Aus dem Institut für Pflanzenproduktion und Agrarökologie in den Tropen und Subtropen
der Universität Hohenheim
Fachgebiet Agrarökologie der Tropen und Subtropen
Prof. Dr. J. Sauerborn

Spatial undergrowth species composition in oil palm (*Elaeis guineensis* Jacq.) in West Sumatra

Dissertation zur Erlangung des Grades eines Doktors
der Agrarwissenschaften
vorgelegt der
Fakultät III – Agrarwissenschaften I
(Pflanzenproduktion und Landschaftsökologie)
der Universität Hohenheim

von
Dipl. -Ing. agr. Jörn Uwe Germer
aus Berlin
Hohenheim, 2003

Die vorliegende Arbeit wurde am 15.01.2003 von der Fakultät Agrarwissenschaften der Universität Hohenheim als „Dissertation zur Erlangung des Grades eines Doktors der Agrarwissenschaften“ angenommen.

Tag der mündlichen Prüfung: 27.02.2003

Dekan:	Prof. Dr. Stahr
Berichterstatter, 1 Prüfer:	Prof. Dr. Sauerborn
Berichterstatter, 2 Prüfer:	Prof. Dr. Böker

Preface

My interest in oil palm started when I learned first about it in Professor Dr. Joachim Sauerborn's lectures on the subject of tropical plant production at the Justus-Liebig-University in Giessen, Germany. Soon I was fascinated by the outstanding potential of oil palm to produce a great volume of vegetable oil on a comparable small area. The unsurpassed development of the oil palm industry over the last decades trapped me even further. There was no other choice than to focus my very first scientific research on this industry. In my MSc thesis I combined my interest with my keen concern about the environment and assessed the potential of oil palm in Indonesia and Malaysia as source of renewable energy. To gather information concerning this subject I travelled in 1995 to Indonesia, Malaysia and Singapore. Padang in West-Sumatra was my first stop where I met Thomas Fairhurst. I am deeply grateful not only for his professional help that was essential for the success of my work throughout the years, but also because of the open friendship I enjoyed with his family! It was in T. Fairhurst's house in Padang where I met one morning Dr. Helmut R. von Uexkuell. He invited me to an oil palm plantation, where I saw my first real oil palm. I am thankful to him for his assistance and the important suggestions he made on my work since we met first. On the plantation we visited I was introduced to Mr. Goh Ing Sing who is the General Manager of Group Plantations. I appreciate highly his friendship, hospitality and his never-ending patience to explain all the details about plantation management, though he made me plant 50 oil palms! I want to thank also Dr. Ernst Mutert who welcomed me at the Potash and Phosphate Institute in Singapore and Marcus Ross and his family who I met in Kluang, Malaysia. M. Ross had taken several pictures of segetal species he found and woke thus my interest for the oil palm undergrowth.

In 1997 I was employed by Group Plantations and worked during three years on several plantations in West-, South- and North-Sumatra. Conducting innumerous field inspections I noticed an unexpected rich diversity of vascular plants in the oil palm undergrowth. Due to the notorious lack of literature that points out harmful and beneficial species

to the field staff, I began with the kind help of Mr. Tan Chin Eng and Ms. Yuliawati to assemble a herbarium. Collecting plant material to be conserved a spatial distribution of some species in the plantation was observed. Writing to J. Sauerborn about my phytosociological interest, I did not expect that he would visit me shortly afterwards. Studying the oil palm fields and their flora during the day and reflecting over one or two Bintangs in the evening, he helped me to line out the research for this work. I am indebted for the encouraging support and the many suggestions he provided for my MSc and PhD research and for his friendship during the years. The identification of the undergrowth species, a key task in this work, was only possible due to the friendly help of the staff at the Herbarium Bogoriense, Singapore Botanic Gardens Herbarium and Botanical Museum Berlin-Dahlem. Thank you to Ms. Erni Herawati who helped to measure solar radiation and prepare soil samples. I want to thank my mother, father, sister and brother for everything including their visits in West Sumatra and for acting as my personal curriers (lots of soil samples, books etc.). I am well aware that without Sílvias support and tried patience it would not have been possible to put all of this to paper. Our daughter Sofia I want to thank for easing our lives through her smiles and happiness. Last but not least I want to thank Sergio Teles for letting me use his office during the last few months.

Contents

Preface V
Contents VII
General introduction 1
Development of the oil palm industry 1
The undergrowth in oil palm plantations 2
Undergrowth and sustainability in oil palm growing 4
Objectives and outline of this study 6

Chapter 1
Phytosociological inventory and assessment of the species distribution in the field zones
Abstract 8
1 Introduction 9
2 Material and Methods 11
2.1 Study area description 11
2.2 Species identification and sampling site establishment 13
2.3 Data interpretation 16
3 Results 17
3.1 Composition of the weed flora 17
3.2 Constancy 18
3.3 Degree of cover 21
3.4 Specific degree of cover 23
3.5 Similarity of plant communities 23
3.6 Species composition in the field zones 24
4 Discussion 30

Chapter 2
Course of solar radiation below the palm canopy and impact on the undergrowth species composition
Abstract....36
1 Introduction....37
2 Material and Methods....38
2.1 Study area....38
2.2 Measurements of vegetative oil palm parameters....39
2.3 Measurements of solar radiation....39
2.4 Vegetation sampling....42
2.5 Data interpretation....42
3 Results....42
3.1 Below canopy solar radiation in relation to oil palm age, petiole cross section and crown radius....42
3.2 Species composition....47
3.3 Species distribution as influenced by below canopy solar radiation....47
4 Discussion....53

Chapter 3
Chemical and physical topsoil properties and their impact on the species composition
Abstract....58
1 Introduction....60
2 Material and Methods....61
2.1 Study area....61
2.2 Soil sampling and analyses....62
2.3 Vegetation sampling....63
2.4 Data interpretation....63
3 Results....64
3.1 Soil texture....65
3.2 Soil carbon and nitrogen....66
3.3 Soil pH, exchangeable Al and Al saturation....67
3.4 Soil phosphorus....67

3.5 Exchangeable base cations and effective cation exchange capacity 67
3.6 Micronutrients 69
3.7 Correlations between chemical soil properties 72
3.8 Species distribution as influenced by soil characteristics 74
Carbon 74
Effective cation exchange capacity 75
4 Discussion 78

Summary 85
Zusammenfassung 89
References 93
Appendix: Complete list of all species identified in the research area 101

General introduction

Development of the oil palm industry

The oil palm (*Elaeis guineensis* Jacq.) is native to tropical West- and Central Africa. The fruit is unusual in producing two valuable vegetable oils – palm oil and palm-kernel oil. The extractable palm oil from the outer flesh (mesocarp) of the ripe orange-coloured fruit constitutes approximately 25% of the fruit bunch's total weight and the palm kernel oil (from the endocarp) another 2.5%. Depending on environment and management oil yields exceeding 10 t ha^{-1} can be achieved from current cultivars (Gerritsma and Wessel, 1997; Armstrong, 1999; Weng, 1999; Lee, 1997). Indigenous people recognized the nutritive value early and already collected the fruit from wild palms over 5,000 years ago (Cottrell, 1991; Berger and Martin, 2000). Though palm oil was known in Europe for centuries, commercial shipping started only when the British suppressed slave trade in 1807 and merchants sought substitute commodities from the West African coasts (Henderson and Osborne, 2000). The German Colonial Economy Committee initiated in 1902 the development of mechanical palm oil extraction (Bücher and Fickendey, 1919) and laid thus the foundation for the modern palm oil industry. Current oil palm mills process hourly up to over 100 tonnes of fresh fruit bunches. The mill capacity and the quick deterioration of the oil palm fruit are the main reasons for the establishment of extensive oil palm monocultures.

Four oil palms planted in 1848 at the Buitenzorg Botanical Gardens (now Indonesian Botanic Gardens) on the island of Java provided seeds for all the plantations in Malaysia and Indonesia in the early 20th century (Moll, 1987). Synchronically in Africa European interest started in the commercial development of plantations in Nigeria, Cameroon and Congo (Henderson and Osborne, 2000). The ideal climate, among other favourable conditions for oil palm growing in South East Asia lead to a steady decline of Africa's importance as a supplier of palm oil. Today, African countries import over 1 million tonnes of palm oil annually. However, the palm oil industry as a whole has experienced an

unsurpassed expansion during the last 3 decades. Within this period of time worldwide vegetable fat production doubled, while the supply of palm oil increased by 850%. Oil palm holds a 26% share of the global vegetable oil market and next to soybean, the most important oil crop. It is planted in many tropical countries on a total of 10 million hectares and produces 24 million tonnes of oil annually. Malaysia, providing 13 million tonnes of palm- and palm kernel oil and Indonesia 8 million tonnes respectively are with distinction the most important producers. The third rank holds Nigeria followed by Colombia and Thailand with each less than 1 million tonnes of oil per year (FAO, 2002a).

Over the past five years worldwide oil palm planting expanded at a rate of about 350,000 ha per year (FAO, 2002a). It is forecasted that this trend will continue well into this century (Mielke and Mielke, 1999). Though a considerable part of the future expansion of the oil palm industry is likely to take part in South East Asia, there are research and planning focuses on potential growth also in Africa and Latin America. The Food and Agricultural Organisation promotes breeding of cold tolerant, high yielding oil palm to boost the local vegetable oil production in countries such as Ethiopia, Cameroon, Malawi and Zambia (FAO, 2002b). Meanwhile the Centre de Cooperation International en Recherché Agronomique pour le Développement tries to control bud rot to develop oil palm growing in Latin America (CIRAD, 2001). The recent International Fund for Agricultural Development / International Development Association approval of a 12.6 million US$ loan for Uganda to support the governments plan to plant some 10,000 ha to oil palm (IFAD, 2002), suggests that large scale oil palm development will in future not continue to be restricted to Malaysia and Indonesia. Sierra Leone seeks also to profit from extensive oil palm plantations, the minister for agriculture and marine resources plans to convert 50,000 ha to oil palm (Anonymous, 2002a).

The undergrowth in oil palm plantations

Oil palms and a ground cover consisting of creeping legume species are normally planted simultaneously and as soon as possible following land clearing and preparation. The most commonly used legume cover crop (LCC) comprises *Pueraria phaseoloides* Benth, *Calopogonium*

muconoides Desv., *Centrosema pubescens* Benth. and *Desmodium ovalifolium* Wall. Where degraded savannah soil is rehabilitated for oil palm planting *Mucuna cochinchinensis* Lour. performs well (von Uexküll and Mutert, 1994). Many other species including alternative species of the mentioned genera, *Flemingia congest* Roxb. and *Arachis pintoi* L. are occasionally used as cover crops (Chee and Chung, 1998; Ortiz and Fernandes, 1992). On acid peat soil there is little advantage of establishing LCC as there is no benefit from nitrogen fixation, the soils are not prone to erosion and additional soil organic matter is not required (Fairhurst et al., 1998). On these soils the natural establishment of ferns such as *Nephrolepis biserrata* (Sw.) Schott and *Dicranopteris linearis* J. Underw. is desired (Turner and Gillbanks, 1974).

The cover plants form a thick blanket over the soil after about three months (Fairhurst, 1996). However, weeded circles are cleared around the base of each palm and kept weed free throughout the life of the plantation (Corley et al., 1976). For the first two years, monthly weeding operations may be required to prevent the inter-row legume cover crop from climbing up the newly planted palms, to facilitate fertilizer application, and to minimise competition between the inter-row vegetation and the newly planted palms (Hartley, 1988). A dense cover crop avoids usually vigorous growth of any other species. After germination LCC species are however vulnerable to draught, have initially a low power of competition and cannot endure flooding. Segetal species establish themselves in gaps in the cover crop canopy, the palm circles and the maintenance paths. Noxious plants are sprayed, poisoned or uprooted. The planter considers species noxious that compete strongly for nutrients (e.g. *Asystasia intrusa* Blume, *Imperata cylindrica* Beauv. and *Mikania micrantha* H.B.&K.), species that obstruct the fieldwork by thorns or pricks (e.g. *Mimosa* ssp. and *Lantana camara* L.), stinging nettles (e.g. *Fleurya aestuans* (L.) ex Miq.), forming a dense coverage (e.g. *Stenochlaena palustris* Bedd., *Pennisetum polystachyon* (L.) Schult.) or fast growing woody species (e.g. *Ficus* ssp., *Melastoma malabathricum* L., *Trema orientalis* Blume). The oil palm canopy closes as the palms grow in height and frond length increases and the species composition gradually changes. The legume covers will disappear to be

succeeded by grasses as they posses only a limited shade tolerance (Reynolds, 1997), while other species become more dominant. The vegetation in the inter-row is usually kept low by frond mulching and slashing at a height of about 0.5 m and in the circle plants are removed manually. Both the circle and the path are sprayed if necessary with herbicides.

The diversity of the accompanying flora coexisting with LCC under oil palm has so far only been investigated in one comprehensive study conducted in a Nigerian plantation (Gill and Onyibe, 1998). In contrast to the general assumption that in the oil palm environment a small number of species strive (MacKinnon et al., 1996) a rich diversity of 174 species was found.

Undergrowth and sustainability in oil palm growing

The contention regarding the environmental impact of the oil palm industry is above all about the conversion of tropical rain forest into plantations (Casson, 2000; Wakker, 1999). The land conversion results in greenhouse gas emission, erosion (Hamer, 1981; Maene et al., 1979) and reduction of biodiversity by fragmentation, disturbance and destruction of natural habitats (Laidlaw, 2000; Robertson and Schaik, 2001; Turner, 1996). A promising option to provide vegetable oil without threatening natural forest offers the conversion of savannah in the humid tropics into oil palm plantations (Germer and Sauerborn, 2002). Nevertheless, to restrain further expansion on virgin land lastingly, high and sustainable yields from land already converted must be ensured. The worldwide average oil yield per harvested hectare oil palm is 2.5 t and national averages in Malaysia and Indonesia are close to 4 t (FAO, 2002a). These figures are inferior to yields achieved from well-managed plantations (Gerritsma and Wessel, 1997; Armstrong, 1999) and far below the theoretically potential estimated at 18.5 t ha^{-1} (Corley, 1996). This yield gap reflects the industries inefficiency and low productivity (Jaafar and Sukaimi, 2001). Particular reasons currently influencing the industries output include low yield and a small oil extraction rate from bunches of too old palms (Kui, 2001), labour shortage and low level of mechanisation (Jaafar and Sukaimi, 2001), poor crop management related to fallen palm oil prices and increased production costs (Casson,

2000; Jaafar and Sukaimi, 2001; Anonymous, 2002b) and the El Ninõ Southern Oscillation phenomenon with the consequent drought and fires in South East Asia (Casson, 2000). Whereas continuing erosion and growing pest pressure might limit yield growth and reduce future yield potential permanently. Erosion is the major constraint to sustainability of plantations (Wycherly, 1969). Under conventional management an annual soil loss of up to 14 t ha^{-1} is to be expected (Maene et al., 1979; Lim, 1990; Ross, 1999). Hamer (1981) states, that soil loss in oil palm plantations is as high as in upland crops including beans, potatoes and sugarcane. Already in the beginning of the 20th century the importance of plantation undergrowth to limit erosion was recognised and clear weeding abolished (Vincent and Hadi, 1993). Data about species suitable to control erosion under the closed canopy of mature oil palm is however rare.

Little information about yield losses related to insect pests is available; however the potential risk of pest outbreaks increases in large monocultures of tropical trees (Nair, 2001). A number of insects potentially dangerous to oil palm in various parts of the world are identified: Palm weevils (*Rhynchophorus* spp.), rhinoceros beetles (*Oryctes* spp.), weevils (*Strategus aloeus*, *Temnoschoita quadripustulata*), leaf-miners (*Coelaenomenodera elaeidis*, *Hispolepis elaeidis*, *Alurunus humeralis*), slug caterpillar (*Parasa viridissima*), nettel caterpillar (*Setora nitens*) and bagworms (*Cremastophysche pendula*, *Mahasena corbetti*, *Metisa plana*).

Well-established plantation undergrowth limits both, erosion (Beaufoy, 2000; Hashim et al., 1997; Ross, 1999; Fairhurst, 1996) and the insect pressure (Wahid et al., 1999; Mexzón and Chinchilla, 1996; Ho and Teh, 1999). In general the function of individual plant species in this respect is still to be investigated. Exceptions are some plant species identified as essential hosts for the natural enemies of *Metisa plana* (Wahid et al., 1999). The existents of other oil palm pest antagonists (Moore, 2001), suggests that alternative undergrowth species could also contribute to the ecological stability of oil palm plantations by hosting predators. The potential of single species or species compositions to limit erosion in oil palm plantations is to be analysed as well. According to varying soil loss

rates under different cultivated crops (Hamer, 1981) alternative oil palm undergrowth might influence erosion specifically too. Further advantages of plantation undergrowth are nitrogen fixation (Hartley, 1988; Turner and Gillbanks, 1974), buffering of leaching losses (Parrotta, 1992), melioration of physical soil properties (Pini et al., 1999; Fairhurst, 1996) and reduction of diurnal soil temperature fluctuations (Fairhurst, 1996). Additionally, undergrowth species may be used as an indicator of the parameters limiting oil palm growth, such as nutrient and water availability or intra-crop light competition.

Comprehensive knowledge of specific niches of undergrowth species in oil palm plantations is essential to investigate their function and potential benefit to the oil palm agro-ecosystem. Sustainability of oil palm growing could then profit from the encouragement of species with a specific advantage in an integrated undergrowth management approach.

Objectives and outline of this study

The objectives of the current research work were to develop a reproducible approach for phytosociological investigation in oil palm plantations and to accomplish a general inventory of the vascular plants associated with oil palm in a given research area. Additionally the aim was to study the undergrowth heterogeneity in the fields and the distribution of species in the plantation in response to solar radiation below the palm canopy, soil type and physical and chemical soil parameters.

In the first chapter all plant species associated with the oil palm are catalogued and their distribution, degree of coverage and association formation in response to soil type assessed. Additionally the species distribution in the field zones: harvesting path, palm circle and inter-row is investigated.

The second chapter analyses the influence of two different soil types, fluvisol and histosol, on the closure of the palm canopy and the solar radiation below the canopy. An investigation of the relationship between solar radiation below the oil palm canopy, palm age, petiole cross-section area and crown radius is conducted and the impact of different levels of solar radiation on the undergrowth species composition in the fields and their zones assessed.

In the third chapter spatial variations of soil texture and chemical properties in the topsoil under oil palm are assessed. The impact of the field structure and management practises on nutrient content in the different field sections is investigated and changes in the undergrowth species composition in response to the soil properties are studied.

Chapter 1

Phytosociological inventory and assessment of the species distribution in the field zones

Abstract

A phytosociological study on the flora associated with oil palm (*Elaeis guineensis* Jacq.) has been carried out between 1997 and 2000 in an oil palm plantation in West Sumatra. In the plantation 298 plant species were identified, 186 dicotyledonae, 77 monocotyledonae and 35 pteridophyta, representing 81 families. The families with most species were Gramineae, Cyperaceae, Compositae, Rubiaceae and Euphorbiaceae.

To study the distribution of plants in the plantation 100 relevés (sampling sites) of 300 m^2 each were sampled. A total of 224 species were recorded in the relevés, 8 species occurred with high constancy (in >80% of the relevés), whereas about three quarter or 172 species remained rare (in ≤20% of the relevés). Only six species developed a large degree of coverage (over 2% of the sampled area): *Mikania micrantha* H.B.&K., *Pueraria phaseoloides* Benth., *Nephrolepis biserrata* (Sw.) Schott, *Ageratum conyzoides* L., *Sparganophorus villanti* Crantz and *Sporobolus diander* Beauv..

Species composition varied within the research area, where soil type was one factor influencing species constancy, abundance and degree of coverage. Species abundance per relevé was significantly higher on fluvisol than on histosol, while the difference in the total number of species between the soil types was small. Species that were found exclusively on fluvisol were *Selaginella plana* Hieron. and *Vitis japonica* Thunb., whereas solely on histosol *Momordica charantia* L. and *Trema orientalis* (L.) Blume occurred.

Due to a particular management practice, oil palm fields can be zoned in harvesting path, palm circle and inter-row. These field zones represent specific microhabitats that host alternative species compositions.

Species that were mainly found in the inter-row are: *Diplazium esculentum* (Retz.) Sw., *Cyclosorus interruptus* (Willd.) H.Ito, *Nephrolepis biserrata* (Sw.) Schott and *Christella dentata* (Forssk.) Brownsey & Jermy. Plants that were found primarily in the other zones were small herb species such as *Hedyotis corymbosa* Lam., *Limnophila rugosa* Merrill, *Borreria setidens* (Miq.) Boldingh and *Peperomia pellucida* H.B.&K., the sedges *Fimbristylis miliacea* Vahl and *Cyperus kyllingia* Endl. as well as the grass *Sporobolus diander* Beauv..
The 8 most frequent species were identified as an abstract plant community: *Mikania micrantha* H.B.&K., *Pouzolzia zeylanica* Benn., *Ageratum conyzoides* L., *Sporobolus diander*, *Nephrolepis biserrata*, *Pityrogramma calomelanos* (L.) Link, *Lygodium microphyllum* (Cav.) R.Br. and *Stenochlaena palustris* Bedd..

1 Introduction

The oil palm (*Elaeis guineensis* Jacq.), native to West and Central Africa, is planted globally on 10 million hectares. Reaching a production of 24 million tonnes oil in 2000, oil palm has become the most important oil crop next to soybean. The major palm oil producers are Malaysia with 2.5 million and Indonesia with 2.6 million hectares under cultivation. Further important palm oil producing countries are located in South East Asia, South America and Africa particulary Nigeria (FAO, 2002a).
Notwithstanding the worldwide importance of oil palm cultivation, little attention is paid to the accompanying flora. The reason for this may lie, among other things, in the fact that the oil palm is a perennial woody crop. Wilmanns and Bogenrieder (1991) pointed out that there is a distinct layering between ground vegetation and crop in the cultivation of woody plants. They conclude that such a layering facilitates undergrowth control and minimises competition above and below ground level. Consequently, available knowledge of plant species abundance and composition in oil palm plantations is minute (Dahlan et al., 1993). However, comprehensive information about undergrowth species and plant-environment interaction may be in the frame of integrated weed management a vital contribution for more sustainable oil palm cultivation. The integrated weed management approach classifies

accompanying species by their beneficial and harmful characteristics and aims to create through selective weeding more advantageous undergrowth (Chee and Chung, 1998).

Owing to oil palm mill throughput and quick deterioration of the harvested fruit, oil palm is usually planted in extensive plantations to keep transport distances low. Large monocultures are much simpler ecosystems than the natural forest cover, and are supposed to support very few plant species (MacKinnon et al., 1996). Whitten et al. (1987) suggest that an oil palm plantation may not support more than 15 species including ferns growing on the palm trunks. In contrast, Gill and Onyibe (1998) identified 174 species in a Nigerian oil palm plantation. The authors resume that oil palm provides with its long and broad fronds a variety of specialized microhabitats of sunny warm to cool moist conditions very conductive for the growth of a diversity of plants. Valuable functions of undergrowth species are: erosion control, soil temperature and moisture regulation and the reduction of leaching losses. There is also a growing concern about the function of oil palm associated plant species as hosts for pest antagonists (Mexzón and Chinchilla, 1999; Wahid et al., 1999). This is of exceptional importance in view of the increased pest pressure in large tropical tree monocultures (Nair, 2001). Additionally, the undergrowth species may be used as indicators for parameters limiting oil palm growth, such as nutrient and water availability or intra-crop light competition. On the other hand, accompanying plants compete with oil palm for nutrients, water and in the case of young palms, light. Further, some plants are undesired due to negative characteristics including *Mikania micrantha* a species releasing root exudates toxic to oil palm (Mainstone and Wong, 1966) and species with thorns, like common in *Mimosa* spp. or stinging needles, as found in *Fleurya aestuans* that obstruct fieldwork (all taxa mentioned in Table 1 with authority).

The accompanying flora of a crop can be distinctly different in its species composition in response to soil, altitude and water availability (Sauerborn, 1985; Kürschner, 1986). Furthermore, under the same crop and in an identical environment, variations in the species composition can be induced by agricultural practices applied (Wilmanns and

Bogenrieder, 1991). The harvesting path, palm circle and inter-row in oil palm fields are managed in a particular way. Therefore, awareness not just of the presence, but also of the pattern of distribution within the field is crucial to enhance the coverage of advantageous species and to diminish the proportion of plants undesired in the oil palm undergrowth.
The objectives of the present study were: (i) to give a general inventory of plant species associated with oil palm, (ii) to assess species characteristics such as their distribution, degree of coverage and association formation in response to soil type and (iii) to investigate the species distribution in the field zones: harvesting path, palm circle and inter-row.

2 Material and Methods

2.1 Study area description

The research area, Gersindo Minang Plantation, is located between the Barisan mountain range and seashore. It lies at 0º8'N and 99º4'E near the village Tanjung Pankal in Pariman, district of West Sumatra, Indonesia. Two rivers embrace the plantation, the large sediment rich Batang Pasaman to the south and the Batang Alin black water stream to the north. The area is a flat floodplain with an elevation of less than 10 m above sea level.
Plantation development commenced in 1992 from natural partly exploited forest. At the time of research (1997-2000) some relicts of natural primary forest still existed in neighbouring areas. Oil palm planting started in 1993 and was completed with a total of about 5.000 ha planted in 2000. The prevailing soil types were determined during field drain establishment, as histosol and fluvisol (according to the FAO 'World reference base for soil resources' (FAO, 1998)). Histosol, nonmineral or predominantly organic soil covers most of the plantation. The occurring histosol comprises two subgroups: hemic tropofibrist and fluvaquentic tropofibrist. The organic matter of hemic tropofibrist is moderately decomposed with some fibrous material present. Fluvaquentic tropofibrist is characterised by highly decomposed organic matter and contains some mineral alluvium material. Eutric fluvisol, a

grey-brown fertile alluvium, is forming the natural river levee of Batang Pasaman (chapter 3). Drained histosols decompose in the tropics at a fast rate and subside about 2 cm per year (Wösten et al., 1997). Therefore, in the course of time a histosol may degrade and an underlying fluvisol becomes exposed. Consequently there is no clear cut between the soil types. In this study vegetation sampling sites were exclusively placed on fluvisol with a thin cover of humus (<5 cm) and on histosol with a strong organic matter layer (>100 cm).

The annual average rainfall as obtained by the companies rain gauge from 1993 to 1999 is 3.088 mm. Average monthly rainfall is above 200 mm throughout the year. There is a precipitation peak in November and December followed by a second peak in April. Heavy rainfall and consequent rising of the rivers during these periods causes occasional flooding of most of the plantation area. Dryer months are February and March during the northwest monsoon and May to August during the southeast monsoon. Average daily temperature is 26.2 C° with a minimum of 23.5 C° and a maximum of 30.3 C°, the yearly amplitude is 1.8 C°. The mean minimum and maximum relative humidity is 64% and 93% with an average of 81% respectively (temperature and humidity data from “Stasiun Meteorologi Tabing Padang”, Padang, West-Sumatra, 2 m above sea level and about 140 km southeast from the research area).

The oil palm fields (about 200 by 1,000 m) in average measuring 20 hectares are surrounded on two linking sides by drains and on the other sides by maintenance roads. The palms are planted in a triangular pattern at a density of 135 per hectare. The fields are structured in palm circles, harvesting paths and inter-rows. The undergrowth in each of these zones is managed in a particular way. It is intended to keep the palm circles weed free to facilitate the collection of oil palm fruit in the process of harvesting. On the harvesting path a shallow plant cover that allows ground visibility is desirable. It reduces erosion and increases traction of footwear and wheels. However, the path must be kept free of creepers, thorny weeds and vigorously growing species. The inter-row ideally needs little weeding. A leguminous ground cover, comprising of *Pueraria phaseoloides*, *Calopogonium muconoides* and *Centrosema*

pubescens during the immature phase and frond mulching under mature oil palm keeps weeds under control. Occasional woody species are uprooted and noxious weeds sprayed with herbicides. Circles and paths are sprayed, depending on height and density of the undergrowth up to four times per year alternately with Glyphosat and Paraquat. Additionally the circles are manually weeded every three months.

2.2 Species identification and sampling site establishment

Field trips were undertaken from 1997 to 2000; during this period the entire oil palm plantation was sampled for plant species. Identification of the species has been carried out with literature by Whistler (1983), Sauerborn and Sauerborn (1984), Soerjani et al. (1987), Piggott (1988), Barnes and Chan (1990) and others. Taxa were confirmed by cross checking with voucher specimens of the Herbarium Bogoriense, Bogor, Indonesia and the Singapore Botanic Gardens.

For ground cover community sampling the relevé method described by Mueller-Dombois and Ellenberg (1974) was applied. Conditions for this method are a uniform sampling site or relevé, a homogeneous plant cover and a large enough area to contain all species belonging to the plant community. Due to the flat topography of the plantation and the systematic field layout, uniformity is given throughout most of the research area. On the other hand the homogeneity requirement could only be fulfilled within the field zones, because of obvious differences in the vegetation between the harvesting path, palm circle and inter-row. The minimal area is defined as the smallest area on which the species composition of the community in question is adequately represented. The size of the minimal area is determined by applying the nested plot technique (Mueller-Dombois and Ellenberg, 1974). First an area of 0.25 m^2 is lined out and all species occurring in this area recorded. Then the area is continuously doubled in size and all additional species listed. The number of species is plotted over the size of the sampled area and the species-area curve fitted.

The minimal area is the sample area at which the initial steep increase of the curve turns horizontal. This is the point along the curve at which an increase in 10 percent of the total sample area yields only 10 percent more species of the total number recorded (Cain, 1938). Ideally, the

minimal area should be established for the community type and not only for one community member of a type (Mueller-Dombois and Ellenberg, 1974). This means that minimal areas should be determined in several recurring plant assemblages of the same kind. The one that indicates the largest minimal area should be used as a guide for the minimum size of a vegetation sample or relevé. In this study the minimal area has been determined three times on each soil type.

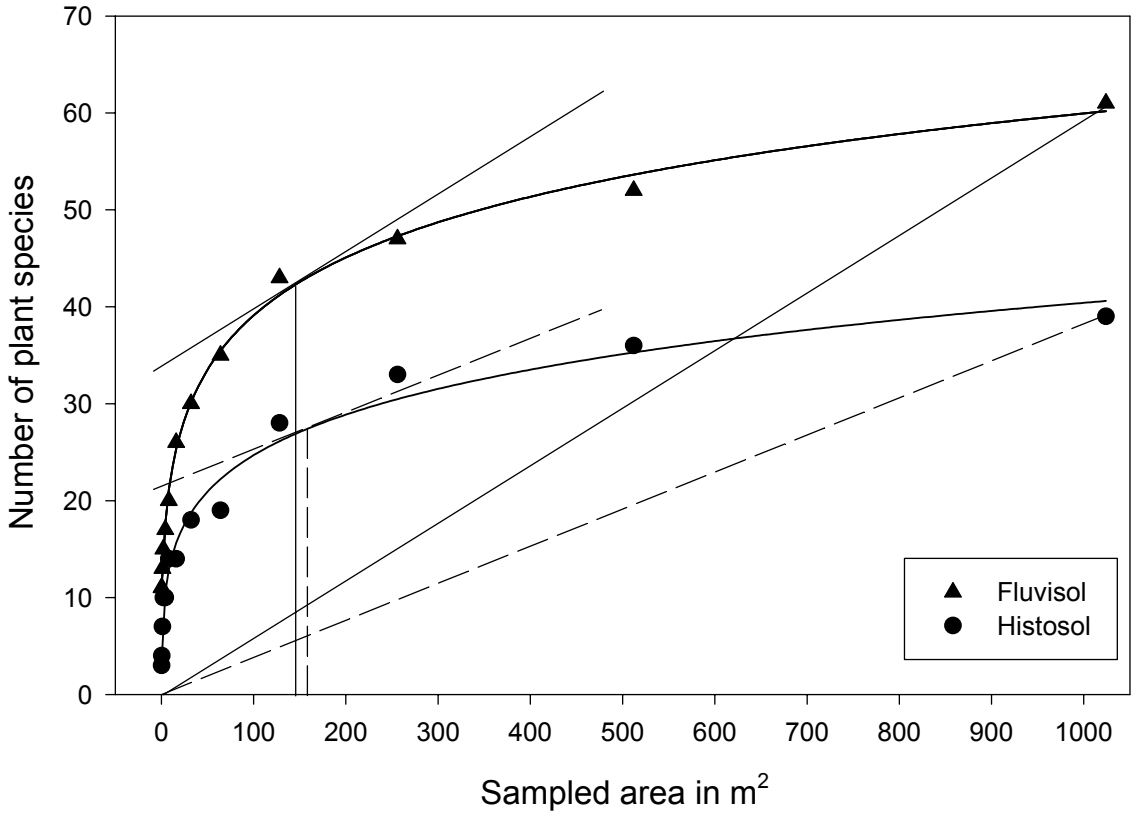


Fig. 1: Species-area curve of undergrowth vegetation in oil palm fields on fluvisol and histosol (excluding oil palm and the vegetation on oil palm trunks, curves fitted: Log Normal Cumulative r^2=0.99 on fluvisol and r^2=0.98 on histosol). Plots of each soil type represent the accumulative number of species found in the respective area. Solid lines represent minimal area estimation for fluvisol (≈145 m^2), dash lines for histosol (≈158 m^2) respectively.

Fig. 1 shows the two species area curves obtained by the nested plot technique, which indicated the highest area requirement on each soil type. The upper curve represents the species presence under six-year-

old oil palm on fluvisol and the lower under oil palm of the same age on histosol. The minimal area requirement that resulted from both curves is about 150 m^2, the sample taken on fluvisol indicates a slightly lower area requirement than the one on histosol. The relevé size was enlarged to 300 m^2 in order to accomodate the study of changes in the species composition between the field zones via frequency plots (Fig. 2).

In each chosen area for undergrowth sampling five relevés were combined in one sampling unit. The relevés were arranged in the sampling unit within a radius of about 50 m, to keep environmental variations low.

Altogether 100 relevés or 20 sampling units, 7 on fluvisol and 13 units on histosol, were investigated. They were placed in the research area with the aim in mind to cover the whole available range of palm ages on both soil types. Sampling units were established in fields of palms from 2 to 6 years of age on fluvisol (palm age was in one unit each 2 and 3 years, in two units 5 and in three units 6 years). Sampling was carried out under palms 1 to 7 years old on histosol (the palm age was in four units 1 year, in one unit 3 years, in four units 4 years, in two units 5 and in one unit each 6 and 7 years).

All species present in a relevé were listed and rating of each species was carried out by applying a modified cover-abundance scale of Braun-Blanquet (1928), where:

6 = cover > 75% - 100 %,
5 = cover > 50 % - 75 %,
4 = cover > 25 % - 50 %,
3 = cover 5 - 25 %,
2 = species numerous, but cover below 5 % and
1 = species few, with small cover less than 1 %.

To facilitate data processing the scale values were set as 1 = 0.5%, 2 = 2.5% and the other values as the mean of their ranges.

To investigate the variation of the species composition between the zones of an oil palm field, a total of 2,000 frequency plots each covering 1 m^2 were laid out. Twenty of these plots were arranged systematically

within each relevé (Fig. 2), five on the harvesting path, five in the inter-row and ten in the palm circles. In every palm circle one frequency plot was placed in the front section towards the harvesting path and one in the back section towards the inter-row. The palm circle was divided into sections to examine differences in the species composition within the circles. All species present in a frequency plot were listed.

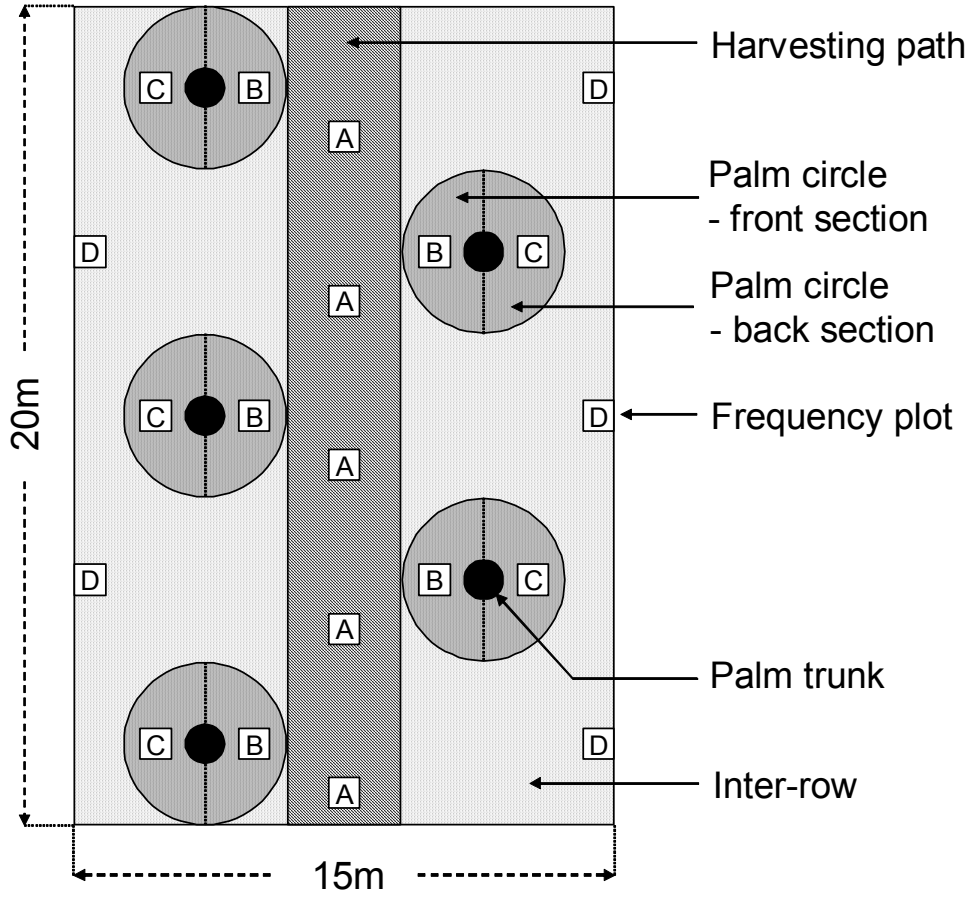


Fig. 2: Relevé layout under oil palm with frequency plots on harvesting path (A), front of palm circle (B), back of palm circle (C) and inter-row (D).

2.3 Data interpretation

Primary data interpretation was preformed in accordance to the methods described by Mueller-Dombois and Ellenberg (1974). These methods include evaluation of abundance or number of species, constancy, degree of coverage and specific degree of coverage. The constancy used is the relative one, or the percent constancy. The terms relative or percent constancy refer to the percentage of relevés in which a species

occurs. The degree of coverage expresses the percentage of ground that a species covers in average of all relevés. Accordingly the specific degree of coverage is the percentage of ground that a species covers in average of all relevés in that the species occurs. To express the similarity of plant communities, the Jaccard index was applied. It is based on the presence-absence relationship between the number of species common to two areas and the total number of species. Therefore, the coefficient expresses the ratio of the common species to all species found in two areas. To determine which species grew predominantly or with a larger degree of coverage on one soil type, all species that occurred at least on one soil type in more than 20% of the relevés were considered. Species were regarded as occurring predominantly on one soil type if they were on this soil type at least 4 times more frequent than on the other. Accordingly species were considered to develop a larger degree of coverage on one soil type, if coverage on this soil was at least 4 times higher than on the other soil type.

A paired *t*-test was used to identify significant differences in the number of species in the field zones and circle sections. The Pearson correlation coefficient was employed to evaluate the correlation of species abundance between the field zones and circle sections. The *t*-test and correlation analyses were preformed using SPSS 10.0.

3 Results

3.1 Composition of the weed flora

In the study area 298 plant species were found growing in association with oil palm. The species were in 277 cases identified to species level and in 21 cases only to genus level. Seven of the species identified to genus level belong to the genera *Uncaria* and *Ficus*, both abundant in the natural forests surrounding the research area. Out of the division of flowerless plants (cryptogams) the subdivision pteridophyta was present with 35 species belonging to 18 families including 33 ferns (pteridopsida) and 2 fern allies (lycopsida). The division of flowering plants (phanerogams) was present with 263 angiosperms, but no

gymnosperms were encountered. Dicotyledonae were present with 186 species belonging to 49 families. Compositae (19 species), Rubiaceae (19 species) and Euphorbiaceae (15 species) were the species richest dicotyledonae families. The group of Leguminosae (comprising Leguminosae-Papilionoideae (12 species), Leguminosae-Caesalpinioideae (6 species) and Leguminosae-Mimosoideae (5 species)) encompassed 12% of all dicotyledonae species recorded. Monocotyledonae contribute 77 species out of 14 families. Of these the major families were Gramineae (30 species), Cyperaceae (20 species) and Araceae (11 species). A complete listing of all taxa encountered is provided in the appendix table.

In average each relevé contained 36 species, with a range of 18 to 60 species per relevé. Species diversity was slightly higher on fluvisol than on histosol. In the 35 relevés on fluvisol 180 species occurred, whereas in the 65 relevés on histosol only 157 species were recorded. The average species abundance of 31 species per relevé on histosol was also lower than on fluvisol. On fluvisol 46 species or 48% more species per relevé occurred. Exclusively on fluvisol 67 species grew and 44 species only on histosol. No correlation between oil palm age and number of species was found.

3.2 Constancy

Out of the 298 species found in the research area 224 appeared in the relevés. Constancy of most of these species in the relevés was low (Fig. 3). Applying constancy classes, as defined by Mueller-Dombois and Ellenberg (1974), only 12 species occurred with moderate high (>60 to ≤80%) to high (>80%) constancy. 40 species were of low (>20 to ≤40%) to intermediate (>40 to ≤60%) constancy and the remaining 172 species or 58% of all species were rare (≤20%). In total, including the 74 species not found in the relevés 214 species were rare in the research area. The most constant broad leaf species were *Mikania micrantha*, *Pouzolzia zeylanica*, *Ageratum conyzoides* and *Phyllanthus debilis*.

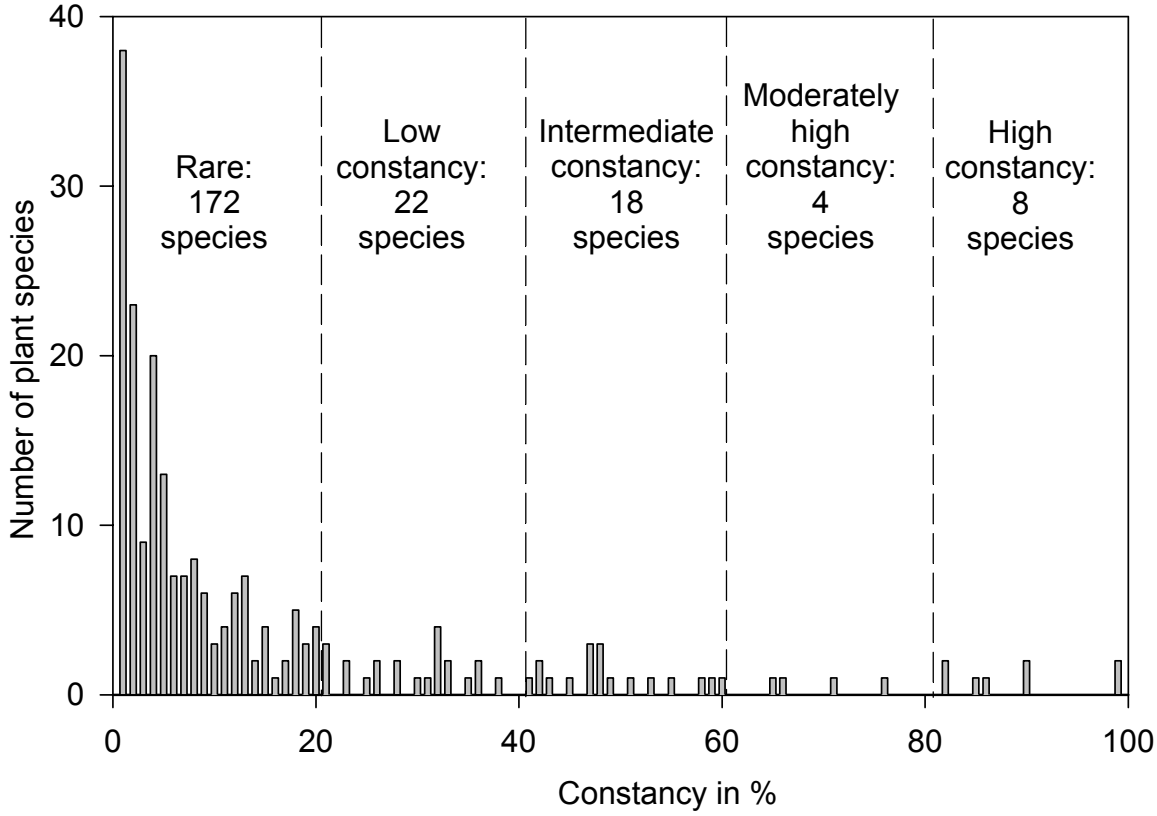


Fig. 3: Species (n=224) constancy in the relevés (n=100) investigated in an oil palm plantation in West-Sumatra.

Remarkable was the high constancy of five ferns: *Nephrolepis bisserata, Pityrogramma calomelanos*, *Lygodium microphyllum*, *Stenochlaena palustris* and *Christella dentata*. *Sporobolus diander*, a grass present in 90% of the relevés was by far the most frequent monocotyledonae. Other important monocotyledonae were voluntary oil palm seedlings, *Cyperus kyllingia* and *Paspalum conjugatum* (Table 1).

There were more species with a moderate high to high degree of constancy on fluvisol than on histosol. On fluvisol 23 species were present with a constancy above 60% and on histosol only 12 species respectively. Species only present in the relevés on fluvisol having a constancy above 20% were: *Adiantum latifolium*, *Alocasia macrorrhiza, Merremia vitifolia*, *Selaginella plana, Synedrella nodiflora* and *Vitis japonica*. Of these, *Selaginella plana* with a presence in 71% of all relevés, was by far the most constant. Four species: *Momordica*

charantia, Trema orientalis, Uncaria ferrea and *U. pedicellata* were only present in relevés on histosol with a constancy above 20%.
Predominantly on fluvisol 25 species grew (Table 1) of which *Ceratopteris thalictroides*, *Colocasia esculenta, Pleocnemia irregularis*, *Polygonum barbatum* and *Sphaerostephanos polycarpus* showed the most distinct pattern of occurrence. Predominantly on histosol 5 species occurred, of which *Borreria latifolia*, *Dicranopteris linearis* and *Vernonia cinerea* showed the clearest difference in distribution.

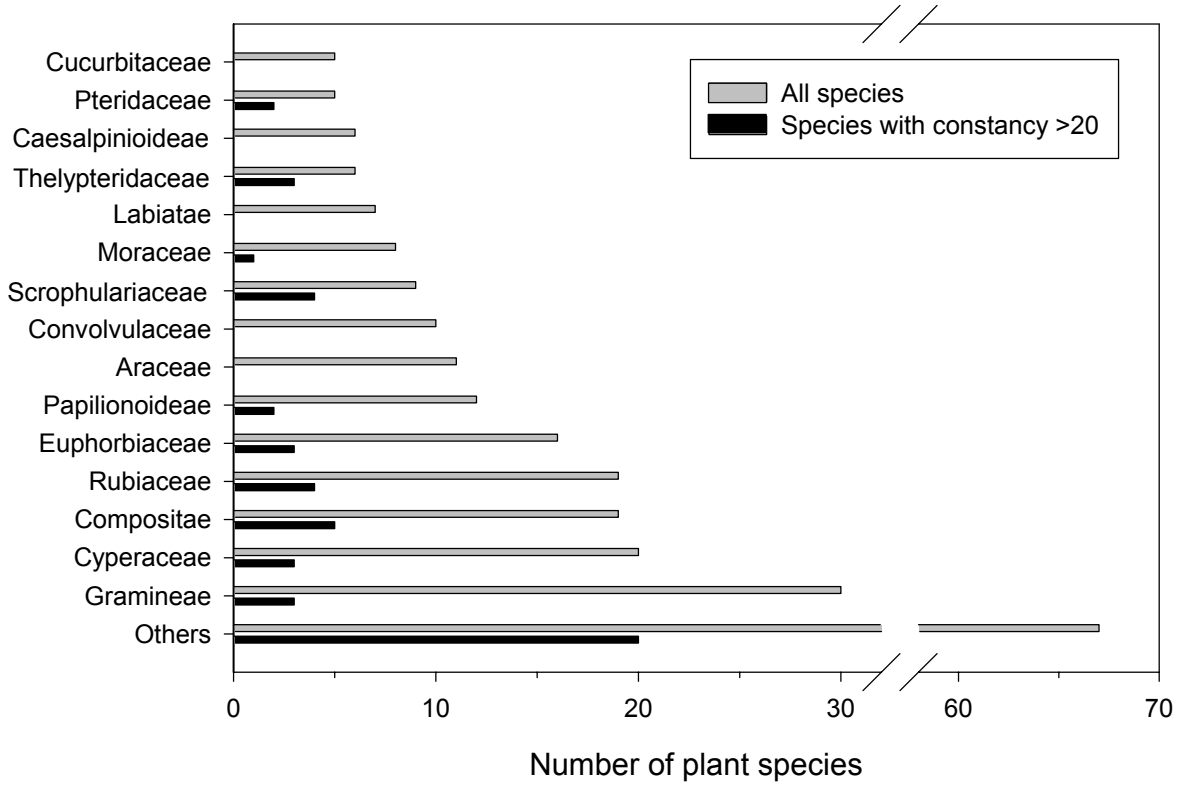


Fig. 4: The most frequent plant families in oil palm undergrowth. Comparison of all species found (n=224) with constant species (n=52) in the relevés (n=100).

No family contributed more than 5 species that were present in over 20% of the relevés (Fig. 4). Gramineae the species richest family contained only 3 species that were not rare. The families Cyperaceae, Compositae, Rubiaceae, Euphorbiaceae and Leguminosae-Papilionoideae encompassed only a few constant species in comparison to their total species diversity. The comparatively small ratio of constant

to rare species of Scrophulariaceae, Thelypteridaceae and Pteridaceae was remarkable. An analysis of the species morphology revealed a dominant rule of grasses, sedges, herbs, ferns and legume creepers in the oil palm undergrowth flora (Fig. 5). Trees, shrubs, climbers and palms were only minor elements of the undergrowth vegetation. Observing all species bar the rare ones, the relative proportion of ferns in the species composition increased in contrast to all other plant types.

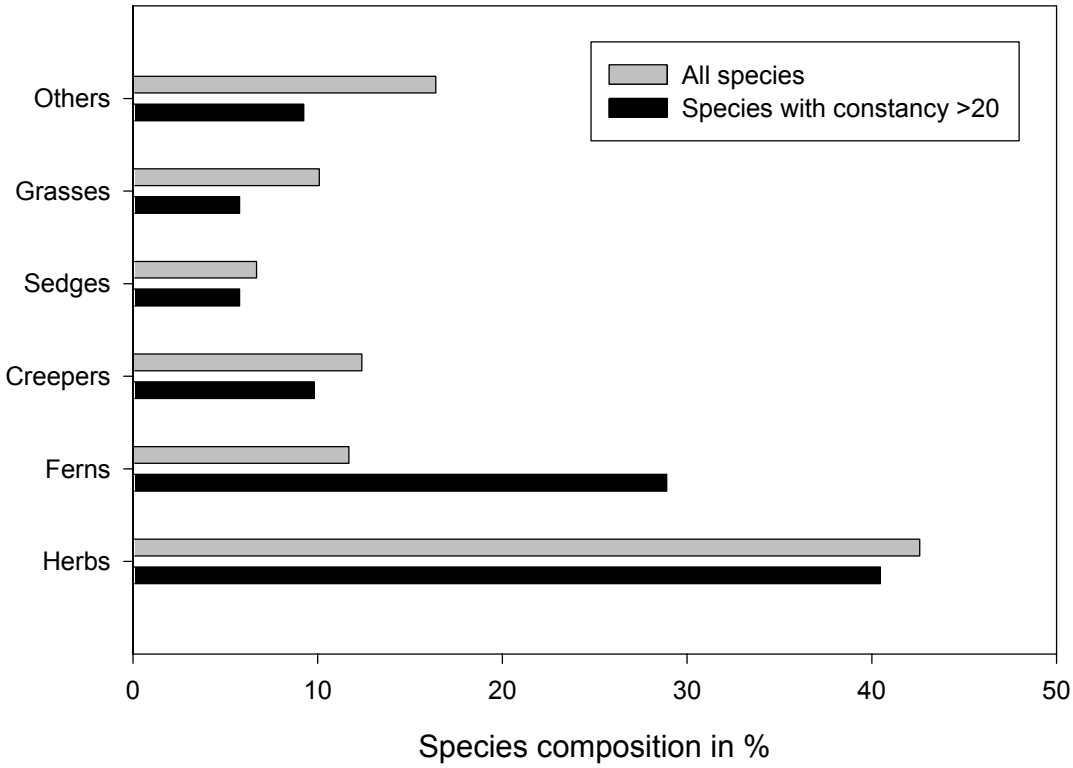


Fig. 5: The most frequent plant types in oil palm undergrowth (others include trees, shrubs, climbers and palms). Comparison of all species (n=224) found with constant species (n=52) in the relevés.

3.3 Degree of cover

The ground in the oil palm fields had an average plant covering of up to 82%. Only 15% of the relevés had a cover of less than 50%. The total degree of coverage on both soil types had the same magnitude. *Mikania micrantha* was the species with the highest degree of coverage, at 20% of the whole area sampled. The degree of coverage of *Pueraria phaseoloides*, a species planted as a cover crop, was 15%. *Nephrolepis*

biserrata, a competitive fern, covered almost 7%. Thus these three species alone covered over 40% of the whole area (Fig. 6). *Ageratum conyzoides*, *Sparganophorus villanti* and *Sporobolus diander* covered each over 2%. Of all species recorded in the relevés only 12% covered more than 0.5%. The remaining 198 species covered together 16% of the sampled area.

Of the species that occurred on both soil types 10 species developed a higher degree of coverage on histosol than on fluvisol (Table 1). The most notable ones were: *Borreria latifolia*, *Dicranopteris linearis*, *Phaseolus calcaratus* and *Imperata cylindrica*. 24 species developed a larger degree of cover on fluvisol. Those that showed the most distinct difference in cover were *Sphaerostephanos polycarpus*, *Polygonum barbatum*, *Ceratopteris thalictroides* and *Colocasia esculenta*.

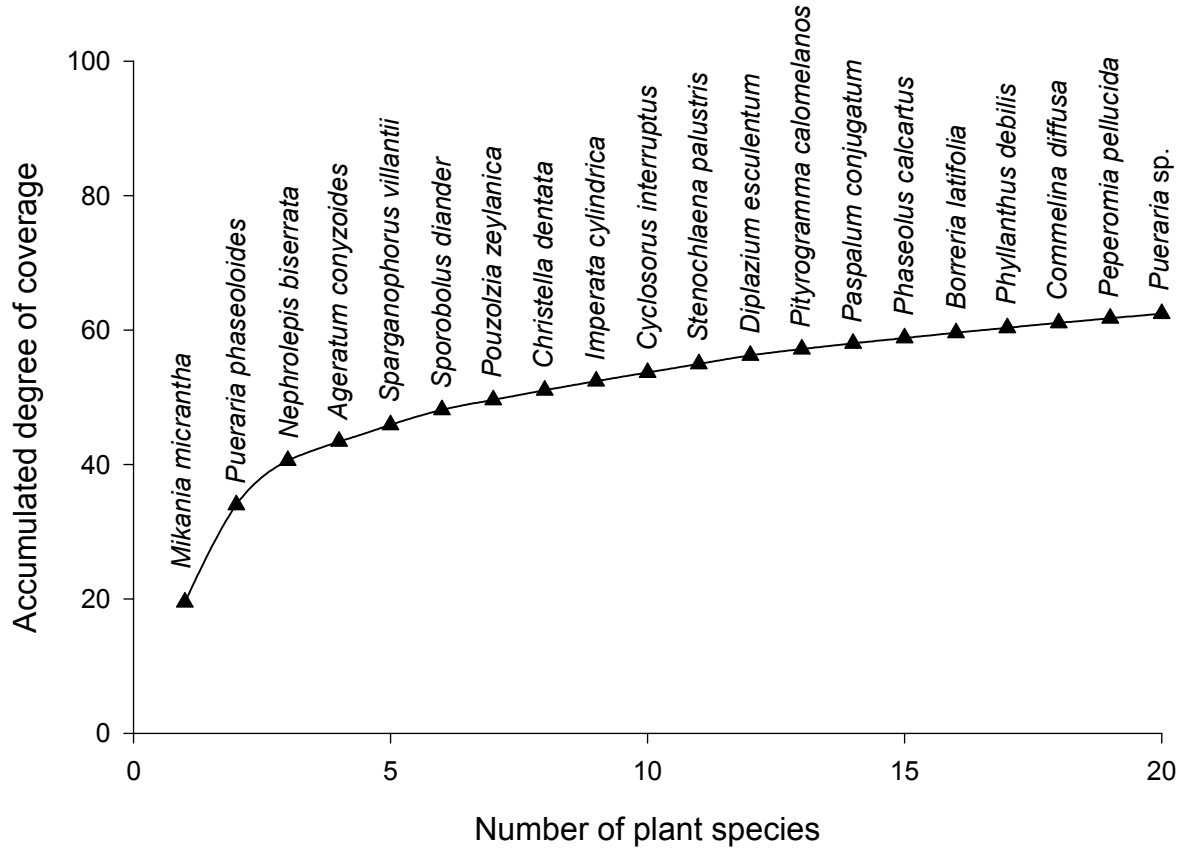


Fig. 6: Accumulated degree of coverage of the 20 plant species with the highest degree of coverage under oil palm in West-Sumatra.

3.4 Specific degree of cover

Pueraria phaseoloides had at 34% the largest specific degree of coverage. A high specific degree of coverage of 20% for *Mikania micrantha* was evident, due to its constancy and degree of coverage. A species belonging to the genera *Pueraria* (not identified to species level) had a specific degree of coverage of 17%, but occurred only in four relevés of the same sampling unit. Further species that occurred less frequently, but with a comparatively high specific degree of coverage were *Phaseolus calcaratus*, *Borreria latifolia*, *Momordica charantia* and *Commelina diffusa*. In total 53 species had a specific degree of coverage above 1%. Analysing exclusively the relevés on fluvisol, there were 33 species with a specific degree of coverage above 1%. On histosol 35 species had a specific degree of coverage above 1%.

3.5 Similarity of plant communities

The application of the Jaccard similarity index showed that there were notable changes in the floristic composition throughout the area of research. The average similarity of the plant communities in all relevés to each other was 28%, within a range of 5 to 72%. Mueller-Dombois and Ellenberg (1974) suggest, that communities of a similarity between 25 and 50% can be considered part of the same association. Above a similarity of 50% further grouping can be ignored and communities considered of the same composition. These threshold values suggest that a variety of different associations might be present. When comparing all relevés that do not belong to the same sampling unit, in 41% of all possible combinations (7,800) the similarity was below 25%. Furthermore the threshold values indicate that even within the sampling units in one third of the cases, the relevés host different floristic compositions. Nevertheless, relevés belonging to the same sampling unit had a distinctly higher degree of similarity, in average 53%.

Observing relevés on the same soil type the average similarity between plant communities in relevés of different sampling units increased to 31% on fluvisol and to 30% on histosol. The average similarity between communities in relevés of the same sampling units was 55% on fluvisol, and 51% on histosol, respectively.

3.6 Species composition in the field zones

The species that were recorded in the frequency plots represent approximately the composition obtained from the relevé analyses. Out of the 224 species present in the relevés 198 or 88% occurred also in the frequency plots. However, the number of species recorded in a single field zone or circle section was characteristically lower. In total 139 species were recorded in the frequency plots on the harvesting path, 132 species in the front of the palm circle towards the harvesting path, 141 species in the back of the circle towards the inter-row and 126 species in the inter-row.

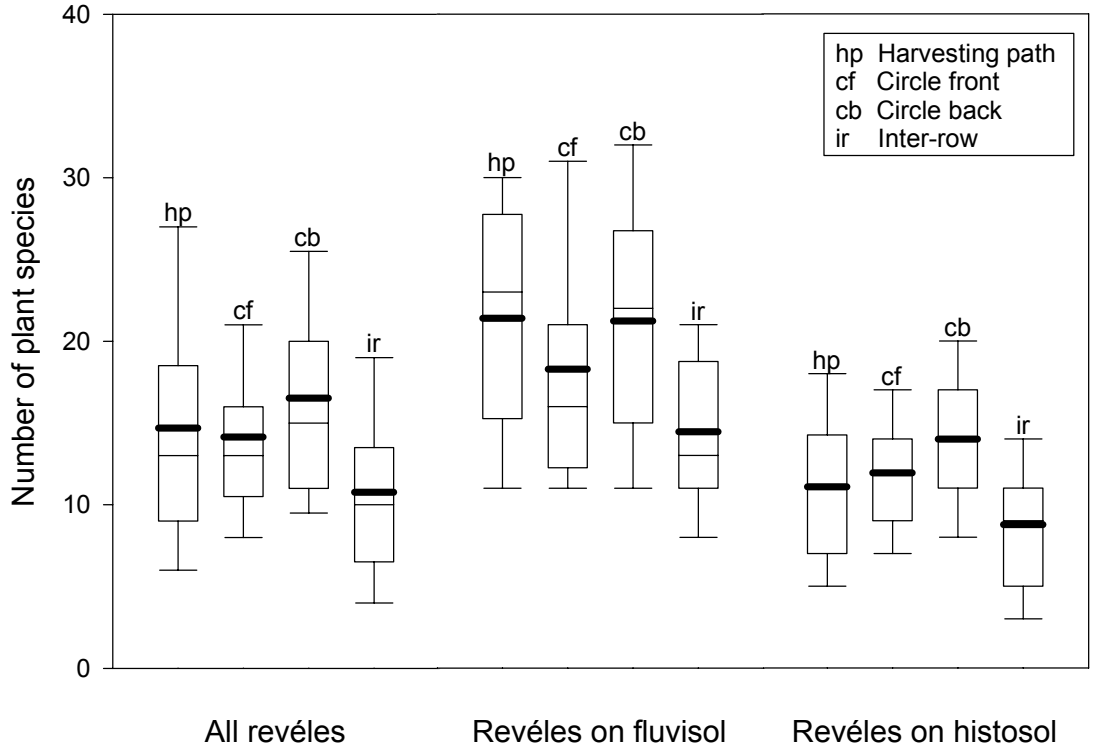


Fig. 7: Plant species abundance in oil palm fields on harvesting path, front and back of palm circle and inter-row. All relevés (n=100), relevés on fluvisol (n=35) and relevés on histosol (n=65), the box-and-whisker diagrams include: (bold line in rectangle) average value, (line in rectangle) median value, (rectangle) range of 50% of the samples and (whiskers) 90% of the samples.

Table 1: Phytosociological parameters of oil palm undergrowth species*

Species	Family	Growth	Constancy			Degree of coverage			Specific degree of coverage			Frequency			
			a[1]	f[2]	h[3]	a[1]	f[2]	h[3]	a[1]	f[2]	h[3]	hp[4]	cf[5]	cb[6]	ir[7]
Mikania micrantha H.B.&K.	Comp	creeper	99	100	98	19.5	16.9	20.8	19.6	16.9	17.6	50.0	37.0	46.8	64.4
Pouzolzia zeylanica Benn.	Urt	herb	99	97	100	1.5	0.8	1.8	1.5	0.9	1.9	32.8	27.4	32.2	22.2
Sporobolus diander Beauv.	Gra	grass	90	83	94	2.2	0.7	**3.0**	2.5	0.8	3.1	40.8	48.8	43.8	10.8
Ageratum conyzoides L.	Comp	herb	90	100	85	2.8	4.4	2.0	3.2	4.4	2.5	35.8	39.2	40.0	19.0
Nephrolepis biserrata (Sw.) Schott	Ole	fern	86	77	91	6.6	2.3	8.9	7.7	2.9	10.6	10.8	19.4	30.6	28.8
Pityrogramma calomelanos (L.) Link	Hem	fern	85	83	86	0.9	0.8	1.0	1.1	0.9	1.3	19.6	15.6	19.0	7.0
Stenochlaena palustris Bedd.	Ble	fern	82	77	85	1.3	1.1	1.4	1.6	1.5	1.7	6.8	5.8	9.4	8.8
Lygodium microphyllum (Cav.) R.Br.	Sch	fern	82	69	89	0.6	0.5	0.7	0.7	0.7	0.8	5.0	14.4	17.0	6.8
Phyllanthus debilis Willd.	Eup	herb	76	89	69	0.7	0.8	0.7	1.0	0.9	1.0	34.4	29.0	32.2	11.8
Ludwigia hyssopifolia (G.Don) Exell	Ona	herb	71	77	68	0.6	0.6	0.6	0.9	0.8	1.0	22.0	9.6	12.2	2.8
Elaeis guineensis Jacq.	Pal	palm	66	71	63	0.4	0.4	0.5	0.7	0.5	0.7	7.8	7.2	8.0	6.0
Christella dentata (Forssk.) Brownsey & Jermy	The	fern	65	100	46	1.4	**3.4**	0.4	2.2	3.4	0.9	7.2	9.2	20.2	17.6
Cyclosorus interruptus (Willd.) H.Ito	The	fern	60	40	71	1.3	0.3	**1.8**	2.2	0.8	2.7	3.4	3.2	10.6	9.4
Pteris tripartita Sw.	Pte	fern	59	60	58	0.4	0.4	0.4	0.6	0.6	0.6	3.6	2.6	3.6	1.2
Ficus sp.	Mor	tree	58	83	45	0.4	0.6	0.4	0.8	0.7	0.8	0.6	0.4	1.0	2.8
Peperomia pellucida H.B.&K.	Pip	herb	55	94	34	0.7	1.0	0.5	1.3	1.1	1.5	32.6	32.2	32.4	9.4
Limnophila rugosa (Roth.) Merrill	Scr	herb	53	83	37	0.4	0.5	0.3	0.7	0.6	0.8	17.0	9.4	12.6	0.2
Pteris vittata L.	Pte	fern	51	40	57	0.4	0.2	0.5	0.8	0.5	1.0	2.8	4.4	4.8	2.4
Sparganophorus villantii Crantz	Comp	herb	49	86	29	2.5	**6.2**	0.5	5.1	7.2	1.7	23.4	30.2	32.6	12.0
Uncaria cf. *glabrata* DC.	Rub	climber	48	31	57	0.6	0.3	0.7	1.2	1.0	1.3	4.2	1.4	2.4	6.0
Diplazium esculentum (Retz.) Sw.	Woo	fern	48	89	26	1.3	**2.7**	0.5	2.6	3.0	1.9	3.0	3.2	10.0	11.8
Hedyotis diffusa Willd.	Rub	herb	48	40	52	0.3	0.2	0.3	0.6	0.5	0.6	11.0	7.6	5.6	0.0
Erigeron sumatrensis Retz.	Comp	herb	47	26	58	0.4	0.1	**0.6**	0.9	0.5	0.9	3.0	6.2	5.6	1.2
Melastoma malabathricum L.	Mel	shrub	47	46	48	0.3	0.2	0.3	0.6	0.5	0.7	1.0	2.4	1.6	2.8
Cyperus kyllingia Endl.	Cpy	sedge	47	83	28	0.5	0.8	0.3	1.0	0.9	1.1	22.8	18.6	17.8	2.0
Borreria setidens (Miq.) Boldingh	Rub	herb	45	71	31	0.5	0.6	0.4	1.1	0.9	1.3	24.8	21.8	15.8	0.6
Lygodium circinatum Sw.	Sch	fern	43	77	25	0.3	0.6	0.2	0.7	0.7	0.6	5.2	7.2	11.0	0.8
Pueraria phaseoloides Benth.	Pap	creeper	42	23	52	14.5	4.9	**19.6**	34.4	21.4	37.5	18.4	7.8	12.8	25.6
Erechtites valerianifolia (Wolf) DC.	Comp	herb	42	51	37	0.3	0.3	0.3	0.7	0.6	0.8	3.4	7.6	5.0	1.4
Nephrolepis tuberosa C.Presl	Ole	fern	41	49	37	0.4	0.8	0.2	1.0	1.6	0.7	1.6	1.4	3.6	2.8
Cleome rutidosperma DC.	Cap	herb	38	31	42	0.3	0.3	0.4	0.9	0.9	0.9	6.4	11.0	10.8	3.6

Species	Family	Growth	Constancy			Degree of coverage			Specific degree of coverage			Frequency			
			a[1]	f[2]	h[3]	a[1]	f[2]	h[3]	a[1]	f[2]	h[3]	hp[4]	cf[5]	cb[6]	ir[7]
Paspalum conjugatum Berg.	Gra	grass	36	34	37	0.9	1.2	0.7	2.4	3.6	1.0	9.0	8.0	8.2	8.0
Lindernia vicosa Merr.	Scr	herb	36	49	29	0.3	0.2	0.3	0.7	0.5	0.9	6.2	6.2	5.4	0.0
Calopogonium muconoides Desv.	Pap	creeper	35	29	38	0.6	0.2	**0.8**	1.7	0.7	2.1	9.8	3.8	3.4	5.8
Dicranopteris linearis J. Underw.	Gle	fern	33	3	**49**	0.4	0.0	**0.6**	1.2	0.5	1.2	0.8	1.2	4.4	2.8
Euphorbia hirta L.	Eup	herb	33	51	23	0.2	0.3	0.2	0.6	0.5	0.8	5.2	2.0	3.4	0.0
Basella alba L.	Bas	creeper	32	9	**45**	0.6	0.9	0.4	1.8	10.8	0.5	6.2	6.6	10.0	4.6
Lindernia crustacea (L.) F.Muell.	Scr	herb	32	43	26	0.2	0.2	0.2	0.7	0.5	0.9	5.8	1.8	3.4	0.4
Fimbristylis miliacea Vahl	Cpy	sedge	32	34	31	0.2	0.2	0.2	0.6	0.5	0.7	10.6	5.6	4.8	0.2
Stachytarpheta indica Vahl	Ver	shrub	32	**71**	11	0.3	**0.8**	0.1	1.0	1.1	0.8	6.0	1.6	2.4	4.6
Imperata cylindrica Beauv.	Gra	grass	31	17	38	1.4	0.1	**2.0**	4.4	0.5	4.8	7.6	5.8	7.2	10.4
Alternanthera sessilis R.Br.	Ama	herb	30	46	22	0.4	**0.7**	0.2	1.2	1.5	0.8	4.6	6.8	5.8	3.4
Phytolacca purpurascens A.Br. & Bouche	Phy	herb	28	29	28	0.2	0.1	0.3	0.9	0.5	1.1	0.8	5.2	4.2	0.6
Pleocnemia irregularis (C.Presl) Holtt.	Dry	fern	28	**66**	8	0.3	**0.7**	0.0	1.0	1.1	0.5	1.8	0.8	3.6	3.0
Fimbristylis dichotoma (L.) Vahl	Cpy	sedge	26	**51**	12	0.2	**0.4**	0.1	0.7	0.7	0.8	8.6	4.4	2.0	0.4
Hedyotis corymbosa Lam.	Rub	herb	26	**54**	11	0.2	**0.5**	0.1	0.9	0.9	0.8	11.8	11.8	10.4	0.2
Selaginella plana Hieron.	Sel	fern	25	**71**	0	0.2	**0.6**	0.0	0.8	0.8	0.0	11.0	9.0	13.8	4.6
Scoparia dulcis L.	Scr	herb	23	29	20	0.1	0.1	0.1	0.5	0.5	0.5	6.8	4.4	3.2	0.6
Sphaerostephanos polycarpus (Bl.) Copel.	The	fern	23	**60**	3	0.4	**1.1**	0.0	1.7	1.8	0.5	2.8	1.2	3.2	3.8
Physalis minima L.	Sol	herb	21	26	18	0.3	0.1	0.4	1.6	0.5	2.4	2.8	1.2	0.8	0.6
Commelina diffusa Brum. f.	Com	creeper	21	40	11	0.7	**1.8**	0.1	3.4	4.5	0.9	11.4	9.0	8.2	8.0
Phyllanthus amarus Schum. & Thonn.	Eup	herb	21	40	11	0.1	**0.2**	0.1	0.5	0.5	0.5	4.4	3.2	3.2	0.2
Borreria latifolia (Aubl.) K. Schum.	Rub	herb	20	3	**29**	0.8	0.0	**1.2**	3.9	0.5	4.1	9.2	4.6	2.0	1.2
Uncaria ferrea DC.	Rub	climber	20	0	**31**	0.1	0.0	**0.2**	0.6	0.0	0.6	0.4	0.8	1.0	0.6
Vernonia cinerea (L.) Less.	Comp	herb	20	3	**29**	0.1	0.0	**0.2**	0.6	0.5	0.6	0.6	1.6	2.4	0.6
Borreria laevicaulis Ridley	Rub	herb	19	29	14	0.2	0.2	0.2	1.0	0.7	1.4	3.0	1.2	2.6	0.4
Cyperus halpan J.Kern	Cpy	sedge	19	**37**	9	0.1	**0.3**	0.0	0.7	0.8	0.5	0.4	1.6	2.6	0.4
Momordica charantia L.	Cuc	creeper	18	0	**28**	0.6	0.0	**1.0**	3.6	0.0	3.7	1.6	2.6	2.4	2.2
Centrosema pubescens Benth.	Pap	creeper	18	20	17	0.3	0.1	0.4	1.5	0.5	2.2	1.4	1.4	1.2	2.0
Securinega virosa Baill.	Eup	herb	18	**37**	8	0.1	**0.2**	0.0	0.6	0.7	0.5	0.0	1.2	0.2	0.6
Uncaria pedicellata Roxb.	Rub	climber	17	0	**26**	0.1	0.0	**0.1**	0.5	0.0	0.5	1.2	0.0	0.8	1.0
Ceratopteris thalictroides (L.) Brongn.	Par	fern	16	**43**	2	0.1	**0.3**	0.0	0.6	0.6	0.5	5.2	0.6	0.8	0.0
Phaseolus calcaratus Roxb.	Pap	creeper	15	9	18	0.8	0.0	1.2	5.3	0.5	6.5	2.2	0.6	0.6	5.0
Blechum finlaysonianum Hook. & Grev.	Ble	fern	15	3	**22**	0.1	0.0	**0.2**	0.9	0.5	0.9	0.0	0.6	1.4	0.0

Species	Family	Growth	Constancy			Degree of coverage			Specific degree of coverage			Frequency			
			a[1]	f[2]	h[3]	a[1]	f[2]	h[3]	a[1]	f[2]	h[3]	hp[4]	cf[5]	cb[6]	ir[7]
Trema orientalis Blume	Ulm	tree	14	0	**22**	0.1	0.0	**0.2**	0.9	0.0	1.0	1.2	1.0	1.6	0.2
Polygonum barbatum L.	Pol	herb	14	**37**	2	0.1	**0.3**	0.0	0.8	0.8	0.5	0.6	0.0	0.4	2.6
Piper aduncum L.	Pip	tree	13	**26**	6	0.1	0.1	0.1	0.8	0.5	1.5	0.0	0.0	0.0	1.0
Flagellaria indica L.	Fla	climber	13	23	8	0.1	**0.2**	0.0	0.7	0.8	0.5	1.2	0.2	0.2	1.0
Scleria bancana Miq.	Cpy	sedge	13	**29**	5	0.1	**0.1**	0.0	0.5	0.5	0.5	0.4	0.0	0.6	0.8
Colocasia esculenta (L.) Schott	Ara	herb	13	**34**	2	0.1	**0.2**	0.0	0.7	0.7	0.5	0.0	0.0	0.2	0.6
Alocasia macrorrhiza Schott	Ara	herb	13	**37**	0	0.1	**0.2**	0.0	0.5	0.5	0.0	0.0	0.2	0.4	0.6
Christella parasitica (L.) H.Lev.	The	fern	12	**26**	5	0.1	**0.3**	0.0	1.0	1.2	0.5	2.8	0.2	1.0	1.6
Echinochloa colona (L.) Link	Gra	grass	12	**31**	2	0.1	**0.2**	0.0	0.5	0.5	0.5	3.4	1.8	0.8	0.0
Hyptis capitata Jacq.	Lab	herb	12	**31**	2	0.1	**0.2**	0.0	0.7	0.7	0.5	0.2	1.4	2.6	1.4
Adiantum latifolium Lam.	Adi	fern	12	**34**	0	0.1	**0.2**	0.0	0.7	0.7	0.0	0.8	1.0	1.4	0.8
Merremia vitifolia Hallier f.	Con	creeper	12	**34**	0	0.2	**0.5**	0.0	1.3	1.3	0.0	2.4	0.6	1.2	4.4
Synedrella nodiflora Gaertn.	Comp	herb	12	**34**	0	0.1	**0.2**	0.0	0.5	0.5	0.0	1.6	1.6	1.0	0.0
Eleusine indica Gaertn.	Gra	grass	11	**26**	3	0.1	**0.1**	0.0	0.5	0.5	0.5	3.0	0.2	0.2	0.0
Lasia spinosa Thw.	Ara	herb	11	**26**	3	0.1	**0.1**	0.0	0.5	0.5	0.5	0.4	0.4	0.8	1.2
Vitis japonica Thunb.	Vit	climber	11	**31**	0	0.3	**0.8**	0.0	2.5	2.5	0.0	2.8	2.0	1.8	3.2
Ficus fistulosa Reinw. ex Blume	Mor	tree	10	**23**	3	0.1	**0.2**	0.0	0.7	0.8	0.5	0.2	0.0	0.0	0.0
Phymatosorus scolopendria Pic. Serm.	Pol	fern	10	**23**	3	0.1	**0.1**	0.0	0.5	0.5	0.5	0.0	0.2	1.0	0.0
Fleurya aestuans Gaudich.	Urt	herb	4	11	0	0.0	0.1	0.0	1.0	1.0	0.0	0.6	0.2	0.4	0.0
Pueraria sp.	Pap	creeper	4	11	0	0.7	1.9	0.0	17.0	17.0	0.0	1.0	0.8	1.0	0.8

* All species with constancy ≥10 throughout all relevés and all species mentioned in the text. [1]all relevés, [2]relevés on fluvisol, [3]relevés on histosol, [4]Frequency of species in frequency plots on the harvesting path, [5]in the front section of the palm circle, [6]in the back section of the circle and [7]in the inter-row. Bold numbers on grey background indicate the soil type, where species occur predominantly or the soil type, where species develop a distinct greater degree of coverage.

Adi=Adiantaceae, Ama=Amaranthaceae, Ara=Araceae, Are=Arecaceae, Asp=Aspidiaceae, Woo=Woodsiaceae, Bas=Basellaceae, Ble=Blechnaceae, Cap=Capparaceae, Com=Commelinaceae, Comp=Compositae, Con=Convolvulaceae, Cuc=Cucurbitaceae, Cyp=Cyperaceae, Eup=Euphorbiaceae, Fla=Flagellariaceae, Gle=Gleicheniaceae, Hem=Hemionitidaceae, Lab=Labiatae, Mel=Melastomataceae, Mor=Moraceae, Ole=Oleandraceae, Ona=Onagraceae, Pap=Leguminosae-Papilionoideae, Par=Parkeriaceae, Phy=Phytolaccaceae, Pip=Piperaceae, Gra=Poaceae, Pol=Polygonaceae, Pte=Pteridaceae, Rub=Rubiaceae, Sch=Schizaeaceae, Scr=Scrophulariaceae, Sel=Selaginellaceae, Sol=Solanaceae, The=Thelypteridaceae, Ulm=Ulmaceae, Urt=Urticaceae, Ver=Verbenaceae, Vit=Vitaceae

In the frequency plots on the harvesting path 15 species were present per relevé in average of both soil types and in the front section of the palm circle 14 species respectively. The largest number of 17 species occurred in the back section of the palm circle, whereas in the inter-row only 11 species were found. In accordance with the lower species abundance on histosol the number of species found in all field zones on this soil type was lower than on fluvisol (Fig. 7).

Using a paired *t*-test, there were significantly less species present in the inter-row than in the other zones on both soil types ($p<0.001$; $n=100$). Further, the number of species in the front section of the palm circle was less than in the back ($p<0.001$; $n=100$). In Fig. 7 it is visible that the variation in species number was larger on the harvesting path and the back section of the circle than in the other areas. This variation in species number was more distinct on fluvisol than on histosol. There is a close correlation of species abundance between the front and back section of the palm circle on fluvisol (0.784**; n=35) and histosol (0.650**; n=65). The correlation of species number between harvesting path and inter-row on fluvisol (0.469**; n=35) and histosol (0.656**; n=65) was less distinct. The correlations of species abundance between the circle sections and both the harvesting path and the inter-row were weak (≤0.37).

Four species were present on the harvesting path and in the front and back of the palm circle, but not in the inter-row: *Euphorbia hirta*, *Ceratopteris thalictroides*, *Lindernia vicosa* and *Hedyotis diffusa*. Plants that were found rarely in the inter-row, but relatively often in the other field zones were usually small soft weeds, such as *Hedyotis corymbosa*, *Limnophila rugosa*, *Borreria setidens* and sedges like *Fimbristylis miliacea* and *F. dichotoma*. Comparing the harvesting path with the inter-row vegetation all the four species that occurred distinctively more frequent in the inter-row were ferns: *Diplazium esculentum, Cyclosorus interruptus, Nephrolepis biserrata* and *Christella dentata.* Species with a large degree of coverage, for instance *Pueraria phaseoloides* and *Mikania micrantha* occurred also more frequently in the inter-row (Table 1). There was no distinct difference in the presence of species between the circle sections and the harvesting path. However, the fern

Ceratopteris thalictroides was more frequent on the harvesting path, whereas *Phytolacca purpurascens* grew almost exclusively in the palm circle. The plant communities in the front and back of the circle were comparatively similar. They differed slightly in the respect that the front section was more similar to the harvesting path and the back section to the inter-row, respectively.

In Table 2 the similarity of species compositions between the harvesting path, inter-row and front and back section of the palm circle of relevés belonging to one sampling unit are compared. The values represent the average similarity of all sampling units. It is evident that the highest degree of similarity is between areas of the same type, e.g. harvesting path and harvesting path. Accordingly the similarity of species composition between the two palm circle sections is relatively great. The largest difference in species composition was found between the inter-row and the harvesting path and the circle sections. Furthermore, the similarity of the inter-row vegetation between relevés belonging to the same sampling unit was also comparatively low.

Table 2: Similarity (Jaccard similarity index) of plant communities between the oil palm field zones and circle sections. The similarity values correspond to the average of the similarities between the respective zones or sections of the relevés belonging to the same sampling unit (each combination n=200).

	Harvesting path	Circle front	Circle back	Inter-row
Harvesting path	44%	34%	34%	31%
Circle front		41%	40%	26%
Circle back			44%	29%
Inter-row				38%

4 Discussion

The species-area curves revealed a natural logarithmic increase of species number with sampled area. At a sampled area of 145 m^2 on fluvisol, a 10% increase in area size yielded 10% more species. Above 1,000 m^2 a further 10% increase of the sampled area resulted only in 1% of additional species (Fig. 1). Assuming that the logarithmic trend would continue if larger areas were sampled, 82 undergrowth species may be expected per hectare on fluvisol and in the case of histosol on one hectare 62 species respectively. A total of 136 species may be expected if the same assumption is applied for the whole plantation area of 5,000 hectares. This underestimates the existing species abundance by 54%. The difference in estimated and observed species number suggests that the species diversity is not only defined by the area size, but also by spatial inconsistencies in the environment of the area. Such patchy species distribution is also common in and contributing to the biodiversity of natural tropical rain forests (Turner, 1996).

The total diversity of 298 species identified in the oil palm plantation is low in comparison with the richness of 820 plant species per hectare in natural forests of Sumatra (MacKinnon et al., 1996). However, most of the forest species are trees and climbers. The ground layer of lowland rain forest experiences deep shade and most of the forest floor is bare (Kiew, 1988). The ground layer of a tropical rain forest plant community in Southeast-Asia (Longman and Jenik, 1987) and the Amazon (Fujisaka et al., 1998) hosts usually only about 50 herbs, shrubs and other small plants. Thus, the total number of species in association with oil palm was lower than in forest, but the plant diversity of the ground layer in oil palm was superior to forest. On one hand, the large proportion of rare species and on the other hand the impact of plantation development and human population pressure on the surrounding forest, suggests a possible decline in undergrowth species abundance in the future. Out of all identified species only 224 were recorded in the relevés. 12 occurred with moderate high to high constancy (in >60% of all relevés), 58% of these species were rare (in ≤20% of all relevés) and 38 species occurred in just one relevé (Fig. 3). Similar to the small number of

consistent species only few species of the undergrowth vegetation contributed considerably to the total ground cover including *Mikania micrantha*, *Pueraria phaseoloides*, *Nephrolepis biserrata*, *Ageratum conyzoides*, *Sparganophorus villanti* and *Sporobolus diander*.

The threat of extinction through local habitat destruction is greatest to rare species (Turner, 1996). Thus, a local adjustment of weed management or drainage may already lead to the loss of plant species diversity. Species diversity in natural forest decreases, either directly by habitat destruction or indirectly due to forest fragmentation (Tilman et al., 1994). Therefore the likelihood of species invading the plantation from the surrounding forests is diminished. Furthermore, the continual heavy shade provided by the oil palm canopy from canopy closure until replanting may reduce species abundance (Wilson and Ludlow, 1990).

In comparison with the 174 species identified in a Nigerian oil palm plantation (Gill and Onyibe, 1998), the species diversity in the current survey is markedly greater. The different nature of the two research areas might contribute to this discrepancy in species diversity. The plantation in Nigeria was 1,500 ha smaller, located about 300 m higher in altitude and precipitation was 1,300 mm less per year. Further, the soil of the Nigerian plantation was derived from loose sandy sediments, whereas this study was conducted on two distinct soil types: histosol and fluvisol. Some species occurred exclusively on one of these soils, thus the diversity of species increases with the number of soils surveyed. Further to the favourable climate and fertile soil the occasional flooding and comparatively poor quality weed management might have contributed to the great species diversity found. Flooding reduces the cover of creepers like leguminous cover crops and *Mikania micrantha* and thus enables the spreading of less competitive species. Additionally the influx of seeds by flooding is assumed to enhance diversity. Compromised weeding quality was not in the least a question of political instability in Indonesia, the Southeast Asian economic crises and the aftermaths of the disastrous forest fires during the 1997/98 El Ninõ Southern Oscillation event.

The environment in oil palm and rubber (*Hevea brasiliensis* Muell.-Arg.) plantations is comparatively similar (Stür and Shelton, 1990) and

undergrowth species diversity alike, if compared with annual crops. Under rubber, in Peninsular-Malaysia, 182 species were identified (Chin, 1985), whereas in *Colocasia esculenta* (L.) Schott in West-Samoa 89 to 98 (Sauerborn, 1985; Kürschner, 1986) and in Javanese rice fields only 26 species (Burhan, 1993) were recorded.

The accompanying floras of oil palm in West-Sumatra and Nigeria and of rubber in Malaysia have ten plants in common: *Ageratum conyzoides*, *Axonopus compressus*, *Eleusine indica*, *Emilia sonchifolia*, *Mimosa pudica*, *Nephrolepis biserrata*, *Pueraria phaseoloides*, *Solanum torvum*, *Synedrella nodiflora* and *Urena lobata*. This group of plants reoccurs in similar habitats (tree plantation in the humid tropics) as undergrowth (distinct structure and physiognomy) and can therefore be classified as an alliance (Mueller-Dombois and Ellenberg, 1974). In the sampled oil palm plantation of West-Sumatra a group of 8 species was found to have high constancy within this alliance. The group encompasses: *Ageratum conyzoides, Lygodium microphyllum, Mikania micrantha*, *Nephrolepis bisserata, Pityrogramma calomelanos*, *Pouzolzia zeylanica*, *Sporobolus diander* and *Stenochlaena palustris*. The identified group cannot be placed into an established vegetation type concept and is therefore an abstract plant community (Mueller-Dombois and Ellenberg, 1974). The presence of *Selaginella plana* solely and with moderately high constancy on fluvisol is a specific response of this abstract community to the soil type. There is also a distinct increase in constancy of *Ceratopteris thalictroides*, *Colocasia esculenta, Pleocnemia irregularis*, *Polygonum barbatum* and *Sphaerostephanos polycarpus* on fluvisol. In contrast no species occurred exclusively and with high or moderate high constancy on histosol. However, the exclusive presence of *Momordica charantia* and *Trema orientalis* and the predominant presence of *Borreria latifolia*, *Dicranopteris linearis* and *Vernonia cinerea* on histosol are likely to be a response of the community on the soil type. Due to the lack of differential species (species that occur always and exclusively in one habitat (Braun-Blanquet, 1928)) the associations formed on the different soil types cannot be considered as communities.

The similarity of species composition in different fields of the plantation is low. One factor contributing to the variation in species composition

was, as demonstrated above, the soil type. Nevertheless, the soil type has only a restricted impact on community formation and consequently other environmental factors are likely to have regulating functions on species composition. As the water table was at a constant level throughout the plantation, it is probable that light transmission through the palm canopy and nutrient availability are key factors. Yet, even within the same field (sampling unit) the average similarity of species composition in the relevés is less than 50%. Two reasons may contribute to the low level of similarity: the large proportion of rare species and the segmentation of the fields in harvesting path, palm circle and inter-row. The zones are managed in a particular way and represent environments that support certain species. This causes a characteristic distribution of some species in the fields and therefore dissimilarity of the species composition between the zones. The species *Sporobolus diander* and *Sparganophorus villantii* for example occurred less frequent in the inter-row than in other field zones. On the other hand, some species as *Nephrolepis biserrata* and *Christella dentata* seemed to be much more competitive in the inter-row than on the harvesting path. Due to the fact that some species are less competitive in one or the other field zones it may be assumed that the field zones are potential borders to the spreading of certain species.

The greatest dissimilarity in species composition within the field was between the inter-row and both harvesting path and palm circle. Assumingly the development of a particular species composition in the inter-row was primarily the result of three circumstances: Weeding intensity in the inter-row was less and herbicides were usually not applied; the soil in the inter-row was not compacted by harvesters and other workers and at the time of harvesting the fruit-bunch supporting frond was cut and placed in the inter-row as mulch. Furthermore, the inter-row vegetation also differed from the other zones as it was composed of less species. Strong competitors such as *Mikania micrantha*, creeping legumes and some ferns appeared to suppress other species. Thus, regular weeding of the strong competitors on the harvesting path and in the palm circle might enhance species abundance. The species composition in the front and back of the palm

circle was relatively similar. Nevertheless, the species composition in the back section resembled more closely the inter-row vegetation than the species composition in the front section of the circle. A difference in weeding and fertilizing practise observed during vegetation sampling seems to be a plausible cause. In contradiction to management guidelines for oil palm plantations, the front of the circle facing the harvesting path had generally a more thorough weeding and was more generously supplied with fertilizer (chapter 3) than the back of the circle. The greater average number of species in the back of the palm circle reflects the difference in weeding quality (Fig. 7).

The large proportion of rare species and the expected decline in species abundance propose that more stable species communities were in the process of formation at the time of research. Further, the specific influence of the soil type on the species composition suggests that other environmental factors might also significantly influence the composition of the undergrowth plant community. A comparison of the obtained results with the comprehensive work from Nigeria gives emphasis to these suggestions. Conducted in a plantation of 1 to 10 year old oil palms Gill and Onyibe (1998) found 174 species on 3,500 hectares. The authors used nine sampling sites that covered the whole area. The similarity in species composition between both studies is notable. Although the two study-sites are situated in different continents the Jaccard index reveals that 10% of all species were common in both sites. Furthermore, it is remarkable that 36% of all species recorded in the current work belong to the same genera as species found in Nigeria. In the African study the number of species of moderately high to high constancy was 28 and the number of rare species 50. The difference of the proportion of constant and rare species in the two studies was apparently a result of the larger relevés in Nigeria. Nevertheless the Nigerian study provides the same result: oil palm plantations with palms under 10 years of age host a small proportion of species with high constancy and a large proportion of rare species. Wilson and Ludlow (1990) state that in the first twelve years after field planting there is a sharp decrease in light transmission through the closing oil palm canopy. In addition, the expanding canopy shades the ground unevenly; the

same oil palm field may be heavily shaded near the palm trunks, whereas direct sunlight infiltrates between the palms (Chen and Bong, 1983). These variations in the light transmission under oil palm have a strong influence on the development of plants (Wong, 1990). Consequently, the deviation of light transmission between and within oil palm fields is likely to be one of the main causes for the large proportion of rare species.

Chapter 2

Course of solar radiation below the palm canopy and impact on the undergrowth species composition

Abstract

Solar radiation intensity below the oil palm canopy and its impact on the undergrowth species composition was studied in a plantation in West-Sumatra. Apart from the planting density the soil type was identified as the single most important factor influencing the course of below canopy solar radiation. The canopies of neighbouring palms started to overlap 2.5 years after field planting on fertile fluvisol, while canopy closure took place only after almost 5 years on histosol. In comparison with palm age and the petiole cross-section area, the crown radius was the most reliable and soil type independent parameter to estimate the below canopy solar radiation.

Distinct dissimilarities in the undergrowth composition were found between sampling sites of different average below canopy solar radiation. Spatial differences of solar radiation within the sampling sites did not enhance the dissimilarity of the undergrowth species composition between the harvesting path, the palm circle and the inter-row. The number of monocotyledonae decreased and the number of pteridophyta increased with reduced solar radiation levels. Dicotyledonae as a group had no dominant preference towards shading or intense solar radiation; thus most dicotyledonae were found in sampling sites that provided both bright and dark niches. The number of melliferous species, which are frequently species important as hosts for pest antagonists, decreased with less available light.

Species consistently more frequent in brighter sampling sites throughout the research area were: *Basella alba* L., *Calopogonium muconoides* Desv., *Commelina diffusa* Brum. f., *Imperata cylindrica* Beauv., *Pueraria phaseoloides* Benth. *and Sporobolus diander* Beauv., whereas *Ageratum conyzoides* L., *Christella dentata* (Forssk.) Brownsey & Jermy,

Diplazium esculentum (Retz.) Sw., *Peperomia pellucida* H.B.&K., *Phyllanthus debilis* Willd., *Pouzolzia zeylanica* Benn. and *Sparganophorus villantii* Crantz preferred darker environments. The changes in the species composition with decreasing levels of solar radiation were not the same throughout the field. In the palm circle and on the harvesting path annual dicotyledonae, sedges and *Selaginella plana* Hieron. occurred more frequently with increased shading, whereas a distinct shift from a creeper and grass to a fern and dicotyledonae dominated undergrowth was observed with falling levels of solar radiation in the inter-row.

1 Introduction

The planting density in oil palm plantations aims to maximise oil yield per hectare and usually little consideration is paid to density related effects on the environment and the sustainability of the production system. At too high planting densities not only the yield decreases (Jalaludin, 1997) but also the sunlight penetrating the canopy is reduced to levels at that just sparse undergrowth can maintain. Bare soil in tree plantations suffers increased rates of wash-off and erosion that lead to severe topsoil and nutrient losses (Ross, 1999; Beaufoy, 2000). Furthermore, most melliferous species in the undergrowth vegetation disappear at low availability of solar radiation and natural pest antagonist populations dependent on these host species are lost (Mexzón and Chinchilla, 1999). Research focusing on the undergrowth in oil palm plantations concentrates primarily on a limited number of plants considered as harmful weeds (Chee and Chung, 1998), fodder species (Chen and Bong, 1983; Dahlan et al., 1993; Jalaludin, 1997) and plants that act as hosts for the beneficial fauna (Mexzón and Chinchilla, 1999; Wahid et al., 1999). Phytosociological studies of oil palm plantation undergrowth in Nigeria (Gill and Onyibe, 1998) and in Indonesia (chapter 1) revealed a diverse segetal flora of 174 and 298 species respectively. In both studies most species occurred infrequently, but several showed a distinctive pattern of distribution within the plantation area. From the results of the Nigerian investigation the authors concluded that the reduced penetration of solar radiation through the aging oil palm canopy

is the chief factor determining the type and distribution of plants. The relationship between palm age and light transmission through the palm canopy depends however strongly on the local environment (Wilson and Ludlow, 1990; Gerritsma and Soebagyo, 1999).

The comparability of results from phytosociological investigations of the oil palm undergrowth is hampered if no information about the below canopy light regime is provided. Measurements of the scattered solar radiation below the palm canopy require either specific instruments or a great number of repetitions. Therefore, the availability of a morphological parameter of the oil palm, that describes the below canopy solar radiation more reliable than the palm age and independent of climate and soil would be a great advantage. Oil palm fields consist of three zones managed in a particular way: harvesting path, palm circle and inter-row. These zones host similar species compositions, however some of the species occur predominantly in one or the other zone (chapter 1). Consequently, changes in the solar radiation below the palm canopy are apt to induce specific shifts in the species composition in each zone.

The objectives of the present study were: (i) to analyse the influence of two different soil types, fluvisol and histosol, on the closure of the palm canopy and the solar radiation below the canopy, (ii) to investigate the relationship between oil palm age, petiole cross-section area, crown radius and the solar radiation below the oil palm canopy (iii) to examine the impact of different levels of solar radiation on the species composition in the fields and their zones.

2 Material and Methods

2.1 Study area

The research area was described in detail in chapter 1. The inventory was based on the vegetation sampling in 20 sampling units that contained 5 sampling sites measuring each 300m^2. The two sampling sites that hosted the most similar undergrowth species composition in comparison with the remaining sites (Jaccard similarity index) were selected to investigate the impact of solar radiation on the undergrowth

species composition. Of the 40 sampling sites selected 14 were located on fluvisol and 26 on histosol. The palm age was in one unit (two sampling sites) each 2 and 3, in two units 5 and in three units 6 years on fluvisol. On histosol the palm age was in four units 1, in one unit 3, in four units 4, in two units 5 and in one unit each 6 and 7 years. The oil palm age was recorded in accordance to plantation practise in years after planting (YAP) of the seedlings in the field.

2.2 Measurements of vegetative oil palm parameters

The trunk height was measured from the soil surface to the base of the lowest frond. To express the degree of palms leaning or kneeling, the inclination of a direct line drawn from the planting point to the crown centre was calculated as the relation of the trunk height to the crown displacement. The displacement of the crown centre of leaning palms was measured as the horizontal distance from the estimated original planting point to the actual crown centre. The crown radius was measured horizontally from the crown centre to the crown circumference. For assessment of the petiole cross-section the height and width of the petiole was measured with a calliper and the cross-section area calculated by assuming a triangular petiole shape (Corley and Breure, 1981).

2.3 Measurements of solar radiation

To improve the comparability between solar radiation measurements taken in different sampling sites the daily course of radiation intensity was assessed in advance under open sky. On 39 randomly chosen days in 1998 half hourly from 6.30 am to 6.30 pm the irradiation was measured. Corresponding to the solar radiation curve obtained (Fig. 8), the radiation maintains at a high level of about 0.9 kW m^{-2} from 10.30 am to 2.00 pm. During this time the inter-day variation of the radiation was also highest. To reduce the influence of this variation, measurements were conducted exclusively in cloudless moments at noon from 12.00 am to 1.30 pm, when the radiation was usually above 1.0 kW m^{-2}.

Light measurements were carried out in the palm circle, the harvesting path and inter-row, depending on the height of the undergrowth in 20 to

50 cm above ground. A total of 180 solar radiation measurement points, 60 per field zone, were distributed systematically in each sampling site (Fig. 9). To enable the comparison of data obtained on different days of measurement solar radiation intensity reference values were taken under open sky throughout measurements.

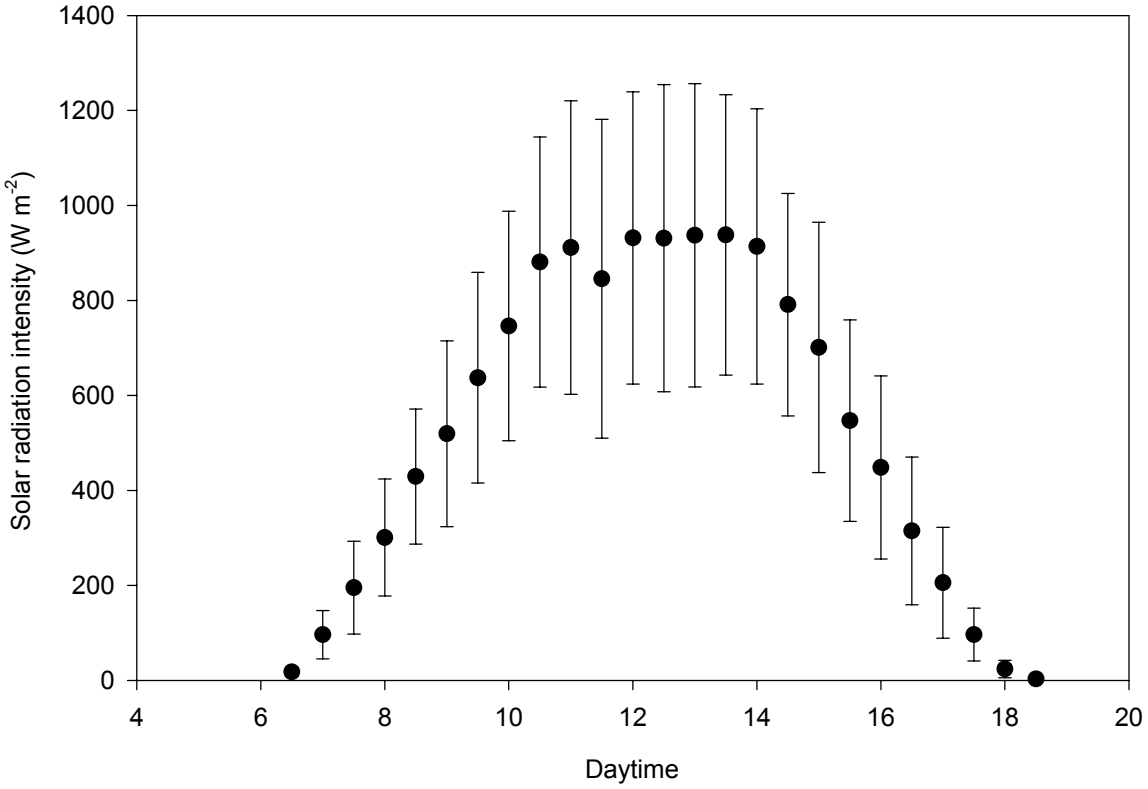


Fig. 8: Solar radiation in Tanjung Pangkal, Pariaman, West Sumatra (measurements taken half hourly on 39 randomly chosen days, dots = average, error bars = range)

An average was calculated for the 60 data obtained in each section and consequently converted into percent of the reference values. To express the solar radiation that penetrates the oil palm canopy and reaches the ground of a sampling site, the below canopy solar radiation (BCSR) was calculated:

$$BCSR = \frac{hp\ 40m^2 + c\ 80m^2 + ir\ 180m^2}{300\ m^2}$$

where *hp* = average solar radiation on the harvesting path in percent of the incident radiation, *c* = average solar radiation in the palm circle and *ir* = average solar radiation in the inter-row respectively. The area figures are in accordance to the proportion each field zone covers in the sampling site.

The photometer available for this work ('Malvolux digital', Gossen GmbH, Germany) was sensitive unselectively to the whole range of visible solar radiation. Green leaves absorb however photosynthetically active radiation (PAR) in the wavelength range from 400 to 700 nm at a higher rate than the remaining solar wavelength spectrum (Ross and Sulev, 2000). The selective wavelength absorption results in a reduced PAR proportion in the radiation below a plant canopy. Thus the PAR below the oil palm canopy is expected to be lower than the obtained solar radiation readings.

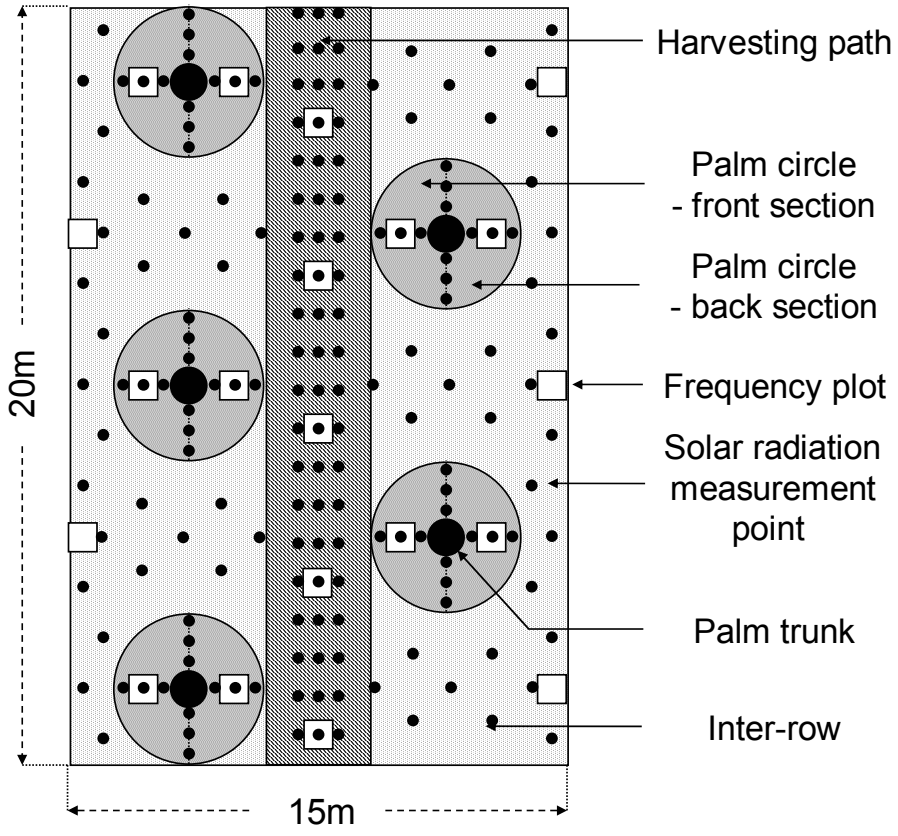


Fig. 9: Relevé layout for assessment of the undergrowth species composition in oil palm fields with frequency plots and solar radiation measurement points.

2.4 Vegetation sampling

The species present were identified in the frame of the phytosociological study described in chapter 1. For the investigation of the vegetation composition in the zones twenty frequency plots were arranged systematically within each sampling site, five on the harvesting path, five in the inter-row and ten in the palm circles. The palm circles were divided into two sections to examine differences in the species composition within the circles. In every palm circle one frequency plot was placed in the front section towards the harvesting path and one in the back section towards the inter-row. All species present in each frequency plot were listed.

2.5 Data interpretation

To express the similarity of plant compositions, the Jaccard index was applied. This index is based on the presence-absence relationship between the number of species common to two areas and the total number of species (Mueller-Dombois and Ellenberg, 1974). Therefore, the coefficient expresses the ratio of the common species to all species found in two areas. To determine which species grew predominantly in an area of a given light regime, all species that occurred in at least 10% of the frequency plots in the brighter or darker areas were considered. Species were regarded as occurring distinctly more frequent in one area if they were in this area at least 2 times more frequent than on the other. The Pearson correlation coefficient was employed to evaluate correlations between soil carbon content and the degree of palms leaning. The *t*-test and correlation analyses were preformed using SPSS 10.0 and curve fitting with TableCurve 2D 5.0.

3 Results

3.1 Below canopy solar radiation in relation to oil palm age, petiole cross section and crown radius

The amount of light penetrating through a tree canopy is determined by the incident solar radiation as well as by the optical and architectural properties of the stand (Ross, 1981). Factors determining the

architecture of an oil palm canopy are apart from the solar radiation the palm age, cultivar, planting density, soil type and precipitation (Gerritsma and Soebagyo, 1999). The planting density in the sampling sites was consistent at 135 palms per hectare and solar radiation and precipitation were assumed uniform within the plantation area. The specific oil palm cultivar planted to each field was not known and any cultivar related impact on the BCSR was neglected. The influence of the cultivar on the canopy architecture is comparatively low (Gerritsma and Soebagyo, 1999) and therefore no significant distortion of the solar radiation-undergrowth relationship was expected. Thus, the palm age and the soil type were the major parameters shaping the course of the BCSR in the research area.

Gerritsma and Soebagyo (1999) defined canopy closure as the moment when the canopies of neighbouring palms start to overlap. At the given planting density of 135 palms per hectare in a triangular planting pattern the distance between the palms is 8.6 m and canopy closure takes consequently place at a crown radius of 4.3 m. The regression curves of the crown radius show that canopy closure and the maximal canopy expansion occurred in average about two years later on histosol than on fluvisol (Fig. 10). The amount of sunlight penetrating the canopy was almost continuously reduced after field planting and reached equilibrium between the 4th and 5th YAP on fluvisol. The crown radius and the solar radiation curves for palm under 2 years of age were fitted without reference data. From the authors' experience it is understood, that curve fitting underestimated crown radius and below canopy solar radiation during the initial time after field planting. On histosol solar radiation below the canopy was almost constant within the first three YAP, following the radiation diminished until the 6th YAP. On both soil types no further reduction of the solar radiation below canopy took place and the solar radiation levels continued on histosol double as high as on fluvisol after the 6th YAP. The low coefficients of determination (Fig. 10) reflect the considerable variations of canopy expansion and consequently canopy closure as well as maximum canopy expansion between the different sampling sites.

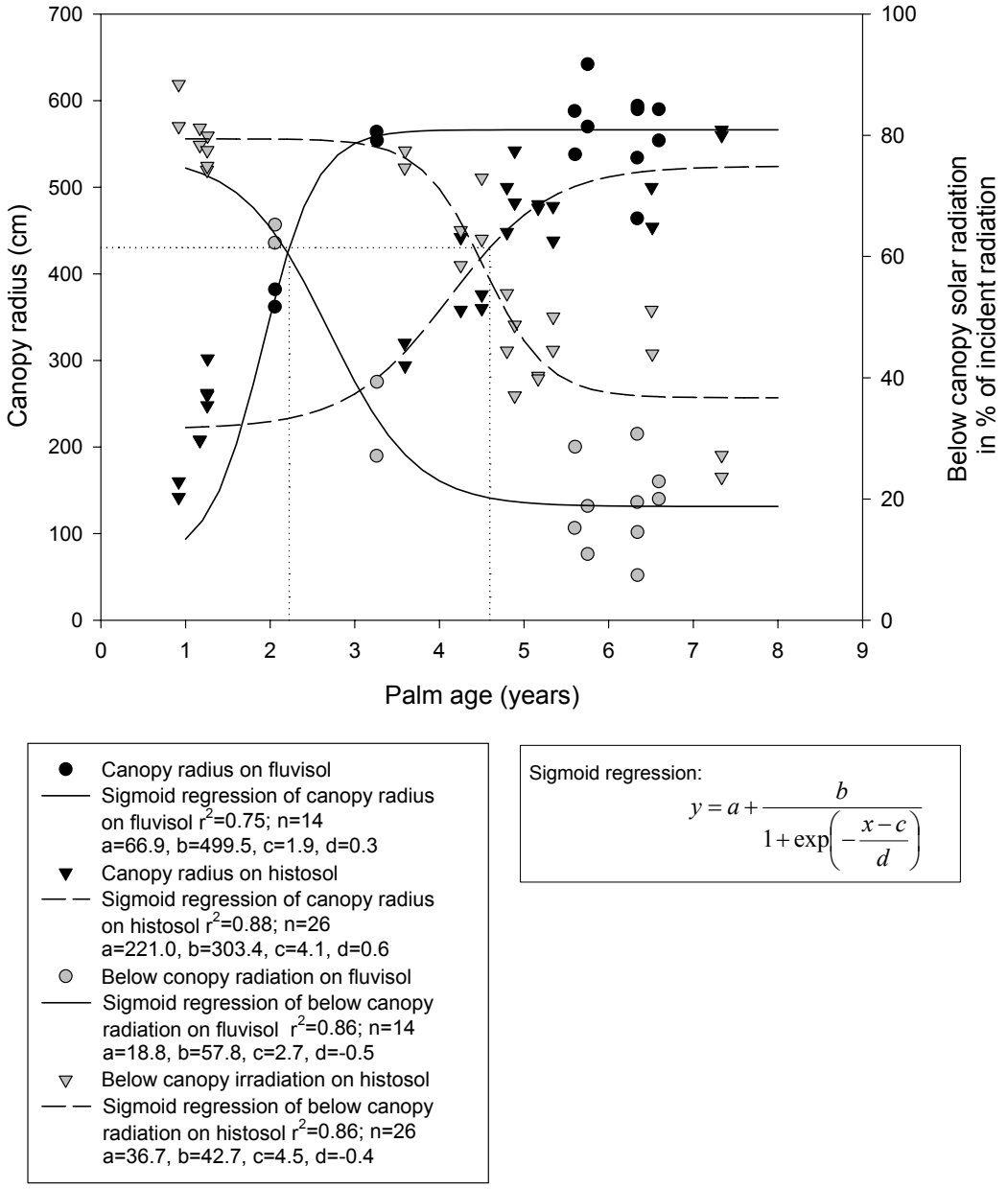


Fig. 10: Relationship between oil palm age and below canopy solar radiation on fluvisol and histosol. The dotted lines indicate the palm age at canopy closure.

Oil palms often lean or kneel where root anchorage is poor, which causes gaps in the canopy. A significant correlation was found between the degree of palms leaning and the soil carbon content (n=25; 0.85**). This suggests that the looser soil structure of histosol was a primary reason for the different BCSR between the soil types. However, the greater number and stronger inclination of palms leaning on histosol

appear to influence the penetration of sunlight only insignificantly at the palm age considered and could not explain the difference of the BCSR. In contrast to the palm age the petiole cross section and the crown radius were related robustly and independently of the soil type to the BCSR. The petiole cross-section is highly correlated to the oil palm mean leaf dry weight (Corley and Breure, 1981). The relationship between leaf dry weight and leaf area is strongly influenced by environmental parameters such as the water availability (Umana and Chinchilla, 1991). Consequently, the petiole cross-section area could predict the BCSR using a Sigmoid regression with a high coefficient of determination (r^2=0.89). Nonetheless, the crown radius was easier to assess particularly on older palms and was the most adequate parameter to gauge the BCSR (Fig. 11).

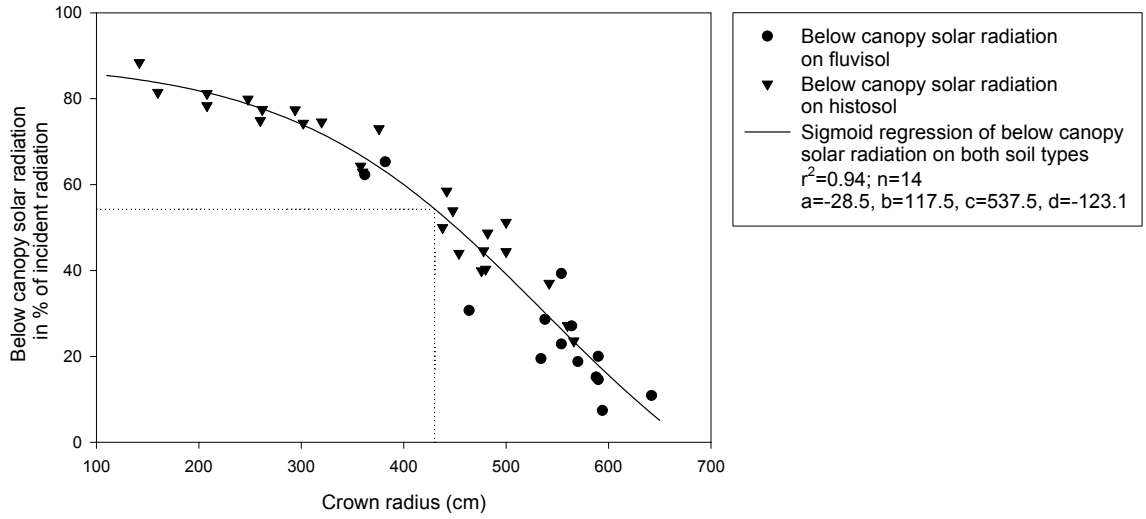


Fig. 11: Reduction of field average below canopy solar radiation with expansion of the crown radius. The dotted lines point out the radiation at the time of canopy closure.

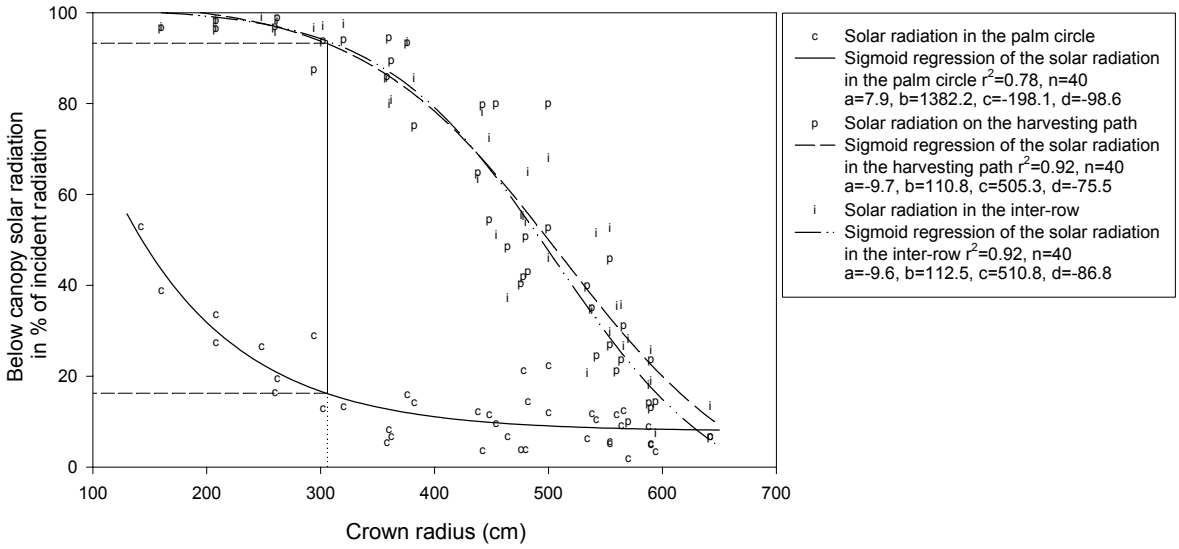


Fig. 12: Reduction of the below canopy solar radiation in the palm circle, harvesting path and inter-row with expansion of the crown radius. The straight line indicates the crown radius when the difference between solar radiation in the circle and other zones is greatest.

The reduction of the BCSR in the palm circle commences decisively earlier than in the other zones (Fig. 12). In the inter-row and the harvesting path the solar radiation maintains unaffected until the crown radius surpasses 250 cm, at the same time the radiation in the circle is already reduced to one fifth of the incident radiation. The difference of the radiation is greatest, when the canopy reached a radius of 305 cm (Fig. 12). At this crown radius the solar radiation in the harvesting path is 93% and in the inter-row 94%, while in the palm circle only 16% of the incident solar radiation. From a radius of about 650 cm onwards the radiation is reduced throughout all sections to an equally low level of below 10% of direct sunlight.

3.2 Species composition

The oil palm undergrowth hosted in the 40 sampling sites analysed 190 vascular plant species. Of these, 161 species comprising of 97 dicotyledonae, 36 monocotyledonae including 12 grasses and 13 sedges and 28 pteridophyta embracing 26 ferns (pteridosida) and 2 fern allies (lycopsida) were recorded in the 800 frequency plots distributed in the sampling sites. In total of all sampling sites 115 species were recorded in the frequency plots on the harvesting path, 112 species in the front of the palm circle towards the harvesting path, 115 species in the back of the palm circle towards the inter-row and 99 species in the inter-row. The similarity between the species composition in the zones was generally low. Although, the difference between the solar radiation in the palm circle and the two other zones diminished with the reduction of the average BCSR (Fig. 12), no significant increase in the composition similarity was identified with decreasing BCSR on both soil types. Most of the species recorded in the plots were rare, 78 occurred in over 1% and just 35 in over 5% of the sampled plots. A distinct difference between composition and total species number was found in the oil palm undergrowth on different soil types (chapter 1). Therefore and due to difference of the solar radiation under the palms on fluvisol and histosol (Fig. 10) the effect of reduced BCSR on the distribution of species was analysed in the following for each soil type separately. The undergrowth composition was examined in sampling sites characterised by BCSR levels below and above 20% of the incident solar radiation on fluvisol. On histosol the vegetation was compared between sites with BCSR below and above 60% respectively.

3.3 Species distribution as influenced by below canopy solar radiation

In fields with high BCSR 102 undergrowth species were recorded while in heavier shaded fields only 90 species were observed on fluvisol. The difference between the average number of species per sampling site was accordingly: 38 species in the brighter and 35 species in the darker fields. The proportion of species abundance in the brighter and darker sampling sites was adverse on histosol. Here less species were

recorded under the open canopy, in total 71 and in average 22 species, whereas at low BCSR 89 in total and in average 27 species occurred. On both soil types dicotyledonae contributed about 60% of the undergrowth species. The number of species contributed by each class to the undergrowth varied greatly between the sampling sites (Fig. 13).

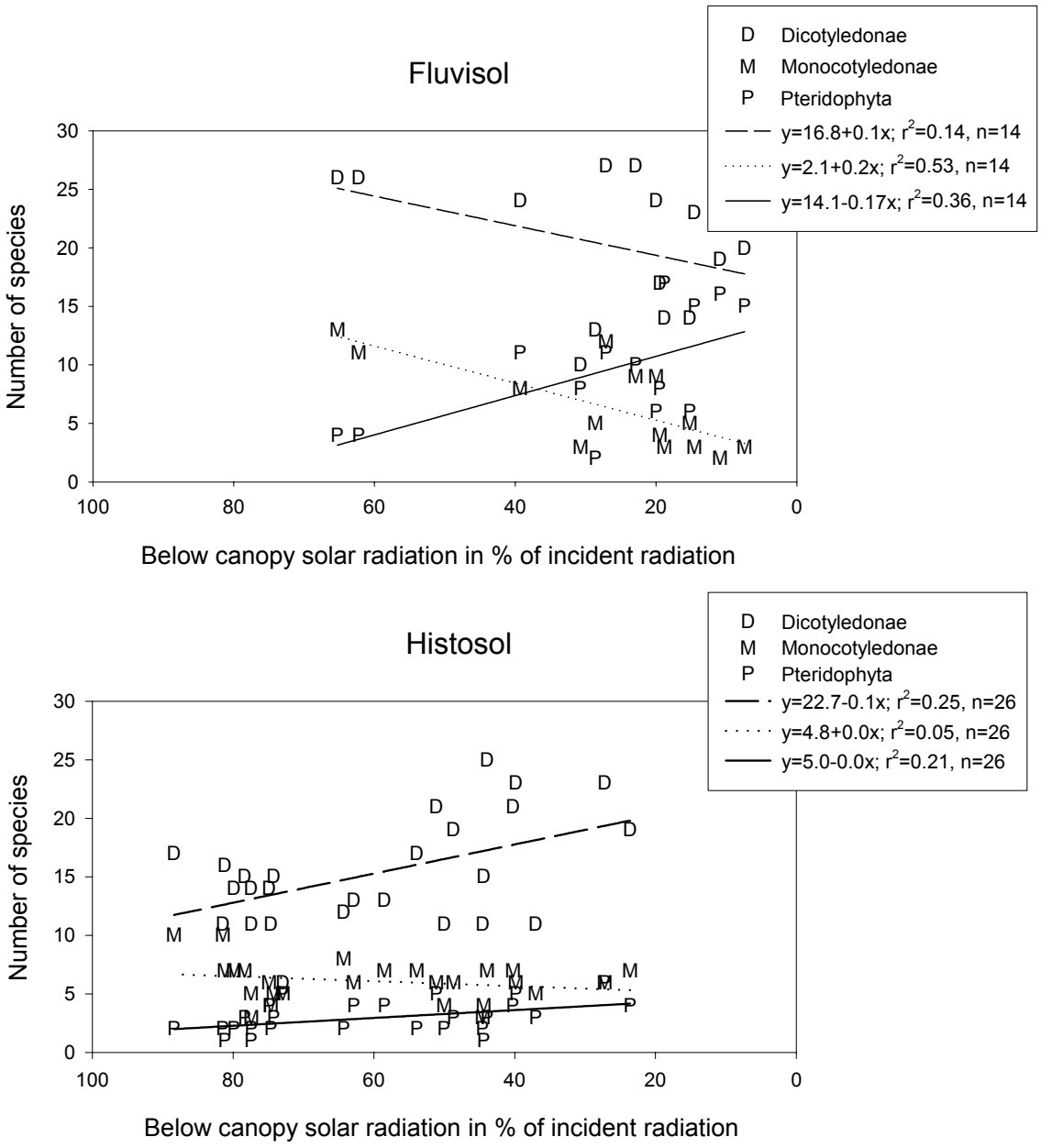


Fig. 13: Shift between the classes of dicotyledonae, monocotyledonae and the subdivision of pteridophyta in undergrowth with decreasing levels of solar radiation under the oil palm canopy.

The linear regressions in Fig. 13 demonstrate a tendency of a decreasing number of pteridophyta and an increasing number of monocotyledonae with augmenting BCSR, while the coefficient of determination was for both regressions very low. The number of dicotyledonae was reduced on fluvisol but enhanced on histosol with intensified shade.

In oil palm fields on fluvisol where the solar radiation below the palm canopy was higher than 20% of the incident radiation 14 species occurred distinctly more frequent than in heavier shaded fields. These included 4 broadleaf species: *Hedyotis diffusa*, *Ludwigia hyssopifolia*, *Pueraria phaseoloides* and *Scoparia dulcis*, two grasses: *Paspalum conjugatum* and *Sporobolus diander,* one sedge: *Fimbristylis miliacea* and one Commelinaceae: *Commelina diffusa* (all scientific names with authority in Table 3). A total of 7 species occurred predominantly under palms with a denser canopy where 20% or less of the incident solar radiation reached the ground. Remarkably, all of these were ferns and allies: *Christella dentata*, *Diplazium esculentum*, *Lygodium circinatum*, *Pityrogramma calomelanos*, *Pleocnemia irregularis*, *Selaginella plana* and *Stenochlaena palustris*. There were 5 species distinctly more frequent in the sampling sites marked by high BCSR values on histosol. Three of these were dicotyledonae: *Basella alba*, *Calopogonium muconoides* and *Erigeron sumatrensis*, the other two monocotyledonae: a grass *Imperata cylindrica* and a Commelinaceae: *Commelina diffusa*. Most of the species distinctly more frequent in the histosol sites that received less than 60% of the incident radiation were small broadleaf species: *Ageratum conyzoides*, *Borreria setidens*, *Ludwigia hyssopifolia*, *Peperomia pellucida*, *Phyllanthus debilis*, *Pouzolzia zeylanica* and *Sparganophorus villantii*. Species that were more frequent in sites on both soil types where the BCSR was high included: *Calopogonium muconoides*, *Commelina diffusa*, *Imperata cylindrica*, *Paspalum conjugatum*, *Pueraria phaseoloides* and *Scoparia dulcis*. While *Ageratum conyzoides*, *Christella dentata*, *Diplazium esculentum*, *Peperomia pellucida*, *Phyllanthus debilis*, *Pouzolzia zeylanica* and *Sparganophorus villantii* were more common in the sampling sites on both soil types where the radiation was low. 10 species showed an

opposite distribution at high and low light levels on the two soil types. More frequent in at least one zone of the bright sampling sites on fluvisol, but more often in darker zones on histosol respectively were: *Hedyotis diffusa*, *Ludwigia hyssopifolia*, *Fimbristylis miliacea*, *Elaeis guineensis*, *Lindernia crustacea*, *Borreria setidens* and *Limnophila rugosa*. *Stenochlaena palustris*, *Erechthites valerianifolia*, *Nephrolepis biserrata* and *Pityrogramma calomelanos* were more common in at least one zone of the dark fluvisol sites and of the brighter histosol sites respectively.

The undergrowth species composition responded not in the same way onto different levels of solar radiation in the field zones, while no significant difference in the front and back section of the palm circle was found. The number of species influenced by the radiation was greatest on the harvesting path and lowest in the inter-row on both soil types. Species that reacted throughout all field zones in their distribution distinctly to different solar radiation levels were only a few. *Commelina diffusa* and *Paspalum conjugatum* were more frequent in every zone of the brighter frequency plots on fluvisol and *Imperata cylindrica* on histosol respectively. Correspondingly *Pityrogramma calomelanos* was more common in the darker fluvisol zones and *Pouzolzia zeylanica* as well as *Phyllanthus debilis* in the darker histosol zones. The response of the species composition to different levels of radiation was more similar in the harvesting path, front of the palm circle and back of the palm circle, than in any of these zones in comparison with the inter-row. Distinctly more frequent in the harvesting path and circle zones, but not in the inter-row of were: *Fimbristylis miliacea* and *Hedyotis diffusa* in the brighter and *Selaginella plana* in the darker fluvisol sites. Accordingly *Commelina diffusa* was more common in the less shaded and *Peperomia pellucida*, *Sparganophorus villantii* and *Lindernia vicosa* in all zones but the inter-row in the heavier shaded sites on histosol. Species identified more frequent in the inter-row of sampling sites marked by higher BCSR levels on fluvisol were: *Pueraria phaseoloides*, *Commelina diffusa*, *Paspalum conjugatum*, *Polygonum barbatum* and *Merremia tridentata*. 7 species were distinctly more frequent in the inter-row of the

Table 3: Response of oil palm undergrowth species on different intensities of solar radiation

Species[1]	Frequency on soil type			Frequency in the field zones on fluvisol										Frequency in the field zones on histosol									
				all[5]		hp[6]		cf[7]		cb[8]		ir[9]		all[5]		hp[6]		cf[7]		cb[8]		ir[9]	
	b[2]	f[3]	h[4]	d[10]	b[11]	d	b	d	b	d	b	d	b	d[2]	b[13]	d	b	d	b	d	b	d	b
Mikania micrantha H.B.&K.	50	50	50	46	55	49	49	29	37	34	57	71	77	43	56	43	65	28	49	43	54	60	57
Sporobolus diander Beauv.	37	29	42	19	**39**	29	31	29	**63**	20	**63**	0	0	31	52	48	35	43	65	29	**72**	5	**35**
Ageratum conyzoides L.	35	51	26	53	50	77	51	57	71	54	60	23	17	**38**	14	**29**	8	40	20	**49**	22	**34**	8
Pouzolzia zeylanica Benn.	29	30	29	34	26	46	43	17	23	31	26	**40**	11	**44**	13	**38**	12	**38**	12	**62**	17	**37**	12
Peperomia pellucida (L.) H.B.&K.	27	56	11	63	49	83	51	63	66	69	71	**37**	9	**20**	2	**29**	0	**25**	3	**25**	6	2	0
Phyllanthus debilis Willd.	26	36	21	37	34	57	46	29	43	46	37	17	11	**35**	6	**48**	3	**31**	6	**42**	12	**20**	3
Sparganophorus villantii Crantz	25	54	10	61	46	57	51	77	57	69	57	40	20	**20**	0	**20**	0	**25**	0	**31**	0	5	0
Nephrolepis biserrata (Sw.) Schott	23	15	28	20	10	9	6	**11**	0	34	20	26	14	24	31	8	**23**	17	**38**	31	37	40	26
Pueraria phaseoloides Benth.	16	10	19	0	**20**	0	**23**	0	6	0	**23**	0	**29**	14	25	11	**32**	3	**15**	11	15	31	37
Cyperus kyllingia Endl.	16	39	3	43	35	60	40	49	46	57	49	6	6	7	0	**11**	0	9	0	6	0	0	0
Borreria setidens (Miq.) Boldingh	16	31	7	24	39	46	51	37	57	14	**46**	0	0	**13**	1	**28**	3	**12**	0	**14**	0	0	0
Pityrogramma calomelanos (L.) Link	15	13	16	**22**	3	**34**	6	**23**	3	**20**	3	**11**	0	15	17	15	20	15	15	25	22	6	9
Christella dentata (Forssk.) Brownsey & Jermy	14	30	6	**41**	20	**26**	0	**29**	9	54	40	54	31	8	3	3	2	6	2	11	9	**11**	2
Ludwigia hyssopifolia (G.Don) Exell	13	18	11	11	**24**	29	34	6	**29**	6	**34**	3	0	**18**	3	**32**	5	**14**	2	**18**	5	9	2
Lygodium microphyllum (Cav.) R.Br.	13	6	17	8	4	3	0	11	9	11	6	6	0	16	17	11	8	14	20	23	29	15	12
Cleome rutidosperma DC.	11	5	13	3	8	6	**14**	3	**11**	3	6	0	0	13	14	6	9	15	18	22	17	8	12
Commelina diffusa Brum. f.	10	18	6	0	**36**	0	**51**	0	**31**	0	**26**	0	**34**	1	**11**	0	**11**	5	**12**	0	**14**	0	8
Limnophila rugosa Merrill	10	20	4	18	23	40	37	17	20	14	**34**	0	0	7	2	**11**	0	9	0	6	6	0	0
Selaginella plana Hieron.	10	27	0	**39**	15	**54**	14	**31**	9	**51**	23	20	14	0	0	0	0	0	0	0	0	0	0
Hedyotis corymbosa Lam.	9	23	1	16	30	26	37	20	**46**	20	37	0	0	2	1	3	3	3	0	2	0	0	0
Stenochlaena palustris Bedd.	9	8	10	**11**	5	**17**	3	0	3	9	6	17	9	8	12	6	**14**	6	8	11	20	8	5
Paspalum conjugatum Berg.	8	11	6	0	**23**	0	**26**	0	**17**	0	**29**	0	**20**	4	8	5	8	5	6	3	8	3	11
Imperata cylindrica Beauv.	8	2	11	1	4	0	3	0	0	3	3	0	9	1	**21**	0	**25**	0	**15**	0	**17**	3	**28**
Diplazium esculentum (Retz.) Sw.	8	18	2	**26**	10	**23**	0	9	3	31	23	**43**	14	3	1	0	0	0	2	5	2	8	0
Lygodium circinatum Sw.	7	18	1	**24**	11	**26**	3	34	17	34	23	3	3	1	1	0	0	2	2	3	3	0	0
Elaeis guineensis Jacq.	7	9	5	6	11	3	**23**	3	9	14	11	3	3	9	2	5	5	**17**	2	9	2	5	0
Calopogonium muconoides Desv.	6	2	8	1	2	3	6	0	3	3	0	0	0	2	**14**	5	**22**	0	9	0	9	3	**17**
Cyclosorus interruptus (Willd.) H.Ito	6	1	8	1	1	0	0	0	0	0	6	6	0	10	7	**11**	2	2	6	9	14	**18**	5
Hedyotis diffusa Willd.	6	9	4	1	**18**	0	**29**	3	**26**	0	**17**	0	0	6	2	**18**	0	0	5	5	2	0	0
Basella alba L.	6	2	8	0	4	0	6	0	0	0	6	0	3	2	**13**	0	**15**	6	9	2	**22**	2	6
Erechthites valerianifolia (Wolf) DC.	6	4	6	5	4	**11**	0	9	11	0	3	0	0	4	8	2	2	12	14	2	**14**	2	5
Alternanthera sessilis R.Br.	5	7	5	9	4	**14**	3	11	6	3	0	9	9	9	0	3	0	**15**	0	**12**	2	5	0

Species[1]	Frequency on soil type			Frequency in the field zones on fluvisol										Frequency in the field zones on histosol									
				all[5]		hp[6]		cf[7]		cb[8]		ir[9]		all[5]		hp[6]		cf[7]		cb[8]		ir[9]	
	b[2]	f[3]	h[4]	d[10]	b[11]	d	b	d	b	d	b	d	b	d[2]	b[13]	d	b	d	b	d	b	d	b
Fimbristylis miliacea Vahl	5	11	2	0	**21**	0	**29**	0	**29**	0	**29**	0	0	5	0	**14**	0	3	0	2	0	0	0
Erigeron sumatrensis Retz.	5	1	8	1	0	3	0	0	0	3	0	0	0	5	**10**	3	9	8	14	8	11	2	8
Lindernia vicosa Merrill	5	5	5	6	4	3	0	9	6	11	11	0	0	10	0	**14**	0	**14**	0	**11**	0	0	0
Stachytarpheta indica Vahl	4	11	0	9	14	11	**26**	6	3	6	11	14	14	0	0	0	0	0	0	0	0	2	0
Fimbristylis dichotoma (L.) Vahl	4	9	0	8	11	20	26	3	9	9	9	0	0	1	0	3	0	0	0	0	0	0	0
Vitis japonica Thunb.	4	10	0	12	8	**20**	6	9	6	6	9	14	11	0	0	0	0	0	0	0	0	0	0
Lindernia crustacea (L.) F.Muell.	4	4	3	1	7	6	3	0	6	0	**17**	0	3	6	0	**17**	2	3	0	3	0	0	0
Scoparia dulcis L.	3	7	1	0	**14**	0	**29**	0	**17**	0	9	0	0	1	2	3	2	0	2	0	0	2	3
Phyllanthus amarus Schum. & Thonn.	3	7	1	8	6	**20**	9	6	6	6	11	0	0	2	1	2	0	2	2	3	2	0	0
Borreria latifolia (Aubl.) K. Schum.	3	0	5	0	0	0	0	0	0	0	0	0	0	9	1	**17**	3	**14**	0	6	0	0	0
Pleocnemia irregularis (C.Presl) Holtt.	3	8	0	**15**	1	**17**	0	6	0	**23**	0	**14**	3	0	0	0	0	0	0	2	0	0	0
Pteris vittata L.	3	1	4	1	1	0	0	0	0	0	0	3	3	0	8	0	5	0	**11**	2	**12**	0	3
Euphorbia hirta L.	3	5	1	1	9	3	**20**	0	6	0	**11**	0	0	3	0	5	0	3	0	3	0	0	0
Nephrolepis tuberosa C.Presl	3	4	2	6	1	3	0	3	0	**11**	3	9	3	2	2	0	3	0	0	5	3	3	0
Sphaerostephanos polycarpus (Bl.) Copel.	2	6	0	9	3	6	3	0	3	3	6	**26**	0	0	0	0	0	0	0	0	0	0	0
Christella parasitica (L.) H.Lev.	2	5	0	7	2	**17**	6	3	0	3	3	6	0	0	0	0	0	0	0	0	2	0	0
Pueraria sp.	2	5	0	1	9	0	**11**	0	9	3	9	3	6	0	0	0	0	0	0	0	0	0	0
Echinochloa colona (L.) Link	1	4	0	1	7	3	**17**	0	6	0	6	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbia heterophylla L.	1	4	0	3	5	6	11	0	3	6	6	0	0	0	0	0	0	0	0	0	0	0	0
Merremia vitifolia Hallier f.	1	4	0	4	4	0	3	0	0	3	0	11	11	0	0	0	0	0	0	0	0	0	0
Ceratopteris thalictroides (L.) Brongn.	1	3	0	4	1	**17**	3	0	0	0	3	0	0	0	0	0	0	2	0	0	0	0	0
Oldenlandia dichotoma Hook f.	1	3	0	5	0	9	0	0	0	**11**	0	0	0	0	0	0	0	0	0	2	0	0	0
Ficus sp.	1	2	0	4	0	0	0	0	0	0	0	**14**	0	1	0	0	0	0	0	2	0	2	0
Polygonum barbatum L.	1	3	0	1	4	0	0	0	0	0	3	3	14	0	0	0	0	0	0	0	0	0	0
Oxalis corniculata L.	1	3	0	5	0	**11**	0	6	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Eleusine indica (L.) Gaertn.	1	2	0	1	4	3	**11**	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Hoya sp.	1	2	0	4	0	**11**	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0
Merremia tridentata (L.) Hallier f.	1	2	0	0	4	0	3	0	0	0	3	0	**11**	0	0	0	0	0	0	0	0	0	0
Phymatosorus scolopendria Pich.Serm.	1	2	0	4	0	0	0	3	0	**11**	0	0	0	0	0	0	0	0	0	0	0	0	0

[1] All species that occurred in at least 10% of the frequency plots in one field zone on one soil type, [2]in the frequency plots on both soil types (n=800), [3]in the frequency plots on fluvisol (n=280), [4]in the frequency plots on histosol (n=520), [5]all frequency plots, [6]harvesting path, [7]circle front, [8]circle back, [9]inter-row, [10]frequency plots in the respective field zone receiving <20% of the incident solar radiation and [11]>20% solar radiation on fluvisol, [12]frequency plots in the respective field zone receiving <60% of the incident solar radiation and [13]>60% solar radiation on histosol

darker sites on fluvisol: *Diplazium esculentum*, *Ficus* sp., *Pityrogramma calomelanos*, *Pleocnemia irregularis*, *Peperomia pellucida*, *Pouzolzia zeylanica* and *Sphaerostephanos polycarpus*. Species found at a higher rate in the inter-row of the bright histosol sites were: *Basella alba*, *Imperata cylindrica*, *Paspalum conjugatum* and *Sporobolus diander*. Correspondingly, more frequent in the inter-row of the darker histosol sites were: *Ageratum conyzoides*, *Christella dentata*, *Cyclosorus interruptus*, *Phyllanthus debilis* and *Pouzolzia zeylanica*.

In the brighter sampling sites more melliferous species were recorded than in the heavier shaded sites on fluvisol. Ten nectar bearing species were found in at least 20% of the frequency plots in the less shaded sites: *Ageratum conyzoides*, *Borreria setidens*, *Commelina diffusa*, *Hedyotis corymbosa*, *Limnophila rugosa, Ludwigia hyssopifolia*, *Mikania micrantha*, *Phyllanthus debilis*, *Pueraria phaseoloides* and *Sparganophorus villantii*. Whereas in the sites marked by a denser palm canopy only 5 melliferous species occurred with a frequency above 20%: *Ageratum conyzoides*, *Borreria setidens*, *Mikania micrantha*, *Phyllanthus debilis* and *Sparganophorus villantii*. The only species of these with a preference for the darker sites was *Sparganophorus villantii*. Less melliferous species were frequently found in the frequency plots on histosol and more of these in the sites where less solar radiation penetrated the palm canopy. Only *Mikania micrantha* and *Pueraria phaseoloides* were found in 20% of the plots in the brighter sites, while *Ageratum conyzoides*, *Mikania micrantha*, *Phyllanthus debilis* and *Sparganophorus villantii* were present in the darker sites on histosol respectively.

4 Discussion

The solar radiation below the oil palm canopy decreases with growing oil palm age, nevertheless this relationship depends strongly on the environment. In this study a delayed canopy closure and less intense maximum shading was observed below palms growing on histosol in comparison with palms on fluvisol. The greater number of leaning palms and their stronger inclination on histosol could not explain this difference. Corley and Mok (1972) showed that better soil fertility resulted in larger

oil palm fronds. This suggests that the limited pool of available nutrients in the low-density organic soil (Widjaja-Adhi, 1995) was the cause for smaller crown radii and higher BCSR levels on histosol. The significant negative correlation between the crown radius and BCSR (-0.95**) was largely independent of the soil type. Thus, the crown radius is a more reliable parameter describing the BCSR than the palm age. In the current study the planting density was constant, nonetheless it is the single most important factor determining the canopy architecture of oil palm (Gerritsma and Soebagyo, 1999). The additional integration of the planting density is therefore essential to assess the BCSR through the crown radius.

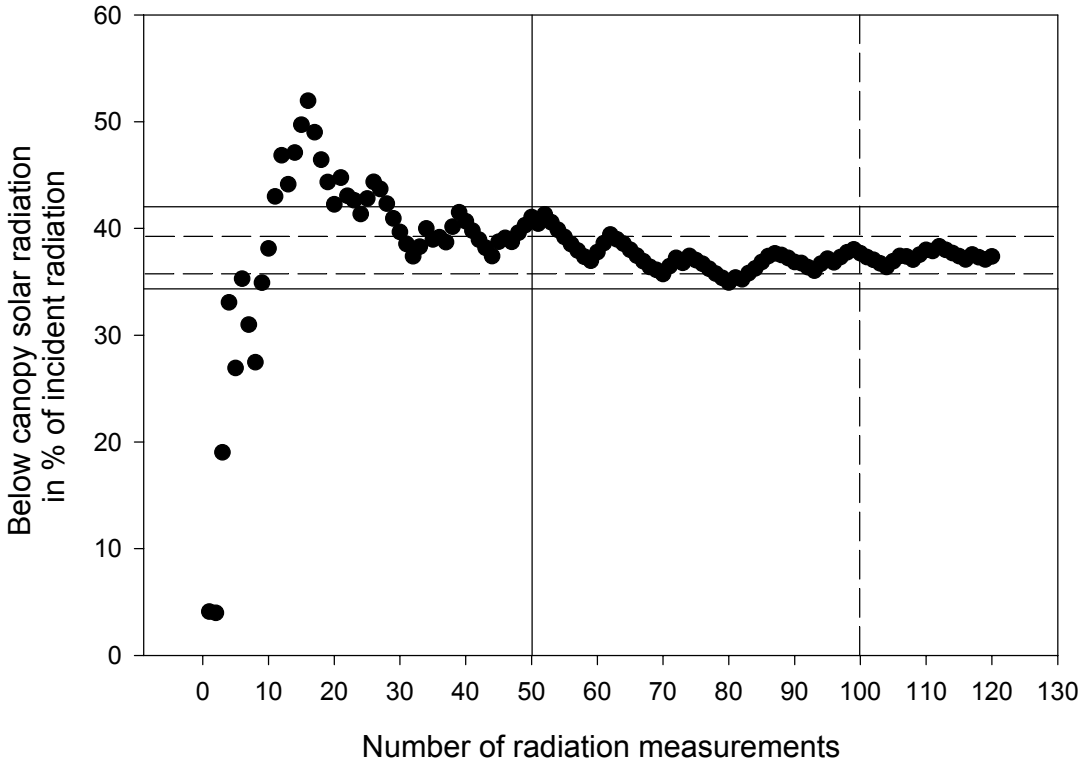


Fig. 14: Example of the accumulative mean of solar radiation measurements in a sampling site at an oil palm crown radius of 5.5 m.

To analyse changes in the species composition the vegetation in the zones was arranged by the average BCSR. Essentially the same species showed the identical reaction towards changing solar radiation levels when the vegetation was sorted by the solar radiation measured

in each particular zone. Therefore, the zone-differentiated solar radiation assessment proved to be of no advantage for the phytosociological investigation. However, for the measurement of the scattered illumination below the canopy a relatively high number of repetitions is needed. The variation of the average below canopy radiation was at 50 measurements <±5.0% and at 100 measurements <±2.5% (Fig. 14).

The solar radiation under the expanding oil palm canopy was initially reduced in the palm circle and subsequently on the harvesting path and in the inter-row. The difference of the radiation intensity between the zones was greatest when the crown expansion was surpassing a radius of 3 m. The similarity between the species compositions in and outside the palm circle was however not inferior in sites where the discrepancy of the solar radiation was greater. The formation of more specific species compositions in the dark and bright areas of the sampling sites was probable hindered by following reasons: a) The solar radiation measurements were carried out at noon and failed to take changes of radiation during the day into account. At lower inclination the sun projects sunflecks through the oil palm canopy illuminating areas exposed to full shade midday. The effect of the sunflecks on the undergrowth depends on their duration and frequency, but in general plant growth approximates a linear function of available light for levels less than 20% full sun (Chazdon, 1988). Therefore even small increases of available light e.g. in the darker palm circle might have a strong effect on the species composition. b) There is a continuous intrusion of plants by the means of stolons, seeds and spores from the neighbouring zones. Due to the short distances to bridge, not only highly invasive species such as *Imperata cylindrica* and *Mikania micrantha*, but also species with less efficient means of dispersal are able to pass from one zone into another. c) Some light loving plants appear to germinate preferably in the dark where humidity is consistently high, though they can only compete if they receive sufficient sunlight. Further, the regular manual weeding in the circles with sickles scares the ground and thus prepares an ideal seedbed. This might explain why *Stenochlaena palustris*, *Erechthites valerianifolia*, *Nephrolepis biserrata* and *Pityrogramma calomelanos* were found more often in the brighter of the

histosol sites but in the darker of the fluvisol sites. d) Species preferring shade encounter below the cover of other undergrowth plants their niche, which encouraged the presence of *Ludwigia hyssopifolia*, *Phyllanthus debilis* and *Pouzolzia zeylanica* outside the circle zone in the relatively bright histosol sites.

The canopy closure was delayed and the palms in average younger and therefore the BCSR higher on histosol than on fluvisol. The fact that more species were found in the brighter of the fluvisol and darker of the histosol sites, suggests that medium shade with great spatial differences in solar radiation (Fig. 10) enhanced the species abundance. Dicotyledonae contributed most species to the undergrowth on both soil types, while their proportion in the vegetation below dense oil palm canopy was lower on fluvisol but greater on histosol. Monocotyledonae occurred generally more frequently in bright areas, exceptions were *Cyperus kyllingia*, *Fimbristylis dichotoma* and voluntary oil palm seedlings. *Cyperus* ssp. and *Fimbristylis* ssp. are common weeds in lowland rice (Soerjani et al., 1987) and are assumed to possess little resistant to draught. Thus the distribution of these sedges might be regulated by water availability rather then by solar radiation. Oil palm seedlings were found more often in the brighter fluvisol sites, which was in all probability due to the fact that the strong dormancy of the seeds is broken by heat (Rees, 1959). The young palms on histosol did not yet produce fertile seeds, therefore here more seedlings were found in the dark sites. Most ferns in the research area preferred darker environments. Three ferns were more frequent in bright sites specifically on histosol: *Nephrolepis biserrata*, *Pityrogramma calomelanos* and *Stenochlaena palustris*. As mentioned above, the frequent presence of these ferns in the darker fluvisol sites was assumingly not because of their competitiveness in this environment, but due to enhanced spore germination at high humidity. This assumption was substantiated by a higher specific degree of coverage of all three of these ferns on histosol (chapter 1). The species that were found more commonly in the histosol sites of higher BCSR were marked by characteristics typical to pioneer plants. They spread fast, either through creeping growth (e.g. *Calopogonium muconoides* and *Commelina diffusa*) or by the production of a

large number of seeds or spores (*Sporobolus diander* and ferns) and other species possess stolons that enable them to endure fire below the soil surface (*Imperata cylindrica* and *Stenochlaena palustris*).

Commelina diffusa was found distinctly more often in the brighter sites on fluvisol and histosol. None of the other species responded in their distribution in the same way on both soil types to solar radiation. This might be due to the different regimes of solar radiation considered below the palm canopy on each soil type. However, some species responded onto the solar radiation intensity similarly on both soil types, though the response was considered only on one soil type as distinct. To these species count the following that were more frequent in brighter environments: *Basella alba*, *Calopogonium muconoides*, *Commelina diffusa*, *Imperata cylindrica*, *Pueraria phaseoloides and Sporobolus diander*. Accordingly *Ageratum conyzoides*, *Christella dentata*, *Diplazium esculentum*, *Peperomia pellucida*, *Phyllanthus debilis*, *Pouzolzia zeylanica* and *Sparganophorus villantii* preferred darker environments on both soil types. The mentioned light-loving plants occurred more often on histosol, where under palms of the same age the canopy was not as dense as on fluvisol and the ground less shaded. The shade-loving plants were more common on the heavier shaded fluvisol respectively (Table 3). This suggests that these species are influenced in their distribution within the research area primarily by light.

The species with a distinct reaction to different levels of solar radiation in the palm circle and the harvesting path occurred in these zones more frequent than in the inter-row (chapter 1). The light-sensitive species in these two zones comprised of small plants including annual dicotyledonae, sedges and *Selaginella plana*. The species in the inter-row that were influenced in their distribution by a solar radiation occurred evenly throughout all field zones. In the inter-row of the brighter sites creepers and grasses were more common, while in the darker sites ferns and dicotyledonae dominated.

Chapter 3

Chemical and physical topsoil properties and impact on the species composition

Abstract

Spatial variations of soil texture and chemical properties in the topsoil (0-20 cm) were assessed under oil palm (*Elaeis guineensis* Jacq.) on a fluvisol/histosol floodplain in a plantation 140 km northwest of Padang in West-Sumatra. Additionally the response of the undergrowth species composition onto the soil properties was investigated.

The fluvisol in the research area was characterised by high effective cation exchange capacity (ECEC) and classified as eutric fluvisol. In and around the previous nursery the subtraction of topsoil resulted primarily in a lower soil carbon content reduced from 6 to 2% and decreased nitrogen content as well as lowered concentrations of K, Mg, Ca, and Cu, increased pH value and decreased exchangeable Al. The clay content was significantly lower, whereas the silt fraction was greater where the topsoil was removed. Comparing the histosol samples from different sampling sites the carbon content was the soil property showing the greatest variations. Histosol from the sites with a lower carbon content, around 20% in comparison with 33% in the carbon rich sites, was marked by reduced nitrogen content, lowered concentration of P, B and Zn as well as increased amount of available Cu. The pH value was higher and effective cation exchange capacity lower on histosol with low carbon content. The soil texture of both soils was silty clay to loamy silt and where the sand content was higher sandy silt loam.

The physical properties were stable within the sites, while the chemical properties were significantly influenced by fertilization. Urea lowered the pH and thus reduced extractable Ca, Mg and the ECEC as it augmented exchangeable Al. Muriate of potash and bunch ash increased extractable potassium, while bunch ash also neutralised acidity on histosol. These effects were not only observed in the fertilized palm

circle in comparison with the remaining area, but also between the front of the palm circle towards the harvesting path and the back of the palm circle towards the inter-row. This was apparently a consequence of more fertilizer applied in the front than in the back of the palm circle. The greater carbon content in the front of the palm circle suggests that the higher nutrient availability encouraged root growth.

The difference of soil carbon content blanketed, apart from the ECEC, the effect of other soil parameters on the undergrowth species composition. On both soil types a distinct distribution of the undergrowth species in response to the soil carbon content was observed. A preference towards low carbon content showed 11 species: *Ceratopteris thalictroides* (L.) Brongn., *Christella dentata* (Forssk.) Brownsey & Jermy, *Christella parasitica* (L.) Lev., *Diplazium esculentum* (Retz.) Sw., *Eleusine indica* (L.) Gaertn., *Hedyotis corymbosa* Lam., *Pleocnemia irregularis* (C.Presl) Holtt., *Polygonum barbatum* L., *Selaginella plana* Hieron., *Sphaerostephanos polycarpus* (Bl.) Copel. and *Stachytarpheta indica* Vahl. These species occurred more frequent on fluvisol than on histosol and more often in the fluvisol sites where the soil carbon content was low. The presence of two species: *Borreria latifolia* (Aubl.) K. Schum. and *Dicranopteris linearis* J. Underw. augmented with increasing soil carbon content. Their occurrence was highest in the carbon rich histosol sites.

In the sampling sites marked by high ECEC ferns were dominant. On fluvisol 11 out of 18 species that occurred more frequently where the ECEC was higher were ferns and on histosol 3 out of 12 species respectively. *Ludwigia hyssopifolia* (G.Don) Exell was found more often in sites marked by low ECEC on both soil types. Further, small species including: *Euphorbia hirta* L., *Fimbristylis dichotoma* (L.) Vahl, *Fimbristylis miliacea* Vahl, *Hedyotis diffusa* Willd., *Phyllanthus amarus* Schum. & Thonn. were more frequent where the ECEC was low on fluvisol and *Sparganophorus villantii* Crantz on histosol respectively.

1 Introduction

The oil palm yields more oil per hectare than any other oil crop (von Uexküll and Fairhurst, 1991). Average production in the main producing countries, Malaysia and Indonesia is above 4 t oil ha^{-1} (FAO, 2002a), while the potential under optimal conditions is superior to 10 t oil ha^{-1} (Weng, 1999; Gerritsma and Wessel, 1997). To achieve and maintain high yields oil palm requires comparatively large nutrient inputs, which makes fertilization the single largest expenditure in established plantations. For the determination of effective fertilizer rates analyses of leaf samples are recommended. Comprehensive knowledge of the field is however necessary, because nutrient deficiencies in oil palm are often caused by secondary constrains, e.g. over-pruning and poor drainage (Fairhurst and Mutert, 1999). Further, the leaf sampling method fails to consider spatial variations of soil properties caused by changes in the field environment. Identification of undergrowth species that respond in their distribution onto particular soil conditions could help to isolate areas with particular properties. Individual leaf sampling in and separate treatment of each isolated area could then reduce the number and cost of leaf samples, lower the fertilizer demand and increase yields.

In Europe numerous plants have been identified that indicate environmental variables such as moisture, soil reaction and nitrogen availability (Ellenberg et al., 1992). The identification and use of indicator species to make out certain environmental characteristics is also gaining importance in North America, Japan and other countries. The available knowledge concerning indicator species in the tropics that could provide information about oil palm environments is however rare. Gill and Onyibe (1998) showed that oil palm provides specialized microhabitats conductive for the growth of a variety of plants. Next to the intensity of the solar radiation below the oil palm canopy (chapter 2) the soil and its properties determines the fertility in these microhabitats and might therefore contribute to formation of adapted undergrowth compositions.

The objectives of the present study were: (i) to assess spatial variation of soil texture and chemical properties in the topsoil under oil palm on a fluvisol/histosol floodplain, (ii) to investigate the impact of the field

structure and management practises on nutrient content in the different field sections and (iii) to assess changes in the undergrowth species composition in response to the soil properties.

2 Material and Methods

2.1 Study area

The research area a commercial oil palm plantation in West-Sumatra, and its climate is described in chapter 1. The prevailing soil types were determined during field drain excavation, as histosol and fluvisol (according to the FAO 'World reference base for soil resources' (FAO, 1998)). Previous to plantation establishment most of the plantation area was covered by swamp forest. Since completion of the drainage system flooding by the adjoining rivers occurred only during the precipitation peaks in November to December and in April. Drainage of peat in the tropics is known to result in fast decomposition of the organic matter (Wösten et al., 1997). The degradation of a histosol may therefore eventually expose an underlying fluvisol; consequently no clear cut between the soil types can be identified. Research for the current work was exclusively conducted on fluvisol with a thin cover of humus (<5 cm) and on histosol with a strong layer of organic matter (>100 cm).

Table 4: Annual fertilizer rates in gram per oil palm during the immature period (first, second and third year after planting (YAP)) and during the mature period (forth and consequent YAP).

	Fluvisol				Histosol				
YAP	Urea	RP	MOP	Borate	UREA	RP	MOP	Borate	Dolomite
1	6,00	0	400	0	600	0	450	0	0
2	7,00	1,000	1,200	50	700	1,000	1,200	50	1,000
3	1,500	1,000	2,500	100	850	1,000	3,000	100	1,000
>=4	2,100	1,300	3,300	50	900	1,300	5,000	50	2,000

RP=Christmas Island rock phosphate, MOP=muriate of potash

The basic fertilization program provided nitrogen (N), phosphorous (P), potassium (K) and boron (B). On histosol dolomite was additionally applied as a source of magnesium (Mg) (Table 4). To reduce volatilisation losses of nitrogen urea was given in the first year in 4 and in the consequent years in 3 splits per year. To control the leaching of potassium muriate of potash (MOP) application was conducted in 3 and of bunch ash in 2 splits per year. Copper sulphate was fertilized at a dosage of 50 g per palm in areas where the palms showed deficiency symptoms. Apart from copper deficiency the palms in the research area showed occasionally symptoms of N, K, Mg and B deficiency.

2.2 Soil sampling and analyses

Soil and vegetation sampling was carried out in 40 sites measuring each 300 m^2, of these 14 were situated on fluvisol and 26 on histosol respectively. The soil samples were taken from 0 to 20 cm depth with a 5 cm diameter auger. Twenty samples were taken from each site, five from the harvesting path, five from the inter-row and ten from the palm circles. From every palm circle two samples were taken one in the front section towards the harvesting path and one in the back section towards the inter-row. The samples from each area, harvesting path, inter-row and circle sections were combined to provide 4 mixed samples per site. Litter covering the soil was removed before taking the samples and life roots were excluded while the samples were mixed. The field moist samples were crumbled to pass through an 8 mm sieve and fan-assisted air-dried. All soil samples were analysed at the 'State Institute for Agricultural Chemistry' at the University of Hohenheim, Germany. Soil texture was analysed by Köhn's combined sieve pipette method, following the oxidisation of organic matter with H_2O_2 (DIN 19683). The pH was determined in a water soil suspension at a ratio of 1:2.5 measuring the conductivity using a glass electrode. The Bray I method was applied to determine the amount of available P (Bray and Kurtz, 1945) (Photometer Cary 50, Varian). Carbon (C) and N were measured by dry combustion with an automatic CN analyser (Vario EL, Elementar). For determination of exchangeable sodium (Na), aluminium (Al), calcium (Ca), K and Mg the material to be analysed was digested with 1M NH_4Cl before measuring with an Inductivity Coupled Plasma-Optical Emission

Spectroscope (ICP-OES PS 1000, Leeman Labs). The micronutrients B, Copper (Cu) and Zinc (Zn) were extracted with $CaCl_2$/DTPA solution and also measured with the ICP-OES (Lindsay and Norwell, 1978).

2.3 Vegetation sampling

The species present were identified in the frame of the phytosociological study in chapter 1. For the investigation of the vegetation composition in the zones twenty frequency plots were arranged systematically within each sampling site, five on the harvesting path, five in the inter-row and ten in the palm circles. The palm circles were divided into two sections to examine differences in the species composition within the circles. In every palm circle one frequency plot was placed in the front section towards the harvesting path and one in the back section towards the inter-row (compare site layout with Fig. 2 in chapter 1). All species present in each frequency plot were listed.

2.4 Data interpretation

The lowest detectable concentration by the applied methods was for P 5 mg kg^{-1} of soil and B and Cu 0,1 mg kg^{-1} of soil. Concentrations of elements inferior delectability were set as zero for demonstration and interpretation purposes. To compare nutrient content and soil properties between the sites, the average was calculated proportionate to the proportion of the zones in the field:

$$Site\,average = \frac{(hp\ 40\ m^2 + cf\ 40\ m^2 + cb\,40\ m^2 + ir\,180\ m^2)}{300\ m^2}$$

where *hp* is the value of the respective soil property measured on the harvesting path, *cf* in the palm circle front, *cb* in the palm circle back and *ir* in the inter-row.

To assess the distribution of species in response to soil properties first the sites hosting the vegetation were separated into two groups and than the occurrence of the species in the frequency plots was counted. The sites were grouped for each soil property that was investigated on its impact on the species composition. All species were considered that occurred in more than 10% of the frequency plots in one group of the

sites. Species were regarded as occurring distinctly more frequent in one group if they were at least 2 times more frequent than in the other group. By considering only the vegetation in the frequency plots on the harvesting path, circle front, circle back and inter-row the species distribution in the field zones was investigated in the same way.
A paired sample *t*-test was used to identify differences in nutrient concentration and soil texture between the zones within a group of sites with similar soil characteristics. To assess differences between the soil properties of two groups the average values of the sites were compared with an independent sample *t*-test. The Pearson correlation coefficient was employed to evaluate correlations between nutrients and soil texture in the sites. The *t*-test and correlation analyses were preformed using SPSS 10.0.

3 Results

In both soil types fluvisol and histosol the carbon content varied considerably. Fluvisol with lower soil carbon content was marked by significantly lower nitrogen content, reduced amounts of K, Mg, Ca, and Cu increased pH value and decreased exchangeable Al. In low carbon fluvisol the clay content was also significantly lower, whereas the silt fraction was greater. The soil properties on histosol characterized by lower carbon content were significantly different from those of histosol with higher carbon content. In the histosol samples poorer in carbon the nitrogen content was reduced, the concentration of P, B and Zn lowered, the amount of available Cu as well as the pH value increased and the effective cation exchange capacity augmented. Due to the great variation of the soil carbon content and its dominant influence on the other soil properties the results of the soil analyses are presented in the following grouped by the carbon content of sampling sites. The average carbon content was <2.4% and ≥2.4% for 7 sites on fluvisol each and <25% and ≥25% for 13 sites on histosol each respectively.

3.1 Soil texture

Most soil samples from both fluvisol and histosol were characterised by a silt fraction of above 40% and a clay and sand fraction below 50%, which classifies their soil texture from silty clay to loamy silt and where the sand content was higher to sandy silt loam. The soil texture within the sites was homogenous; except for three sites on histosol, where a distinctly larger sand fraction in the back of the palm circle and/or the inter-row was detected (Fig. 15). The clay fraction in the low carbon

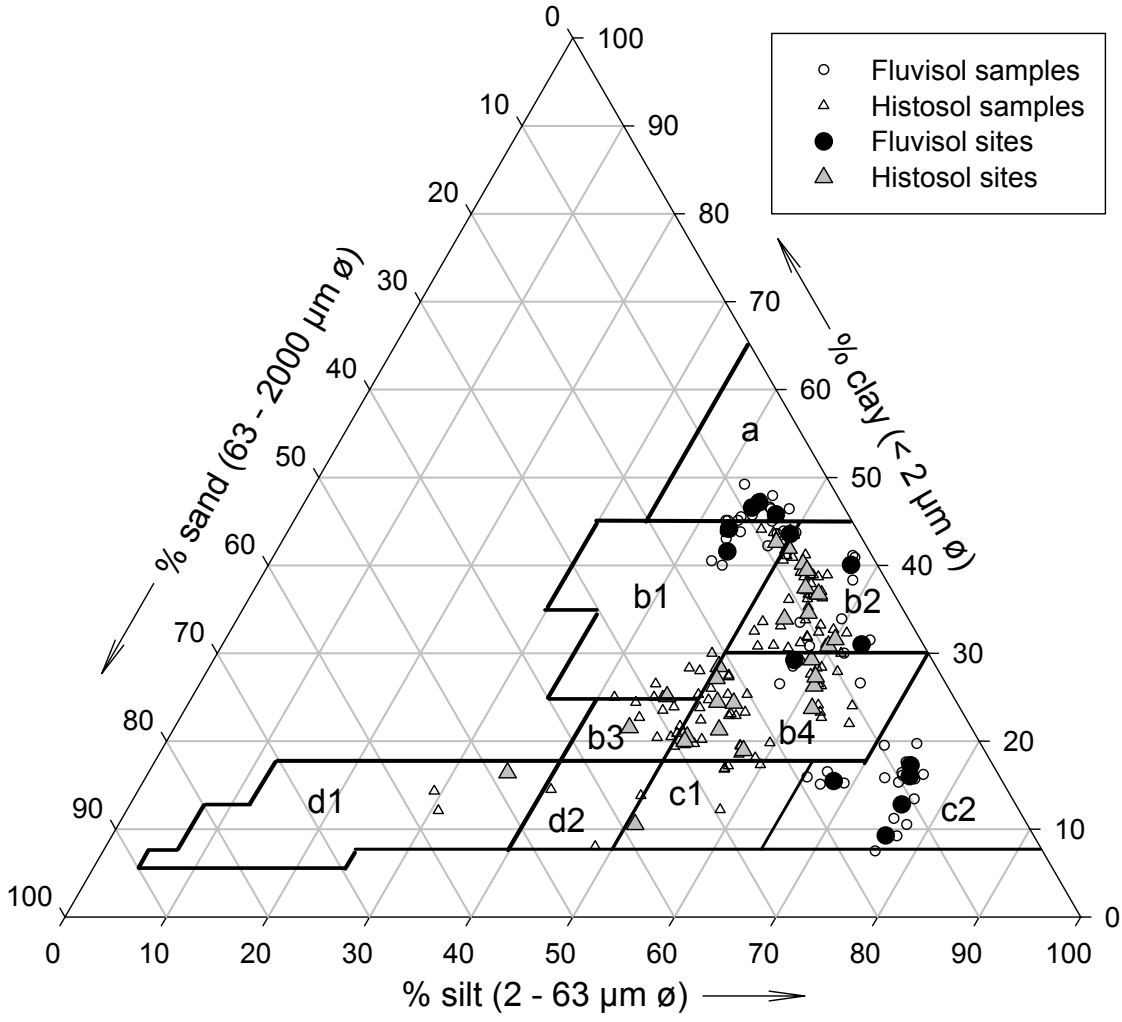


Fig. 15: Topsoil texture (upper 20 cm) in an oil palm plantation on a floodplain in West Sumatra. The graph includes the texture of each sample analysed and site averages. Fluvisol samples n=56, histosol samples n=104; a: silty clay, b1: clay loam, b2: clay silt loam, b3: sandy silt loam, b4: silty loam, c1: loamy sandy silt, c2: loamy silt, d1: loamy sand, d2: loamy silt sand (in accordance to DIN 4220 (Schachtschabel et al., 1992)).

fluvisol sites was in average 20% and significantly lower ($p<0.001$) than in carbon rich sites, where the average clay fraction was 44%. Apart from one exception the fluvisol sites marked by a lower clay fraction had also a smaller soil carbon content. The silt fraction was smaller in sites with larger carbon content ($p<0.001$), but no significant difference in the sand fraction was found. There was no significant difference in soil texture between the carbon rich and carbon poor histosol sites. However, in twelve sites close to the northern and western border of the plantation the sand fraction was in average 29% and thus distinctly larger ($p<0.001$) than in the remaining histosol sites, where the sand fraction was around 10%. In sites with a larger sand fraction both, the mean clay ($p<0.001$) and silt fraction ($p<0.01$) were smaller.

3.2 Soil carbon and nitrogen

In accordance to the nature of the soils, the average soil carbon and nitrogen on fluvisol was less than on histosol ($p<0.001$). In the carbon rich fluvisol sites the carbon content was 5.75% and therefore almost 3 times higher than in the carbon poor sites where the carbon content was 2% ($p<0.01$) (Fig. 16a). The nitrogen content was accordingly double as high ($p<0.001$) (Fig. 16b). The difference of the mean carbon and nitrogen content between the two groups of histosol sites was also significant ($p<0.001$). In the carbon rich sites the carbon content was 33% and in the carbon poor sites 20%. On both soil types soil carbon and nitrogen were lowest in the back section of the palm circle. In the carbon poor fluvisol sites the carbon and nitrogen content were increased in the frond mulched inter-row, though not significantly. The average C/N ratio was 19 on histosol and thus almost double as wide as on fluvisol where the ratio was 10. The ratio was also wider in the carbon rich fluvisol sites ($p<0.01$) and in the carbon rich histosol ($p<0.001$). There were no significant differences in the C/N ratio between the field zones.

3.3 Soil pH, exchangeable Al and Al saturation

Average pH was distinctly lower ($p<0.001$) (Fig. 16c) and the concentration of exchangeable Al almost eight times higher on histosol than on fluvisol ($p<0.001$) (Fig. 16d). The carbon rich sites on fluvisol ($p<0.01$) and the sites with a high carbon content on histosol ($p<0.01$) proved to be more acid. In the fluvisol sites this resulted in a significant increase of exchangeable Al ($p<0.01$) from less than 1 to almost 7 $mmol_c\ kg^{-1}$ of soil. In the front of the palm circle the soil was more acid with higher concentration of exchangeable Al in comparison with the back of the palm circle and the other field zones on both soils. The Al saturation was significantly lower on fluvisol (2.4%) than on histosol (21.6%) ($p<0.001$). In the carbon rich fluvisol sites the Al saturation was higher than in the other fluvisol sites. In the sites with the larger carbon content the Al saturation was higher in the circle front than in the harvesting path and the inter-row ($p<0.05$). There was no difference in the Al saturation between the histosol sites with high and low carbon content, but in the histosol sites with less carbon the Al saturation was significantly higher in the circle front than in the inter-row ($p<0.01$).

3.4 Soil phosphorus

The average amount of available P was similar in both soil types. The concentration of available P varied largely and there was no significant difference in P concentration between the carbon poor and carbon rich sites on fluvisol. More available P was detected in soil with higher carbon content obtained from the histosol sites ($p<0.01$), while no significant difference was found between P availability the field zones (Fig. 16e).

3.5 Exchangeable base cations and effective cation exchange capacity

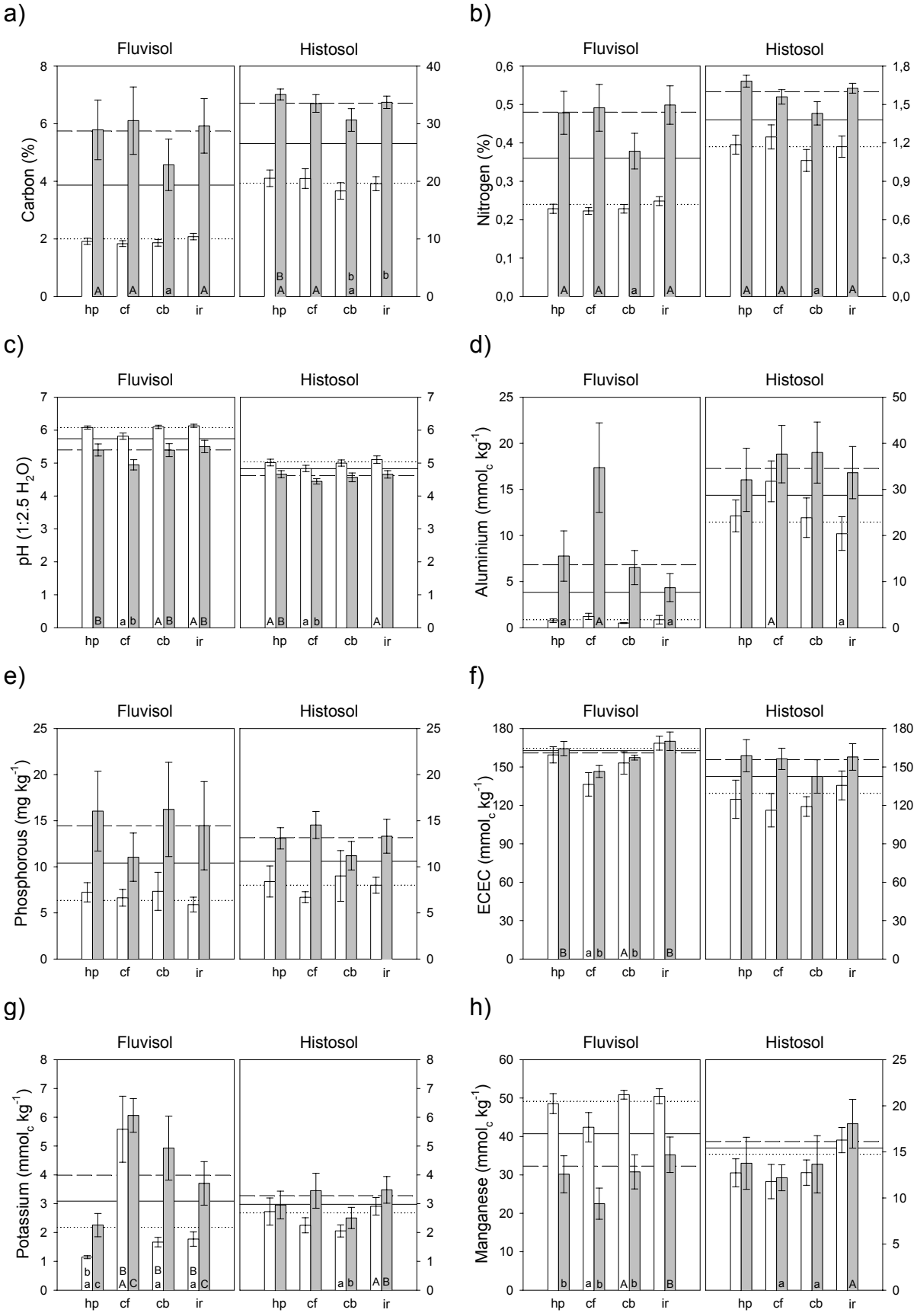
The amount of exchangeable K was equivalent in both soil types (Fig. 16g), whereas the concentrations of Mg (Fig. 16h) and Ca (Fig. 16i) were larger on fluvisol ($p>0.001$). The average concentration of exchangeable K was larger ($p<0.01$) and of exchangeable Mg ($p<0.01$) and Ca ($p<0.05$) smaller in low carbon sites on fluvisol. The amount of

all exchangeable cations was similar in the sites rich and poor in carbon on histosol. However, in eight sites cleared recently, within less than two years before soil sampling from forest were marked by significantly higher amounts of K ($p<0.001$) and Mg ($p<0.05$). A very large difference in the concentration of exchangeable K was found between the circle front and the other field zones on the carbon poor fluvisol sites ($p<0.05$). The K concentration decreased in both groups of fluvisol site in the following order: front of palm circle > back of palm circle > inter-row > harvesting path. A slightly larger amount of exchangeable K was detected in the inter-row than in the other zones on histosol, though this relationship was only significant between the back of the palm circle and the inter-row ($p<0.05$).

The amount of exchangeable Mg was lower in the carbon rich fluvisol sites ($p<0.01$). The carbon content proved to have no significant influence on the Mg concentration in the histosol sites. In all cases the amount of exchangeable Mg was lower in the circle front and larger in the inter-row than in the other circle sections and the harvesting path. The only exception was an insignificantly higher Mg concentration in the back of the palm circle in the low carbon sites on fluvisol. The amount of exchangeable Ca was significantly larger on fluvisol than on histosol ($p<0.05$). The concentration of Ca was lower in the circle sections than in the harvesting path and the inter-row on both soil types. The amount of exchangeable Na was in all analysed samples below the detectable concentration of 1 mmol kg^{-1} soil. The ECEC ranged from 42 to 258 $mmol_c$ kg^{-1} of soil on histosol, whereas the ECEC of the fluvisol samples was more stable varying between 105 and 205 $mmol_c$ kg^{-1} of soil (Fig. 16f). In the carbon poor histosol sites the ECEC was lower than in the sites with higher carbon content. The ECEC was, in all but the carbon poor histosol sites lower in the front and back of the palm circle than in the other zones. On both soils the base saturation was dominated by Ca, which contributed in average of all sites 68% to the extractable cations. The Mg saturation was 21% on fluvisol and thus significantly higher than on histosol where the Mg saturation was below 11%.

3.6 Micronutrients

The amount of available boron ($p<0.05$) (Fig. 16j) and zinc (n.s.) (Fig. 16l) was larger on histosol, while the concentration of available copper was significantly greater on fluvisol ($p<0.001$) (Fig. 16k). In the low carbon fluvisol sites copper concentrations were higher than in the carbon rich ones. The copper concentration was lower and Zn higher in the sites with a high carbon content on histosol. Due to unusual large amounts of boron between 1.9 and 2.8 mg kg^{-1} on the path and in the circle front of two histosol sites the average B concentration appeared higher in the carbon rich histosol sites. Excluding these four extreme values there was no significant difference in the B concentration between the histosol sites and their zones. In the carbon rich fluvisol sites the B concentration was lower in the circle back than in the circle front ($p<0.05$). The concentration of available copper on fluvisol was about four times larger than on histosol ($p<0.001$). In the front of the palm circle there was less available Cu than on the harvesting path and in the inter-row ($p<0.05$). The Cu concentration was also in the back of the palm circle lower than in the inter-row ($0<0.05$). Extremely large amounts of available copper of above 16.5 mg kg^{-1} were detected in three samples from the circle front on histosol. These outliers increased distinctly the mean Cu value, but did not conceal any significant differences between the Cu concentrations in the zones. The concentration of exchangeable zinc was similar on both soil types and showed the same pattern of distribution within the field. In the front and the back of the palm circle there was significantly less available zinc than on the harvesting path and inter-row ($p<0.01$). In contrast to B and Cu in none of the samples extreme high Zn values were found.


a)
b)
c)
d)
e)
f)
g)
h)
Fluvisol
Histosol
Carbon (%)
Nitrogen (%)
pH (1:2.5 H2O)
Aluminium (mmolc kg-1)
Phosphorous (mg kg-1)
ECEC (mmolc kg-1)
Potassium (mmolc kg-1)
Manganese (mmolc kg-1)
hp
cf
cb
ir

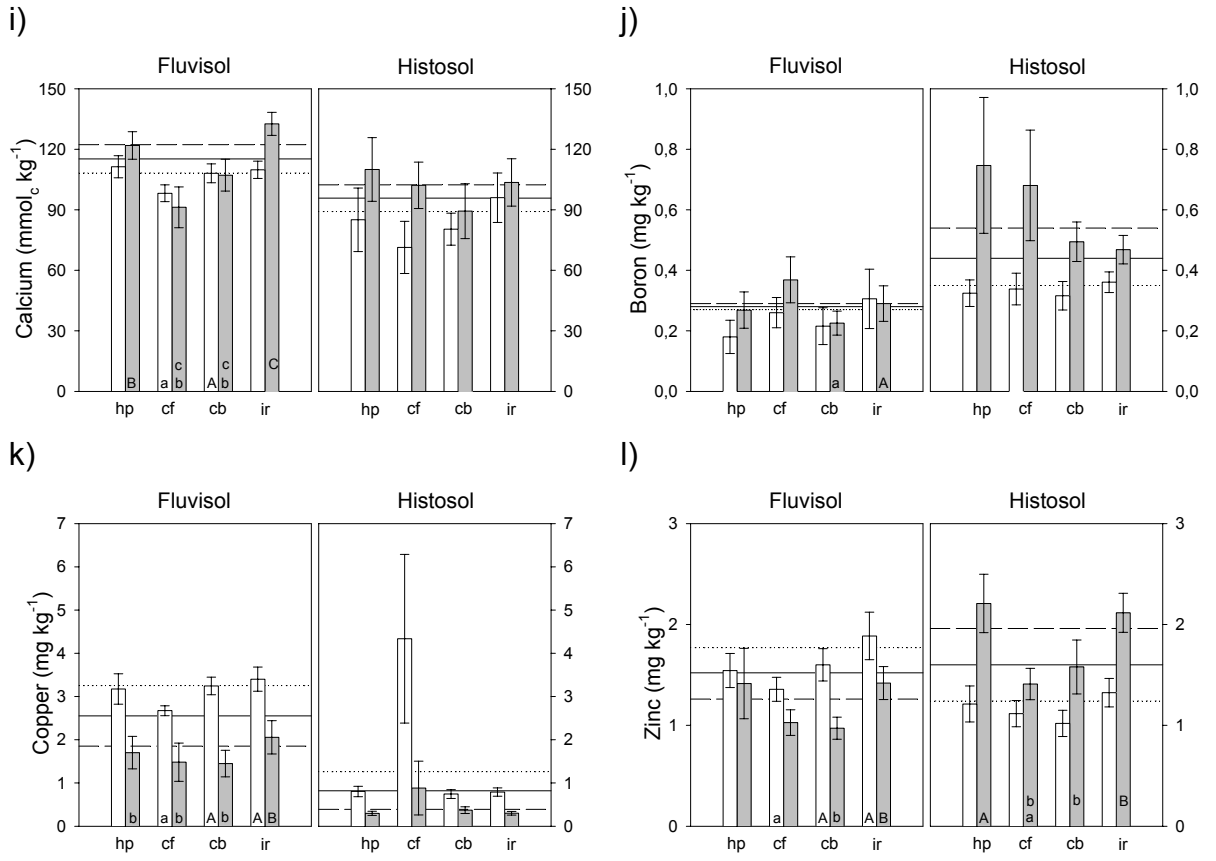


Fig. 16: Chemical soil properties of the topsoil (0-20 cm) in the field zones (hp=harvesting path, cf=front of the palm circle towards the harvesting path, cb=back of the palm circle towards the inter-row, ir=inter-row) on fluvisol and histosol in the research area. The white bars represent the sites with an average carbon content <2.4% on fluvisol and <25.0% on histosol and the grey bars the sites with a soil carbon content ≥2.4% on fluvisol and ≥25.0% on histosol (whiskers = standard error). A capital letter in the bar indicates where a value of a soil property measured was significantly greater ($p<0.05$) in comparison with a bar containing the corresponding small letter. The solid reference lines stand for the average value of a soil property throughout the research area, the dotted one for the fluvisol sites and the dashed lines for the histosol sites respectively.

3.7 Correlations between chemical soil properties

A strong positive correlation between C and N and a tight negative correlation of both of the latter elements to the pH value was observed throughout all samples. There was also a steady negative correlation between the pH value and exchangable Al (Fig. 17). The observed relationships among the chemical properties were generally stronger on fluvisol than on histosol (Table 5). However, the relationship between Ca to pH, K, Mg, Al and Zn and between K and P were more distinct on histosol. An opposite sign marked the correlations between K and Mg as well as between Zn and C, N and P on the two soil types. Correlations of the chemical properties with B and the soil texture fractions were in all cases weak.

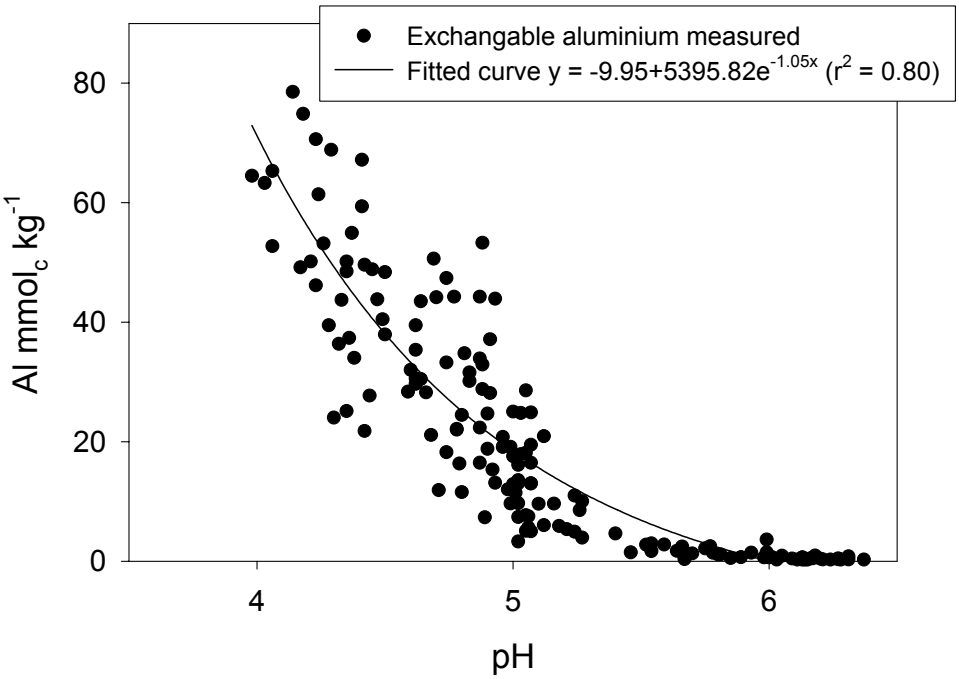


Fig. 17: Relationship between soil pH (1:2.5 H_2O) and exchangeable aluminium in fluvisol and histosol topsoil (0-20 cm) under oil palm (n=160).

The correlations between the chemical properties were not steady throughout the field but often particular in each zone. Most outstanding in this respect was K on fluvisol. In the inter-row K was strongly correlated to pH (-0.92***), C (0.80***), N (0.82***), P (0.57*), Mg (-0.88***) as well as Al (0.85***). The correlations between these soil

properties were similar in the harvesting path, whereas in the front of the palm circle weak if present at all. Also the weak correlation between C and Ca (Table 5) was due to the poor relationship in the front of the palm circle, while in the other zones and especially in the inter-row a tighter relationship was observed (0.67**). Correlations between soil chemical properties found exclusively in the front of the palm circle were between Ca and B (0.73***), Cu (0.64*) and Zn (0.57*) and between P and Al (-0.70***). On histosol the correlations between K and Ca as well as Mg were distinct in the inter-row (K:Ca 0.39*; K:Mg 0.69***), in the back of the palm circle and harvesting path (K:Ca >0.62***; K:Mg >0.69***), whereas between these elements no significant correlation was found in the front of the palm circle. There was also no correlation between pH and Ca, except for a weak but significant correlation between pH and P (-0.51***) found in the palm circle front on histosol. In contrast to all other topsoil properties the ECEC and the amount of soluble Zn were not correlated strongly to C in any of the field zones.

Table 5: Correlations between chemical soil properties in samples taken from the harvesting path, front and back of the palm circle and inter-row of oil palm fields on fluvisol (n=56) and histosol (n=104).

		C	N	P	K	Ca	Mg	Al	Cu	Zn	ECEC
pH	fluvisol	-0.87[3]	-0.86[3]	-0.60[3]	-0.46[3]	0.03	0.94[3]	-0.84[3]	0.69[3]	0.52[3]	0.28[1]
	histosol	-0.58[3]	-0.58[3]	-0.18	0.21[1]	0.45[3]	0.42[3]	-0.81[3]	0.08	-0.13	0.20[1]
C	fluvisol		0.98[3]	0.75[3]	0.27[1]	0.33[1]	-0.82[3]	0.74[3]	-0.54[3]	-0.32[1]	0.10
	histosol		0.82[3]	0.39[3]	0.20[1]	0.25[1]	0.16	0.41[3]	-0.19	0.50[3]	0.48[3]
N	fluvisol			0.68[3]	0.31[1]	0.29[1]	-0.83[3]	0.73[3]	-0.58[3]	-0.35[2]	0.05
	histosol			0.37[3]	0.18	0.18	0.19[1]	0.43[3]	0.05	0.66[3]	0.42[3]
P	fluvisol				0.09	0.41[2]	-0.52[3]	0.47[3]	-0.35[2]	-0.27[1]	0.26
	histosol				0.41[3]	0.24[1]	0.24[1]	0.05	-0.03	0.35[3]	0.34[3]
K	fluvisol					-0.29[1]	-0.53[3]	0.31[1]	-0.40[2]	-0.38[2]	-0.41[2]
	histosol					0.44[3]	0.53[3]	-0.29[2]	-0.18	0.37[3]	0.46[3]
Ca	fluvisol						0.05	-0.25	0.27[1]	0.32[1]	0.93[3]
	histosol						0.74[3]	-0.62[3]	-0.16	0.45[3]	0.94[3]
Mg	fluvisol							-0.80[3]	0.70[3]	0.54[3]	0.36[2]
	histosol							-0.58[3]	-0.07	0.46[3]	0.73[3]
Al	fluvisol								-0.58[3]	-0.44[3]	-0.37[2]
	histosol								-0.01	-0.01	-0.33[3]
Cu	fluvisol									0.68[3]	0.48[3]
	histosol									-0.10	0.19
Zn	fluvisol										0.47[3]
	histosol										0.57[3]

[1] significance <0.05, [2] significance <0.01, [3] significance <0.001

3.8 Species distribution as influenced by soil characteristics

Carbon

A distinct connection between soil carbon content and the occurrence of some species was detected in the research area. Analysing the vegetation in all frequency plots irrespective field zones 13 species showed a preference towards low carbon content, while only 6 occurred more frequently in the high carbon sites on fluvisol. Six species *Fimbristylis miliacea*, *Hedyotis corymbosa*, *Hedyotis diffusa*, *Limnophila rugosa*, *Ludwigia hyssopifolia* and *Lygodium circinatum* were present more often on the harvesting path and the circle sections, but not in the inter-row of the low carbon sites. In the same sites *Merremia tridentate*, *Pleocnemia irregularis* and *Polygonum barbatum* were more often recorded in the inter-row. 33 species occurred more frequently in at least one zone or circle section of the sampling sites on low carbon fluvisol than where the soil carbon was higher (Table 6). Most of these species were already previously recognized as more common on fluvisol, including 11 that were over 4 times more frequent on fluvisol than on histosol: *Ceratopteris thalictroides*, *Christella dentata*, *Christella parasitica*, *Diplazium esculentum*, *Eleusine indica*, *Hedyotis corymbosa*, *Pleocnemia irregularis*, *Polygonum barbatum*, *Selaginella plana*, *Sphaerostephanos polycarpus* and *Stachytarpheta indica* (compare chapter 1). Accordingly 15 species were found more frequent in at least one zone or circle section of the fluvisol sampling sites rich in soil carbon. In chapter 1 7 of these species were identified as more common on histosol: *Cleome rutidosperma*, *Hedyotis diffusa*, *Lygodium microphyllum, Paspalum conjugatum*, *Pityrogramma calomelanos*, *Pueraria phaseoloides* and *Sporobolus diander*.

Taking all frequency plots into consideration 5 species were found more often in the low carbon sites and 3 species were found more often in the high carbon sites on histosol. The distribution of less species was connected with the soil carbon content on histosol; 12 species were more frequent in at least one zone or circle section in the low carbon

sites and 15 species in the high carbon sites respectively. 9 of the species more widespread in the carbon rich histosol sites were found previously more common on histosol than on fluvisol. Two of these were found over 4 times more frequent on histosol: *Borreria latifolia* and *Dicranopteris linearis* (compare chapter 1).
In the inter-row where the intra-species competition is strongest more species occurred consistently were the soil carbon content was low on fluvisol and more species were the soil carbon content was high on histosol (Table 6).

Effective cation exchange capacity
Grouping of the vegetation by ECEC revealed that some species were consistently more frequent in the sites with high ECEC. In the group of fluvisol sites that were distinct by a lower ECEC, the ECEC was in average 155 $mmol_c$ kg^{-1} of soil and in the sites with a higher ECEC 170 $mmol_c$ kg^{-1} of soil. On histosol the ECEC was 119 $mmol_c$ kg^{-1} of soil and 166 $mmol_c$ kg^{-1} respectively. 6 species were found more frequently where the ECEC was higher on fluvisol: *Alternanthera sessilis*, *Diplazium esculentum*, *Nephrolepis biserrata*, *Pityrogramma calomelanos*, *Pleocnemia irregularis* and *Pueraria* sp.. Remarkably, of the total of 18 species that occurred at least in one field zone of the sites marked by a higher ECEC 11 were ferns. In the fluvisol sites with a lower ECEC a group of 11 species was found more often: *Commelina diffusa*, *Euphorbia hirta*, *Fimbristylis dichotoma*, *F. miliacea*, *Hedyotis diffusa*, *Ludwigia hyssopifolia*, *Phyllanthus amarus*, *Pueraria phaseoloides*, *Scoparia dulcis*, *Sporobolus diander* and *Stachytarpheta indica*. In at least one zone of the fluvisol sites with a low ECEC 25 species were recorded more often, of which only one was a fern: *Ceratopteris thalictroides*. Less species seemed to be influenced in their distribution by the ECEC on histosol than on fluvisol. Next to *Imperata cylindrica* and *Paspalum conjugatum* three further species were more common in the high ECEC histosol sites: *Calopogonium muconoides*, *Erigeron sumatrensis* and *Nephrolepis biserrata*. In total 12 species including three ferns were found more often in at least one zone where the ECEC was higher on histosol. Four species were encountered more frequently in the histosol sites with lower ECEC: *Basella alba*,

Cyclosorus interruptus, *Ludwigia hyssopifolia* and *Sparganophorus villantii*. *Alternanthera sessilis* occurred more often in the palm circle and *Ageratum conyzoides*, *Phyllanthus debilis*, *Pouzolzia zeylanica* and *Uncaria* cf. *glabrata* in the inter-row of the histosol sites with a low ECEC.

Table 6: Species distribution in the oil palm undergrowth in relation to soil carbon content and effective cation exchange capacity. Italics indicate that a species was found more often where the soil carbon content or effective cation exchange capacity (ECEC) was high. Bold font styles indicate that a species occurred more frequently where the soil carbon content or the ECEC was low. The numbers refer to the percentage of frequency plots in which a species was encountered (s=whole site, hp=harvesting path, cf=front of the palm circle, cb=back of the palm circle and ir=inter-row) (Example: *A. sessilis* was recorded in 11% of the frequency plots in the sampling sites that were marked by a high soil carbon content on fluvisol).

Species	Soil carbon content										Effective cation exchange									
	Fluvisol					Histosol					Fluvisol					Histosol				
	s	hp	cf	cb	ir	s	hp	cf	cb	ir	s	hp	cf	cb	ir	s	hp	cf	cb	ir
Adiantum latifolium Lam.	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*11*	*0*	**0**	**0**	**0**	**0**	**0**
Ageratum conyzoides L.	*0*	*0*	*0*	*0*	*31*	**35**	**29**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*	**0**	**0**	**0**	**0**	**32**
Alternanthera sessilis R.Br.	*11*	*17*	*14*	*0*	*0*	**0**	**0**	**15**	**12**	**0**	*10*	*14*	*0*	*0*	*14*	**0**	**0**	**15**	**12**	**0**
Basella alba L.	**0**	**0**	**0**	**0**	**0**	**12**	**11**	**15**	**17**	**0**	**0**	**0**	**0**	**0**	**0**	**11**	**0**	**14**	**17**	**0**
Borreria latifolia (Aubl.) K. Schum.	**0**	**0**	**0**	**0**	**0**	*0*	*14*	*0*	*0*	*0*	**0**	**0**	**0**	**0**	**0**	*0*	*18*	*14*	*0*	*0*
Borreria setidens (Miq.) Boldingh	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*11*	*0*	**0**	**0**	**0**	**51**	**0**	*0*	*0*	*0*	*0*	*0*
Calopogonium muconoides Desv.	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	*12*	*18*	*0*	*0*	*14*
Ceratopteris thalictroides (L.) Brongn.	**0**	**14**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**14**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*
Christella dentata (Forssk.) Brownsey & Jermy	**0**	**20**	**0**	**0**	**0**	**0**	**0**	**0**	**15**	**0**	*0*	*20*	*26*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Christella parasitica (L.) Lev.	**0**	**17**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	*0*	*17*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Cleome rutidosperma DC.	**0**	**17**	**14**	**0**	**0**	**22**	**14**	**25**	**29**	**18**	**0**	**14**	**11**	**0**	**0**	*0*	*0*	*0*	*0*	*0*
Commelina diffusa Brum.f.	**36**	**51**	**31**	**26**	**34**	*0*	*0*	*12*	*11*	*0*	**30**	**43**	**26**	**23**	**29**	*0*	*0*	*12*	*11*	*0*
Cyclosorus interruptus (Willd.) H.Ito	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*	**0**	**0**	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**0**
Cyperus kyllingia Endl.	**64**	**77**	**77**	**91**	**11**	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	**0**	**0**	**0**	**0**	**0**
Dicranopteris linearis J. Underw	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*11*	*14*	*0*	*0*	*0*	*0*	*0*	**0**	**0**	**0**	**0**	**0**
Diplazium esculentum (Retz.) Sw.	**0**	**17**	**0**	**0**	**43**	*0*	*0*	*0*	*0*	*0*	*29*	*20*	*0*	*46*	*43*	**0**	**0**	**0**	**0**	**0**
Echinochloa colona (L.) Link	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*	**0**	**20**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Elaeis guineensis Jacq.	**0**	**23**	**0**	**0**	**0**	*0*	*0*	*14*	*0*	*0*	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*17*	*0*	*0*
Eleusine indica (L.) Gaertn.	**0**	**11**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*	**0**	**14**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*
Erechthites valerianifolia (Wolf) DC.	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**14**	**0**	**0**	*0*	*0*	*0*	*11*	*0*
Erigeron sumatrensis Retz.	**0**	**0**	**0**	**0**	**0**	*11*	*11*	*15*	*0*	*0*	**0**	**0**	**0**	**0**	**0**	*11*	*0*	*20*	*0*	*0*
Euphorbia heterophylla L.	**0**	*17*	*0*	*0*	**0**	*0*	*0*	*0*	*0*	*0*	**0**	**17**	**0**	**11**	**0**	*0*	*0*	*0*	*0*	*0*
Euphorbia hirta L.	**0**	*0*	*0*	*0*	**0**	*0*	*0*	*0*	*0*	*0*	**10**	**23**	**0**	**11**	**0**	*0*	*0*	*0*	*0*	*0*
Fimbristylis dichotoma (L.) Vahl	**0**	*0*	*0*	*14*	**0**	*0*	*0*	*0*	*0*	*0*	**16**	**37**	**0**	**17**	**0**	*0*	*0*	*0*	*0*	*0*
Fimbristylis miliacea Vahl	**21**	**29**	**29**	**29**	**0**	*0*	*0*	*0*	*0*	*0*	**21**	**29**	**29**	**29**	**0**	*0*	*0*	*0*	*0*	*0*

Species	Soil carbon content										Effective cation exchange									
	Fluvisol					Histosol					Fluvisol					Histosol				
	s	hp	cf	cb	ir	s	hp	cf	cb	ir	s	hp	cf	cb	ir	s	hp	cf	cb	ir
Hedyotis corymbosa Lam.	**46**	**60**	**66**	**57**	**0**	*0*	*0*	*0*	*0*	*0*	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*
Hedyotis diffusa Willd.	**19**	**29**	**29**	**17**	**0**	*0*	*0*	*0*	*0*	*0*	**14**	**0**	**20**	**17**	**0**	*0*	*0*	*0*	*0*	*0*
Hewittia sublobata (Lf) Kuntze	**0**	**0**	**0**	**0**	*11*	*0*	*0*	*0*	*0*	*0*	**0**	**0**	**0**	**0**	**11**	*0*	*0*	*0*	*0*	*0*
Imperata cylindrica Beauv.	**0**	**0**	**0**	**0**	*0*	*17*	*20*	*12*	*15*	*22*	**0**	**0**	**0**	**0**	**0**	*17*	*18*	*12*	*15*	*23*
Lasia spinosa (L.) Thw.	**0**	**0**	**0**	**0**	*11*	*0*	*0*	*0*	*0*	*0*	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*
Limnophila rugosa Merrill	**29**	**54**	**29**	**34**	**0**	*0*	*0*	*0*	*0*	*0*	**0**	**0**	**0**	**34**	**0**	*0*	*0*	*0*	*0*	*0*
Lindernia crustacea (L.) F. Muell.	**0**	**0**	**0**	**17**	**0**	*0*	*17*	*0*	*0*	*0*	**0**	**0**	**0**	**14**	**0**	*0*	*15*	*0*	*0*	*0*
Lindernia vicosa Merrill	**0**	**0**	**14**	**20**	**0**	*0*	*12*	*11*	*0*	*0*	**0**	**0**	**14**	**17**	**0**	**0**	**0**	**0**	**0**	**0**
Ludwigia hyssopifolia (G.Don) Exell	**28**	**46**	**29**	**37**	**0**	**15**	**0**	**12**	**0**	**0**	**30**	**49**	**31**	**37**	**0**	**17**	**0**	**14**	**18**	**0**
Lygodium circinnatum Sw.	**27**	**23**	**43**	**40**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*20*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Lygodium microphyllum (Cav.) R.Br.	**0**	**0**	**14**	**0**	**0**	**0**	**0**	**0**	*0*	*25*	*0*	*0*	*14*	*0*	*0*	*0*	*14*	*0*	*0*	*22*
Merremia tridentata (L.) Hallier f.	**0**	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**0**	**0**
Merremia vitifolia Hallier f.	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**17**	**0**	**0**	**0**	**0**	**0**
Mikania micrantha H.B.&K.	*0*	*0*	*49*	*63*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*49*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Nephrolepis biserrata (Sw.) Schott	*0*	*0*	*11*	*0*	*0*	*47*	*25*	*48*	*55*	*58*	*21*	*14*	*11*	*37*	*0*	*37*	*23*	*0*	*0*	*46*
Nephrolepis tuberosa C.Presl	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*11*	*0*	*0*	*0*	*0*	*0*	*0*
Oldenlandia dichotoma Hook f.	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**0**	**0**	**0**
Oxalis corniculata L.	**0**	**11**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*0*	*0*	*11*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Paspalum conjugatum Berg.	**22**	**26**	**17**	**26**	**20**	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*10*	*0*	*0*	*0*	*14*
Peperomia pellucida H.B.&K.	**0**	**0**	**89**	**0**	**0**	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*34*	*0*	*0*	*0*	*0*	*0*
Phaseolus calcaratus Roxb.	**0**	**0**	**0**	**0**	**0**	*0*	*0*	*0*	*0*	*12*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Phyllanthus amarus Schum. & Thonn.	*11*	*26*	*0*	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**14**	**26**	**11**	**17**	**0**	**0**	**0**	**0**	**0**	**0**
Phyllanthus debilis Willd.	**48**	**71**	**51**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**17**
Phytolacca purpurascens A.Br. & Bouche	**0**	**0**	**0**	*11*	*0*	*0*	*0*	*12*	*0*	*0*	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Pityrogramma calomelanos (L.) Link	**0**	**0**	**0**	**17**	**0**	**0**	**0**	**0**	*0*	*12*	*18*	*29*	*23*	*17*	*0*	*0*	*25*	*0*	**0**	**0**
Pleocnemia irregularis (C.Presl) Holtt.	**0**	**0**	**0**	**0**	**14**	**0**	**0**	**0**	*0*	*0*	*12*	*14*	*0*	*20*	*0*	*0*	*0*	*0*	**0**	**0**
Polygonum barbatum L.	**0**	**0**	**0**	**0**	**14**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Pouzolzia zeylanica Benn.	**0**	*0*	*31*	*0*	**0**	**0**	**0**	**0**	**0**	**35**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**38**
Pteris tripartita Sw.	**0**	*0*	*0*	*11*	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Pteris vittata L.	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**12**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Pueraria phaseoloides Benth.	**19**	**23**	**0**	**20**	**29**	**0**	**0**	**15**	**20**	**0**	**20**	**23**	**0**	**23**	**29**	**0**	**0**	**0**	**0**	**0**
Pueraria sp.	*10*	*11*	*0*	*11*	*0*	*0*	*0*	*0*	*0*	*0*	*10*	*11*	*0*	*11*	*0*	*0*	*0*	**0**	**0**	**0**
Scoparia dulcis L.	**14**	**29**	**17**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**10**	**29**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Selaginella plana Hieron.	**0**	**49**	**0**	**51**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Sparganophorus villantii Crantz	**0**	**0**	**0**	**0**	**0**	**14**	**15**	**0**	**22**	**0**	**0**	**0**	**0**	**0**	**0**	**15**	**17**	**17**	**23**	**0**
Sphaerostephanos polycarpus (Bl.) Copel.	**0**	**0**	**0**	**0**	**20**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Sporobolus diander Beauv.	**41**	**0**	**63**	**60**	**0**	**0**	**0**	**0**	**0**	**0**	**42**	**46**	**66**	**57**	**0**	**0**	**0**	**0**	**0**	**0**
Stachytarpheta indica (L.) Vahl	**0**	**26**	**0**	**0**	**20**	**0**	**0**	**0**	**0**	**0**	**19**	**31**	**0**	**17**	**20**	**0**	**0**	**0**	**0**	**0**
Stenochlaena palustris Bedd.	*11*	*0*	*0*	*0*	*23*	*0*	*0*	*11*	**0**	**0**	*0*	*17*	*0*	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Uncaria cf. *glabrata* (Bl.) DC.	*0*	*11*	*0*	*0*	*11*	*0*	*0*	*0*	**0**	**11**	*0*	*11*	*0*	**0**	**0**	**0**	**0**	**0**	**0**	**11**
Vitis japonica Thunb.	*19*	*23*	*14*	*14*	*23*	*0*	*0*	*0*	**0**	**0**	*0*	*0*	*11*	**11**	**0**	**0**	**0**	**0**	**0**	**0**

4 Discussion

Intermittent flooding of the adjoining rivers and the fact that most of the research area was covered by swamp previous to drainage, suggests that natural genesis of both soil types was in progress until plantation development started in 1992. Flooding seemed to have had a significant influence on the genesis and physical and chemical properties of the upper 20 cm topsoil layer in the research area. The soil texture ranging from silty clay to loamy silt was marked in all samples by a comparatively high clay and silt fraction. Though no analysis of the water suspension was carried out, the visibly sediment laden turbid Batang Pasaman river was apparently the source of the silt and clay deposits. The high base saturation classifies the topsoil of the fluvisol as a eutric horizon (FAO, 1998). The eutric fluvisol developed from a histic fluvisol in consequence of the fast decomposition of a thick litter and humus layer that originally covered the fluvisol areas. A further loss of carbon is possible if the clay fraction diminishes and the stabilizing effect of clay onto organic matter is lost. In an oil palm plantation in Ivory Coast a 35% clay deprivation over 40 years was observed (Yeboua and Ballo, 2000). However, the outstanding difference found between the clay content in the fluvisol samples in this work was probably not due to natural soil genesis but a consequence of topsoil loss during the plantation establishment. All fluvisol sites characterized by a distinctly smaller clay fraction were located in proximity to the nursery. The topsoil from the nursery and adjoining areas was used as filling material for the nursery bags for up to 4 generations of oil palm seedlings. The removal of the topsoil resulted also in a reduced carbon content and a larger silt fraction.

The larger sand fraction in the samples from the histosol sites of the northeastern part of the plantation suggests that this area received little alluvial material from Batang Pasaman and was more frequently exposed to flooding from the Batang Alin black water stream. The proximity of this area to the beach might be a further reason for the higher sand content in the northeast of the plantation. Most of the carbon rich histosol sites were located in the far west and east, while the sites

with lower carbon content were situated in the middle of the plantation on a stripe reaching from the south to the north. This area is a depression as indicated by the drainage water flux and the fact that it is the major inlet of water from Batang Pasaman during flooding events. In all histosol sites the carbon content was above 18%, which reconfirmed the soil type classification. The high fibre content and the partly decomposed nature of the organic matter noted while the soil samples were taken categorized the elevated histosol soils as hemic tropofibrist. The histosol in the lower parts of the plantation contained often layers of alluvial material visible in soil cores and at the edges of drains classifying the soil as fluvaquentic tropofibrist (FAO, 1998).

Fluvisol was marked in comparison with histosol by a lower carbon and nitrogen content as well as an increased pH value and less extractable Al. Further, the concentration of B was greater on histosol, but the cation concentration of Mg and Ca as well as Cu was superior on fluvisol. On both soil types areas of lower and higher carbon content were identified. The pH was lower and due to the negative exponential correlation between pH and Al the amount of exchangeable Al distinctly larger in the sampling sites with greater carbon content. The topsoil of the fluvisol sites with a lower carbon content contained less nitrogen and available K and higher amounts of Mg, Cu and Zn. The variations of the soil carbon and nitrogen content, pH value, extractable Al and Mg were as indicated by larger standard errors (Fig. 16) on fluvisol of higher carbon content where the topsoil was not disturbed during plantation establishment. In the carbon rich histosol sites more P was available, the concentration of Zn larger and the concentration of Cu lower. The larger area, but also the greater difference of time passed since land use change adds to the variation of the soil properties on histosol. There were significantly higher amounts of K and Mg in the fields cleared latest, while in the sites cleared earlier most of the nutrients released by burning of the felled forest biomass were probably lost by leaching and fixation or taken up by the vegetation. However, apart from extractable B and Cu the standard errors of the elements were not distinctly different between histosol of high and low carbon content.

Natural soil genesis and operations during plantation establishment have thus created areas of different physical and chemical properties within the research area. A comparison of the obtained soil parameters with soil fertility evaluation data for oil palm from Mutert (1999) revealed that the amount of available P was low in all cases on both soils and exchangeable K low in some sites on fluvisol. The extremely high concentration of exchangeable Mg found in several samples might however suppress K uptake of oil palm (Turner and Gillbanks, 1974). A critical ratio for soil exchangeable Mg:K of 2 was proposed by Tinker and Ziboh (1959), while in the present study an average ratio of 13 was found on fluvisol and of 5 on histosol respectively.

The most outstanding difference of the chemical soil properties between the field zones and circle sections on both soil types was a lower pH and an increased concentration of exchangeable Al in the front of the palm circle. Further, the concentration of Ca and the amount of exchangeable Zn were in the circle zones lower than in the harvesting path and the inter-row. The amount of exchangeable K was consistently larger in the front of the palm circle and the C and N content lower in the back of the palm circle. A larger amount of exchangeable Mg characterized the samples from the inter-row.

The lower pH in the front of the palm circle was apparently the consequence of continuous urea application. Ammonium fertilizers cause significant acidification of agricultural soil (Schachtschabel et al., 1992; Malhi et al., 1998). Nitrogen fertilizer induced acidification was also observed in a similar environment on alluvial soils in Papua New Guinea (Hartemink, 1998). The higher pH values in the circle back suggest that here less fertilizer was applied. Task paid workers are inclined to spread fertilizers from the path over the front of the palm circle to avoid circumference of the trunk. As a result of the lower pH the amount of exchangeable Al was higher and less exchangeable Mg was available. The weak bondage between negatively loaded soil colloids and Mg results in high leaching rate of Mg under humid conditions (Mengel, 1991). The causal relationship between pH and both elements Al and Mg was reconfirmed by a strong correlation found between these parameters. Though the nitrogen fertilizer induced shifts of the soil

properties were observed on both soils they were generally stronger on fluvisol. This was probably due to the lowered buffering capacity of fluvisol where the topsoil was removed and the different types and rates of fertilizers applied on the two soil types. Not only urea was applied at about half the rate on histosol, but the circles of mature palms on histosol received additionally large rates of caustic bunch ash. Dolomite was spread in the inter-row and did thus not neutralise the acidifying effect of nitrogen fertilization in the palm circle. Alkaline rock phosphate was also applied in the inter-row and at same rates on both soil types.

Uneven fertilizer application was also indicated by the larger amount of exchangeable K in the front of the palm circle. In the fluvisol sites marked by a lower carbon content K availability was over three times higher in the circle front (5.6 $mmol_c\ kg^{-1}$) than in the circle back (1.7 $mmol_c\ kg^{-1}$). The amount of available K was also higher in the circle front on histosol, though here the difference was not significant. The smaller difference of available K in the circle zones on histosol was assumed to be a result of the high K-leaching rate on peat (Silfverberg, 1998). Further, bunch ash the K fertilizer used for mature oil palm on histosol was applied usually more evenly due to the large volume applied at each round of fertilization. The concentration of Cu in the front of the palm circle was lower on fluvisol. The higher carbon content in this circle section suggests that a considerable part of the extractable Cu was fixed due to the strong binding of Cu to organic matter. This binding regulates the Cu dynamics in histosol too, however here the more frequent application of copper sulphate were susceptibly also uneven and raised extractable Cu in the circle front above the concentration found in the circle back.

The soil carbon content was lower in the circle back than in the other field zones, though neither the circle front nor the circle back received any organic matter through frond mulching or weed debris. Haron et al. (1998) found in Malaysia that oil palm roots contribute significantly to the soil organic matter. This is due to the high self-pruning rate that affects up to 60% of the primary root mass emitted annually (Jourdan and Rey, 1997). Nutrient supply particularly of N and P has a strong effect on the growth, morphology and distribution of roots in the soil profile

(Marschner, 1995). Thus root distribution in the palm circle may be a response to the placement of fertilizers. It is therefore concluded that the higher availability of nutrients in the front of the palm circle increased the carbon content through stimulation of oil palm root growth. The inter-row in oil palm plantations receives usually considerable amounts of organic matter through mulching of the pruned fronds. In a smallholder plantation in proximity to the research area an annually input of 13 t ha^{-1} frond dry matter was measured (Fairhurst, 1996). In this work mulching did not increase the carbon content in the inter-row. Similar findings were obtained from other works and it was suggested, that most of the frond material decomposes on the soil surface and does not significantly affect the soil carbon pool (Jourdan and Rey, 1997; Fairhurst, 1996). In the inter-row of the histosol sites the carbon content was even significantly lower than on the harvesting path. There is no causal explanation for this difference, but the faster decomposition of the well-aerated organic matter in the inter-row and the better growing environment for the oil palm roots in the denser and more humid soil of the harvesting path might be key factors.

P accumulates in the topsoil (Schachtschabel et al., 1992), because a major part of the soil P is usually bound in organic forms (Mengel, 1991; Agbenin and Goladi, 1997) and added P is quickly immobilised as it combines with Ca to Ca-phosphates or is fixed to Al and Fe compounds (Rankine and Fairhurst, 1999). Accordingly less available P was detected in the samples from the fluvisol sites marked by lower carbon content in consequence of topsoil removal, though this relationship was not significant. In spite of the active role of organic matter complexed with Al and Fe oxides and hydrous oxides in P fixation (Fairhurst, 1996; Mengel, 1991) significantly more available P was measured in the histosol sites marked by higher carbon content. It is therefore assumed that the high rate of soil organic matter decomposition (Wösten et al., 1997) and organic P mineralization (Mengel, 1991) provides more P than fixation makes unavailable. This explains also the positive correlation between soil carbon content and P availability in the carbon rich fluvisol sites. The negative correlation of P to the pH value was a consequence of the strong positive correlation between soil carbon and

the pH value. An increase of the pH value decreases the soil's P fixation capacity by reducing Al and Fe solubility (Sanchez, 1976; Juo and Manu, 1996). In accordance with this the pH value was lower, exchangeable Al higher and available P reduced in the front of the palm circle of the carbon rich fluvisol sites (Fig. 16).

Rankine and Fairhurst (1998a, b), Hartley (1988) and Turner and Gillbanks (1974) published guidelines for fertilizer application in oil palm. It is generally recommended that nitrogen and micronutrient fertilizers are spread homogenously in the palm circle. The same accounts for P and K fertilizers under immature palms. Under bearing palms these two fertilizers are to be applied also on the frond stacks in the inter-row. Consequently nutrient levels and soil chemical parameters are ideally uniform within each field segment. In this study however the most outstanding and from the agronomic, economic and environmental viewpoint perturbing finding was the significant difference of the chemical soil parameters between the front and the back of the palm circle.

The carbon content was the single most important soil property influencing the oil palm undergrowth species composition. Soil genesis and topsoil removal caused significant spatial differences of the soil carbon content in the research area. Organic matter being the principal pool of soil carbon influences through decomposition, mineralization, fixation, acidification and changes in the physical soil properties the concentration and availability of nutrients (Mengel, 1991; Schachtschabel et al., 1992). These interactions and the large variation of the carbon content are assumed to have blanketed relationships between other soil properties and species distribution. The only parameter largely independent of soil carbon content with a distinct impact on the species composition was the ECEC.

A preference towards low carbon content showed 11 species. These were more common on fluvisol than on histosol (chapter 1) and occurred more frequently in the fluvisol sites poorer in carbon: *Ceratopteris thalictroides*, *Christella dentata*, *Christella parasitica*, *Diplazium esculentum*, *Eleusine indica*, *Hedyotis corymbosa*, *Pleocnemia irregularis*, *Polygonum barbatum*, *Selaginella plana*, *Sphaerostephanos*

polycarpus and *Stachytarpheta indica*. Accordingly the presence of two species: *Borreria latifolia* and *Dicranopteris linearis* augmented with increasing soil carbon content.

In the sampling sites marked by high ECEC ferns were dominant.

The greatest K values were measured in the sites cleared latest. In these the below canopy solar radiation was also higher due to the younger palm age. It is therefore assumed that the frequent presence of *Basella alba*, *Imperata cylindrica* and *Stenochlaena palustris* in these sites was rather because these species are pioneer invaders with a high light demand than due to the higher K availability.

The intensity of below canopy solar radiation apparently influenced also the distribution of four species that showed a contradictive response to soil carbon content; they were more frequent on histosol, but demonstrated a preference towards sites poor in soil carbon on fluvisol. These species were previously identified as distinctly more common in fluvisol sites with higher values of solar radiation below the palm canopy: *Hedyotis diffusa*, *Paspalum conjugatum*, *Pueraria phaseoloides* and *Sporobolus diander* (compare chapter 2).

Summary

The area planted to oil palm expanded during the last decades substantially, making it become the world's second most important oil crop. Despite its current significance the oil palm remains remarkably unknown (Henderson and Osborne, 2000). Little attention is paid also to the oil palm undergrowth, though it is important in stabilizing the agro-ecosystem in plantations (Mexzón and Chinchilla, 1999; Ho and Teh, 1999; Fairhurst, 1996).

In the current research work a reproducible approach for phytosociological investigation of the undergrowth in oil palm plantations was developed. The approach enables not only the comparison of the vegetation between fields, but also between the differently managed zones of the fields. The basic element of all sampling and measurements was a relevé or sampling site measuring 300 m^2 each. In every relevé five frequency plots at each 1m^2 were positioned on the harvesting path, in front of the palm circle towards the harvesting path, in the back of the palm circle towards the inter-row and in the inter-row. The vegetation was sampled and the degree of coverage of every species estimated in all relevés. The presence of all species in each frequency plot was recorded. To investigate correlations between the undergrowth species composition and shading, solar radiation was measured on harvesting path, palm circle and inter-row. Soil samples were taken from each frequency plot and the influence of soil physical and chemical properties on the species composition assessed.

A rich diversity of almost 298 species, 186 dicotyledonae, 77 monocotyledonae and 35 pteridophyta (ferns and allies), representing 81 families were identified in the research area. The number of species found was less than in natural forest of the region, but greater than in the ground vegetation of forests. Similar to rainforests, plants with a high consistency were few, while most of the species occurred only sporadically in the oil palm undergrowth. The 8 most frequent species were identified as an abstract plant community (an abstract plant community is a group of species that cannot be placed into an established vegetation type concept (Mueller-Dombois and Ellenberg,

1974)): *Mikania micrantha* H.B.&K., *Pouzolzia zeylanica* Benn., *Ageratum conyzoides* L., *Sporobolus diander* Beauv., *Nephrolepis biserrata* (Sw.) Schott., *Pityrogramma calomelanos* (L.) Link, *Lygodium microphyllum* (Cav.) R.Br. and *Stenochlaena palustris* Bedd..

Due to particular management practice, oil palm fields can be zoned in harvesting path, palm circle and inter-row. These field zones represent specific microhabitats that host alternative species compositions. Species that were mainly found in the inter-row were: *Diplazium esculentum, Cyclosorus interruptus* (Willd.) H.Ito*, Nephrolepis biserrata* and *Christella dentata.* Plants that were found primarily in the other zones were small herb species such as *Hedyotis corymbosa*, *Limnophila rugosa* Merrill, *Borreria setidens* (Miq.) Boldingh and *Peperomia pellucida*, the sedges *Fimbristylis miliacea* Vahl and *Cyperus kyllingia* Endl. as well as the grass *Sporobolus diander*.

Environmental parameters with the greatest impact on the species composition within the research area were solar radiation below the palm canopy, soil type, its carbon content and effective cation exchange capacity (ECEC). The planting density was consistent throughout the plantation and expansion of the crown radius the major parameter determining the below canopy solar radiation. It was found that the canopies developed slower on histosol than on fluvisol and assumed that the main reason for this difference was the lower nutrient pool in low-density organic soil.

Distinct dissimilarities in the undergrowth composition were found between sampling sites of different average below canopy solar radiation, while the spatial heterogeneity of solar radiation within the sampling sites had little influence on the undergrowth species composition. The number of monocotyledonae decreased and the number of pteridophyta increased with reduced levels of solar radiation. Melliferous species, which are often important as hosts for pest antagonists, were infrequent where less light was available. In the inter-row a distinct shift from a creeper and grass to a fern and non-creeper dicotyledonae dominated undergrowth was observed with falling levels of solar radiation. Species consistently more frequent in brighter sampling sites throughout the research area were: *Basella alba* Linn.,

Calopogonium muconoides Desv., *Commelina diffusa* Brum.f., *Imperata cylindrica* Beauv., *Pueraria phaseoloides* Benth. and *Sporobolus diander*, whereas *Ageratum conyzoides*, *Christella dentata* (Forssk.) Brownsey & Jermy, *Diplazium esculentum* (Retz.) Sw., *Peperomia pellucida* H.B.&K., *Phyllanthus debilis* Willd., *Pouzolzia zeylanica* and *Sparganophorus villantii* Crantz preferred more shaded environments.

The soil analyses revealed, that the soil carbon content was not only distinctly different between histosol and fluvisol, but also between individual sites on the two soil types. Next to the carbon content the effective cation exchange capacity varied largely between sites. The physical soil properties were stable within the sites, while the chemical properties were significantly influenced by fertilization. Urea lowered the pH and thus reduced extractable Ca, Mg and the ECEC as it augmented exchangeable Al. Muriate of potash and bunch ash increased extractable potassium, while bunch ash also neutralised acidity on histosol. These effects were not only observed in the fertilized palm circle in comparison with the remaining area, but also between the front of the palm circle towards the harvesting path and the back of the palm circle towards the inter-row. This was apparently a consequence of more fertilizer applied in the front than in the back of the palm circle. The greater carbon content in the front of the palm circle suggests that the higher nutrient availability encouraged palm root growth.

Species abundance per relevé was significantly higher on fluvisol than on histosol, while the difference in the total number of species between the soil types was small. 11 species showed a preference towards low soil carbon content: *Ceratopteris thalictroides* (L.) Brongn., *Christella dentata*, *Christella parasitica* (L.) Lev., *Diplazium esculentum*, *Eleusine indica* (L.) Gaertn., *Hedyotis corymbosa* Lam., *Pleocnemia irregularis* (C.Presl) Holtt., *Polygonum barbatum* L., *Selaginella plana* Hieron., *Sphaerostephanos polycarpus* (Bl.) Copel. and *Stachytarpheta indica* Vahl. Accordingly the presence of two species: *Borreria latifolia* (Aubl.) K. Schum. and *Dicranopteris linearis* J. Underw. augmented with increasing soil carbon content. In the sampling sites marked by high ECEC ferns were dominant. On fluvisol 11 out of 18 species that occurred more frequently where the ECEC was higher were ferns and

on histosol 3 out of 12 species respectively. The distinct difference of soil carbon content blanketed, apart from the ECEC possible effects of variations of other soil parameters on the undergrowth species composition.

Zusammenfassung

Die weltweit mit Ölpalmen kultivierte Fläche dehnte sich in den letzten Dekaden stark aus, damit wurde die Ölpalme global zur zweitwichtigsten Ölpflanze. Trotz ihrer Bedeutung als wichtige Nahrungspflanze ist die Ölpalme relativ unbekannt (Henderson and Osborne, 2000). Dem Unterwuchs in Ölpalmplantagen wird, obwohl er wichtige stabilisierende Wirkungen auf das Agroökosystem hat (Mexzón and Chinchilla, 1999; Ho and Teh, 1999; Fairhurst, 1996) ebenfalls wenig Aufmerksamkeit geschenkt.

In der vorliegenden Arbeit wurde ein reproduzierbarer Ansatz für die phytosoziologische Inventur von Unterwuchs in Ölpalmplantagen in Abhängigkeit von abiotischen Faktoren entwickelt. Der Ansatz ermöglicht einen Vergleich der Vegetation zwischen Feldern und zwischen den unterschiedlich behandelten Zonen einzelner Felder. Die grundlegende Einheit für alle Vegetationsaufnahmen war ein Relevé oder Aufnahmefläche von 300 m^2. Alle im Relevé vorkommenden Pflanzenarten wurden registriert und ihr Deckungsgrad geschätzt. Zusätzlich wurden in jedem Relevé fünf Frequenzparzellen (á 1 m^2) auf dem Erntepfad, in dem vorderen (zum Erntepfad) und hinteren (zu den Zwischenreihen) Teil der Baumscheiben und in den Zwischenreihen platziert. Um den Einfluss des Lichteinfalls auf die Zusammensetzung des Unterwuchses zu untersuchen wurde die Sonneneinstrahlung unter dem Blätterdach der Palmen in allen Feldzonen gemessen. Bodenproben sollten Aufschluss über einen Zusammenhang zwischen Bodeneigenschaften und Pflanzenbewuchs geben.

Im Untersuchungsgebiet wurden 298 Pflanzenarten, 186 Dicotyledonae, 77 Monocotyledonae und 35 Pteridophyta (Farne und farnähnliche Pflanzen) aus insgesamt 81 Familien gefunden. Die Artenvielfalt war geringer als in den natürlichen Wäldern der Region, aber wesentlich höher als im Unterwuchs dieser Wälder. Ähnlich wie im tropischen Regenwald war die Zahl der stetig vorkommenden Arten gering und der sporadisch anzutreffenden Arten

hoch. Acht mit höchster Stetigkeit gefundene Arten wurden als abstrakte Vegetationsgesellschaft für das Untersuchungsgebiet identifiziert (eine abstrakte Vegetationsgesellschaft ist eine Artengruppe, die nicht in ein feststehendes Vegetationsformenkonzept eingegliedert werden kann (Mueller-Dombois and Ellenberg, 1974)): *Mikania micrantha* H.B.&K., *Pouzolzia zeylanica* Benn., *Ageratum conyzoides* L., *Sporobolus diander* Beauv., *Nephrolepis biserrata* (Sw.) Schott., *Pityrogramma calomelanos* (L.) Link, *Lygodium microphyllum* (Cav.) R.Br. and *Stenochlaena palustris* Bedd..

Die verschiedenen Feldzonen, der Erntepfad, die Baumscheiben und die Zwischenreihen unterliegen einem unterschiedlichen Management und Pflege. Es konnte nachgewiesen werden, dass in den spezifischen Mikrohabitaten der Zonen angepasste Artenzusammensetzungen vorkommen. Zu den Arten die vorwiegend in den Zwischenreihen gefunden wurden gehören: *Diplazium esculentum, Cyclosorus interruptus* (Willd.) H.Ito*, Nephrolepis biserrata* and *Christella dentata.* Wogegen in den anderen Zonen überwiegend niedrigwüchsige krautige Arten wie: *Hedyotis corymbosa*, *Limnophila rugosa* Merrill, *Borreria setidens* (Miq.) Boldingh und *Peperomia pellucida*, die Seggen *Fimbristylis miliacea* Vahl und *Cyperus kyllingia* Endl. wie auch das Gras *Sporobolus diander* dominierten.

Die abiotischen Faktoren, die am stärksten die Zusammensetzung des Unterwuchses beeinflussten waren die Sonneneinstrahlung unterhalb der Palmenkronen, der Bodentyp, der Kohlenstoffgehalt und die effektive Kationen-Austauschkapazität des Bodens. Die Pflanzdichte war konstant und die Beschattung des Bodens hauptsächlich von der Ausdehnung des Kronenradius beeinflusst. Es wurde eine verzögerte Entwicklung der Palmenkrone auf Histosol festgestellt und angenommen, dass diese Verzögerung mit dem geringeren Nährstoffvorrat auf organischem Boden mit geringerer Dichte zusammenhängt. Die Zahl der einkeimblättrigen Arten nahm bei reduzierten Lichtverhältnissen ab und die Zahl der Farn-

pflanzen zu. Nektarbildende Arten, welche oft wichtige Zwischenwirte für Schädlingsantagonisten sind, waren seltener unter starker Beschattung. Mit abnehmender Sonneneinstrahlung wurde in den Zwischenreihen eine deutliche Verlagerung von kriechenden Bodendeckern und Gräsern zu Farnen und nichtkriechenden Zweikeimblättrigen in der Vegetation festgestellt. Arten die wesentlich öfter in den wenig beschatteten Relevés vorkamen waren: *Basella alba* Linn., *Calopogonium muconoides* Desv., *Commelina diffusa* Brum.f., *Imperata cylindrica* Beauv., *Pueraria phaseoloides* Benth. und *Sporobolus diander*, wogegen *Ageratum conyzoides*, *Christella dentata* (Forssk.) Brownsey & Jermy, *Diplazium esculentum* (Retz.) Sw., *Peperomia pellucida* H.B.&K., *Phyllanthus debilis* Willd., *Pouzolzia zeylanica* und *Sparganophorus villantii* Crantz direkte Sonneneinstrahlung mieden.

Die Bodenanalysen zeigten auf, dass der Kohlenstoffgehalt des Fluvisols wesentlich geringer war als des Histosols, aber auch zwischen den verschiedenen Relevés der beiden Bodentypen wurden deutliche Differenzen gefunden. Neben dem Kohlenstoffgehalt wurde eine starke Abweichung der effektiven Kationen-Austauschkapazität zwischen den Aufnahmeflächen festgestellt. Innerhalb der Relevés waren die physikalischen Bodeneigenschaften stabil, während die chemischen Parameter signifikant durch die Düngung beeinflusst wurden. Harnstoffgaben führten zu niedrigeren pH Werten verbunden mit geringerem austauschbaren Ca, Mg und effektiver Kationen-Austauschkapazität, gleichzeitig erhöhten Harnstoffgaben lösliches Al im Boden. Kaliumchlorid und die bei der Verbrennung der ausgedroschenen Ölpalmfruchtstände gewonnene Asche steigerten austauschbares Kalium. Die Fruchtstandasche neutralisierte auf Histosol die saure Bodenlösung. Diese Effekte wurden nicht nur zwischen den gedüngten Baumscheiben und den übrigen Feldzonen, sondern auch zwischen der vorderen und hinteren Hälfte der Baumscheiben beobachtet. Der Unterschied der chemischen Bodeneigenschaften zwischen den

beiden Hälften der Baumscheiben beruhte offensichtlich darauf, dass in der vorderen Hälfte mehr Dünger appliziert wurde. Es wurde angenommen, dass der höhere Kohlenstoffgehalt im Boden unter der vorderen Hälfte der Baumscheiben auf verstärktem Wurzelwachstum der Palmen beruhte, hervorgerufen durch bessere Nährstoffverfügbarkeit.

Die Artenvielfalt pro Relevé war auf Fluvisol signifikant höher als auf Histosol, wobei die absolut auf den beiden Bodentypen gefundene Artenzahl nur geringfügig abwich. 11 Arten wuchsen bevorzugt auf Böden mit geringem Kohlenstoffgehalt: *Ceratopteris thalictroides* (L.) Brongn., *Christella dentata*, *Christella parasitica* (L.) Lev., *Diplazium esculentum*, *Eleusine indica* (L.) Gaertn., *Hedyotis corymbosa* Lam., *Pleocnemia irregularis* (C.Presl) Holtt., *Polygonum barbatum* L., *Selaginella plana* Hieron., *Sphaerostephanos polycarpus* (Bl.) Copel. und *Stachytarpheta indica* Vahl. Dagegen kamen nur zwei Arten deutlich öfters auf Kohlenstoff reichem Boden vor: *Borreria latifolia* (Aubl.) K. Schum. und *Dicranopteris linearis* J. Underw.. In den Relevés, die sich durch hohe effektive Kationen-Austauschkapazität auszeichneten traten Farne verstärkt auf, auf Fluvisol 11 von 18 Arten und auf Histosol drei von 12 Arten. Der starke Unterschied im Kohlenstoffgehalt maskierte, abgesehen von der effektiven Kationen-Austauschkapazität, mögliche Auswirkungen anderer Bodeneigenschaften auf die Zusammensetzung der Vegetation.

References

Agbenin, J.O. and Goladi, J.T. (1997) Carbon, nitrogen and phosphorus dynamics under continuous cultivation as influenced by farmyard manure and inorganic fertilizers in the savanna of northern Nigeria. Agriculture, Ecosystems and Environment, 63, 17-24.

Anonymous (2002a) 50,000 hectares oil palm to be cultivated near Freetown. In: Concord Times, 12 March 2002, Freetown, Sierra Leone.

Anonymous (2002b) Palm oil production will plateau. Available at: www.agjournal.com, Accessed on: 02.05.2002.

Armstrong, D.L., ed. (1999) The oil palm - fact file. Better Crops International, 13, 28-29.

Barnes, D.E. and Chan, L.G. (1990) Common weeds of Malaysia and their control. 3rd edn., Ancom Berhad, Persiaran Selangor, Malaysia.

Beaufoy, G. (2000) The olive oil regime. In: CAP Regimes and the European countryside - prospects for integration between agriculture, regional and environmental policies (eds Brouwer, F. and Lowe, P.), pp. 155-178. CAB International, Wallingford, UK.

Berger, K.G. and Martin, S.M. (2000) Palm oil. In: The Cambridge world history of food (eds Kiple, K.F. and Ornelas, K.C.). Cambridge University Press, Cambridge, UK.

Braun-Blanquet, J. (1928) Pflanzensoziologie - Grundzüge der Vegetations-kunde. 2nd edn., Springer, Wien, Austria.

Bray, R.H. and Kurtz, L.T. (1945) Determination of total, organic, and available forms of phosphorus in soils. Soil Science, 59, 39-45.

Bücher, H. and Fickendey, E. (1919) Die Ölpalme. Auslandswirtschaft in Einzeldarstellungen, Auswärtiges Amt, Berlin, Germany.

Burhan, H.A. (1993) Studies on weeds in low-land rice in the northern coastal plain of West-Java, Indonesia. Plits 11(5), Verlag J. Margraf, Stuttgart, Germany.

Cain, S.A. (1938) The species-area curve. American Midland Naturalist, 19, 573-581.

Casson, A. (2000) The hesitant boom: Indonesia's oil palm sub-sector in an era of economic crisis and political change. Occasional Paper 29, CIFOR, Bogor, Indonesia.

Chazdon, R.L. (1988) Sunflecks and their importance to forest understory plants. Advances in Ecological Research, 18, 1-63.

Chee, Y.K. and Chung, G.F. (1998) Integrated weed management in oil palm. In: MOSTA Symposium 5: Recent Advances in the Oil Palm Sector, 15-17 October 1998, pp. 1-14. Malaysian Oil Scientists' and Technologists' Association (MOSTA) and The Incorporated Society of Planters (ISP), Lumut, Malaysia.

Chen, C.P. and Bong, J.I. (1983) Performance of tropical forages under the closed canopy of the oil palm. I. Grasses. MARDI Research Bulletin, 11, 248-263.

Chin, S.C. (1985) Survey of vegetation and flora in and around the proposed site of the Ciba-Geigy Agricultural Experiment Station, Malaysia, at Sungei Layang, District of Rembau, Negeri Sembilan, West Malaysia. Department of Botany, University of Malaya, Kuala Lumpur, Malaysia. In: Scholaen,S. 1991. Untersuchungen zur Entwicklung der Flora bei der Umwandlung von Hevea-Plantagen in Ackerfläche mit unterschiedlicher Bodenbearbeitung in West Malaysia. Verlag J. Margraf, Stuttgart, Germany.

CIRAD (2001) Oil palm programme. Available at: www.cirad.fr/presentation/-en/program-eng/palmier.shtml, Accessed on: 16.04.2002.

Corley, R.H.V. (1996) What is the upper limit to oil extraction ratio? In: Proceedings of the International conference on oil and kernel production in oil palm - A global perspective (eds Rajanaidu, N., Henson, I.E. and Jalani, B.S.), pp. 256-269. PORIM and Ministry of Primary Industries, Malaysia, Kuala Lumpur, Malaysia, 27-28 Sep 1996.

Corley, R.H.V. and Breure, C.J. (1981) Measurements in oil palm experiments, Internal Report. Unipamol Malaysia Sdn. Bhd.

Corley, R.H.V. and Mok, C.K. (1972) Effects of nitrogen, phosphorus, potassium and magnesium on growth of the oil palm. Experimental Agriculture, 8, 347-353.

Corley, R.H.V., Rajaratnam, J.A., and Chan, K.W. (1976) Ground cover management. In: Oil Palm Research (eds Corley, R.H.V., Hardon, J.J. and Wood, B.J.), pp. 285-289. Elsevier, Amsterdam, Netherlands.

Cottrell, R.C. (1991) Introduction: Nutritional aspects of palm oil. American Journal of Clinical Nutrition, 53, 989-1009.

Dahlan, I., Yamada, Y., and Mahyuddin, M.D. (1993) Botanical composition and models of metabolizable energy availability from undergrowth in oil palm plantations for ruminant production. Agroforestry Systems, 24, 233-246.

Ellenberg, H., Weber, H.E., Dull, R., Wirth, V., Werner, W., and Paulissen, D. (1992) Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica, 18, 1-258.

Fairhurst, T. (1996) Management of nutrients for efficient use in smallholder oil palm plantations. PhD Thesis, University of London, Wye, Ashford, Kent, UK.

Fairhurst, T. and Mutert, E. (1999) Interpretation and management of oil palm leaf analysis data. Better Crops International, 13, 48-51.

Fairhurst, T., Mutert, E., and von Uexküll, R. (1998) Agronomic management of oil palms on deep peat. In: 1998 International Oil Palm Conference jointly organized by the 'Indonesian Oil Palm Research Institute' and the 'Indonesian Palm Oil Producers Association', Bali, Indonesia.

FAO (1998) World reference base for soil resources. Available at: http://www.fao.org, Accessed on: 20.10.01.

FAO (2002a) FAOSTAT. Available at: http://www.apps.fao.org, Accessed on: 16.03.2002.

FAO (2002b) Oil palm in western Kenya. Available at: www.fao.org/ag/-magazine/0202sp1.htm, Accessed on: 16.04.2002.

Fujisaka, S., Escobar, G., and Veneklaas, E. (1998) Plant community diversity relative to human land uses in an Amazon forest colony. Biodiversity and Conservation, 7, 41-57.

Germer, J. and Sauerborn, J. (2002) Impact of oil palm plantation establishment on the greenhouse gas balance. (submitted to Agriculture, Ecosystems and Environment).

Gerritsma, W. and Soebagyo, F.X. (1999) An analysis of the growth of leaf area of oil palms in Indonesia. Experimental Agriculture, 35, 293-308.

Gerritsma, W. and Wessel, M. (1997) Oil palm: Domestication achieved? Netherlands Journal of Agricultural Science, 45, 463-475.

Gill, L.S. and Onyibe, H.I. (1998) Phytosociological studies of the weed flora of oil palm (*Elaeis guineensis* Jacq.) in Nigeria. Journal of Plantation Crops, 16, 88-99.

Hamer, W.I. (1981) Soil conservation, Rep. No. INS/78/006. Consultant's report, Technical Note No.7 and No. 10. UNDP, In: MacKinnon, K., Hatta, G., Halim, H., and Mangalik, A. (1996): The Ecology of Kalimantan, Periplus Editions (HK) Ltd, Singapore.

Haron, K., Brookes, P.C., Anderson, J.M., and Zakaria, Z.Z. (1998) Microbial biomass and soil organic matter dynamics in oil palm (*Elaeis guineensis* Jacq.) plantations, West Malaysia. Soil Biology & Biochemistry, 30, 547-552.

Hartemink, A.E. (1998) Acidification and pH buffering capacity of alluvial soils under sugarcane. Experimental Agriculture, 34, 231-249.

Hartley, C.W.S. (1988) The oil palm. Agricultural Series, 3rd edn., Longman, Harlow, UK.

Hashim, G.M., Yussoff, W.A., and Ciesiolka, C. (1997) Overland flow and soil erosion in sloping agricultural land. Malaysian Journal of Soil Science, 1, 35-49.

Henderson, J. and Osborne, D.J. (2000) The oil palm in all our lives: how this came about. Endeavour, 24, 63-68.

Ho, C.T. and Teh, C.L. (1999) The use of *Euphorbia heterophylla* L. for natural reduction of leaf pests damage to oil palm. In: Proceedings of the 1999 PORIM International Palm Oil Congress - Agriculture. Emerging Technologies and Opportunities in the Next Millennium, pp. 139-164. Palm Oil Research Institute of Malaysia (PORIM), Kuala Lumpur, Malaysia, 1-6 February 1999.

IFAD (2002) Approved project for Uganda - Vegetable oil development project. Available at: www.ifad.org/operations/projects/regions/PF/des/-UG.htm, Accessed on: 10.04.2002.

Jaafar, M. and Sukaimi, J. (2001) The future of palm oil in the new millennium in Malaysia. Burotrop Bulletin, 16, 10-13.

Jalaludin, S. (1997) Integrated animal production in the oil palm plantation. In: Second FAO electronic conference on tropical feeds: livestock feed resources within integrated farming Systems, 9 September 1996 - 28 February 1997. Food and Agriculture Organization of the United Nations. Available at: www.fao.org, Accessed on: 20.11.2000.

Jourdan, C. and Rey, H. (1997) Architecture and development of the oil-palm (*Elaeis guineensis* Jacq.) root system. Plant and Soil, 189, 33-48.

Juo, A.S.R. and Manu, A. (1996) Chemical dynamics in slash-and-burn agriculture. Agriculture, Ecosystems and Environment, 58, 49-60.

Kiew, R. (1988) Herbaceous flowering plants. In: Key environments: Malaysia (ed Cranbrook, E.). Pergamon Press, Oxford, UK.

Kui, Y.T. (2001) Surviving the low prices of palm oil. In: New Straits Times, 08 April 2001, Kuala Lumpur, Malaysia.

Kürschner, E. (1986) Untersuchungen zu Art, Dynamik und Bedeutung der Segetalflora in West-Samoa unter besonderen Berücksichtigung von Taro (*Colocasia esculenta* (L.) Schott). Plits 4(4), Verlag J. Margraf, Stuttgart, Germany.

Laidlaw, R.K. (2000) Effects of habitat disturbance and protected areas on mammals of Peninsular Malaysia. Conservation Biology, 14, 1639-1648.

Lee, C.H. (1997) Yield potential of Golden Hope D x P oil palm planting materials. Planter, 73, 201-213.

Lim, K.H. (1990) Soil erosion control under mature oil palms on slopes. In: Proceedings of the 1989 PORIM International Palm Oil Development Conference. Module II Agriculture, Palm Oil Research Institute of Malaysia, Kuala Lumpur.

Lindsay, W.L. and Norwell, W.A. (1978) Development of DTPA test for zinc, iron, manganese and copper. Soil Science Society of America Journal, 42, 421-428.

Longman, K.A. and Jenik, J. (1987) Tropical forest and its environment. Longman Scientific & Technical, Essex, UK.

MacKinnon, K., Hatta, G., Halim, H., and Mangalik, A. (1996) The ecology of Kalimantan. The Ecology of Indonesia Series Volume III, Periplus Editions (HK) Ltd, Singapore.

Maene, L.M., Thong, K.C., Ong, T.S., and Mokhtaruddin, A.M. (1979) Surface wash under mature oil palm. In: Proceedings of Symposium on Water in Malaysian Agriculture (ed Pushparajah, E.), pp. 203-216. Malaysian Society of Soil Science, Kuala Lumpur, Malaysia.

Mainstone, B.J. and Wong, P.W. (1966) If *Mikania* invades. The Planter, 42, 3-7.

Malhi, S.S., Nyborg, M., and Harapiak, J.T. (1998) Effects of long-term N fertilizer-induced acidification and liming on micronutrients in soil and in bromegrass hay. Soil & Tillage Research, 48, 91-101.

Marschner, H. (1995) Mineral nutrition of higher plants. Academic Press, London, UK.

Mengel, K. (1991) Ernährung und Stoffwechsel der Pflanzen. Gustav Fischer Verlag, Jena, Germany.

Mexzón, R.G. and Chinchilla, C.M. (1996) Natural enemies of harmful arthropods in oil palm (*Elaeis guineensis* Jacq.) in tropical America. ASD Oil Palm Papers, 13, 9-33.

Mexzón, R.G. and Chinchilla, C.M. (1999) Plant species attractive to beneficial entomofauna in oil palm (*Elaeis guineensis* Jacq.) plantations in Costa Rica. ASD Oil Palm Papers, 19, 1-22.

Mielke, S. and Mielke, T., eds. (1999) Oil world 2020 - supply, demand and prices from 1976 through 2020. ISTA Mielke GmbH, Hamburg, Germany.

Moll, H.A.J. (1987) The economics of oil palm. Economics of Crops in Developing Countries No 2, Pudoc, Wageningen, Netherlands.

Moore, D. (2001) Population regulation of palm pests. In: Insects on palms, pp. 233-266. CABI Publishing, London, UK.

Mueller-Dombois, D. and Ellenberg, H. (1974) Aims and methods of vegetation ecology. John Wiley & Sons, New York, USA.

Mutert, E. (1999) Suitability of soils for oil palm in Southeast Asia. Better Crops International, 13, 36-38.

Nair, K.S.S. (2001) Pest outbreaks in tropical plantations: is there a greater risk for exotic tree species. CIFOR, Bogor, Indonesia.

Ortiz, R.A. and Fernandes, O. (1992) Early growth of young oil palm under different leguminous cover crops. ASD Oil Palm Papers, 6.

Parrotta, J.A. (1992) The role of plantation forests in rehabilitating degraded tropical ecosystems. Agriculture, Ecosystems and Environment, 41, 115-133.

Piggott, A.G. (1988) Ferns of Malaysia in colour. Tropical Press Sdn. Bhd., Kuala Lumpur, Malaysia.

Pini, R., Paris, P., Benetti, A., Vigna Guidi, G., and Pisanelli, A. (1999) Soil physical characteristics and understory management in a walnut (*Juglans regia* L.) plantation in central Italy. Agroforestry Systems, 46, 95-105.

Rankine, I. and Fairhurst, T. (1998a) Field handbook: Oil palm series - Immature. Phosphate and Potash Institute, Singapore.

Rankine, I. and Fairhurst, T. (1998b) Field handbook: Oil palm series - Mature. Phosphate and Potash Institute, Singapore.

Rankine, I. and Fairhurst, T. (1999) Management of phosphorus, potassium and magnesium in mature oil palm. Better Crops International, 13, 10-15.

Rees, A.R. (1959) Germination of oil palm seed: Large scale germination. Journal of West African Institute for Oil Palm Research, 3, 76-82.

Reynolds, S. (1997) Integrated animal production in coconut plantations. In: Second FAO Electronic Conference on Tropical Feeds: Livestock Feed Resources within Integrated Farming Systems, 9 September 1996 - 28 February 1997. Food and Agriculture Organization of the United Nations, Available at: www.fao.org/waicent/faoinfo/agricult/aga/agap/-frg/TFCONF2.HTM, Accessed on: 20.10.1999.

Robertson, J.M.Y. and Schaik, C.P.v. (2001) Causal factors underlying the dramatic decline of the Sumatran orang-utan. Oryx, 35, 26-38.

Ross, J. (1981) The radiation regime and architecture of plant stands. Dr. W. Junk, The Hague, Netherlands.

Ross, J. and Sulev, M. (2000) Sources of error in measurements of PAR. Agricultural and Forest Meteorology, 100, 103-125.

Ross, M. (1999) Auswirkungen verschiedener Rodeverfahren und des Unterbewuchses auf Bodenfruchtbarkeit, Bodenwasserhaushalt, Erosion, und Bestandsentwicklung eines Ölpalmenbestandes. Berichte aus der Agrarwissenschaft, Shaker Verlag, Aachen, Germany.

Sanchez, P.A. (1976) Properties and management of soils in the tropics. John Wiley, New York, USA.

Sauerborn, E. and Sauerborn, J. (1984) Plants of cropland in Western-Samoa with special reference to Taro. Plits 2(4), Verlag J. Margraf, Stuttgart, Germany.

Sauerborn, J. (1985) Untersuchungen zur Segetalflora in Taro (*Colocasia esculenta* (L.) Schott) und zur Keimungsbiologie ausgewählter Unkrautarten auf West-Samoa. Plits 3(1), Verlag J. Margraf, Stuttgart, Germany.

Schachtschabel, P., Blume, H.-P., Brümmer, G., Hartge, K.-H., and Schwertmann, U. (1992) Lehrbuch der Bodenkunde. 13th edn., Ferdinand Enke Verlag, Stuttgart, Germany.

Silfverberg, K. (1998) The leaching of nutrients from ash- and PK-fertilised peat. Suo, 49, 115-123.

Soerjani, M., Kostermans, A.J.H.G., and Tjitrosoepomo, G. (1987) Weeds of rice in Indonesia. BIOTROP, Bogor, Indonesia.

Stür, W.W. and Shelton, H.M. (1990) Review of forage resources in plantation crops of Southeast Asia and the Pacific. In: Forages for plantation crops, Proceedings of a workshop, 27-29 June, 1990 (eds Shelton, H.M. and Stür, W.W.), pp. 25-31, Sanur Beach, Bali, Indonesia.

Tilman, D., May, R.M., Lehman, C.L., and Nowak, M.A. (1994) Habitat destruction and the extinction debt. Nature, 371, 65-66.

Tinker, P.B.H. and Ziboh, C.O. (1959) Soil analysis and fertiliser response. Journal of West African Institute of Oil Palm Research, 3, 52-75.

Turner, I.M. (1996) Species loss in fragments of tropical rain forest: a review of the evidence. Journal of Applied Ecology, 33, 200-209.

Turner, P.D. and Gillbanks, R.A. (1974) Oil palm cultivation and management. The Incorporated Society of Planters, Kuala Lumpur, Malaysia.

Umana, L.H. and Chinchilla, C.M. (1991) Symptomatology associated with water deficit in oil palm. ASD Oil Palm Papers, 3, 11-4.

Vincent, J.R. and Hadi, Y. (1993) Malaysia. In: Sustainable agriculture and the environment in the humid tropics (ed Committee on Sustainable Agriculture and the Environment in the Humid Tropics - National Research Council), pp. 440-482. National Academic Press, Washington, USA.

von Uexküll, H.R. and Fairhurst, T.H. (1991) Fertilizing for high yield and quality: the oil palm, IPI Bulletin 12. International Potash Institute, Worblaufen-Bern.

von Uexküll, H.R. and Mutert, E.M. (1994) Rehabilitation and lasting improvement of degraded land in Indonesia. In: Giessener Beiträge zur Entwicklungsforschung. Reihe 1 (Symposien) Band 21., pp. 47-65, Wissenschaftliches Zentrum Tropeninstitut, Giessen, Germany.

Wahid, M.B., Siburat, S., Ravigadevi, S., and Arshad, O. (1999) Beneficial plants for natural enemies of bagworm in oil palm plantations. In: 1999 PORIM International Palm Oil Congress, 1-6 February 1999, pp. 165-179. PORIM, Kuala Lumpur, Malaysia.

Wakker, E. (1999) Forest fires and the expansion of Indonesia's oil-palm plantations. WWF Indonesia, Jakarta.

Weng, C.K. (1999) Towards higher yield potential, production and its prediction in oil palm, PORIM Bulletin, Rep. No. 39. PORIM, Kuala Lumpur, Malaysia.

Whistler, W.A. (1983) Weed handbook of Western Polynesia. GTZ series No. 157, Deutsche Gesellschaft für Technische Zusammenerbeit (GTZ) GmbH, Eschborn, Germany.

Whitten, A.J., Damanik, S.J., Anwar, J., and Nazaruddin, H. (1987) The ecology of Sumatra. 2nd edn., Gadjah Mada University Press, Yogjakarta, Indonesia.

Widjaja-Adhi, I.P.G. (1995) Step in developing peatlands for agriculture. Indonesian Agricultural Research Development Journal, 17, 65-70.

Wilmanns, O. and Bogenrieder, A. (1991) Chapter 19: Phytosociology in vineyards - results, problems, tasks. In: Modern ecology - basic and applied aspects (eds Esser, G. and Overdieck, D.), pp. 399-441. Elsevier, Amsterdam, Netherlands.

Wilson, J.R. and Ludlow, M.M. (1990) The environment and potential growth of herbage under plantations. In: Forages for Plantation Crops, Proceedings of a workshop, 27-29 June, 1990 (eds Shelton, H.M. and Stür, W.W.), pp. 10-24, Sanur Beach, Bali, Indonesia.

Wong, C.C. (1990) Shade tolerance of tropical forages: A review. In: Forages for plantation crops, Proceedings of a workshop, 27-29 June, 1990 (eds Shelton, H.M. and Stür, W.W.), pp. 64-69, Sanur Beach, Bali, Indonesia.

Wösten, J.H.M., Ismail, A.B., and Wijk, v.A.L.M. (1997) Peat subsidence and its practical implications: a case study in Malaysia. Geoderma, 78, 25-36.

Wycherly, P.R. (1969) Conservation in Malaysia. IUCN Publication New Series. Suppl. Paper No. 22., Morges, Switzerland.

Yeboua, B. and Ballo, K. (2000) Caractéristiques chimiques du sol sous palmeraie. Agricultures, 9, 73-76.

Appendix: Complete list of all species identified in the research area

(dg = degree of coverage, sdg = specific degree of coverage, degree of coverage based on 100 relevés á 300 m^2; hp = number of time a species was found in a frequency plot on the harvesting path, cf = circle front, cb circle back and ir = inter-row; 5 frequency plots á 1 m^2 per revele and field zone/circle section)

Species	Family	dg	sdg	hp	cf	cb	ir
Abelmoschus moschatus Medik.	Malvaceae	0.0	0.5	0	0	0	0
Abroma angusta L.f.	Sterculiaceae	0.0	0.5	0	6	1	0
Acalypha lanceolata Willd.	Euphorbiaceae	0.0	0.5	1	2	1	3
Achyranthes aspera L.	Amaranthaceae	0.0	0.5	0	0	0	0
Acrostichum aureum L.	Pteridaceae	0.0	0.0	0	0	0	0
Adiantum latifolium Lam.	Adiantaceae	0.1	0.7	4	5	7	4
Aeschynomene americana L.	Papilionoideae	0.0	2.5	2	0	0	1
Ageratum conyzoides L.	Compositae	2.9	3.2	179	196	200	95
Alocasia denudata Engl.	Araceae	0.0	0.5	0	0	0	0
Alocasia macrorrhiza Schott	Araceae	0.1	0.5	0	1	2	3
Alstonia spathulata Blume	Apocynaceae	0.1	0.5	0	1	0	1
Alternanthera sessilis R.Br.	Amaranthaceae	0.4	1.2	23	34	29	17
Amaranthus blitum L.	Amaranthaceae	0.0	0.5	0	0	0	0
Amphineuron immersum (Blume) Holttum	Thelypteridaceae	0.0	0.5	2	0	3	0
Antidesma hosei Pax & K. Hoffm.	Euphorbiaceae	0.0	0.5	0	0	0	0
Archidendron clypearia (Jack) I.Nielsen	Mimosoideae	0.0	0.5	0	0	0	1
Artocarpus communis Forst.	Moraceae	0.0	0.5	0	0	0	0
Artocarpus elasticus Reinw.	Moraceae	0.0	0.5	0	0	0	0
Asplenium longissimum Blume	Aspleniaceae	0.0	0.0	0	0	0	0
Asplenium nidus L.	Aspleniaceae	0.0	0.5	0	1	1	0
Asystasia coromandeliana Nees	Acanthaceae	0.0	0.0	0	0	0	0
Asystasia intrusa Blume	Acanthaceae	0.0	0.0	0	0	0	0
Axonopus compressus (Sw.) P.Beauv.	Gramineae	0.0	0.0	0	0	0	0
Bacopa procumbens Greenm.	Scrophulariaceae	0.0	0.5	1	1	0	0
Basella alba Linn.	Basellaceae	0.6	1.8	31	33	50	23
Bauhinia kockiana Korth.	Caesalpinioideae	0.0	1.5	0	0	0	1
Bauhinia sp.	Caesalpinioideae	0.0	0.0	0	0	0	0
Begonia semperflorens Link & Otto	Begoniaceae	0.0	0.0	0	0	0	0
Bidens pilosa L.	Compositae	0.0	0.5	0	0	1	1
Blechum finlaysonianum Hook. & Grev.	Blechnaceae	0.1	0.9	0	3	7	0
Blumea balsamifera DC.	Compositae	0.0	0.5	0	0	1	0
Blumea lacera DC.	Compositae	0.1	0.6	4	5	9	0
Borreria laevicaulis Ridley	Rubiaceae	0.2	1.0	15	6	13	2
Borreria latifolia (Aubl.) K. Schum.	Rubiaceae	0.8	3.9	46	23	10	6
Borreria setidens (Miq.) Boldingh	Rubiaceae	0.5	1.1	124	109	79	3
Brachiaria mutica (Forssk.) Stapf	Gramineae	0.0	0.0	0	0	0	0
Brachiaria ramosa (L.) Stapf	Gramineae	0.0	0.0	0	0	0	0
Bridelia insulana Hance	Euphorbiaceae	0.0	0.5	0	0	0	1
Caesalpinia sappan L.	Caesalpinioideae	0.0	0.0	0	0	0	0

Species	Family	dg	sdg	hp	cf	cb	ir
Calopogonium muconoides Desv.	Papilionoideae	0.6	1.7	49	19	17	29
Cardamine hirsuta L.	Brassicaceae	0.0	0.5	2	4	4	0
Cassia alata L.	Caesalpinioideae	0.0	0.0	0	0	0	0
Cassia occidentalis L.	Caesalpinioideae	0.0	0.0	0	0	0	0
Cassia tora L.	Caesalpinioideae	0.1	2.5	10	5	2	11
Cayratia trifolia (L.) Domin	Vitaceae	0.0	0.0	0	0	0	0
Celosia argentea L.	Amaranthaceae	0.0	0.5	2	2	3	0
Centella asiatica (L.) Urb.	Umbelliferae	0.0	0.5	2	0	0	0
Centotheca lappacea Desv.	Gramineae	0.3	1.5	7	7	6	10
Centrosema pubescens Benth.	Papilionoideae	0.1	0.6	26	3	4	0
Ceratopteris thalictroides (L.) Brongn.	Parkeriaceae	0.0	0.0	0	0	0	0
Chloris barbata Sw.	Gramineae	1.4	2.2	36	46	101	88
Christella dentata (Forssk.) Brownsey & Jermy	Thelypteridaceae	0.1	1.0	14	1	5	8
Christella parasitica (L.) H.Lev.	Thelypteridaceae	0.0	0.5	0	1	3	0
Cissus quadrangularis L.	Vitaceae	0.0	0.0	0	0	0	0
Cladium mariscus (L.) Pohl	Cyperaceae	0.3	0.9	32	55	54	18
Cleome rutidosperma DC.	Capparaceae	0.0	0.0	0	0	0	0
Cleome viscosa L.	Capparaceae	0.0	0.5	0	0	1	0
Clibadium surinamense L.	Compositae	0.1	0.5	2	4	3	4
Clidemia hirta Don	Melastomataceae	0.0	0.5	0	0	0	0
Clitoria ternatea L.	Papilionoideae	0.0	0.0	0	0	0	0
Coix lacryma-jobi L.	Gramineae	0.0	0.0	0	0	0	0
Colocasia esculenta (L.) Schott.	Araceae	0.1	0.7	0	0	1	3
Colocasia sp.	Araceae	0.0	0.5	0	0	0	0
Commelina benghalensis L.	Commelinaceae	0.0	0.0	0	0	0	0
Commelina diffusa Brum.f.	Commelinaceae	0.7	3.4	57	45	41	40
Commersonia bartramia (L.) Merr.	Sterculiaceae	0.0	0.5	0	0	0	0
Corchorus capsularis L.	Tiliaceae	0.0	0.0	0	0	0	0
Costus speciosus Sm.	Zingiberaceae	0.0	0.5	0	0	0	2
Crotalaria pallida Aiton	Papilionoideae	0.0	0.0	0	0	0	0
Croton hirtus L'Her.	Euphorbiaceae	0.0	0.0	0	0	0	0
Cuphea carthgenensis (Jacq.) J.F.Macbr.	Lythraceae	0.0	0.5	1	0	0	0
Curanga fel-terrae Merr.	Scrophulariaceae	0.0	0.5	1	0	0	4
Curcuma domestica Valeton	Zingiberaceae	0.0	0.0	0	0	0	0
Cyclosorus interruptus (Willd.) H.Ito	Thelypteridaceae	1.3	2.2	17	16	53	47
Cynodon dactylon (L.) Pers.	Gramineae	0.0	0.5	1	1	0	0
Cyperus brevifolius (Rottb.) Hassk.	Cyperaceae	0.1	0.8	12	9	9	3
Cyperus cyperinus (Retz.) J.V.Suringar	Cyperaceae	0.0	0.0	0	0	0	0
Cyperus digitatus Roxb.	Cyperaceae	0.0	0.5	2	0	0	0
Cyperus elatus L.	Cyperaceae	0.0	0.0	0	0	0	0
Cyperus halpan J.Kern	Cyperaceae	0.1	0.7	2	8	13	2
Cyperus iria L.	Cyperaceae	0.0	0.5	4	6	2	1
Cyperus kyllingia Endl.	Cyperaceae	0.5	1.0	114	93	89	10
Cyperus pilosus Vahl	Cyperaceae	0.0	0.5	1	1	0	0
Cyrtococcum accrescens Stapf	Gramineae	0.0	0.5	3	3	3	0
Dactyloctenium aegyptium (L.) P.Beauv.	Gramineae	0.0	0.0	0	0	0	0
Davallia denticulata (Burm.) Mett.	Davalliaceae	0.0	0.5	0	2	0	1
Dendrocnide sp.	Urticaceae	0.0	0.5	0	0	0	0
Desmodium heterophyllum DC.	Papilionoideae	0.0	0.0	0	0	0	0
Dicranopteris linearis J. Underw.	Gleicheniaceae	0.4	1.2	4	6	22	14
Dieffenbachia maculata Sweet.	Araceae	0.0	0.0	0	0	0	0

Species	Family	dg	sdg	hp	cf	cb	ir
Digitaria setigera Roem. & Schult	Gramineae	0.1	0.5	10	8	9	4
Dioscorea bulbifera L.	Dioscoreaceae	0.1	0.7	6	3	6	2
Dioscorea nummularia Lam.	Dioscoreaceae	0.0	0.5	0	1	3	1
Diplazium asperum Blume	Woodsiaceae	0.0	0.5	0	0	1	0
Diplazium esculentum (Retz.) Sw.	Woodsiaceae	1.3	2.6	15	16	50	59
Dissochaeta sp.	Melastomataceae	0.0	0.5	1	0	1	0
Donax canniformis (G.Forst.) K. Schum.	Marantaceae	0.0	0.0	0	0	0	0
Echinochloa colona (L.) Link	Gramineae	0.1	0.5	17	9	4	0
Echinochloa crus-galli (L.) P.Beauv.	Gramineae	0.0	0.0	0	0	0	0
Eclipta prostata L.	Compositae	0.0	0.5	0	1	1	0
Elaeis guineensis Jacq.	Palmae	0.4	0.7	39	36	40	30
Eleusine indica (L.) Gaertn.	Gramineae	0.1	0.5	15	1	1	0
Emilia sonchifolia (L.) DC. ex Wight	Compositae	0.0	0.5	0	0	1	0
Enhydra fluctuans Lour.	Compositae	0.0	0.0	0	0	0	0
Epipremnum silvaticum Alderw.	Araceae	0.0	0.5	0	0	1	3
Eragostis tenella Roem. & Schult.	Gramineae	0.0	0.5	1	0	1	0
Erechtites hieracifolia Raf. ex DC.	Compositae	0.1	0.5	2	1	1	0
Erechtites valerianifolia (Wolf) DC.	Compositae	0.3	0.7	17	38	25	7
Erigeron sumatrensis Retz.	Compositae	0.4	0.9	15	31	28	6
Eulophia squalida Lindl.	Orchidaceae	0.0	0.5	0	0	0	0
Eulopia graminea Lindl.	Orchidaceae	0.0	0.5	0	0	1	0
Euphorbia heterophylla L.	Euphorbiaceae	0.1	0.8	9	1	5	0
Euphorbia hirta L.	Euphorbiaceae	0.2	0.6	26	10	17	0
Euphrobia prostrata Aiton	Euphorbiaceae	0.0	0.5	1	1	2	0
Ficus callosa Willd.	Moraceae	0.0	0.5	0	0	1	0
Ficus cf. *bengalensis* L.	Moraceae	0.0	0.5	0	0	1	1
Ficus cf. *heterophylla* L.f.	Moraceae	0.1	0.7	1	0	0	0
Ficus cf. *scandens* Lam.	Moraceae	0.0	0.5	0	0	0	0
Ficus fistulosa Reinw. ex Blume	Moraceae	0.0	0.5	0	0	0	0
Ficus sp.	Moraceae	0.4	0.8	3	2	5	14
Fimbristylis bisumbellata Bubani	Cyperaceae	0.0	0.0	0	0	0	0
Fimbristylis dichotoma (L.) Vahl	Cyperaceae	0.2	0.7	43	22	10	2
Fimbristylis miliacea Vahl	Cyperaceae	0.2	0.6	53	28	24	1
Flagellaria indica L.	Flagellariaceae	0.1	0.7	6	1	1	5
Fleurya aestuans Gaudich.	Urticaceae	0.0	1.0	3	1	2	0
Fuirena umbellata Rottb.	Cyperaceae	0.0	0.0	0	0	0	0
Geophila repens (L.) I.M.Johnst.	Rubiaceae	0.0	0.5	1	2	3	0
Geunsia pentandra Merr.	Verbenaceae	0.0	0.5	0	0	0	0
Gymnopetalum leucosticum Miq.	Cucurbitaceae	0.0	0.5	5	1	0	5
Hedyotis corymbosa Lam.	Rubiaceae	0.2	0.9	59	59	52	1
Hedyotis diffusa Willd.	Rubiaceae	0.3	0.6	55	38	28	0
Hedyotis philippinensis Merr. ex C.B.Rob.	Rubiaceae	0.0	0.5	0	0	2	0
Hedyotis verticillata Lam.	Rubiaceae	0.0	0.5	6	1	0	0
Hedyotis vestita R.Br. & G.Don.	Rubiaceae	0.0	1.0	1	0	0	0
Heliotropium indicum L.	Boraginaceae	0.0	0.0	0	0	0	0
Hewittia sublobata Kuntze	Convolvulaceae	0.1	0.8	3	0	2	6
*Hibiscus sur*attensis L.	Malvaceae	0.0	0.0	0	0	0	0
Hippobroma longiflora G.Don	Campanulaceae	0.0	0.5	4	3	2	0
Homalomena pendula (Blume) Bakh.f.	Araceae	0.0	0.5	0	0	0	0
Hoya sp. 1	Asclepiadaceae	0.1	1.3	8	1	1	4
Hoya sp. 2	Asclepiadaceae	0.0	0.5	0	0	0	0

Species	Family	dg	sdg	hp	cf	cb	ir
Hymenachne acutigluma (Steud.) Gilliland	Gramineae	0.0	0.0	0	0	0	0
Hyptis brevipes Poit.	Labiatae	0.0	0.5	1	0	0	0
Hyptis capitata Jacq.	Labiatae	0.1	0.7	1	7	13	7
Imperata cylindrica Beauv.	Gramineae	1.4	4.4	38	29	36	52
Ipomoea aquatica Forssk.	Convolvulaceae	0.0	0.0	0	0	0	0
Ipomoea cairica Sweet	Convolvulaceae	0.0	0.0	0	0	0	0
Ipomoea triloba L.	Convolvulaceae	0.1	1.1	4	5	2	3
Ischaemum muticum L.	Gramineae	0.0	0.0	0	0	0	0
Juncellus alopecuroides (Rottb.) C.B.Clarke	Cyperaceae	0.0	0.5	2	0	0	1
Lactuca indica L.	Compositae	0.0	0.0	0	0	0	0
Lantana camara L.	Verbenaceae	0.0	0.5	0	0	0	0
Lasia spinosa Thw.	Araceae	0.1	0.5	2	2	4	6
Leea indica Merr.	Vitaceae	0.0	1.0	0	0	1	0
Lepistemon binectariferum Kuntze	Convolvulaceae	0.0	0.5	0	0	0	0
Leptochloa chinensis Nees	Gramineae	0.0	0.0	0	0	0	0
Leucas flaccida R.Br.	Labiatae	0.0	0.5	0	0	0	0
Leucas lavandulaefolia Sm.	Labiatae	0.0	0.0	0	0	0	0
Limnocharis flava (L.) Buchenau.	Limnocharitaceae	0.0	0.0	0	0	0	0
Limnophila rugosa Merr.	Scrophulariaceae	0.4	0.7	85	47	63	1
Lindernia anagallis (Burm.f.) Pennell	Scrophulariaceae	0.0	0.5	0	1	0	0
Lindernia cordifolia Merr.	Scrophulariaceae	0.0	0.5	0	0	0	1
Lindernia crustacea (L.) F.Muell.	Scrophulariaceae	0.2	0.7	29	9	17	2
Lindernia vicosa Merr.	Scrophulariaceae	0.3	0.7	31	31	27	0
Lobelia cf. *zeylanica* L.	Campanulaceae	0.0	0.5	0	1	1	0
Ludwigia adscendens (L.) H.Hara	Onagraceae	0.0	0.0	0	0	0	0
Ludwigia hyssopifolia (G.Don) Exell	Onagraceae	0.6	0.9	110	48	61	14
Ludwigia octovalvis (Jacq.) P.H.Raven	Onagraceae	0.0	0.5	0	0	1	3
Ludwigia peruviana (L.) H.Hara	Onagraceae	0.0	0.0	0	0	0	0
Lycopodium cernuum L.	Lycopodiaceae	0.0	0.5	5	0	0	0
Lygodium circinatum Sw.	Schizaeaceae	0.3	0.7	26	36	55	4
Lygodium microphyllum (Cav.) R.Br.	Schizaeaceae	0.6	0.7	25	72	85	34
Macaranga hosei King ex Hook.f.	Euphorbiaceae	0.1	0.8	1	0	0	2
Macaranga triloba Mull.Arg.	Euphorbiaceae	0.0	0.5	0	0	0	1
Mallotus paniculatus (Lam.) Mull.Arg.	Euphorbiaceae	0.0	0.5	1	0	0	0
Manihot esculentua Crantz	Euphorbiaceae	0.0	0.5	0	0	0	0
Mariscus compactus Druce	Cyperaceae	0.0	0.5	0	1	0	0
Mariscus sumatrensis (Retz.) J.Raynal	Cyperaceae	0.3	0.6	5	12	8	14
Melastoma malabathricum L.	Melastomataceae	0.0	0.5	1	1	0	1
Melochia concatenata L.	Sterculiaceae	0.1	0.5	6	5	1	7
Melothria affinis King	Cucurbitaceae	0.0	0.0	0	0	0	0
Merremia gemella Hallier f.	Convolvulaceae	0.0	0.5	0	0	0	0
Merremia peltata (L.) Merr.	Convolvulaceae	0.1	0.8	1	0	2	6
Merremia tridentata (L.) Hallier f.	Convolvulaceae	0.0	1.0	0	0	0	0
Merremia umbellata (L.) Hallier f.	Convolvulaceae	0.2	1.3	12	3	6	22
Merremia vitifolia Hallier f.	Convolvulaceae	0.1	0.5	0	2	1	7
Microlepia speluncae (L.) T.Moore	Dennstaedtidaceae	19.5	19.7	250	185	234	322
Mikania micrantha H.B.&K.	Compositae	0.1	0.8	0	1	3	1
Mimosa invisa Mart. ex Colla	Mimosoideae	0.0	0.0	0	0	0	0
Mimosa pigra L.	Mimosoideae	0.0	0.5	0	1	2	0
Mimosa pudica L.	Mimosoideae	0.1	0.6	0	0	0	2
Mollugo pentaphylla L.	Molluginaceae	0.0	0.5	6	2	4	0

Species	Family	dg	sdg	hp	cf	cb	ir
Momordica charantia L.	Cucurbitaceae	0.6	3.6	8	13	12	11
Monochoria vaginalis C.Presl.	Pontederiaceae	0.0	0.0	0	0	0	0
Murdannia nudiflora (L.) Brenan	Commelinaceae	0.0	0.5	9	5	3	2
Musa sp.	Musaceae	0.0	0.0	0	0	0	0
Nauclea sp.	Rubiaceae	0.0	0.5	0	0	0	1
Nepenthes gracilis Salisb.	Nepenthaceae	0.0	0.0	0	0	0	0
Nephrolepis biserrata (Sw.) Schott	Oleandraceae	6.6	7.7	54	97	153	144
Nephrolepis falcata (Cav.) C.Chr.	Oleandraceae	0.0	0.5	1	3	5	2
Nephrolepis multiflora (Roxb.) F.M.Jarrett	Oleandraceae	0.0	2.5	0	0	0	0
Nephrolepis tuberosa C.Presl	Oleandraceae	0.4	1.1	8	7	18	14
Neptunia oleracea Lour.	Mimosoideae	0.0	0.0	0	0	0	0
Nymphoides indica (L.) Kuntze	Menyanthaceae	0.0	0.0	0	0	0	0
Oldenlandia dichotoma Hook f.	Rubiaceae	0.0	0.5	6	1	8	0
Oleandra pistillaris (Sw.) C.Chr.	Oleandraceae	0.0	0.5	0	0	0	0
Ophioglossum reticulatum L.	Ophioglossaceae	0.1	1.3	9	1	3	0
Orthosiphon spiralis Merr.	Labiatae	0.0	0.0	0	0	0	0
Ottelia alismoides (L.) Pers.	Hydrocharitaceae	0.0	0.0	0	0	0	0
Ottochloa nodosa (Kunth) Dandy	Gramineae	0.0	0.0	0	0	0	0
Oxalis barellieri L.	Oxalidaceae	0.0	0.0	0	0	0	0
Oxalis corniculata L.	Oxalidaceae	0.0	1.0	6	4	1	0
Panicum maximum Jacq.	Gramineae	0.0	0.5	0	0	0	1
Paspalum conjugatum Berg.	Gramineae	0.9	2.4	45	40	41	40
Paspalum scrobiculatum L.	Gramineae	0.0	0.5	0	1	1	0
Passiflora foetida L.	Passifloraceae	0.0	0.5	0	1	1	1
Pennisetum alopecuroides Spreng	Gramineae	0.0	0.0	0	0	0	0
Pennisetum polystachyon (L.) Schult.	Gramineae	0.0	0.5	0	0	0	0
Pennisetum purpureum Schumach.	Gramineae	0.0	0.0	0	0	0	0
Peperomia pellucida H.B.&K.	Piperaceae	0.7	1.3	163	161	162	47
Phaseolus calcaratus Roxb.	Papilionoideae	0.8	5.3	11	3	3	25
Phyllanthus amarus Schum. & Thonn.	Euphorbiaceae	0.1	0.5	22	16	16	1
Phyllanthus cf *urinaria* L.	Euphorbiaceae	0.1	1.5	3	2	0	0
Phyllanthus debilis Willd.	Euphorbiaceae	0.7	1.0	172	145	161	59
Phymatosorus scolopendria Pich.Serm.	Polypodiaceae	0.1	0.5	0	1	5	0
Physallis minima L.	Solanaceae	0.3	1.6	14	6	4	3
Phytolacca purpurascens A.Br. & Bouche	Phytolaccaceae	0.2	0.9	4	26	21	3
Piper aduncum L.	Piperaceae	0.1	0.8	0	0	0	5
Pistia stratiotes L.	Araceae	0.0	0.0	0	0	0	0
Pityrogramma calomelanos (L.) Link	Hemionitidaceae	0.9	1.1	98	78	95	35
Pleocnemia irregularis (C.Presl) Holttum	Dryopteridaceae	0.3	1.0	9	4	18	15
Ploiarium alternifolium Melch.	Guttiferae	0.0	0.5	1	0	0	3
Pogostemon menthoides Blume	Labiatae	0.0	0.5	1	0	0	0
Polygala paniculata L.	Polygonaceae	0.0	0.5	6	5	3	2
Polygonum barbatum L.	Polygonaceae	0.1	0.8	3	0	2	13
Polygonum cf. *hydropiper* L.	Polygonaceae	0.0	0.5	0	0	0	0
Pongamia pinnata (L.) Pierre	Papilionoideae	0.1	1.1	2	0	1	1
Porophyllum ruderale Cass.	Compositae	0.0	0.5	1	2	0	1
Portulaca oleraceae L.	Portulacaceae	0.0	0.5	6	0	0	0
Pouzolzia zeylanica Benn.	Urticaceae	1.5	1.5	164	137	161	111
Pronephrium asperum (C.Presl) Holttum	Thelypteridaceae	0.0	0.5	1	0	0	0
Psidium guajava L.	Myrtaceae	0.0	0.5	0	0	0	1
Pteridium caudatum (L.) Maxon	Pteridaceae	0.1	0.8	4	1	4	7

Species	Family	dg	sdg	hp	cf	cb	ir
Pteris ensiformis Burm.f.	Pteridaceae	0.0	0.0	0	0	0	0
Pteris tripartita Sw.	Pteridaceae	0.4	0.6	18	13	18	6
Pteris vittata L.	Pteridaceae	0.4	0.8	14	22	24	12
Pueraria phaseoloides Benth.	Papilionoideae	14.5	34.4	92	39	64	128
Pueraria sp.	Papilionoideae	0.7	17.0	5	4	5	4
Pueraria triloba Makino	Papilionoideae	0.0	0.0	0	0	0	0
Rhinacanthus sp.	Acanthaceae	0.0	0.0	0	0	0	0
Rhynchelytrum repens (Willd.) C.E.Hubb.	Gramineae	0.0	0.0	0	0	0	0
Rhynchospora corymbosa (L.) Britton	Cyperaceae	0.0	0.0	0	0	0	0
Richardia brasiliensis Gomez	Rubiaceae	0.0	0.5	0	0	0	0
Rottboellia exaltata L.f.	Gramineae	0.0	0.0	0	0	0	0
Rubus moluccanus L.	Rosaceae	0.0	0.5	0	0	0	0
Saliva riparia H.B.&K.	Labiatae	0.0	0.5	1	0	0	1
Scirpus grossus L.f.	Cyperaceae	0.0	0.5	0	0	0	1
Scleria bancana Miq.	Cyperaceae	0.1	0.5	2	0	3	4
Scleria sumatrensis Retz.	Cyperaceae	0.0	0.5	0	0	0	2
Scoparia dulcis L.	Scrophulariaceae	0.1	0.5	34	22	16	3
Securinega virosa Baill.	Euphorbiaceae	0.1	0.6	0	6	1	3
Selaginella plana Hieron.	Selaginellaceae	0.2	0.8	55	45	69	23
Setaria palmifolia Stapf	Gramineae	0.0	0.0	0	0	0	0
Sida rhombifolia L.	Malvaceae	0.0	0.5	2	1	0	2
Solanum denticulatum Blume	Solanaceae	0.0	0.5	0	0	0	0
Solanum ferox L.	Solanaceae	0.0	0.5	0	1	0	0
Solanum torvum Sw.	Solanaceae	0.1	0.6	1	4	1	1
Sparganophorus villantii Crantz	Compositae	2.5	5.1	117	151	163	60
Sphaerostephanos polycarpus (Bl.) Copel.	Thelypteridaceae	0.4	1.7	14	6	16	19
Spigelia anthelmia L.	Loganiaceae	0.0	0.5	2	1	0	0
Spilanthes filicaulis (Schumach. & Thonn.) C.D.Adams	Compositae	0.0	0.5	0	0	1	1
Sporobolus diander Beauv.	Gramineae	2.2	2.5	204	244	219	54
Stachytarpheta indica Vahl	Verbenaceae	0.3	1.0	30	8	12	23
Stachytarpheta jamaicensis (L.) J.Vahl	Verbenaceae	0.0	0.0	0	0	0	0
Stenochlaena palustris Bedd.	Blechnaceae	1.3	1.6	34	29	47	44
Synedrella nodiflora Gaertn.	Compositae	0.1	0.5	8	8	5	0
Tetracera scandens Merr.	Dilleniaceae	0.0	0.0	0	0	0	0
Themeda gigantea Hack.	Gramineae	0.0	0.0	0	0	0	0
Timonius philippiensis Merr.	Rubiaceae	0.0	0.5	0	0	0	1
Torenia ciliata Sm.	Scrophulariaceae	0.0	0.0	0	0	0	0
Trema orientalis (L.) Blume	Ulmaceae	0.1	0.9	6	5	8	1
Trichosanthes sp.	Cucurbitaceae	0.0	0.5	0	0	0	0
Trichosanthes wallichiana Wight	Cucurbitaceae	0.0	0.0	0	0	0	0
Typhonium trilobatum (L.) Schott	Araceae	0.0	0.5	0	0	0	0
Uncaria cordata Merr.	Rubiaceae	0.0	0.0	0	0	0	0
Uncaria cf. *glabrata* DC.	Rubiaceae	0.6	1.2	21	7	12	30
Uncaria ferrea DC.	Rubiaceae	0.1	0.6	2	4	5	3
Uncaria pedicellata Roxb.	Rubiaceae	0.1	0.5	6	0	4	5
Uncaria sp. 1	Rubiaceae	0.0	0.5	0	0	1	0
Uncaria sp. 2	Rubiaceae	0.0	0.5	0	0	0	0
Uraria crinita Desv.	Papilionoideae	0.0	0.5	0	0	0	0
Urena lobata L.	Malvaceae	0.0	0.5	2	0	0	0
Utricularia aurea Lour.	Lentibulariaceae	0.0	0.0	0	0	0	0
Uvaria grandiflora Roxb.	Annonaceae	0.0	0.5	0	0	0	0

Species	Family	dg	sdg	hp	cf	cb	ir
Vernonia cinerea (L.) Less.	Compositae	0.1	0.6	3	8	12	3
Vernonia patula Merr.	Compositae	0.0	0.5	0	0	0	2
Vitis japonica Thunb.	Vitaceae	0.3	2.6	14	10	9	16
Xanthosoma robustum Schott	Araceae	0.0	0.0	0	0	0	0