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Indigenous knowledge in a 'modern' sustainable agroforestry system — a case study from eastern Brazil

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Abstract. The case of an agroforestry farm in the coastal mountain area of the federal state of Bahia, Brazil, is used to highlight benefits of the integration of traditional knowledge into a scientifically based farming system. Special attention is given to the selection, combination and management of the crops cultivated. Working hypotheses on the rationale of some major measures are suggested and discussed from a synecological point of view. The results show that under the site conditions the 'forest garden' provides cocoa yields without external inputs at a level which, in the surrounding cocoa plantations, can only be attained by the use of considerable amounts of fertilizer and pesticides.

1. Introduction

For millenia indigenous societies have been living in Amazonia, developing their strategies for the management of forests and fields. The importance of integrating this indigenous knowledge in the design of 'modern' resource management systems is increasingly being recognized.

Using the example of an agroforestry farm in the coastal mountain area of the federal state of Bahia, Brazil, this paper is to show how important elements of traditional 'forest garden' management practices can be integrated in the development of a highly productive agroforestry system.

The study was done on a farm of approx. 500 ha in the Gandu District about 200 km north of the port of Ilheus. The climate of the region is tropical and humid with average temperatures of 24 °C, approx. 1800 mm annual rainfall and 2 months dry season (Fig. 1). Upland soils are Oxisols, while soils in depressions are hydromorphic. Initially the pH of the soils was around 4.5; however, 2.4 t of lime per ha applied every two years increased the pH on the areas under cultivation. Before the farm was established, the site was covered with degraded pasture and secondary forest or, on a smaller scale, with primary forest. Within the last 6 years 100 ha have been cultivated successively.

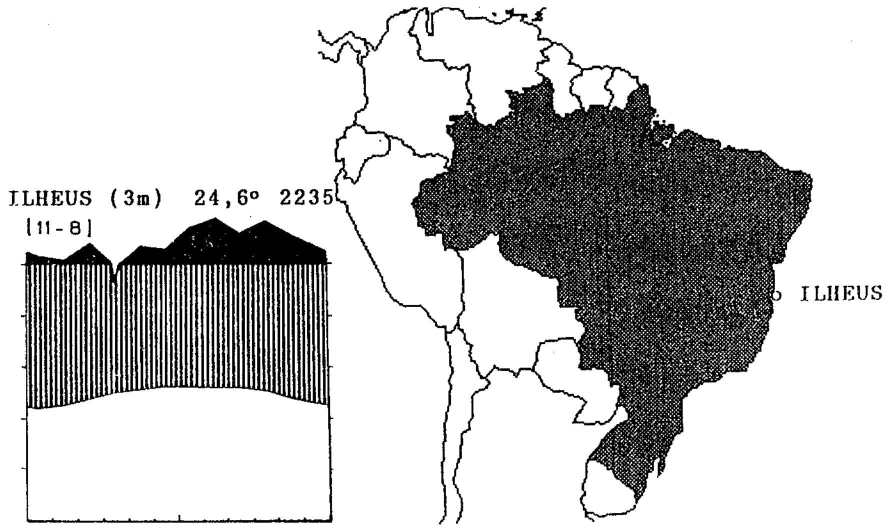

Fig. 1. Climate diagram of Ilheus [Walter and Lieth, 1960].

2. Principles of organic farm management

2.1. *Species composition and vegetation structure*

From the practices of traditional farmers in tropical Mexico the term 'forest gardens' (*selvas-huertas*) has been introduced to refer to forest communities managed to contain a high percentage of useful native trees. Management of these forest gardens consists of selection of certain species, elimination of others, introduction of species from outside sources, and protection of the forest from fire [Gomez-Pompa and Kaus, 1990].

Derived from traditional practices the deliberate combination of different plant species is a crucial management element on the study farm; it is done on the basis of detailed knowledge of the succession stages of the vegetation up to primary forest. There are two strategies for the choice of plants for use in the studied system.

(i) *Native species without commercial value are deliberately left in or incorporated into the system.* In conventional cocoa plantations they are regarded as weeds and are thus removed. The seeds of these native species either germinate spontaneously on the site or they are collected in the surrounding secondary and primary forests. They are appreciated because of their presumed growth promoting effect on associated species.

This strategy is based on traditional techniques: In the succession management of fallow land, the traditional farmers in the Maya Region of Southern Mexico gather seeds from the surrounding forests. These seeds are planted, the seedlings protected and looked after as are parts of the spontaneously germinating vegetation [Gomez-Pompa and Kaus, 1990]. According to Posey [1985] the Kayapo Indians from Brazil's Amazon Basin perform gathering trips to primary and secondary forests to collect appropriate plants for transplanting into old fields. Huastec Indian farmers cultivate coffee and cocoa within native secondary forests [Alcorn, 1981]; a similar practice was described for the coffee agroecosystems on the eastern coast of Mexico [Gomez-Pompa and Jiminez-Avila, 1982].

(ii) *A portion of the native species is substituted by ecophysiologically similar cultivated ones.* Equally this strategy of integrating cultivated plants from outside sources is modelled on traditional agroforestry systems of Indian groups: Although most species encountered in the forest patches of the Kayapo Indians are common campo species, the Kayapo indicate that certain varieties with specific desired qualities (e.g. taste for food, texture for wood or fibre, medicinal properties etc.) were acquired from Indian groups such as from the Tapirape, Karaja, Mundrucu, Assurini, Shavante and others. This implies that vegetation of their cultivated forest patches is composed of a range of cultivated plant varieties brought from an area the size of Europe [Posey, 1985].

There is no apparently deliberate spatial arrangement of species and varieties in the investigated system. However, as a cultivated forest system, it is a kind of 'structured chaos': Each plant should be provided with enough space to cover its need for water, energy and nutrients. To provide the structure in this 'chaos', appropriate cultivation is necessary.

2.2. *Succession management*

Management of the studied forest garden is the attempt to mimic and direct the natural process of species succession. It is guided by two important consideration. They are suggested by the farm manager as 'working hypotheses':

(i) *There is an allelopathic growth reducing effect of maturing plants at the end of their life cycle on their neighbouring plants.* And conversely: *There is a growth stimulating effect by young plants on the vegetative development of adjacent plants.* This hypothesis is regarded as an overall paradigm consistently applied to the various management practices. It may be supported by the observation of inhibition of biological nitrogen fixation on fields in old forests caused by allelopathic effects [Rice and Pancholy, 1972, 1973].

By removing plants and groups of plants immediately before maturity, succession within the cultivated forest garden is accelerated. Through short-cutting the homeostatic phases of the different succession stages any antagonistic growth reduction is removed, while the suggested positive effects of phases of strong growth on the ecosystem are enhanced.

(ii) *There is a positive relationship between carbon and nitrogen cycles within the cropping system and its productivity.* This hypothesis is an additional reason for integrating native plants from the succession of surrounding secondary forests into the forest garden. Since these species have shown their synecological optimum in these conditions, they provide high biomass yields for enhancing the carbon cycle. When periodically cut back, such vegetatively growing plants contribute further to growth stimulation in neighbouring plants as stated in the first hypothesis.

This source of carbon provides the 'driving force' for the unusually high productivity of the system, in that it also determines the activity of nitrogen fixing microorganisms. Indirectly, therefore these 'associated plants' with their high potential for biomass production drive the nitrogen supply of the system. Furthermore, the integration of native secondary forest species results in an accelerated nutrient cycle on the site.

3. Putting the principles into practice: the forest garden management

3.1. *Structure*

The principles as presented above, i.e. the imitation of the structure of the autochthonous vegetation and the management of its succession stages, can be illustrated by the following examples within the study farm.

Between 3% and 8% of the trees in the surrounding native forests belong to the family Annonaceae. In the forest garden a similar share of Annonaceae species is targeted, to be composed of native and introduced cultivated species; the native species are appreciated because of their production of edible fruit of high quality. Advantage is taken of the genetic diversity and adaptability of the native Annonaceae by using some of them as rootstocks for grafting cultivated species.

Plant species in the primary forest from the Moraceae family are partly replaced by Jaca (*Artocarpus heterophylla*) which belongs to the same family. The fruits of 3—12 kg can be used for human consumption, for alcohol and sugar production or as fodder.

A further example of the use of ecological niches is the increase of wild citrus trees which reproduce themselves spontaneously. Table 1 shows a list of species integrated in the production system. The species are sorted by the period they are used in the system before they are taken out of the vegetation cycle. For example, Papaya only grows well in the first three years, later light becomes a limiting factor. Corindiba (*Trema micrantha*), on the other hand, a typical tree from the secondary forest, terminates its vegetative growth after five to ten years. It is then felled and used as mulch.

This use pattern of the species is in agreement with the traditional practices of the Kayapo on their new fields. The peak in production of the principal domesticated crops is in the first two or three years, but they continue to produce for many years: e.g. sweet potatoes for four to five years, yams and taro for five to six years and papaya for five or more years. Some

Table 1. List of species used on the agroforestry farm, sorted by period of use.

Botanical name	Local name	English name	Family
1st–2nd year:			
Brassica napus L.	Nabo	Turnip	Brassicaceae
Brassica nigra (L.) Koch	Mostarda	Mustard	Brassicaceae
Glycine max (L.) Merr.	Soja	Soya bean	Fabaceae/Pap.
Phaseolus sp.	Feijao	Beans	Fabaceae/Pap.
Zea mays L.	Milho	Maize	Gramineae
1st–4th year:			
Cajanus cajan (L.) Millsp.	Guandu	Pigeon pea	Fabaceae/Pap.
Carica papaya L.	Mamao	Papaya	Caricaceae
1st–10th year:			
?	Cabo de cachimbo		Euphorbiaceae
?	Fi d'agua		?
?	Piticoba		?
?	Solteira		Combretaceae
Acnistus arborescens (L.) Schlecht.	Coarana		Solanaceae
Alchornea iricurana Casar.	Lave-pratos		Euphorbiaceae
Cecropia hololeuca Miquel	Embauba		Moraceae
Euphorbia heterophylla L.	Leiteiro		Euphorbiaceae
Manihot esculenta Crantz	Mandioka	Cassava	Euphorbiaceae
Miconia calvescens DC.	Munduru		Melastomataceae
Nicotiana glauca Graham	Fumo bravo		Solanaceae
Pothomorphe umbellata L. Miq.	Capeba		Piperaceae
Solanum paniculatum L.	Juribuiba		Solanaceae
Trema micrantha Blume	Corindiba		Ulmaceae
Species which remain in the forest garden for more than 10 years:			
?	Ceboleira		Meliaceae
?	Fruta de parai		Meliaceae
?	Macaco preto	Sapotaceae	
Achras sapota L.	Sapoti	Sapotill tree	Sapotaceae
Ananas comosus (L.) Merril	Abacaxi	Pineapple	Bromeliaceae
Annona cherimolia Mill.	Cherimoya	Cherimoya	Annonaceae
Annoma muricata L.	Graviola	Soursop	Annonaceae
Annona squamosa L.	Fruta de conde	Sweetsop	Annonaceae
Artocarpus heterophyllus Lam.	Jaca	Jackfruit	Moraceae
Bauhinia fusconervis D. Diert.	Unha da vaca		Fabaceae/Caesalp.
Cariniana lagalis (Mart.) O. Ktze.	Jequitiba		Lecythidaceae
Carpotroche brasiliensis Endl.	Canudeiro		Flacourtiaceae
Cassia multijuga Rich.	Cobi		Fabaceae/Caesalp.
Citrus aurantiifolia Cristm.	Laranja-lima	Lime	Rutaceae
Citrus limon L.	Limao	Lemon	Rutaceae
Citrus reticulata Blanco	Tangerinas	Mandarin	Rutaceae
Citrus sinensis (L.) Osbeck	Laranja	Orange	Rutaceae
Cordia nodosa Lam.	Baba de boi branco		Boraginaceae
Dalbergia nigra (Vell.) Fr. Allem.	Jacaranda da Bahia	Brasilian rosewood	Fabaceae/Caesalp.
Dichymopanax morototoni Decne. & Planch.	Matauba		Araliaceae

Table 1 (continued).

Botanical name	Local name	English name	Family
Erythrina poeppigiana (Walp.) Cook.	Eritrina do alto		Fabaceae/Pap.
Euphoria longana Lam.	Longan	Longan	Sapindaceae
Garcinia mangostana L.	Mangostan	Mangosteen	Clusiaceae
Guilielma gasipaes (HBK.) Bailey	Pupunha	Peach palm	Palmae
Helicostylis tomentosa (Poepp. & Endl.) Rusby	Amora preta		Moraceae
Himathantus lancifolius (Muell. Arg.) Woodson	Janauba		Apocynaceae
Holopyxidium sp.	Inhaiba		Lecythidaceae
Hymenaea courbaril L.	Jatoba	Courbaril locust tree	Fabaceae
Inga edulis Mart.	Inga	Food inga	Fabaceae/Mim.
Jacaranda puberula Cham. s.l.	Carobinha		Bignoniaceae
Lecythis pisonis Camb.	Sapucaia	Sapucaia oil tree	Lecythidaceae
Lecythis lurida Miers.	Inhaiba gigante		Lecythidaceae
Litchi chinensis Sonn.	Lechia	Litchi	Sapindaceae
Mangifera indica L.	Manga	Mango	Anacardiaceae
Melanoxylon barauna Schott.	Brauna	Black steer	Lecythidaceae
Musa sp. L.	Banana	Banana	Musaceae
Naucleopsis mello-baretoi (Standl.) C.C. Berg	Amora		Moraceae
Nectandra sp.	Louro		Lauraceae
Parkia multijuga Benth.	Juerana branca		Fabaceae/Mim.
Passiflora spp.	Maracuja	Passionfruit	Passifloraceae
Persea americana L.	Abacate	Avocado	Lauraceae
Pouteria sp.	Aca		Moraceae
Rollinia sp.	Pinha-brava		Annonaceae
Roupala sp.	Adernofaia-rosa		Proteaceae
Slonea sp.	Gindiba preta		Elaeocarpaceae
Spondias lutea L.	Caja	Ashanti plum	Anacardiaceae
Swartzia macrostycha Benth.	Jacaranda branco		Fabaceae/Caesalp.
Sweetia fruticosa Spreng.	Sucupira-amarela		Fabaceae/Caesalp.
Theobroma bicolor Humb.	Pataste		Sterculiaceae
Theobroma cacao L.	Cacao	Cocoa	Sterculiaceae
Theobroma grandiflorum (Spreng.) K. Schum.	Cupuacu		Sterculiaceae

banana varieties continue to bear fruit for 15—20 years, and the Cucurbitaceae cupa (*Cissus gangyloides*) even for 40 years. The Kayapo consistently revisit old fields for harvesting these fruits [Posey, 1985].

Some species of this list (Table 1) are more predominant on the farm than others. In the present stage of the forest garden, bananas, cocoa, corindiba (*Trema micrantha*), coarana (*Acnistus arborescens*), jackfruit (*Artocarpus heterophylla*), capeba (*Pothomorphe umbellata*) and pineapple — in this order — are the most dominant plants with the highest coverage.

Other frequent species are (not in order of dominance): maniok, embauba (*Cecropia palmata*), piticoba, solteira (Botanical names not identified), oranges (mainly lima or uncultivated species), mandarines, pataste (*Theobroma bicolor*), avocado and various Annonaceae.

Part of the plants, e.g. timber trees like jacaranda (*Dalbergia nigra*) or inhaiba (*Holopyxidium* spp. or *Lecythis* spp.), were still very small at the time of the study due to their relatively slow growth and partly due to late sowing.

3.2. *Management*

The practical result of the working hypotheses as described above is that the vegetation is 'kept young'. Every 3 to 4 months the site is cultivated and 'rejuvenated', i.e. light and space conditions of the cultivated plants are improved by cutting down those shrubs and trees of the succession which have completed their vegetative development.

Plants which have fulfilled their synecological functions according to the first hypothesis are removed from the growing mixed forest of several storeys to make room for the trees of the following succession stage.

Some of the plants have such a short vegetative cycle that they ratoon immediately, growing to man-size and setting seed again before the next cultivation four months later (e.g. Capeba, *Pothomorphe umbellata*). Other plants, mainly originating from the secondary forest, have a somewhat longer vegetative cycle. They reach the culmination of their development after five to ten years and would then according to the allelopathy hypothesis above have a negative effect on the development of the neighbouring plants. Before that stage these secondary forest species are an important element for the structure and productivity of the system.

In order to increase the biomass turnover, all mulch material remains in the production system, and is treated in preparation of rapid mineralization: during cultivation organic material like branches, thin trunks, banana leaves etc. are cut coarsely by machete. At harvest banana stems are cut into pieces of about 1 m length; to avoid fermentation and consequent damage to plant roots, and in order to promote mineralization, these stems are then split length-wise and laid down on the slope contour with the cut side facing downwards, preferably beneath the cocoa trees as the main cash crop; after this the ground is covered with a mulch layer 10—20 cm thick which after 4 months is completely decomposed except for a few coarser parts of the plants, such as banana stems or pieces of wood.

At the beginning of site cultivation using this system there was little organic material on the plot so that mulch material was placed only beneath the crowns of cultivated plants. Due to less microbiological activity in the soil and unfavourable microclimatic conditions, the mineralization rate of mulch material was slow in the first few years.

The cultivation measures on the study farm have the following objectives:

1. Protection of the soil from direct influence of weather (sun, wind, rain), resulting in reduced erosion and in increased microbial activity in the soil.
2. Decrease of water loss by reduced run-off, improved drainage, higher water retention capacity and decreased evaporation.
3. Humus accumulation.
4. Maximization of nutrient cycling.
5. Management of light and space for the cultivated species.
6. Management of positive and negative allelopathic effects as described in the working hypothesis.

Just as the principles of the farm management, the applied practices correspond with the ones developed in the traditional agroforestry system of the Kayapo Indians: Old fields serve as important repositories of 'semi-domesticated' plants. The term 'semi-domesticated' is used to describe plants which are manipulated by the Indians, who intentionally modify plant habitats to stimulate growth. Beside providing food for human subsistence, fruit and nut producing trees are also planted to attract game, birds and even fish during high water. Thus old fields should perhaps be called 'game-farm-orchards' to emphasize their diverse functions [Posey et al. 1984].

It has been reported that the Kayapo Indians carry a small leather bag filled with a variety of seeds. These seeds are especially used for trailside planting between settlements and fields or in earlier times for the establishment of 'forest fields', i.e. living food reservoirs along their migration routes during their trips of up to some months [Posey, 1985]. This element of the traditional Kayapo system is a further important component of the management strategy applied on the study farm. During the cultivation procedure seeds from such a bag are put into the soil wherever the vegetation appears too sparse. Even the cocoa trees were directly sown. Going beyond the traditional Kayapo system, recently germinated cultivated plants in the forest garden of the study farm are marked with a branch for protection in further cultivation passes.

3.3. *Fertilization*

The only nutrient input into the system are 2,3 t of lime per/ha every two years, and approx. 20 to 30 t of sawdust yearly. The sawdust is used as litter for the 15 pigs and 20 chicken on the farm and is then brought out to particularly poor areas. No extra feed is bought for these animals.

No herbaceous legumes are grown as green manure. As the trees are not planted in rows, the control of such climbing leguminous species would cause an unjustified amount of work. Non-climbing woody legumes with an upright habitus could be used but this was only done to a small degree. Due to the high biomass production of the native secondary forest species incorporated into the system, sufficient plant material for mulching can be obtained. Thus it is assumed that nitrogen fixing microorganisms provide adequate nitrogen supply for the whole agroecosystem.

An attempt was made to estimate the annual amount of mulch produced, composed of natural litter fall and plant material cut during cultivation; measurements were made on three sites of the farm using five containers of 1 m^2 each, and four study areas of 100 m^2 each. The amount of mulch material varied between 8 and 16 t DM per hectare and year according to the location of the trial plot (P. Hinn, pers. comm.). This value falls within the range quoted for other agroforestry associations: In shaded plantations of cocoa under a wide range of site conditions total annual litterfall, including pruning residues is reported to vary between 5 t and 20 t/ha/a [Beer, 1988]. On the 6 year old conventional cocoa plantation of the neighbouring farm the litterfall varied between 1,5 and 5 t DM/ha/a.

3.4. *Plant protection*

Up to now no pesticides have been used on the farm. In agreement with the definition of an ecosystem as an 'open self-regulating system of coexisting and related organisms and their abiotic environment' [Ellenberg, 1986], this agroecosystem is in a stable condition. By the structure of the forest garden and the regular cultivation measures, a dynamic 'self regulating system' has been established which up to now has made the use of pesticides unnecessary.

3.5. *Yields*

At the beginning of the cocoa production, 100 kg of dried cocoa beans per hectare were harvested from the 4—5-year-old trees. P. Hinn (pers. comm.) estimated the yields of 5—6-year-old trees by sampling three areas of 2000 m^2 each planted with cocoa of the same age but with different vegetation structures; reflecting the previous use and their respective fertility and vegetation, yields of 2475, 4835 and 8285 cocoa fruits, respectively, were harvested on these three plots. Using the CEPLAC[1] calculation of 1000 fruits as equivalent to 45 kg dry cocoa beans the yields range from 110 kg/ha, over 220 kg/ha to 370 kg dry cocoa beans per ha for 5 1/2-year-old cocoa trees.

These yields achieved without external inputs compare favourably with those of the demonstration farm of CEPLAC which states a production objective of 225 kg/ha for 5—6-year-old trees; CEPLAC recommends an annual nitrogen application of 130 kg/ha to obtain this yield. Regular use of fungicides against 'Podridão parda' (*Monilinia fructicola*) and Antracnose (*Colletotrichum gloeosporioides*) as well as various insecticides against bugs, lice and thrips are elements of 'modern' cocoa farming without which the intended yields cannot be attained.

The overall productivity of the forest garden is higher than that of the CEPLAC farm considering the variety of other plant products harvested besides the cash crop cocoa. Pineapples, manioc, pataste (*Theobroma bicolor*), oranges, mandarines, lemons, peach palm, avocado and papaya can be harvested for home consumption at this early stage of the plantation.

Originally cocoa was planted as the main source of income. In the meantime, due to the low price of cocoa, bananas have become the main cash crop: In a solar dryer banana slices are prepared for export to Western Europe. The diversity of its products provides to the agroforestry system its ability to quickly respond to changes in the market place. The importance of diversification of cocoa production systems in Bahía has been emphasized earlier [Alvim and Nair, 1986].

A further benefit of the agroforestry system is water harvesting: At the beginning of the farm there was not a single spring of water, while in the meantime 17 creeks have appeared on the farm site.

4. Concluding remarks

Even considering that some elements of the agroforestry system described need adequate scientific investigation, particularly aspects of the alleged allelopathic effects, the successful operation of the farm studied confirms that integrating traditional experience with modern knowledge not only provide the basis of an ecologically sound but also of an economically viable and highly productive land use system. It is important to note that the development of such an 'integrated' agroforestry system needs extraordinarily advanced observation skills from the farmer. The use of traditional farming techniques has proved to be of great value for designing the sustainable production system suggested here. The challenge for scientists and practitioners is not only to integrate the results of traditional experience but to conceive agroforestry to a substantial degree as an art rather than a science.

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Note

[1] Commissão Executiva do Plano da Lavoura Cacaueira: the Brazilian Cocoa Research Center.

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