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Root development of tropical useful plants in the early state of plantation on degraded sites in Amazonia

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ABSTRACT

The root development of four tropical plant species has been studied in the initial phase of a polyculture near Manaus. According to these preliminary qualitative studies it could be ascertained that the root systems of the selected species are significantly different in phenotype and root distribution. *Bixa orellana* (urucúm) revealed a huge rooting area especially near the soil surface. *Bertholletia excelsa.* (paranut), *Theobroma grandiflorum* (cupuaçu) and *Hevea brasiliensis* (seringueira) did not differ strongly from each another in root distance and spatial area but revealed differences in root distribution in soil depths. The inoculation with vesicular-arbuscular mycorrhiza fungi (AMF) did not result in different root growth and development patterns of the plants. Different levels of fertilization (30 % and 100 % of recommended dose) may significantly enhance the spatial root area as shown for *B. orellana*. The results are discussed with regard to the spatial and temporal coincidence of the mycorrhizal symbionts in the field and the common field management practice.

RESUMO

Investigamos o desenvolvimento das raízes de quatro plantas úteis tropicais após a primeira phase de uma policultura perto de Manaus. Esses primeiros estudos mostram que as sistemas das raízes podem ser caracterizadas pôr fenotipo e distribuição no solo. *Bixa orellana* (urucúm) revela uma vasta área ocupada pelas raízes, especialmente perto da superfície do solo. Entre *Bertholletia excelsa* (castanha do Brasil), *Theobroma grandiflorum* (cupuaçu) e *Hevea brasiliensis* (seringueira) não tem grandes diferenças com respeito a distancia maximal das raízes do tronco nem a área ocupado pelas raízes enquanto nos descobrimos diferenças em distribuição na profundidade. A inoculação com fungus micorrhiza-VA não esteve relacionado com o desenvolvimento das raízes. O nível de adubação (30 % e 100 % da adubação recomendada) pode ser evidente para a extensão do sistema das raízes como demonstrado pôr *B. orellana*. Os resultados são discutidas com respeito a coincidência espacial e temporal entre as comunidades da micorrhiza e com respeito a administração comum ao campo.

ZUSAMMENFASSUNG

Untersucht wurde die Wurzelentwicklung von vier tropischen Nutzpflanzen in der Installationsphase eines Polykultursystems bei Manaus. Diese ersten qualitativen Studien ergaben signifikante Unterschiede im Phänotypus von Grob- und Feinwurzeln und in der Wurzelausbreitung im Boden. *Bixa orellana* (Urucúm) weist ein sehr ausgedehntes Wurzelsystem auf, respektive nahe der Bodenoberfläche. *Bertholletia excelsa* (Paranuß-Baum), *Theobroma grandiflorum* (Cupuaçu) und *Hevea brasiliensis* (Kautschuk-Baum) zeigen nur geringe Unterschiede hinsichtlich der Wurzelsystem-Ausdehnung vom Stamm, jedoch eine deutlich unterscheidbare Wurzelverteilung in den untersuchten Bodenschichten. Ein Einfluss durch Inokulation mit VA-Mykorrhiza auf die Wurzelverteilung konnte nicht festgestellt werden. Unterschiedliche Düngergaben (30 % und 100 % der empfohlenen Menge) wirkten sich am Beispiel *B. orellana* signifikant auf die Wurzelsystem-Ausdehnung aus. Die Ergebnisse werden in ihrer möglichen Bedeutung für das herkömmliche Feldmanagement diskutiert.

INTRODUCTION

Agriculture systems in Central Amazonia have to be adapted to the extreme tropical climate and poor soil conditions. In contrary to the investigations in the temperate climates (Atkinson 1980) for endogenous plants of the tropics and particularly of Amazonia little is known about root growth, root distribution, strategy of nutrition uptake and their possible role in field cultivation. The knowledge about the genetically and environmentally influenced root patterns is of great importance for field management and plant breeding. (Fitter et al. 1991). Perennial plants commonly are pre-cultivated in nurseries. The environmental factors of nursery pots or plastic bags are characterized by low volume, adequate substrate, and equilibrated regimes of fertilization and irrigation. Additionally the plants in the pots can be inoculated with high contents of effective arbuscular mycorrhiza fungi (AMF) of commonly exogenic genotypes (Feldmann et al. 1995). Inoculation of useful plants with selected arbuscular mycorrhizal fungi can guarantee highly effective symbiosis by 1. prior introduction of exogenous AMF in the case of deficiency in the field, 2. providing adapted AMF with nutrient concentration tolerance and 3. enhancing or maintaining the effectiveness of autochthon AMF e.g. due to avoiding of removal of secondary vegetation (Feldmann 1994). In the field the plants are set into holes, fertilized according to local recommendations, and then surrounded by organic material and disturbed soil of the B-horizon, both containing few infection units of native AMF. There, in the early stages of development the young plants have to overcome drastic environmental changes as soon as the roots are growing into the adjacent soil. This relatively undisturbed field soil is characterized by chemical and physical degradation, e.g. low nutrient availability, low pH and often compactness. When roots grow into the undisturbed field soil thy come the first time into contact with native AMF which could successfully compete with the inoculated AMF species.

How do such changes of the environment affect the root distribution of crop species? Further could root distribution throughout the soil horizons give information on adapted fertilization regime, planting conditions and capability of covering the degraded soils? We tried to answer these questions by selecting four plant species with high economic potential which are presumed to form different types of root systems and made preliminary investigations of the root growth, spread, and distribution in the installation phase of a polyculture system.

MATERIAL AND METHODS

The following species have been investigated: *Bixa orellana* L., Bixaceae; *Bertholletia excelsa* Humb. et Bonpl., Lecythidaceae, *Theobroma grandiflorum* (Willd. ex Spreng) Schum. Sterculiaceae, and *Hevea brasiliensis* Muell. Arg., Euphorbiaceae. The perennial plants were precultivated in nurseries for two months. Inoculum production, inoculation by mixing AMF (*Glomus etunicatum*) with substrate and estimation of root colonization were done by Feldmann and Idczak (1993). In the field the plants were set into holes (diameter and depth ca. 30 cm), surrounded by organic material and disturbed soil of the B-horizon. They were fertilized in graduated levels (30 % and 100 % of recommended dose). 100 % fertilizer dose contained 157 g Super-P, 112 g KCl, 50 g $MgSO_4$, 52 g urea, and 200 g lime. Before and four months after planting in the experimental field near Manaus, Amazonia, the root system and root distribution throughout the soil horizons were described. The fine roots were characterized by morphological parameters to enable detection under field conditions. To allow further studies on the same individuals only half root systems, 12 in total, were dug up manually, inclusively the fine roots. Fertilizer induced differences in root distribution are described for *B. orellana*.

RESULTS

In the nursery the average inoculum potential of autochthonous AMF in the substrate was 2 spores/ cm^3, in the substrate of the plant hole 4 and in the field soil 10 spores/ cm^3 (table 2). Contrary the inoculum potential of exogenous AMF has only been found in the substrate of the plastic bags and of the plant hole (10, 8 spores/ cm^3, respectively) but not in the surrounding field soil. The degree of root colonization in the nursery differed enormously between the plant species. In the initial phase of field cultivation the fertilization regime just had a clear influence on the colonization rate. Contrary to the other plant species the roots of *T. grandiflorum* showed only a very slight infection by AMF, even in the nursery (table 1).

Table 1: Degree of root colonization [%]

plant species	nursery	field	
	inoculated plants	30 % fertilizer	100 % fertilizer
B. orellana	59 ± 10	64 ± 23	39 ± 25
T. grandiflorum	1 ± 1	1 ± 2	2 ± 2
B. excelsa	< 1	74 ± 12	52 ± 9
H. brasiliensis	n.d. *	72 ± 18	42 ± 7

* plants were inoculated after planting

Table 2: Inoculum potential of AMF [n spores/ cm^3]

	autochthonous AMF	exogenous AMF
field soil	10	0
substrate plant hole	4	8
substrate plastic bag	2	10

Root system and fine roots of all four plant species reveal specific morphological characteristics and thus can be identified under field conditions (table 3). Root systems of *B. excelsa* and *H. brasiliensis* developed only a few amount of fine roots compared to the other species studied. *B. orellana* is characterized by the most wide spread root system (table 3, figure 2). The other plant species do not differ strongly from another in root distance and spatial area. However, they reveal differences in root distribution in soil depths (figures 1 to 3).

Table 3: Root characteristics of the investigated plant species

plant species	max. stem distance [cm]	max. root depth [cm]	fine root system [cm]	min. root diameter [cm]	symbionts	root phenotype
B. orellana	68 - 123	>56	intensive	0.02	arbuscular mycorrhiza	root order: 5, color: red-orange, no root hairs visible
T. grandiflorum	36 - 42	45 - 53	intensive	0.01-0.02	arbuscular mycorrhiza	root order: 5, color: brown, no root hairs visible
B. excelsa	35 - 45	47 - 52	scarce	0.03	arbuscular mycorrhiza	root order: 3, color: brown to white yellowish, no root hairs visible
H. brasiliensis	43 - 47	>63	scarce	0.03	arbuscular mycorrhiza	root order: 6, color: brown-grey, no root hairs visible, roots are fragile

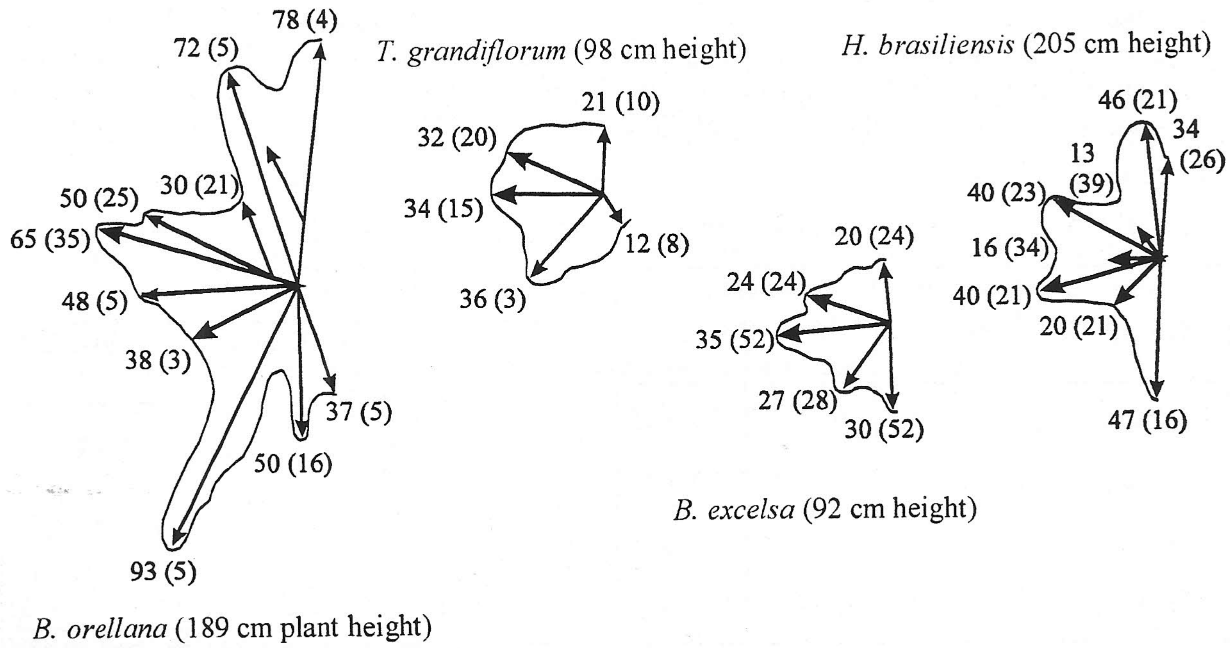

Figure 1: Spatial root distribution of half the root system [cm]

The arrows represent the roots of at least 0.4 cm diameter. The numbers in parentheses indicate rooting depth. All plants were inoculated with mycorrhiza and were treated with 30 % fertilizer dose.

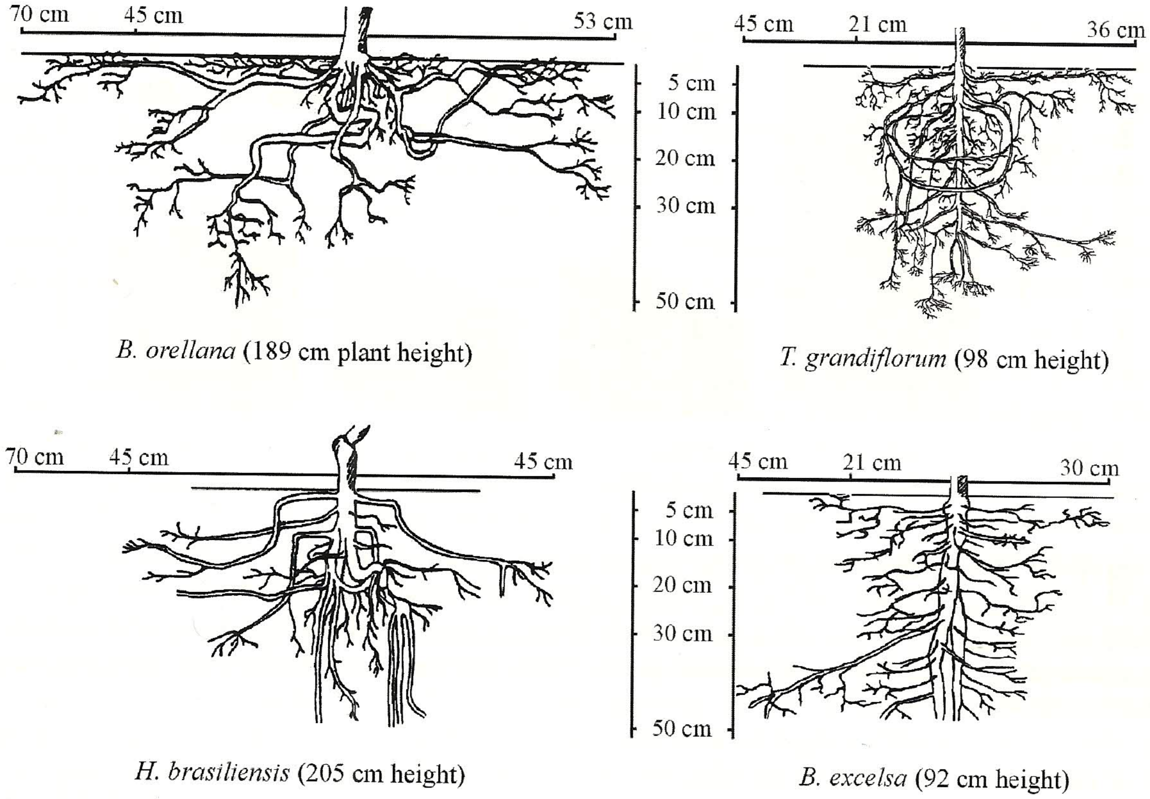

Figure 2: Root distribution throughout soil horizons

The true to scale drawings represent typical vertical root distributions of the selected species. Roots were digged up as deep as 50 to 55 cm. Root distribution did not differ between plants treated with different levels of fertilization. Growth of some roots of *T. grandiflorum* indicates unfavorable conditions in the nursery.

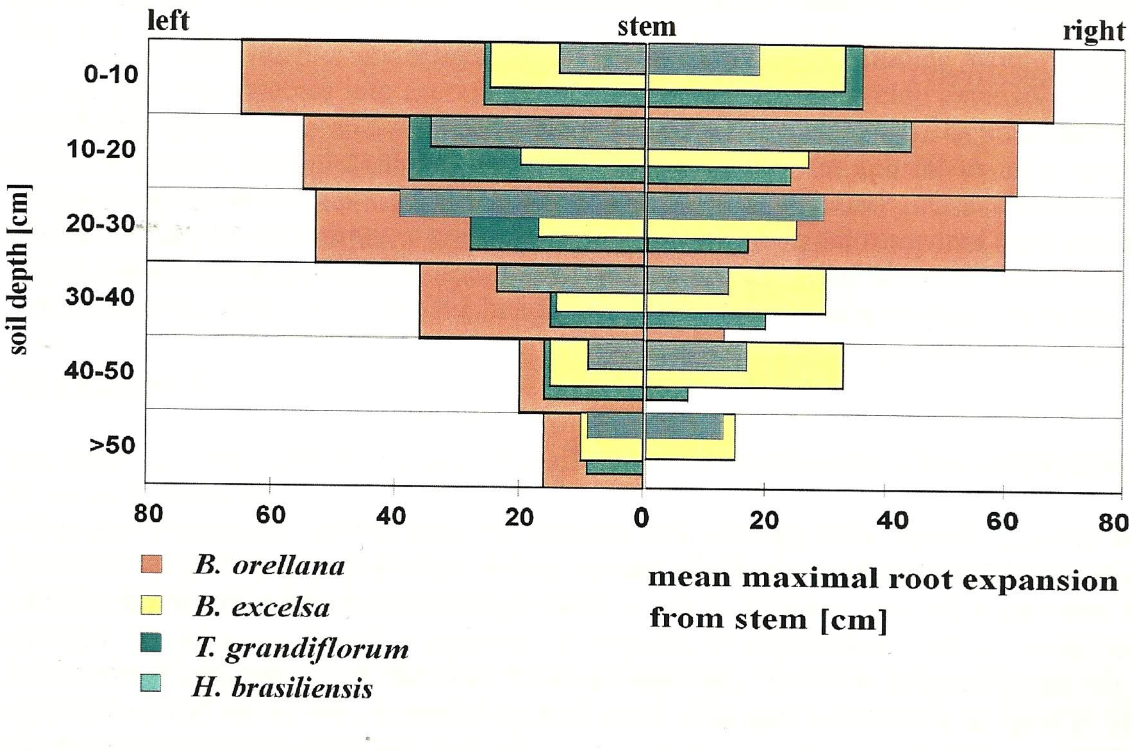

Figure 3: Mean maximal rooting distances throughout soil depths

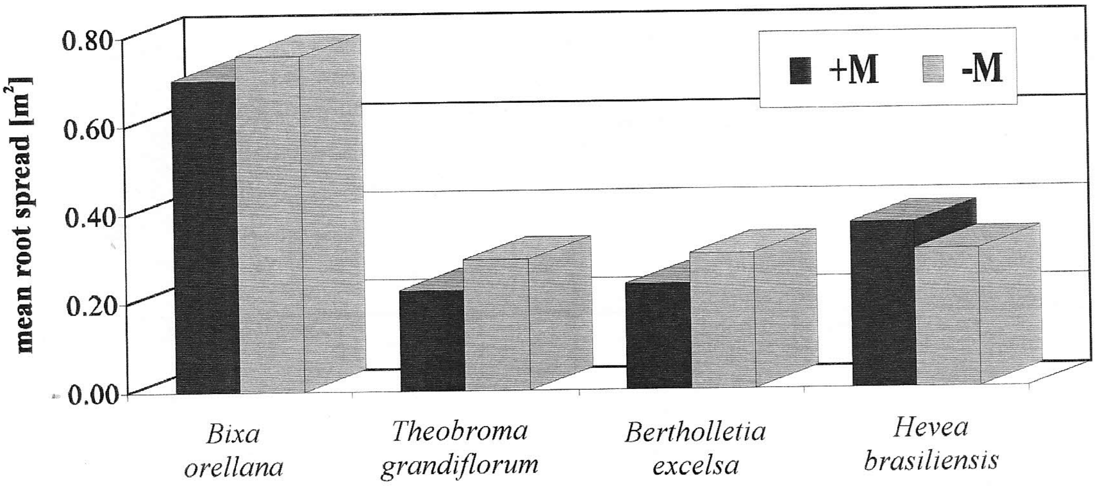

Figure 4: Influence of AMF on the spatial root distribution

+M = inoculated with AMF, -M = not inoculated

Fertilization regime for all plants was 30 % of the recommended dose. Mean root spread of *B. orellana* was significantly higher than the ones of all other species. Plants inoculated with AMF and not inoculated were not significantly different.

Four months after planting the root systems of all species have grown into the field soil and thus are in contact with autochthonous AMF. Following the presented parameters the results give rise to the suggestion that there actually was no influence or an equal effect of both, autochthonous and exogenous AMF; neither root characteristics, root distribution nor spatial root area (figure 4) was significantly effected. The measurement of plant heights did not reveal differences, also if plants were low fertilized (*T. grandiflorum* 1.09 m ± 0.1 and 1.14 m ± 0.08, *B. orellana* 1.4 m ± 0.12 and 1.53 m ± 0.06, AMF-inoculated and non inoculated, respectively).

The influence of different levels of fertilization has been studied for *B. orellana*. Whilst the inoculation with AMF did not show an influence on the investigated parameters high fertilization led to an enormous increase in root spread of *B. orellana*. Mean spatial root area was 2.03 m^2 ± 0.41 whereas for plants with 30 % fertilization regime a root spread of 0.76 m^2 ± 0.18 (non regarding AMF-inoculation or not) was measured. Fertilization did not effect general root distribution or plant height (1.4 m ± 0.12 and 1.47 m ± 0.15, AMF-inoculated and not inoculated, respectively).

CONCLUSIONS

In the first four months after planting into the field all plant species had already overcome the artificial environment of the plant hole and are grown into the field soil. Within this early state of cultivation the root systems of the selected species are significantly different. The characterization of root distribution of all species indicate different strategies in nutrient uptake and establishing in the field. The importance of root mats for the recycling of mineral elements in tropical ecosystems has been described by Schubart (1977). In fact our studies revealed that *B. orellana* covers a huge area near the soil surface with its relatively high nutrient contents. In contrary, the root systems of the other species seem not to prefer this first soil layer but deeper horizons (figure 3). For these plants studies on the unrestrictedly and restrictedly nutrient pools (Van Noordwijk and De Willigen, 1991) could reveal more details on nutrient uptake efficiency in deeper soil depths. Additionally, *H. brasiliensis* and *T. grandiflorum* did show very slight fine root development. However, e.g. 10 years old trees of *H. brasiliensis* in an abandoned rubber plantation near the experimental field show a dense fine root system nearby the soil surface. Thus it will be necessary also to observe root growth and distribution patterns of the selected plant species at later phases of development. These are being made by S. Emmerich (unpublished data).

AMF-treatment did not result in different growth and development patterns of the plants (figures 2, 4). While the importance of VA-mycorrhizal fungi for root mats of polyculture systems has been confirmed (Diederichs and Moawad 1993), and effectiveness of autochthonous and exogenous AMF could be observed by Feldmann (1994) e.g. on shoot growth and yield the presented parameters did not show an influence of mycorrhiza. However, effectiveness of the same inoculum of *G. etunicatum* on maracuja plants (*Passiflora edulis*) has been observed for at least the first 6 months of field cultivation (Müller et al. 1993). Table 2 indicates that the exogenous AMF did not have the capability to survive under field conditions, probably due to concurrence from autochthonous mycorrhiza that managed to colonize the roots (table 1). A further understanding of the coincidence of mycorrhiza symbionts will be of particular interest for the introduction of highly effective AMF that can survive and coexist under native soil conditions in the field. In this context it also has to be taken into consideration that the level of fertilization affects the degree of colonization due to favorable nutrient conditions for the host. The data for *B. orellana* clearly show that high fertilization enhances the rooting area (figure 4). However, fertilization or AMF-treatment did not result in different root characteristics and root distribution in the soil horizons. Thus it could be deduced that in the early plant developmental phase root growth is governed by species specific traits rather than by environmental traits.

More detailed further investigations to these preliminary studies would help to take appropriate plant species into account, which on the one hand develop extensive root systems near to the soil surface and/or, on the other hand root in greater soil depths, and thus may reduce losses of mineral elements. It has to be analyzed when and to which extent the root systems will be influenced by field management processes in later phases of the polyculture system development. Further it has to be studied to which extent root-root interactions of the species combined in polyculture systems are synergistic or competitive.

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