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A trait-based characterization of cover plants to assess their potential to provide a set of ecological services in banana cropping systems

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ABSTRACT

Cover plants are one of the means to increase the functional biodiversity of fields and to enhance the ecological functions of the communities. However, the design of cropping systems including cover plants relies largely on expert knowledge. There is a lack of methods to select the best suited cover plants according to their role in the agrosystem. We propose to use functional traits to select cover plants suited to sustain ecological services in the banana agrosystems of the French West Indies. Our objectives were (i) to characterize a collection of cover plants on a trait basis, according to their potential to provide the services expected in a banana agrosystem and (ii) to discuss the potential use of this characterization for the design of innovative multi-species banana cropping systems. In these systems, four main services are targeted, i.e. controlling weeds, controlling plant-parasitic nematodes, improving soil fertility and particularly N availability, and avoiding competition with banana for resource acquisition. Three experiments were conducted, under field and controlled conditions, to evaluate the potential of a collection of 28 tropical cover plants to achieve the functions related to these services. For each cover plant, a functional profile was constructed from a combination of plant traits that are easy to assess experimentally. It described plants' potential to achieve the functions expected in a banana agrosystem. Functional profiles required for cover plant usages were also identified. The comparison of the plant functional profiles and the functional profiles required for their usages enabled us to select the best suited plants for each usage. However, these functional profiles rarely corresponded, meaning that a cover plant is rarely sufficient to achieve all the functions required for a usage. Functional complementarities obtained by the mixture of different species of cover plants are thus often required. Compared to classical approaches of innovative cropping system design based on the experimental testing of spatial and temporal plant combinations, such a trait-based approach saves time by focusing on a shortlist of cover plants best suited according to their functions in the agrosystem.

1. Introduction

Increasing plant functional diversity is expected to enhance ecological functions and is needed to maintain ecosystem services (Isbell et al., 2011). There is increasing evidence that functional biodiversity restores biological regulations, exploits synergies between component species, confers stability, and increases productivity both in natural ecosystems (Thebault and Loreau, 2005; Tilman, 1988; Tilman et al., 1997) and in cultivated agrosystems (Altieri, 1999; Newton et al., 2009; Tilman et al., 1996; Vandermeer, 1989). As a consequence, increasing plant functional diversity in the agrosystem can maintain productivity while reducing the levels of chemical inputs.

Cover plants are one of the means to increase the functional biodiversity of fields. Used by farmers for a long time as green manure or fodder, they have had renewed interest since the 1990s because of their roles in the control of erosion, the control of weeds and pests, the input of N by atmospheric fixation, the improvement of nutrient cycling, and the limitation of water and nutrient losses (Lu et al., 2000). As a consequence, cover plants are increasingly studied, as attested by the number of scientific articles that contain "cover crop", "cover-crop" or "cover plant" in the title, abstract or key-words, which rose from 2 in the 1980s to 73 in 2000 and 178 in 2011 (analyzed from Web of Science data). However, the design of cropping systems including cover plants relies largely on expert knowledge. Moreover, there is a lack of methods to select

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Table 1
Agroecosystem services expected in banana agrosystems, a choice of related plant functions, associated plant coarse characteristics, and effect traits used to assess the potential of cover crops to achieve these functions.

Service	Plant functions	Plant characteristics	Plant traits observed	Unit
R. similis control – *regulating service*	• Pest direct control	Ability to multiply nematodes	Host status	–
Weed control – *regulating service*	• Aboveground competition by rapid spread on the soil surface	Speed of growth	Absolute growth rate of the plant leaf area (AGR)	cm^2/pl/day
	• Persistent soil surface colonization	Plant persistence	Duration of plant life cycle	*qual*
		Ability to be propagated by vegetative multiplying	Presence of vegetative propagation organs/ability to grow from cuttings	*qual*
	• Physical barrier to germination provided by mulch	Volume of mulch	Dry aboveground biomass	kg/m^2
		Speed of decomposition	Dry matter content of aboveground biomass (DMC)	%
Competition with banana–*dis-service*	• Aboveground competition	Ability to grow above banana	Plant height	*qual*
		Ability to climb onto banana	Growth habit	*qual*
	• Belowground competition	Density of exploration in the banana rooting zone	Mean root impact density in the 0–30 m soil layer (RID)	/dm^2
		Plant demand on a soil area basis	Dry aboveground biomass	kg/m^2
Improvement of soil fertility – *supporting service*	• Facilitation of growth through N return	Quantity of N in plant organs	Quantity of N contained in the aboveground biomass (QN), composed of	kg/m^2
			Dry aboveground biomass	kg/m^2
			N content on a mass basis	%
		Speed of mineralization of mulch	C/N of the aboveground biomass	–

the best suited cover plant species according to their role in the agrosystem.

A promising method for selecting the best suited cover plants involves functional traits as simplified indicators of plant functions. Functional traits have been extensively used in comparative ecology studies to describe the relationships between plant diversity, community structure, and ecosystem properties. They are defined as the morphological, physiological, and phenological features, measurable at the plant level, that impact plant performances (Violle et al., 2007). Functional traits are associated with plant functions in the ecosystem, i.e. their effect on ecosystem properties (effect traits), but also with plant responses to the environment (response traits) (Lavorel and Garnier, 2002). Functional traits approaches have been used to study the role of plants in agrosystems and cultivated grasslands for a decade (for a review, see Garnier and Navas, 2012). Traits related to growth and light capture served to identify plant capacity to suppress weeds (e.g. de Vida et al., 2006; den Hollander et al., 2007; Gibson et al., 2003). The ability of grassland species to survive drought was also evaluated from plant traits (Volaire, 2008; Volaire et al., 1998). A trait-based typology of grasses was constructed integrating plant phenology and their fodder value (Ansquer et al., 2004). We propose, in this article, to use functional traits to select cover plants suited to the banana agrosystems of the French West Indies.

In the tropical climate of the French West Indies, annual and perennial weeds grow fast all year and may strongly compete with banana plants for soil resources. In such conditions, pathogen pressure is also very high. Plant-parasitic nematodes and particularly Pratylenchidae *Radopholus similis* are one of the main pests of banana. They lesion the root system, impair plant nutrition, and cause toppling and uprooting of banana plants. To decrease such parasitic nematode populations and their subsequent damage, growers have to drive a one year sanitation fallow after every five or six production cycles of banana. This fallowing period is also aimed at restoring soil fertility. In recent years, cover plants have consistently been used during the fallowing period (as sequential cropping) or in association with banana (as intercropping). Considering the constraints of banana agrosystems, suited cover plants are expected to control weeds and plant-parasitic nematodes (regulation service, senso Zhang et al., 2007), to improve the soil fertility and particularly N availability (supporting service, senso Zhang et al., 2007), but also not to compete with banana for resource acquisition (dis-service, senso Zhang et al., 2007). Tixier et al. (2011) proposed a modeling approach to evaluate the potential of 11 cover plants to achieve some of these services. In this article, we develop a more generic method to characterize plants' potential to achieve functions in an agrosystem, based on a functional traits characterization. More precisely, our objectives were (i) to characterize a collection of cover plants on an effect trait basis, according to their potential to provide the main ecological services expected in a banana agrosystem, i.e. controlling weeds, controlling plant-parasitic nematodes, improving the soil N availability, and avoiding competition with banana for resource acquisition, and (ii) to discuss the potential use of this characterization for the design of innovative multi-species banana cropping systems. To reach these objectives, three experiments were conducted on a collection of 28 tropical cover plants ranging from small herbaceous to shrubby plants.

2. Materials and methods

2.1. Selection of traits to be assessed

In the banana agrosystems of the French West Indies, cover plants are generally grown to control plant-parasitic nematodes (particularly *R. similis*), to decrease or suppress weed pressure, to improve soil fertility (particularly N), and to avoid competition with banana for resources. These ecological services were analyzed in terms of related plant functions and plant effect traits (Table 1).

The ability of cover plants to control *R. similis* was assessed through their host status toward that nematode species, i.e. their ability to increase *R. similis* populations in their roots. Host status