Plant Functional Traits and Types: their relevance for a better understanding of the functioning and properties of agroforestry systems.

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Abstract

Complex Agroforestry Systems (AFS) in the humid tropics are mixed forest-like ecosystems that often display high species diversity that makes their structure and functioning difficult to understand and simulate. Plant Functional Traits and Types (PFTT) are broadly used concepts in community and ecosystem ecology to address the responses of species to changes in the environment and/or the contribution of species to ecosystem functions. The relevance of these concepts, developed for natural ecosystems, for a better understanding of AFS is unknown but we hypothesize that they might be useful to gain a better understanding of the resilience properties of AFS and to answer the following questions: What is the role of AFS species composition in ecosystem functions? and, conversely: How do environmental changes affect that species composition, and hence AFS performance?

We propose here to analyse the potential and limitations of the PFTT concepts in the case of AFS in the humid tropics, notably referring to rainforest dynamics regarding succession patterns. This analysis is based on case studies from coconut-based AFS in Melanesia and coffee-based AFS in West Africa. Plant functional traits, such as growth form, life form, phenology, and height were first used to describe these AFS. Since AFS are a result of farmers interventions, to evaluate their performance specific traits, corresponding to agronomic characteristics of species such as the production cycle, and part of the plant used, need to be considered in addition to traits considered for natural forests.

Resumen

Los Tipos y Carácteres Funccionales de Plantas (TCFP) son un concepto ampliamente utilizado en ecologia para medir las respuestas de ciertas especies a cambios ambientales y/o sus contribuciones a funciones del ecosistema. La eficiencia de aquel concepto, desarrollado para ecosistemas naturales, para el mejor entendimiento de los SAF es desconocida, pero ponemos la hipotesis que podria permitir un mejor entendimiento de la resiliencia de los SAF y permitiría contestar a las siguientes preguntas: ¿Cuál es el papél de la composición específica de los SAF para dar las funcciones del ecosistema? Y al opuesto, ¿Cómo podrían los afectar cambios ambientales a esta composición específica y entonces las potencialidades de estos SAF?

Proponemos un análisis de potencialidades y límites del concepto de TCFP en el caso de SAF en el trópico húmedo, en particular referiendonos a las dinámicas, de sucesión en bosques naturales húmedos. Este análisis esta basado en estudios realizados en SAF basados en producción de coco en Melanesia, y en SAF cafetaleros de Africa del Oeste. TCFP, tales cómo tipo de crecimiento, tipo de architectura, de fenología o de altura, fueron utilizados en un primer paso para describir estos SAF. Dado que los SAF son un resultado de las intervenciones de los agricultores, los carácteres específicos que corresponden a características agronómicas de las especies tales cómo el ciclo de producción o las partes de la planta utilizadas, deben ser considerados además de los

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carácteres tomados en cuenta para bosques naturales, con el fin de evaluar sus potencialidades.

Introduction

Plant Functional Traits and Types (PFTT) are broadly used concepts in community and ecosystem ecology to address the responses of species to changes in the environment and/or the contribution of species to ecosystem functions (Lavorel and Garnier, 2002). Complex Agroforestry Systems in the humid tropics (AFS) are agrosystems whose structure and properties may be close to rainforests (Ewel and Bidgelow, 1996). However, the relevance of PFTT concepts used for natural ecosystems, to gain a better understanding of AFS, is unknown. We hypothesize here that PFTT concepts may be used as a surrogate to assess the resilience properties of AFS and to answer the following questions: How do environmental changes affect species composition and hence AFS performance? What is the role of AFS species composition in ecosystem functions? We propose in this article a first attempt to use the PFTT concept in the case of AFS and an analysis of the potentials and limitations of this methodology.

The use of PFTT in ecology

As defined by Violle et al. (2007), a functional trait is any morphological, physiological or phenological feature measurable on an individual level, from cell to whole organism, without reference to the environment or any other level of organization. Plant traits may be related to: i) plant *responses* to environmental change (e.g. climate, soil resources, including water and nutrient availability), disturbance (including fire, ploughing); ii) plant competitive strength and plant "defence" against aggressors or pathogens; or iii) plant *effects* on biochemical cycles and disturbance regimes (Lavorel and Garnier, 2002). They include: whole plant traits, such as plant height or life form; leaf traits, such as specific leaf area (SLA), leaf size or leaf phenology; stem and belowground traits, such as specific root length or bark thickness; and finally regenerative traits, such as dispersal mode, seed mass or resprouting capacity (Cornellissen et al., 2003). Hence a trait may characterize the ability of a species to grow, reproduce or survive in a given environment.

The very great species diversity that characterizes many AFS, as in tropical forests, makes it necessary to create functional "types" or "groups" able to represent the performance of groups of species. The PFTT concept proposes that species can be grouped according to common *responses* to the environment and/or common *effects* on ecosystem processes. Both groups include traits related to plant morphology, plant physiology (e.g. growth rate) or phenology. They make it possible to account and predict for observed successions and dynamics. For example, in tropical rainforests, traits relative to growth (maximum height, SLA, wood density) and regeneration (number of seeds, dispersal) can be used to predict more or less precisely the distribution of species in groups relative to their performance and dynamics, corresponding to "distinct ecological groups" that are involved in a specific way in the progress of the successions (Gourlet-Fleury et al., 2005, Delcamp, 2007). Regarding plant strategies, ecologists have classed plants in two groups based on two major types of demographic strategies in ecosystems: **r** strategy plants, which favour reproduction and **K** strategy plants which favour biomass production (MacArthur and Wilson, 1967). An analysis of functional traits linked to reproduction and growth makes it possible to class plant species in one or other of these groups, in a more or less distinct continuum. High multiplication rate, growth rate, interspecific competition, number of seeds, early sexual maturity, low life duration and high mortality characterize **r** plants vs. **K** plants which have opposite values for those traits. Moreover, main plant strategies (i.e. copping with disturbance, competition, and stress of resources) involved in the "plant strategy scheme" of Grime (1977) can be approached using biological traits. Height at maturity, specific leaf area and seed mass are considered as relevant proxies to reveal plant strategies (Westoby, 1988).

Relevance of PFTT in agroforestry

This functional classification can be applied to the successions found in different AFS. A comparison of the structures of three different AFS in the same region of Forest Guinea showed that the significant differences in the structure and species composition between these AFS revealed changes in PFTT (Diabaté *et al.*, 2007). The different functional groups could be related to the nature, time and degree of disturbance in each system (table 1).

Table 1. Composition of three agroforestry systems (AFS) in Forest Guinea in relation with plant functional traits and types and disturbance.

AFS	Nb. of tree and shrub species	Main functional group	Type of disturbance
Old coffee agroforest	50	K	low
Young coffee agroforest	45	r (K)	intermediate
Elaeis parkland (rice field)	2-8	r	high
Elaeis parkland (fallow of 4 years)	19	r	(slash and burn)
Elaeis parkland (fallow of 7 years)	30	r	(slash and burn)

In old coffee agroforests, ***K*** plant species dominated. Investment in biomass was high, growth rate was low. Species were typical dense rainforest species and included high value forest trees such as *Daniellia thurifera*. In young coffee agroforests, **r** plants such as *Terminalia ivorensis* dominated but **K** plants such as *Piptadeniastrum africanum* appeared when disturbance was low. In *Elaeis* parklands, **r** plant species such as *Anthonotha macrophylla*, which are typical of high and frequent disturbances (slash and burn every 3 to 7 years), were present. These systems included food crops (rice, tomato, cassava, etc.). They were pioneer plants adapted to unstable ecosystems, characterized by early maturity, high fecundity, and high energy and nitrogen needs that allowed high productivity.

Coconut-based AFS in Vanuatu are cultivated systems whose dynamics can also be similar to those of secondary forest systems. The total number of species varies over time, as do the types of species present (Lamanda et al., 2007). Plant type changes with time, switching from a preponderance of tubers (type **r**) to type **K** forest and fruit tree species. The appearance of gaps (senescent coconut palms) enables the reintroduction of type **r** sun-loving species, thereby ensuring the beginning of a new cycle in the plot. Hence, AFS dynamics, like rainforest dynamics, are a combination of slow and gradual processes (growth, death, regeneration) and rapid processes (disturbances), largely driven by man in the case of AFS.

A need for other classifications and for identifying relevant traits

Functional traits can also be used to assess the ecological properties of agrosystems. Ecosystem properties depend on *effect* traits weighted according to the relative abundance of species (Violle et al., 2007). Such relations, to estimate aboveground productivity or soil fertility sustainability in AFS or other variables of interest directly or indirectly linked to any ecological service, need to be studied.

Depending on the aims many other classifications can be defined to group the species existing in AFS, based on a limited number of traits, or on integrated traits that reflect a large number of other traits. Other traits, including traits related to human use, may be defined; for example, to group species according to a longevity index (annual crops vs. perennial crops), a use index (food, textile, medicinal, construction, etc.), depending on the plant organ used (fruit, stem, seed, leaf, root, sap, etc.), the morphotype and size, the existence of lignin (herbaceous *vs.* woody plant), the relation to man (cultivated, semi-wild, wild). The type of use (sold *vs*. consumed/used) is a social criterion. It is therefore possible to define ecological, agronomic, economic or social traits which, when used to create a framework of groups, will make it possible to characterize the systems studied, their performance and how they evolve.

Conclusion

Plant traits are widely used to address questions at various scales in natural ecosystems. We believe that their use in rainforest-like ecosystems, such as many AFS, may significantly improve our capacity to understand, simulate and improve the performance of existing AFS. Applying PFTT to AFS should therefore make it possible to more accurately predict or optimize the species succession process in these AFS, through a better understanding of organism responses to disturbances (response traits) but also a better understanding of the effect of AFS on key environmental variables, such as soil organic matter in the soil. The first stage in that approach has been described here: it involves the functional characterization of diversity in AFS and their dynamics. Applying PFTT to a mechanistic approach of interspecific interactions, or the response of species and AFS to environmental changes, also offers promising prospects yet to be explored.

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