Röhrig and Gussone 1990). This raises the question of whether or not the construction of yield tables is indeed efficient for approaching MPTS species selection and their silvicultural management. The case for the compilation of yield tables can be made with the argument that the assessment of a tree's biomass productivity is the necessary starting point for evaluating its suitability for a given site. This indicator, regardless of the intended end use, implies a species' overall productivity, even if such data does not adequately express its ability to:

- perform in a management context and yield desired products on a sustainable basis
- fit in the context of the aforementioned flexibility issue.

At the same time, the 'cost' of biomass production with regard to the species' competitiveness with other crops is easily overlooked. This is the reason for evaluating an MPTS' product-specific yields in trials that simulate representative management patterns.

Accommodating the concept of product-specific yield assessment as opposed to biomass productivity alone presents challenges in the design of appropriate measurement techniques. The morphology of MPTS needs to be categorized, and product-specific standards and management characteristics need to be classified. However, product-specific attributes, in terms of quality characteristics, depend on regional utilization patterns, so some of the problems of product-specific yield studies may require site-specific consideration.

Other aspects, such as the question of grouping and controlling the variables that influence yields still need to be addressed objectively, especially where yields are to be monitored as part of an on-farm research programme. This is already a problem, as significant yield variability must still be expected, due to genetic variability and because propagation material that has been selected and genetically improved is often not available. Likewise, there is a lack of experience on optimum nursery practices and the early management of MPTS.

Type of trials

Most MPTS evaluation trials that are conducted under researcher-controlled conditions can be categorized as follows (Burley and Wood 1976, Huxley et al. 1985):

- *species elimination trials* (short-term comparisons of a large number of different species on one or a number of sites, with the aim of selecting a smaller number of promising species for more intensive trials);
- *species testing or performance trials* (comparison of a restricted number of promising species, based on previous experience, on sites within a broad climatic region); and
- *MPTS management trials* (to confirm, under management conditions, the results shown by a small number of species that have demonstrated superior performance in earlier trials).

Early species elimination trials generally include many entries, often with little replication. Species testing or performance trials usually involve fewer treatments with more replicates. MPTS management trials involve even fewer species often in factorial combination with management treatments.

It is sometimes suggested that this series of trials can be planned so that the criteria of a species elimination trial can be modified and continued as a species testing or management trial. This is done by planning for the occurrence of border effects in the design stage, and ensuring that plots are sufficiently large and stocked with enough trees, using species for which there are already indicators that they will do well. Doing this can be cost-efficient and save time. It requires foresight, experience with the species under consideration, access to labour and sufficient land.

However, this approach may also go quite wrong when survival is less than 80 % for example, because entries that have failed were planted with unnecessarily large plot sizes and replications. Furthermore, layout complications may be introduced by random gaps in the middle of the trial, and problems with data analysis may arise. As the risk of wasting resources is high, this "shortcut" can generally not be recommended.

The term *MPTS management trial* must eventually be expanded to *MPTS management intercropping trials*. These trials test species for specific agroforestry technologies. They may focus on measuring recurrent, product-specific yields over time. An equally important aspect is that they evaluate the performance of the agricultural component. The imposition of management practices of agroforestry technologies and the evaluation of the interaction between different plant components will be quite complex. It is therefore assumed that species selection with a view to assessing a plant's ability to produce desired products has already occurred.

The last category of management intercropping trials may be conducted both on- and off-station. The trials off-station are ideally complemented by MPTS yield surveys which can give valuable information about the limitations and success of agroforestry technology designs. This approach is of special

Table 1 – *Assessment criteria for three types of MPTS trials (Wolf 1990)*

Assessment criteria	Type of trial Spp. elimination	Spp. performance	Spp. management
Survival (%)	x	x	
Tree morphology	x	x	
Merchantable height		x	depends on technology
Total height	x	x	depends on technology
Basal area		x	depends on technology
Diameter at the base of the tree	x	x	depends on technology
Diameter at breast height		x	depends on technology and species' morphology
Crown width			depends on technology
Leaf retention and renewal		depends on technology	depends on technology
Branch: numbers		depends on technology	depends on technology
Branch: spread		depends on technology	depends on technology
Form		depends on technology	depends on technology
Biomass: above ground	x	x	
Volume, weight of the product-specific biomass			x
Response to silvicultural manipulations			x

interest to extension projects that have already promoted agroforestry practices and wish to evaluate the impact of their recommendations.

The matrix in Table 1 gives an overview of the measurements that are carried out in each trial category. There is some overlap between trial categories. Some measurements within a category are either/or measurements (e.g. *either* total height, *or* height of longest shoot, not both).

Most of the measurements in the category of species management trials carry a note "depends on technology" to be evaluated. Table 2 attempts to distinguish between four important agroforestry technologies for which MPTS are currently being tested, for example in the research network of the International Centre for Research in Agroforestry (ICRAF). Within these technologies, MPTS are typically utilized for either poles or posts, firewood, fodder, and mulch, or any combination thereof. The appropriate assessment technique

Table 2 – *Performance criteria in the evaluation of MPTS for defined agroforestry technologies (Wolf 1990)*

Assessment criteria[1]	Agroforestry technology (desired product) Alley cropping (leafy biomass, fuelwood)	Border plantings (timber, poles fuelwood)	Woodlots (fuelwood, poles)	Fodder banks (leaf and twig biomass)
Weight: litter	x			x
Weight: woody biomass	x	x	x	
Basal area		x	(x)	
Diameter at breast height		x	(x)	
Total height		x	(x)	
Merchantable[2] height		x		
Volume[3]	x	x	x	x
Spec. gravity		x	x	
Morphology, branchiness		x		
Rooting pattern	x	x		
Competition w/field crops	x	x		
Reaction to tree or stand manipulations	e.g. response to coppicing	e.g. species composition, spacing, response to thinning	e.g. spacing	e.g. response to frequent coppicing
Output-oriented	e.g. N-content, decomposition rate	e.g. straightness, resist. to termites	e.g. calorific value	e.g. lignin and protein content

[1] NB: Assessment criteria may overlap for different technologies.
[2] Depends on local quality standards (dimensions) (e.g. minimum length, diameter, etc.).
[3] May be calculated from other, already measured values (e.g. SG, weight).

varies accordingly, and is a function of management and the end product desired (which is implicit in the agroforestry technology employed). The parameters marked with an 'x' indicate the minimum measurements that are required for *product-specific* yield evaluation within the context of defined agroforestry technologies.

The foregoing matrix indicates the minimum recommended measurements to be taken for each of the four agroforestry technologies. Other measurements may be added, e.g. testing the calorific value of fuelwood, branching pattern, decomposition rates for mulch, moisture content of wood, etc. However, the latter steps are not essential for the basic performance evaluation of MPTS. Sometimes this information may be obtained from other researchers or from literature.

When considering additional aspects that are required to evaluate the performance of MPTS in agroforestry practices (e.g. MPTS management intercropping trials) and that distinguish MPTS research from conventional measurements, the following points may need to be considered:

- phenology,
- response to associated field crops,
- nutrient content of biomass,
- success of vegetative propagation techniques,
- response to tree manipulations (response to coppice cuts, pruning, etc.),
- response and resistance to insects and diseases,
- rooting characteristics (biomass, extent and spread),
- association with microsymbionts, response to inoculation, nodulation, etc.

Equally important is site and season characterization and evaluation that permits yield data to be put into context with the growing site, and to compare, unambiguously, the performance of MPTS across ecological gradients. Suggestions on "minimum data sets" to do this are made by Young (1985), Briscoe (1990) and MacDicken et al. (1991).

The evaluation of MPTS must eventually include their suitability to yield products other than wood. Products like fodder, fruit, mulch, gums, oils, etc. may be equally as important as wood products. Besides the expression of solid wood volume in m^3 for timber, the yields of other products in relation to a unit area and time may be expressed by one or more of the following units:

- Volume stacked (m^3): e.g.: fuelwood
- Volume of fluid (litres): e.g.: exudates, etc.;
- Weight (green, air-dry or oven-dry): e.g. fodder, fuelwood, fruit, etc.
- Piece units: e.g. poles that are graded on minimum dimensions and, in addition, on quality characteristics, like straightness, length, bending strength, etc.

These *units* are generally accepted when evaluating agroforestry technologies from the point of view of end products. However, there is some difficulty in defining *product standards*, such as what should be described as fuelwood or fodder. The problem of defining minimum dimensions is illustrated by the following example. Wolf (1990) tested the common recommendation of separating branch biomass (i.e. fuelwood) from leafy biomass based on the lignification stage. Using several species, the area of lignification, and therefore the dividing point, differed for each and changed with the season and environment. Furthermore, lignification occurs gradually and over a considerable length of the aging shoot, thus introducing subjective judgement in deciding where to separate lignified and non-lignified biomass.

Similar observations were made when attempting to qualify leafy biomass, including semi-lignified branchlets that might be suitable as fodder. The diameter of the lignified material that is browsed may exceed 1 cm, depending on the species, and animal and browsing pressure. Feeding tests conducted in Western Kenya demonstrated that goats feed on twigs of *Leucaena* spp. up to a diameter of 0.7 cm, whereas cattle consumed semi-lignified material up to a diameter of 1.1 cm. At the same time, farmers indicated that branchlets are used for stick-fuelwood with the minimum diameter being 1 cm. Similarly, it is well known that standards on dimensions and quality of fuelwood change regionally with availability and consumption patterns. Based on the author's field observations, one may define fuelwood as any section of the stem or lignified branch with a diameter of 1 cm or more. This will be different in other countries or regions. For instance, in Costa Rica, a minimum diameter of 2.5 cm is suggested for woody material that rates fuelwood (Catie 1984). One aspect that is virtually never addressed is the acceptable maximum diameter of fuelwood. Accordingly, it is necessary to decide on minimum and maximum dimensions that are acceptable and adhere to them when embarking on product-related research.

Several conclusions can be drawn from the foregoing. The dimensions of tree products are usually implicit with the product type in location-specific studies. However, these dimensions differ between regions. Where they are different, it is often not possible to extrapolate results. This shows the limitations of product-specific yield studies, as long as standards are not adhered to or remain undefined. These difficulties may explain the preference for straightforward biomass evaluation in current MPTS research. Still, replicable approaches are required to express product-specific yields, as this information is essential for extension efforts that promote the utilization of MPTS in agricultural land use.

MPTS yield surveys

MPTS yield surveys are one possible approach to the collection of information on product-specific yield under managed conditions. It is important to identify the range of applicability for the study, like with experimental field trials. In a survey, this is generally done by defining the sampling frame – the population from which the sample is drawn.

It is important to understand the difference between the results from a yield survey and a field trial. Different types of conclusions can be drawn from each. A trial is designed to answer specific questions about sets of treatments used in the study. The inferences drawn are restricted to the sets of treatments applied. However, as a result of the randomization used in an experiment, one can be certain that the results are due to the treatments, and not to some other associated factor. In other words, if these tree species are grown again under the same conditions, one can be confident that similar results will be observed.

On the other hand, a survey works with a defined population that has a known structure. A sampling scheme is defined according to that known structure. The data obtained in that manner are used to make inferences about the wider population from which they are drawn.

A survey can only show associations in the population from which it is drawn. One will get the same result when sampling from the same population again. For instance, if a survey shows that alley cropping plots with a certain type and dimension of *Leucaena leucocephala*, produce twice as much biomass as similar alleys with *Gliricidia sepium*, then this may be because of the biological production capability of the two species. However, it could also be that the former species is grown on better sites, while the latter species is being grown on more marginal sites. Perhaps extension workers had advised farmers against growing *Leucaena* on some sites. The fact that one cannot necessarily expect to find a similar difference when the two species are grown side by side on the same site limits the usefulness of the survey approach.

Control of external factors

However, it is possible to increase the likelihood that the results can be reproduced by watching for the effect of other possible factors that may influence the production of the tree species. In the foregoing example, one might check the effect of different sites or soil type. There will generally be several outside factors that affect MPTS production that one wishes to control. The factors in Table 3 all seem relevant for an agroforestry technology:

Table 3 – *Key factors in agroforestry technology design*

1. For which users is it appropriate?	
	Size and type of farm
	Effect on other land users (e.g. landless, pastoralists)
2. For which sites is it appropriate?	
	Kinds of soils, rainfall, slope, etc.
	In which landscape niche
3. For what products is it recommended?	
	What are they used for
	What are trade-offs between products
4. Which species/varieties are recommended?	
	Multipurpose trees and shrubs species
	Special varieties
	Companion crops, associated livestock
5. Which arrangements are recommended?	
	Configuration, spacing
	Mixtures
6. What management practices are recommended?	
	Tree establishment and replacement of old trees
	Tree management/manipulation
	Management of companion crops
	Timing of tree and crop harvest
7. What type of performance can be expected?	
	Expected tree product yields
	Expected crop yields
	MPT service functions and benefits
	Economic returns
	Risks involved
8. What inputs are required?	
	Quantity of labour, land, cash
	Level of management skills
	Necessary infrastructure for inputs, training, marketing

The control of these factors can be handled in three ways:

- Restricting the survey to only one level of that factor.
- Splitting the population into several groups, known as strata, so that a factor has only one level within each stratum. For instance, one might have one stratum for each main soil type in the region. A sample is drawn from within each stratum and the results pooled with those found from other samples within other strata. When the stratifying factors are of specific interest, results may also be presented stratum by stratum.

– Proceed with the design and data collection of the survey, disregarding the factor, but in each case recording its value. Then, the species differences can be corrected for the effect of the factor at the analysis stage using general regression methods.

One problem with all these approaches is the assumption that the actual underlying factor that is affecting MPTS production is being observed. This may be difficult when it is some characteristic of the farming household (such as wealth). For instance, those households with external income may use additional resources (fertilizer, for example) to help establish trees, something which may benefit certain species more than others. Alternatively, the wealthier households may be more interested in products that are saleable and manage them better.

The purpose of restricting the survey is very simple – it merely redefines the sampling frame and hence the range of applicability. However, it limits the results of the survey to the level of the factor that has been chosen. An MPTS survey will generally be restricted to a certain specific function of the MPTS, to a specific region, and to specific types of management.

Although one may expect the factors that are used for restriction to affect the actual production of MPTS, they may be expected to have less effect on the differences between the tree species. If so, then the results may be extended carefully beyond the levels used. For instance, if the difference between *Leucaena* and *Gliricidia* spp. may be the same on good sites and poorer sites, the results found on good sites may extend to poor sites. However, if all sites were sampled randomly, one would get a biased view of the difference between the two species, particularly if one species is grown more often than the other on one type of site.

Stratification is standard practice in many types of surveys. However, it can only handle a few major factors as the mechanics of sampling within each stratum become more complicated as the number of strata increase.

The method of correcting for the factors at the analysis stage is standard practice in social science surveys. However, it requires access to computer facilities, a good statistics package and some training in the handling of survey data. This latter approach is therefore only to be recommended to organizations that possess such facilities, such as the major agroforestry research organizations.

Wolf et al. (1990) suggested that small field-based extension projects with no computer facilities could collect useful information by limiting the survey to several important factors. When several factors are used, the number of possible classes becomes very large and few farms will fall into each class. However, an extension project with local knowledge will know the most commonly used combinations of practices: for instance, hedgerow intercropping with 5 to 7 metre wide alleys, with two major species, using only one specific tree nursery, on moderately sloping land with stony sandy soils. Many other factors, such as climate, will be automatically limited by the geographical restriction of the project. The very simple statistics that can be extracted from such surveys can help the extension project to prioritize its advice to meet local information needs. An example of how factors and factor levels may be organized is given in Table 4.

There appear to be two distinct levels at which the survey method is appropriate for MPTS assessment. Firstly, there is the aforementioned, restricted low input survey, where the results will be localized. The results can be extended, if care is taken and if thought is given to the possible ways in which the other factors may affect the results. Secondly, there is the larger, more sophisticated survey, which is less restricted. This usually combines stratification for one or two major factors with adjustment for further factors using regression techniques at the analysis stage.

Types of yield surveys

Wolf et al. (1990) described two main types of surveys which involve the yield evaluation of on-farm agroforestry technologies:

- Design-specific surveys;
- Design-comparison surveys.

Design-specific surveys provide information about the yields of a particular agroforestry design. A design represents a complete specification (a species, with a detailed management recommendation) for a technology. A design-specific survey is appropriate, for instance, if a project attempts to assess the performance of one species in one technology. It is essential to be able to identify a particular "agroforestry design" for analysis. Such a study may be used to evaluate the yields of a particular species or management practice to see whether it is worth recommending its use beyond a limited area.

Design-comparison surveys are used to compare yields of different species, or different management recommendations or site conditions within a technology design. For instance, different MPTS species in the same basic arrangement and management, or different management practices for the same MPTS species, may be compared. Such a study could attempt to answer such questions as the choice of an appropriate tree species for border plantings in a particular region by comparing yields from existing plots using these species.

In the sampling, the basic difference between the two types of surveys is that in a design-comparison survey the factor for comparison is used to declare strata. This ensures that the proportion of farms sampled in each category is

- Proceed with the design and data collection of the survey, disregarding the factor, but in each case recording its value. Then, the species differences can be corrected for the effect of the factor at the analysis stage using general regression methods.

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- Design-specific surveys;
- Design-comparison surveys.

Design-specific surveys provide information about the yields of a particular agroforestry design. A design represents a complete specification (a species, with a detailed management recommendation) for a technology. A design-specific survey is appropriate, for instance, if a project attempts to assess the performance of one species in one technology. It is essential to be able to identify a particular "agroforestry design" for analysis. Such a study may be used to evaluate the yields of a particular species or management practice to see whether it is worth recommending its use beyond a limited area.

Design-comparison surveys are used to compare yields of different species, or different management recommendations or site conditions within a technology design. For instance, different MPTS species in the same basic arrangement and management, or different management practices for the same MPTS species, may be compared. Such a study could attempt to answer such questions as the choice of an appropriate tree species for border plantings in a particular region by comparing yields from existing plots using these species.

In the sampling, the basic difference between the two types of surveys is that in a design-comparison survey the factor for comparison is used to declare strata. This ensures that the proportion of farms sampled in each category is

Table 4 – *Possible factors and factor levels used in the classification of hedgerow intercropping design (note: inputs like labour, cash and land resources are reflected in the design factors of the management prescription)*

Function	Components	Site Factor	Level	Arrangement Factor	Level	Management Factor	Level
mulch, green manure, soil erosion control, fodder, fuelwood, other . . .	woody perennials of specified species, annual crops	cropping history:	new site, 2–3 years, more than 3 years;	number of tree rows per hedge:	single, double, triple rows	age of trees in hedges:	≤ 0.5 yr 0.5–1 yr 1 –1.5 yrs 1.5–2 yrs 2 –3 yrs 3 –4 yrs etc.
		slope:	flat, gentle, moderate, steep;	spacing betw. tree rows per hedge:	0.2 – 0.4 m 0.4 – 0.6 m 0.6 – 0.8 m 0.8 – 1.0 m	age at first cut-back	0.5–1 yr 1.0–1.5 yr 1.5–2 yrs 2 –3 yrs 3 –4 yrs 4 –5 yrs etc.
		soil reaction:	acid, neutral, alkaline;	spacing betw. trees of one row	0.0 – 0.2 m 0.2 – 0.4 m 0.4 – 0.6 m 0.6 – 0.8 m	freq. of cuttings since first cut-back	0 1/year 2/year 3/year etc.
		soil texture and physical property	sand, loam, clay; shallow, deep, rocky, etc.	alley width:	2 – 3 m 3 – 5 m 5 – 7 m 7 – 9 m	height of remaining stumps	0– 30 cm 30– 45 cm 45– 60 cm 60– 80 cm 80–110 cm
		rainfall category: (use 200 mm steps)	0–200 mm, 200–400 mm, 400–600 mm, etc.	orientation of hedges: (may not be applicable if hedges follow the contours of a hill)	N – S E – W	harvested material (foliage) utilized:	removed, spread in alley or under hedge
		rainfall distribution category:	uniform, unimodal, bimodal;	crops in alleys:	no crop, annuals, annuals mixed, perennials, perennials mixed with annuals;	crops in alley are fertilized	yes, no
		altitude category: (use 200 m steps)	0–200 m 200–400 m 400–600 m etc.				

optimal. It is always possible to compare sub-groups from other classifications of the farms when using either of these types of survey, as long as these factors have not been restricted. For instance, do MPTS yield more on farms where the head of the household is a woman? In such cases, the numbers of farms in each category will depend upon the frequency of each class in the population. If the frequencies are very disproportionate, the precision will be low.

The design-comparison survey generally requires a larger sample of farmers to provide usable results. It should be clear that the design-comparison survey is only a rough substitute for "comparison plots" established on-farm, or formal experiments on-station. It can only indicate that samples drawn from a certain population with certain characteristics produce certain yields. It *cannot* suggest that modifying these characteristics will induce a comparable modification in yield. Such conclusions can only be drawn from properly randomized experiments. In other words, yield studies of this type only provide indicators of relative performance, but are not scientifically conclusive. However, if care is taken to monitor all the possible associated factors, then there is a good chance that future management practices, where the characteristic under study is modified, will show similar improvements in yield.

Design-comparison studies are most applicable where there is already debate among farmers or extension workers as to the desirability of a particular species, management practice, or the suitability of a site for given agroforestry interventions. In some circumstances, new plots can be set up with farmers and monitored from the date of establishment in areas where only a few farmers use a proposed technology. This prospective approach can reduce variability between farmers and within plots, and may be more reliable than surveying established plots. The main advantage of this is that any differences observed can be attributed to the differences in technology with reasonable confidence, rather than to some other related characteristic. Its disadvantage is that results are not available for some time. Extension projects are encouraged to set up such prospective "technology evaluations" early in a project's life.

Yield surveys and observations

The decision on what section of a farm the measurements are made is equally important. Some sections produce well, others poorly, there may be gaps due to tree mortality; the farmer may manage some parts of the plot more intensively than others; etc. There are thus three basic approaches for addressing the problems of variability:

- Measure the whole plot. This gives an indication of the *actual* productivity of the agroforestry plot. This approach includes areas of poor establishment and poor management, along with the good areas.

- Measure only the best parts of the plot, ignoring areas of poor growth or mortality. This gives an indication of the technology's *potential* productivity.
- Measure only those parts of the plot which represent the productivity (growth) that can be *expected* when the plot is *managed as specified* in the extension recommendations.

The third approach is the most worthwhile for extension purposes, as it records data on the yields a farmer may reasonably expect if he or she follows the technology specifications recommended by an extension programme. However, this approach includes a much more subjective judgement than either of the other two, particularly regarding which parts of the plot to include and exclude. Also, it does not represent any of the problems involved in implementing the technology with regard to areas where the technology has failed.

The third option (and to some extent the second) reduces the variability of the observations, which, in turn, enable the total number of plots that have to be measured in order to obtain a desired level of precision to be reduced. However, the method may introduce large biases, as personal judgement must be used to decide when to include or exclude parts of a sample plot. As such it is difficult, if not impossible, to make absolute comparisons between studies. Consequently, the only scientifically valid approach is through the use of the first option.

It is tempting to perceive MPTS yield surveys as a shortcut that circumvents the need to establish formal agroforestry trials. It therefore must be emphasized that they *cannot* fulfil such a role. Nevertheless, their value as a complement to agroforestry experimentation should be appreciated. Firstly, they demonstrate the performance of MPTS and an agroforestry technology under field conditions. Secondly, they may be the only practical way to obtain information about farmer response to agroforestry technologies. Thirdly, if correctly implemented, they can provide preliminary data on MPTS and their performance for projects. This is essential, as the present geographical coverage of MPTS trials, as well as the number of species under observation, falls well short of providing the results that correspond to the information requirements of agroforestry extension projects.

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