Spatial and Temporal Change of the Spontaneous Vegetation in an Agricultural Field Experiment

Preisinger, H.[1], Coêlho, L.F.[2], Gasparotto, L.[3] and Lieberei, R.[4]

[1, 4] Universität Hamburg, Deutschland

[2] INPA, Manaus-AM, Brasil

[3] EMBRAPA Amazônia Ocidental, Manaus-AM, Brasil

1 Introduction

Objectives of the SHIFT field trial carried out on an area of 17 ha at the experimental site of EMBRAPA Amazônia Ocidental near Manaus, Amazonas, Brazil, are to try out the re-use of an abandoned agricultural site by mixed cropping systems and to survey some of the most important ecological interactions between the growth of the useful plants, the spontaneous vegetation in the field, and management and site factors.

The role of the spontaneous vegetation in a plantation of perennial useful plants in the humid tropics is as well discussed controversely among scientists, as there is also no common practice among farmers how to manage the spontaneous vegetation. Many smallholders in the Central Amazon control the wild vegetation rigidly, especially in the vicinity of their houses. This practice leads to bare soil between the useful plants and often, as a consequence, to soil erosion. Others leave a dense vegetation cover standing between the crops. This is not necessarily a question of different philosophies, but primarily of available manpower and the size of the plantation. However, two contradictory views on the role of the spontaneous vegetation in a plantation of perennial useful plants in the humid tropics can be formulated:

1. The spontaneous vegetation means primarily competition to the useful plants. It is therefore necessary to control the wild plants and/or introduce a herbaceous cover crop, preferrably a legume.
2. The spontaneous vegetation is an integral part of the agro-ecosystem and serves primarily to ensure a sustainable use of agricultural sites. A plantation management has to be carried out which permits a spontaneous vegetation as diverse as possible in the agro-ecosystem.

The first is often an agronomist's, the second a biologist's view. In practice, it has to be compromised between the two contradictory views.

The type of management carried out in the experimental plantation was directed to protect the useful plants from the competition of the spontaneous vegetation, and a cover crop of *Pueraria phaseoloides* had been established, i.e. the plantation management followed "view 1". However, the spontaneous vegetation in the plots of the experiment developped differently, with regard to floristic and structural characteristics (like cover and growth-form composition). This is because of different ecological conditions in the 90 plots, caused by the experimental varients (5 blocks, 5 plantation systems and the 2 fertilization levels) and by other site factors (e.g. site history, differences in chemical soil qualities, inclination of the plots).

The spontaneous vegetation in all of the plots of the experiment had been surveyed four times, in terms of flora and growth-form composition. The data set, together with biometric and harvest data of the useful plants, enables us to analyze the spatial and temporal change of the vegetation. This permits the development of hypotheses on the factors controlling the spontaneous vegetation and on the role of the different types of spontaneous vegetation on the development of the useful plants.

In the following text, the term "vegetation" means the spontaneous vegetation of wild plant species growing between and under the useful plants, which are trees only. "Vegetation" includes the cover crop Kudzu (*Pueraria phaseoloides)*, which was formerly introduced but then grew spontaneously together with the other wild plant species.

2 Material and methods

2.1 The experimental plantation

The experimental area of approx. 14 ha concerns terra firme lands on the EMBRAPA site to the north of Manaus, which were first cleared of primary forest about sixteen years ago to make way for a rubber plantation. The plantation was abandoned soon after. In August/September 1992, the approximately eight-year-old secondary forest which had evolved in the meantime was cleared and burnt in the traditional manner. The area was devided into 90 plots of 1.600 m^2 each. In the field test, 18 variants are being laid out in five separate, i.e. repeat blocks. The position of the variants within the blocks is completely randomized. The layout of the plots is determined by an elongated, irregular shape of the experimental area.

Fourteen species of mainly perennial useful plants were

	Plantation systems								
	Polyculture systems no.				Monoculture systems no.				
	1	2	3	4	6	7	8	9	
Rubber tree (*Hevea brasiliensis* (Adr.Juss.) Muell. Arg.)	*		*	*	*				perennial useful plants
Cupuaçu (*Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum.)	*	*	*			*			
Peach palm (*Bactris gasipaes* Kunth)	*	*					*		
Brazil nut (*Bertholletia excelsa* Humb. & Bonpl.)		*							
Urucum (*Bixa orellana* L.)		*							
Coconut palm (*Cocos nucifera* L.)			*						
Orange tree (*Citrus sinensis* (L.) Osbeck)			*					*	
Paricá (*Schizolobium amazonicum* Ducke)			+	+					
Mahagony (*Swietenia macrophylla* King)				*					
Andiroba (*Carapa guianensis* Aubl.)				*					
Papaya (*Carica papaya* L.)	+								short-lived useful plants
Cassava (*Manihot esculenta* Crantz)		+	+						
Cow pea (*Vigna sinensis* L.)			+						
Maize (*Zea mays* L.)			+						

Tab. 1: Useful plants and plantation systems.
Explanations:
"System 5" are fallow plots serving as a reference;
* = species present in a certain plantation system;
+ = species present in the initial phase of the experiment only;
bold frames = plantation systems analysed by multivariate analysis.

Growth-form types		Definitions and plant characteristics	Response to disturbance and/or stress	Strategy types	
1	Trees / Treelets	Branched out trees with an acrotonic ramification, medium or small leaves	± flexible response to rare disturbance events, e.g. by sprouting from roots and stumps, but sensitive against frequently occurring disturbances	(CR -) C - SC	Plants mostly native to rainforests
		Short-lived treelets with mesotonic, sparse ramifications, which regenerate mainly from seeds, forming a canopy consisting of few, but broad or medium, simple, lobed or compound leaves	Flexible response to disturbance events by growing new plants from seeds in suitable places (= forest gaps, disturbed areas)	CR - SR	
2	Shrubby plants	Woody, at least at base, mostly fast growing, short to longer-lived plants with basitonic to mesotonic ramifications and medium to small leaves	Flexible response to frequently occurring disturbances, by rapid sprouting from the base of the stem, sometimes from roots	CR - SC	
3	Lianas	Winding or twining plants, herbaceous or woody	Plant group which responds very flexible to disturbance (= mechanical damage) and stress (= shading, inter alia)	all strategy types except R	
4	Rhizomatous and tussock grasses	Graminoid herbs, forming tussocks or spreading by rhizomes	Tolerant against destruction of overground biomass and periods of drought, but sensitive to shading	SC - CSR	mostly invasive plants of cultivated areas
5	Rhizomatous herbs	Long-lived, herbaceous plants with rhizomes (in the experimental site: bracken - *Pteridium aquilinum*)		SC	
6	Stolon grasses	Graminoid herbs, spreading by stolons	Flexible response to frequently occurring disturbances	R - CSR	
7	Herbs	Short-lived, herbaceous, upright or prostrate growing herbs with medium or small leaves	Tolerant against frequently occcurring disturbances	R	

Tab. 2: Growth-form system designed for the vegetation under study (after PREISINGER et al. 1999, simplified form), and supposed range of strategy types in the C-S-R strategy concept (GRIME 1979, GRIME et al. 1988). C = competition, S = Stress, R = Ruderal strategy.

planted in the experimental field. Four different mixed cultivation systems (systems 1-4, see Tab. 1) and four conventio-nal monocultures (systems 6-9) were to be compared in the field trial. System 5 is land which was prepared in the same way as the other systems and then left to follow its own course. Perennials, short-term crops for planting between the rows and cover plants are being used in the systems. The choice of crops was based largely on current marketing prospects.

System 1 is a comparatively intensive cultivation system with little space left between the rows. More space was left between rows in systems 2 and 3, which can be used for growing short-term crops in the first year. In practice, this would help farmers survive the first years after establishment of the plantation while the longer-lived species do not bring any income. System 4 is the most "extensive" of the test systems. The species planted produce timber. Secondary vegetation is tolerated among the trees. In systems 1-3 and in monocultures 6-8, on other hand, cover plants (*Pueraria phaseoloides*) were sown. The nine plantation systems described were established in different fertilization variants which include zero fertilizer, 30% and 100% of the recommended dose for the respective species. The plantation management followed mainly conventional practices of EMBRAPA. The vegetation around the trunks and the tendrils of Pueraria climbing on the trees were regularly removed, and from time to time the whole vegetation cover in the plots was cut using a machete. The intervals between the measures largely depend on the season (approx. every 2 to 3 months).

2.2 Growth-form system

In the approach presented here we proceed from the well-known fact that growth-forms of vascular plants (in the sense of RAUNKIAER 1937) represent a complex of characteristics closely linked to the ecological behavior of the species and their site conditions (cf. also HALLÉ et al. 1978). Growth-forms can therefore be a starting point for autecological studies, including the search for indicator species with regard to site conditions for agriculture.

The plant species found in the experimental site (primary forest plots, secondary forest plots and plantation plots) were classified with regard to their growth-form types. The classification is based on a growth-form system of 15 types designed for the vegetation of the study area (see

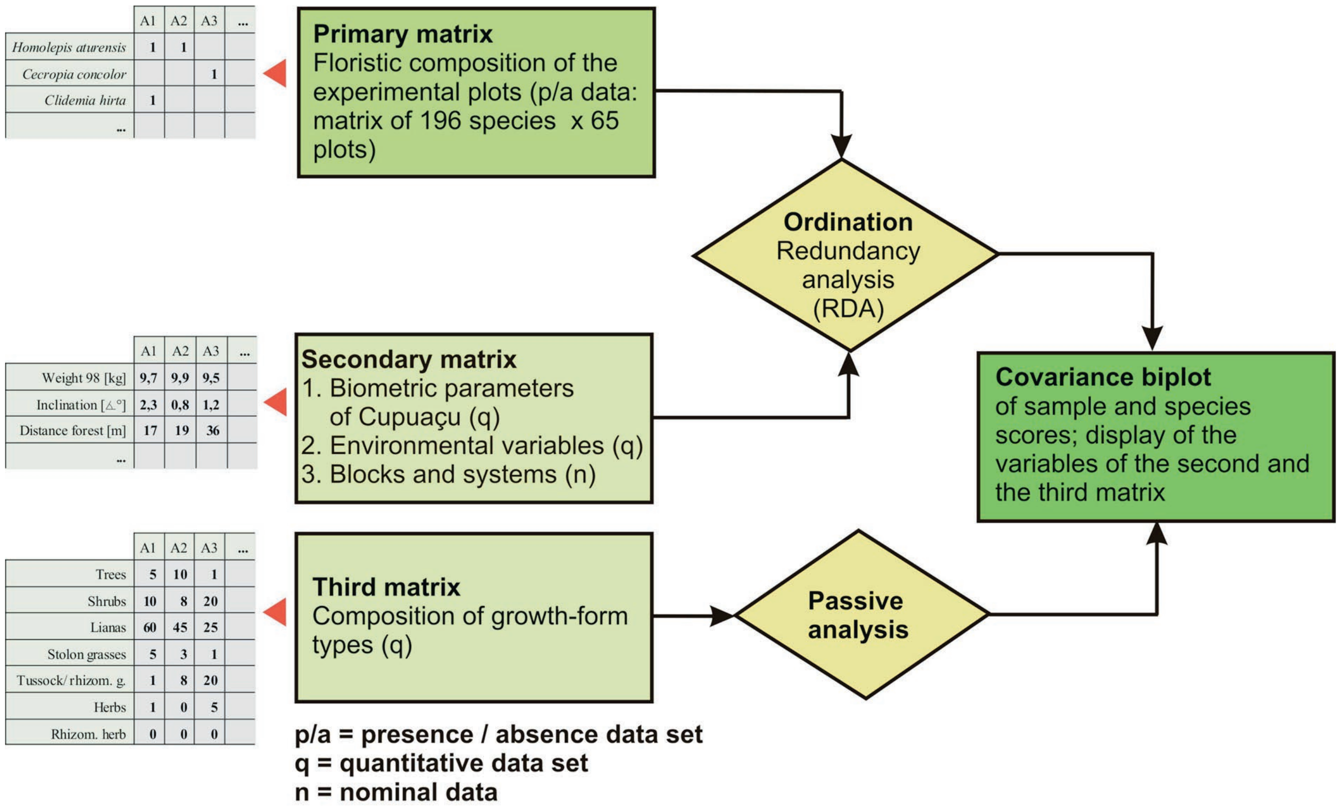


Fig. 1: Multivariate analysis of vegetation, useful plants and environmental factors: Data sets and procedure of (multivariate) data analyses.

PREISINGER et al. 1999), but used here in a simplified form of 7 types (see Tab. 2).

2.3 Data sets and analyses

The vegetation in the 90 plots of the experiment had been surveyed four times (6 months after slashing and burning in 1993 and in 1995, 1998 and in 2000). We found it necessary to analyze the whole range of vegetation occurring in all the plots of the experimental area of 14 ha. We therefore had to develop a methodology which permittens to carry out the vegetation survey in this large area with an acceptable effort in labor and time on the one hand and to accumulate ecologically meaningful, quantitative data on the other. The solution was to work out and combine two different data sets, the first being presence-absence data of flora of all the plots and the second quantitative data of cover of the growth-form types (see above). In detail, the following vegetation parameters were recorded and analyzed:

Flora
- Recording of all the vascular plants in the 90 plot of the experiment (presence-absence data set);
- Number of species in the plots (species diversity);

Structural traits of vegetation
- Cover of the 7 growth-form types in the 90 plots (quantitative data set).
- Total cover of the vegetation in the plots [%];

Substitutes for environmental variables
- Plantation systems (systems no. 1-9), which are the summarized effects of the planted trees to the vegetation;
- Position of the plots in one of the 5 experimental blocks;
- Nearest distance of the plots to the forest margin;
- Maximum inclination of the plots.

Biometric and harvest data of the useful plants
- Tree heights, trunk diameters and weight of fruits of *Theobroma grandiflorum* (Cupuaçu).

The parameters presented above allow a large number of analyses and comparisons. In the present article, we present a comparison between the number of species per plot in the 5 blocks and the 9 plantation systems in 1998, the temporal change of the growth-form composition from 1993 to 2000 and an attempt is being made to analyze the complex interactions between the useful plants, the vegetation and key environmental factors in the polyculture plantation systems 1, 2, 3 and the monoculture system 7 with the help of a multivariate analysis. In the analysis, Cupuaçu (*Theobroma grandiflorum, Sterculiaceae*) is being used as an example for a useful tree species. The species, a locally important fruit tree native to the Central Amazon and used for the production of juice, desserts, sweets and ice cream, is planted in the four plantation systems mentioned above.
The multivariate analysis starts from the floristic composition of the experimental plots, i.e. from a presence-absence data set of 196 species and 65 plots ("primary matrix", cf. Fig. 1). A second matrix concerns the substitutes for environmental factors available which seem to be of importance for the development of the vegetation, and additionally, harvest and biometric parameters of Cupuaçu. The primary and the secondary matrix were analyzed together applying Redundancy Analysis = RDA, the cano-

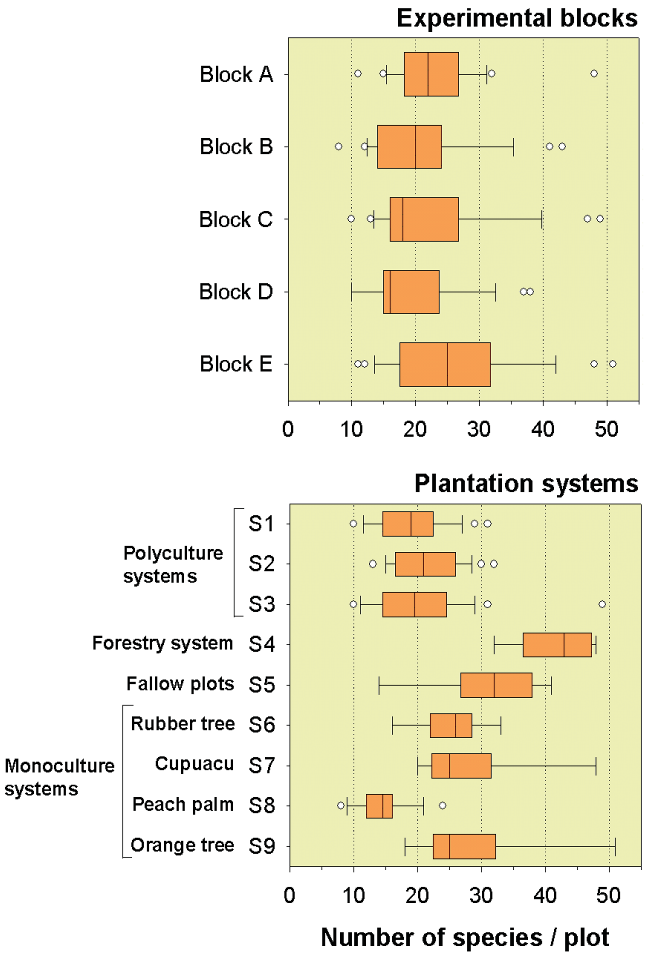


Fig. 2: Spatial variation of species richness with regard to experimental blocks (above) and plantation systems (below).

nical form of Principal Component Analysis = PCA (cf. JONGMAN et al., 1987). In a second step, a third matrix, concerned with the composition of the growth-form types in the plots (= quantitative data set), was correlated passively with the result of the RDA. All results were displayed graphically as covariance biplots in accordance with CORSTEN and GABRIEL (1976).

3 Results and discussion

3.1 Spatial variation of vegetation

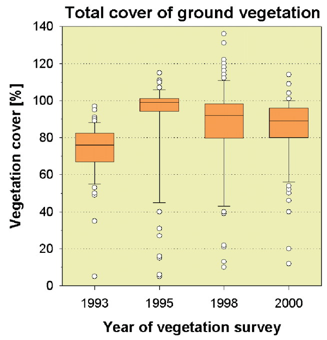
The number of species in the experimental plots varies roughly between 10 and 50 (survey in 1998). Quantitative data on the structure of dominance in the experimental plots (e.g. expressed as Evenness [%], see HAEUPLER 1980, 1982) are not available because it was not possible to estimate the cover of the single plant species in the plots (see methodology). We found only few among the 196 species in the experimental plots capable to form single-species stands or to reach dominance under the site conditions of frequently occurring disturbances. Examples:

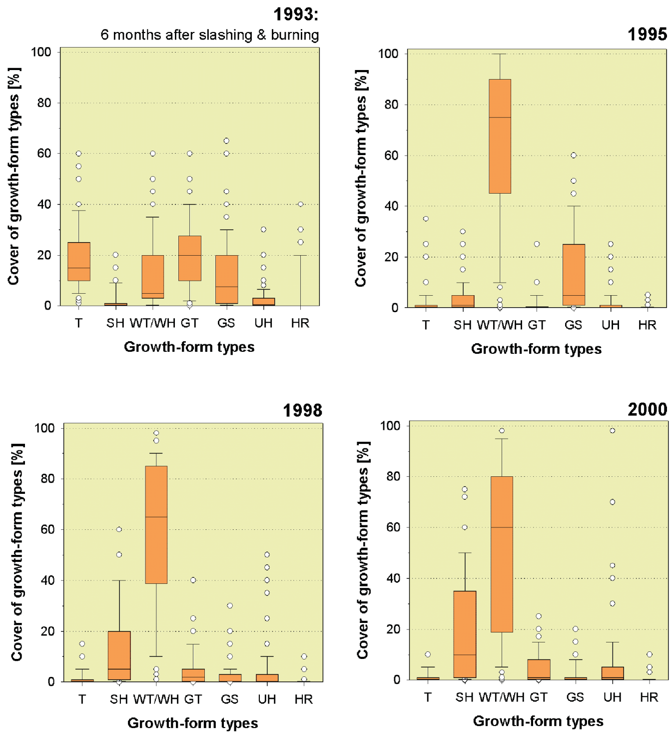
Pueraria phaseoloides (Roxb.) Benth., Fabaceae (sown out as a cover crop)
Clidemia hirta, C. rubra (Aubl.) Mart., Melastomataceae
Rolandra fruticosa (L.) Kuntze, Rubiaceae
Borreria verticillata (L.) G.Mey., Rubiaceae
Homolepis aturensis (Kunth) Chase, Poaceae (and some other grasses)

The spatial variation in the number of species in the plots shows differences with regard to the mean values in the blocks, indicating differences in the site conditions along the elongated shape of the experimental site (Fig. 2, above). The causes have to be sought in differences in the pre-use of the sites. The differences in the number of species with regard to the plantation systems is more obvious because the different combinations of useful plant species in the plots are strongly responsible for the site conditions of the vegetation (Fig. 2, below). The forestry system (S4), being the most extensive of the plantation systems, is the one with the highest species diversity (median value) in the experiment. It is the only system where a low frequency of disturbance permits many secondary forest and some primary forest species to regenerate. The plantation system with the lowest number of species is the peach palm system (S8). There is little space left between the useful plants and the ground is shaded, which leads to a sparse cover of vegetation of mainly herbaceous plants. The number of species in the polyculture systems S1, S2 and S3 is higher than in the peach palm system, and there is no significant difference between them. The rubber tree, the Cupuaçu and the orange tree monoculture systems permit considerately more wild plant species to grow because more space was left between the trees than in the polyculture systems and the management intensity - or the intensity of disturbance for the wild plants, respectively - is lower than in the polyculture systems.

The fallow plots (S5) were slashed and burned in the same way than all the other plots, but then left unattended. The vegetation could therefore follow its own course without any intermediate disturbance. The results show that the number of species in the fallow plots is lower than in the (extensive) forestry system S4.

Fig. 3: Temporal change of growth-form composition from 1993 to 2000. Abbreviations for growth-form types: T = trees and treelets, SH = shrubs, WT/WH = woody and herbaceous lianas, GT = tussock grasses, GS = stolon grasses, UH = upright or prostrate growing herbs, HR = rhizomatous herbs.





3.2 Temporal change of growth-form composition

The composition of growth-form types is a reliable indicator for past site conditions which lead to the present vegetation. "Site conditions" mean complexes of environmental factors like "disturbance" and "stress" as defined by GRIME (1979). Both terms include single environmental factors which influence strongly the vegetation under study, but cannot be measured quantitatively with the help of technical equipment: Mechanical damage, like slashing and burning, cutting and hoeing, trampling and digging, is the key factor in the vegetation of the experimental plantation. The only way to describe and quantify this factor in the vegetation under study is to indicate "past disturbance" by the growth-form composition. The knowledge of the indicator value of the seven growth-form types of the system used here, which is required for the approach, is in general available from Raunkiaer's and many other works from all over the world, and for the particular vegetation from our own observation (see Tab. 2).

The survey of the growth-form composition in the plantation had been carried out four times within 7 years, that is from 1993, the moment of installation (= 6 months after slashing and burning), to 2000. The results show significant temporal changes which can be interpreted as follows (Fig. 3):

In the moment of planting of the useful plants in 1993, the 7 growth-form types were ± evenly distributed with regard to their cover values. It is important to note that the recovery of the tree layer went on rapidly, reaching a cover of 18% in a period of 7 months (median value), and the total cover of vegetation had reached 75%. In 1995, two years of plantation management had changed the growth-form composition drastically. The cover of trees and rhizomatous and tussock grasses had decreased, whereas the cover of shrubs had increased. The cover of lianas had rushed to a median value of 75% because the herbaceous liana *Pueraria phaseoloides*, which had been sown out as a cover plant, had reached dominance. From 1995 to 2000, mainly the following trends are being observed:

1. The total cover of vegetation decreases slightly,
2. the cover of lianas (mainly *Pueraria phaseoloides*) and the stolon grasses (mainly *Homolepis aturensis*) also decrease,
3. the cover of shrubby growth-form types increases significantly, and the cover of the rhizomatous and tussock grasses increase slightly.

The strategies (in accordance with GRIME 1979) of the species belonging to the growth-form types which gained an increased importance from 1995 to 2000, range from "Competitive Ruderal (CR)" or "CSR strategists" to "Stress tolerant - Competitive strategists (SC)" (see Tab. 2). The ecological characteristics and behavior linked with SC strategists permit the hypothesis that agricultural use and plantation management lead to drier site conditions in the experimental plantation.

3.3 Interactions between vegetation, useful plants and environmental factors

The analysis of the complex interactions between the vegetation, the useful plants and key environmental factors in the experimental plantation requires a multivariate analysis. Trials with the primary matrix (= floristic composition of the experimental plots, cf. Fig. 1) and of similar data sets had shown that Principal Component Analysis (PCA), which relates to a linear response model (see JONGMAN et al., 1987, TER BRAAK & SMILAUER, 1998), results in ordination models which are ecologically better interpretable than those obtained by Correspondance Analysis (CA). We therefore applied Redundancy Analysis (RDA), the canonical - or constrained - form of Principal Component Analysis (PCA) for the detection of patterns of variation in the species data that can be explained by the environmental variables available, or substitutes of environmental variables, respectively.

The resulting ordination model , displayed in Figs. 4 and 5, shows the sample and the species scores and environmental variables which are supposed to be responsible for the composition of the wild flora. They are substitutes for environmental factors which are in part not available by measurement, e.g.

- differences in past disturbance events (including plantation management);
- differences in competition of the useful plants to the wild plants (depending on the species planted, or the plantation system, respectively) for light, space and nutrients;
- differences in soil qualities (physical and chemical).

Additionally, the seven growth-form types and the number of species are displayed (Fig. 5b, below), as a result of a passive correlation analysis with the main matrix. The diagrams (correlation biplots) can be superimposed on each other but are shown here, for more clarity, as separate diagrams. The ordination model (Figs. 4 and 5) shows that there is a continuum in the species composition of the analyzed plots. Within the continuum, four extreme types can be classified which are linked to one of the four quadrants of the coordination system of the model (see Fig. 4, below):

Type 1 (quadrant 1):
Sites where the number of woody and herbaceous species is high (> 20 species per plot), and were tussock and rhizomatous grasses dominate; locally bracken (*Pteridium aquilinum*) is abundant.

Type 2 (quadrant 2):
Sites where there is a high diversity of mainly woody species abundant (> 30 species per plot) and were forest species are still regenerating.

Type 3 (quadrant 3):
Sites where *Pueraria phaseoloides* is highly dominant, the number of species is low (< 20 species per plot) and the vegetation cover is high (> 85%).

Type 4 (quadrant 4):
Sites where the number of species and the vegetation cover are low; vegetation is dominated mainly by lianas and grasses.

The classification of the plots with regard to the experimental blocks (see sample scores, Fig. 4, above) shows that the vegetation types are not evenly distributed within the five blocks, e.g. vegetation type 1 is mainly restricted to block E and type 4 mainly to block D. The position of the centroids of the experimental blocks in the ordination plain (Fig. 5, above) represents a summarization of this fact. The result reveals that the floristic pattern which was found in the experimental site five months after slashing and burning of the secondary forest in 1993 (see PREISINGER et al. 1994) was still present in 1998, after five years of plantation management. The causes of these patterns have to be sought in the history of the sites, which are in particular the vegetation pattern of the former primary forest and different intensities and duration of agricultural use (= rubber plantation) after the first slashing and burning. The four plantation systems (see Tab. 1) provide different environmental conditions for the vegetation, because the tree species planted together form different spatial patterns, and therefore the practice of management is slightly different. Hence, the positions of the centroids of the plantation systems S1, S2, S3 and S7 in the ordination plain differ significantly from each other (Fig. 5, above), representing different combinations of wild plant species. The plots of system 1, being the most intensive plantation system with little space left between the trees, tend towards "vegetation type 4", whereas the plots of the Cupuaçu monoculture system (S7), being a more extensive plantation system with more space left between the trees, tend towards "type 2". The average number of wild plant species increases from S1 to S7 (see Fig. 5, below). We suggest that the intensity of disturbance caused by the plantation management increases from S7 to S1. It can be concluded that intensive cultivation systems mean higher intensities of disturbance and stress to the vegetation than extensive cultivation systems. High intensities of disturbance lead to a vegetation poor in number of species where regenerating trees and other long-lived forest species are absent, and which are dominated by short lived herbs (e.g. *Alternathera*

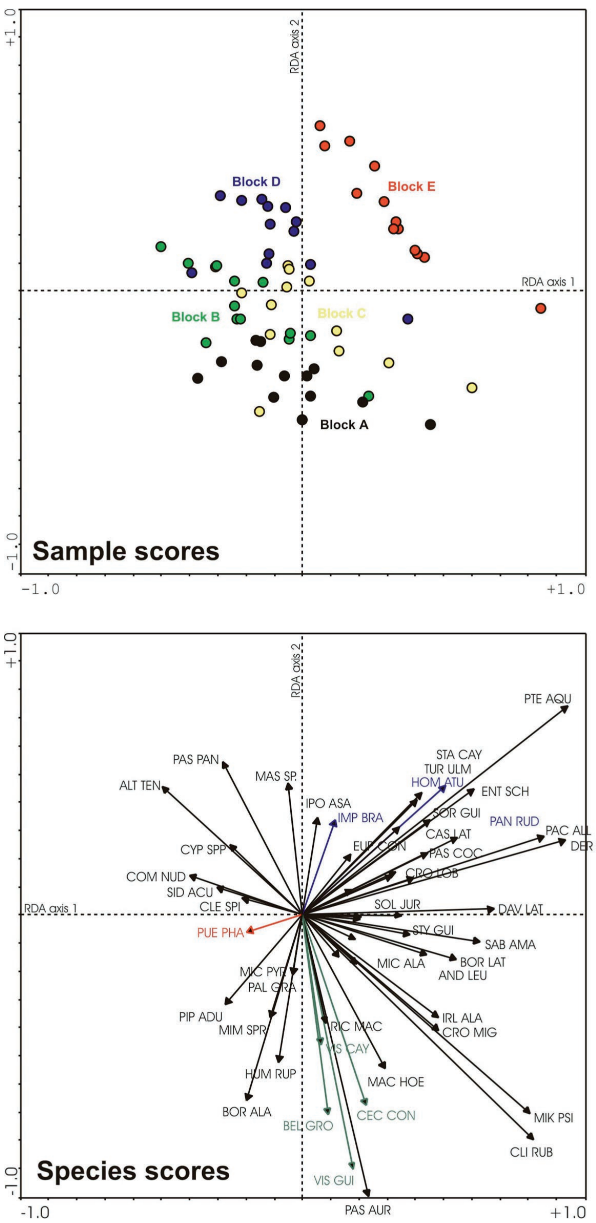


Fig. 4: Ordination model (Redundancy Analysis, RDA).
Above: Sample scores and differentiation of experimental blocks;
Below: Species scores (showing only a selection of the 196 species).

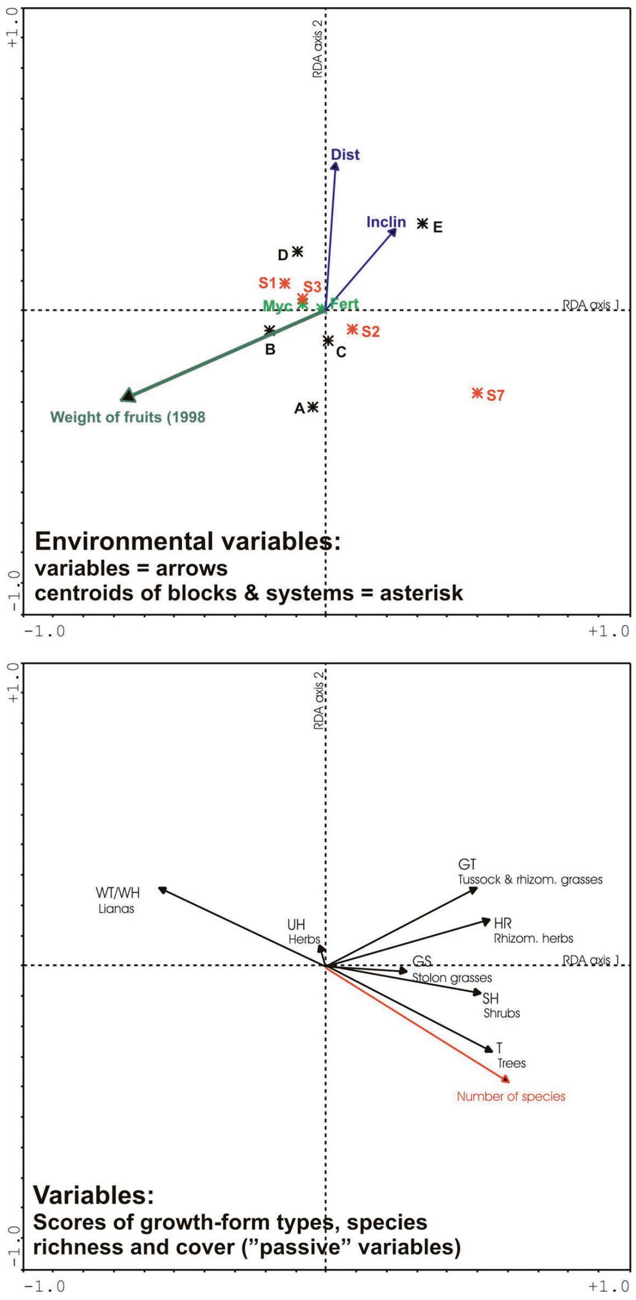


Fig. 5: Ordination model (Redundancy Analysis, RDA).
Above: Environmental variables (arrows= cardinal variables, asterisk = nominal variables, i.e. centroids of blocks and plantation systems;
Below: "Passive" variables = scores of growth-form types and number of species.

tenella Colla, *Commelina nudiflora L.*), lianas (e.g. *Mascagnia spp.*), sedges (*Cyperus spp.)* and few grasses *(Paspalum paniculatum L.)*, as can be seen in the 2. quadrant of Fig. 4 (below).

In the multivariate analysis, the development of Cupuaçu in the different plots of the experiment is being used as an example for possible interactions between the development of a planted tree species and characteristics of the vegetation. The parameter used here as a substitute for the development of the trees are the weights of the fruits, which show a close correlation to other growth parameters like trunk diameter and height of the trees. The main objective of the approach is an identification of indicator species within the local flora which can be used in agriculture. The mean inclination of the plots and the nearest distance of the plots to the forest margin were analyzed as additional environmental variables. Especially the second parameter has already proved to be a relevant factor for the development of Cupuaçu (see REISDORFF 1998). The ordination model shows that the Cupuaçu trees are best developed in plots where the diversity of the vegetation is low and the liana *Pueraria phaseoloides* reaches dominance (= quadrant 3, see Fig. 4, below), whereas bracken (*Pteridium aquilinum*) indicates infavorable site conditions for Cupuaçu and for other planted tree species (see Fig. 4, below, quadrant 1). Moreover, the analysis reflects the fact that Cupuaçu grows best near the forest margin and where the plots are not inclined (Fig. 5, above, quadrant 1).

The passive correlation of the portions of the growth-form types of the experimental plots with the existing ordination model (Fig. 5, below) supports some of the interpretations made above: The proportions of the trees and the shrubs (and the number of species) are negatively correlated to the proportion of the lianas. The proportions of tussock and rhizome grasses show weak positive correlations to the portions of trees and shrubs, and strong negative correlations to the weight of the fruits of Cupuaçu.

4 Summary and conclusions

The results of the study implies that species richness, species composition and growth-form structure of the spontaneous vegetation in the experimental plantation depend primarily on duration, type and intensity of plantation management, or "disturbance", respectively. The number of wild plant species in the polyculture systems is lower than in the monoculture systems because intensity and frequency of disturbance in the polyculture systems is higher than in the monoculture systems.

For a short-term agricultural use (7 years), the results of the analysis supports the view that spontaneous vegetation means primarily competition, and that *Pueraria phaseoloides* as a cover crop creates favorable site conditions for the useful plants. More than that, a dense cover of *Pueraria* prevents the soil from drying out during the dry season. However, the analysis and observations in the field also showed that there are sites where *Pueraria* could not reach dominance. There is evidence that these sites were subject to a higher intensity of past disturbance than the others, leading to drier site conditions. The plantation management (= cutting and hoeing), carried out for 7 years, lead to the following changes in the spontaneous vegetation of the field experiment:

- a slight decrease in total vegetation cover;
- a drastic decrease in the number of tree species;
- a deminishing importance of *Pueraria* and the stolon grasses;
- a growing importance of shrubs and tussock grasses.

These temporal changes of structural parameters of the vegetation indicate drier conditions and a decrease of site fertility at long date. From the ordination model, a number of wild plant species and certain growth-form types (shrubs, tussock and rhizomatous herbs and grasses) can be identified which indicate unfavorable site conditions for perennial useful plants, or infertile sites, respectively.

This is also a shift from species and growth-form types native to the rain forest to elements which are disturbance-tolerant and show a wide-spread or even pantropic distribution in the experimental plantation.

5 References

Corsten, L. C. A. & Gabriel, K. R. 1976. Graphical exploration in comparing variance matrices. Biometrics 32, 851-863.

Grime, J. P. 1979. Plant strategies and vegetation processes. Chichester: Wiley & Sons. (222 pp)

Grime, J. P., Hodgson, J. G. & Hunt, R. 1988. Comparative plant ecology. London: Unwin Hyman. (742 pp).

Haeupler, H. 1980. Das Informationsmaß nach SHANNON als Indikator für Bestandesänderungen in der Phytocoenologie. Wissensch. Beitr. MLU Halle 27 (P11), 31-39 (Bioindikation 4).

Haeupler, H. 1982. EVENNESS als Ausdruck der Vielfalt in der Vegetation - Untersuchungen zum Diversitätsbegriff (Habil.- Schrift). Vaduz: Verlag J. Cramer. (Diss. Botan. Bd. 65, 268 pp).

Hallé, F., Oldeman, R. A. A. & Tomlinson, P. B. 1978. Tropical trees and forests. An architechtural analysis. Heidelberg Berlin New York: Springer.

Jongman, R. H. G., ter Braak, C. J. F. & Van Tongeren, O. F. R. 1987. Data analysis in community and landscape ecology. Wageningen: Pudoc. (299 pp).

Preisinger, H., Coêlho, L. F., Siqueira, M. d. S. G. & Lieberei, R. 1994. Analysis of growth form types and floristic composition of the spontaneous vegetation in an agricultural test area near Manaus, Amazonas, Brazil. Angew. Botanik 68, 40-46.

Preisinger, H., Dünisch, O., Morais, R. R. d., Richter, K. & Araújo, R. d. C. 1999. Comparative studies on morpho-physiological traits of six Amazonian species of Bellucia and Miconia (Melastomataceae) and implications for their ecological behaviour. Mitt. BFH 193 (Investigations on tree species suitable for the recultivation of degraded land areas in Central Amazonia), 113-138.

Raunkiaer, C. 1937. Plant life forms. Oxford: Clarendon. (104 pp).

Reisdorff, C., Lieberei, R., Gasparotto, L., Araújo, R.C. & Moraes, C.R.A. 1998. The development of Cupuaçu plants (*Theobroma grandiflorum* (Willd. ex Spreng.) Schum.) in different mixed cultivation systems and the effect of topographic features. Proc. 3rd. SHIFT workshop, Manaus-AM, March 15-19, 1998, 329-339.

ter Braak, C. J. F. & Smilauer, P. 1998. CANOCO reference manual and user's guide to Canoco for windows: Software for Canonical Community Ordination (vers. 4). NY Ithaca: Microcomputer Power (352 pp).