How to Integrate Cover Crops to Enhance Sustainability in Banana and Citrus Cropping Systems

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Abstract

In Martinique (French West Indies), because of the susceptibility of the insular environment, the demand from society and policy-makers is high for sustainable and environmentally friendly fruit production systems. In tropical wet areas, weed management is crucial but difficult to control without herbicides. Herbicide becomes the most important pesticide input in banana plantations and orchards, thus developing herbicide-free alternatives are a priority. Cover crop intercropping constitutes the best option. Besides weed control, we considered their ability to reduce runoff and soil erosion, to compete with the main crop for water and nutrients, to host pests and natural enemies, and to preserve biodiversity. Thus, cover crops turn into global services crops. A multi-step and multi-criteria grid was built to select the ideal cover crop. We tested it on banana fields and citrus orchards. First, cover crop pre-selection was common and checked for climate suitability, seed availability, height, status of noninvasive species and capacity to be perennial. Second, we assessed the agronomic behaviour of seven pre-selected cover crops under field conditions. We measured cover crop specific traits (germination rate, covering rate, perenniality, biomass production, root depth, nutrient uptake or recycling, regrowth after mowing, adaptation to shade). Last, according to each cropping system specifications, we designed prototypes with the most relevant cover crops. In citrus orchards, grasses characterized by a high covering index associated with a low biomass production were selected, but natural enemies hosting services were poor. In banana fields, grasses were intercropped too, but nitrogen competition, was too high and led to loss in banana yield. As a conclusion, we showed that the concept of an ideal cover plant has to be implemented and combined in a more efficient mixed cover system (grasses mixed with nitrogen fixing plants).

INTRODUCTION

In a tropical island, on account of the susceptibility of insular environment, the demand from society and policy-makers is high for more sustainable and environmentally friendly fruit production systems. This demand is a major issue in the context of Martinique (French West Indies), characterized by a high density of inhabitants (380/km^2), and where impacts of agriculture on the fragile environment (coral reefs, rain forest) and water resources have to be reduced (Rawlins et al., 1998). At the same time, the tropical humid climate is favourable to the fast growth of weeds. Weed control is difficult without herbicides. For this reason, herbicide becomes the most important pesticide input in banana and fruit fields. Developing herbicide-free alternatives is thus a priority (Firth and Wilson, 1995). To date, the weed management remains based on herbicides, and herbicides residues are regularly found in water sources (DIREN, 2007). Furthermore, orchards and banana cropping systems, which are now regularly using herbicides, lead to added environmental impacts: during the rainy season bare soil leads to high soil erosion (Duran Zuazo and Rodriguez Pleguezuelo, 2008; Dorel et al., 2010). Thus, from an environmental point of view, herbicide use is not sustainable. Due to the topography of plots, alternatives based on mowing weeds are not viable. The most promising alternative for weed management is to intercrop cash crop with a selected cover crop.

Cover crop species should achieve multi-criteria objectives and thus the choice of the most suitable species remains difficult. Some criteria are of priority: climate suitability, seed commercial availability, non-invasive status and low management expenses. Selecting a cover crop species means searching for the plant with the best compromise between competition ability against weeds and competition with the cultivated crop for the best compromise between its efficiency and its management requirements (Picard et al., 2010; den Hollander et al., 2007). Finding an appropriate cover crop is thus a key stage in the design of cover-cropping systems, and agronomists need rapid and easy tools to assess the growth of new cover crop species. Here, we present a multi-criteria method for the screening of species of cover crops dedicated to banana and citrus cropping systems. We present how the evaluation criteria were chosen and how thresholds were selected both for banana and citrus systems.

MATERIAL AND METHODS

Selection of Evaluation Criteria

We have defined four types of evaluation criteria related to regulation and market constraints, coverage factors, technical compatibility, and biodiversity conservation. Constraints related to the regulation and the market, have taken in account the non-invasive status of the cover crop and its seed availability. We have assessed the coverage , measuring two critical stages for intercropping: its ability to establish and then to be perennial in the intercropping conditions. We have assessed the technical compatibility by cover crop agronomical suitability (climate and foliage height), its capacity to compete with the main crop for mineral resources, its volubility, its needs for additional work for mowing, and its compatibility with workers and agricultural machinery. We have assessed the biodiversity conservation, taking into account both possible drawbacks in terms of hosting pests and services (conservation of natural enemies and wild species). Finally, to determine if a species of cover crop is suitable for either banana or orchard intercropping, it should have no prohibitive value for any criteria.

Regulation and Market Constraints

The non-invasive status of a cover crop is crucial, even more when its use was intended for insular cropping systems. We have checked the non-invasive status with the IUCN Global invasive species database (IUCN, 2005-2010). The seed availability has been checked on the website catalogue of the main international suppliers (Heritage Seeds, 2007; Wolf Seeds, 2007).

Coverage Service Factors

The cover crops ability to germinate during the first weeks after sowing is a critical stage on which the weed control efficiency will depend. We have assessed the cover crop capacity to grow at the 8^{th}, 12^{th} and 22^{th} week after sowing using the percentage of soil cover, through the CEB method. This has led to a quantitative rating from 0 to 9 (Marnotte, 1984). The capacity to be perennial in the intercropping conditions was assessed on the base of the same indicator, 12 months after sowing. It has also led to a quantitative rating.

Technical Compatibility

The sustainability of a cover-cropping system lies in its adaptation to climatic conditions, to its consistence with farmer's constraints and field practicability, and to the competition for water and mineral resources between the cover crop and the cash crop. We have checked the climate adaptation according to published data and dedicated websites (Tropical Forages, 2005; FAO Grassland species profiles). We have assessed the potential of competition with the maximal biomass produced by the cover crop during year 2008. It was considered high if above 2 $kg.m^{-2}$ and low if below 1 $kg.m^{-2}$. The shade tolerance was an important criterion for banana plantations regarding the perenniality of the cover-crop. The other main technical compatibility drawback is the extra work necessary for the mowing or the maintenance of the cover crop (depending on the cover crop height and its biomass). It was considered as too high above 30cm for banana and 50 cm for orchard. The volubility of the cover crop was also an important criterion due to the extra work it may require. The last technical criterion we have assessed was the ability to tolerate the human and machine traffic in the inter-row.

Biodiversity Conservation

The main drawback of adding a cover crop in terms of biodiversity changes is that cover crops may host pests and natural enemies. We assessed the host status of the main pests of banana and citrus, using bibliographic data or by measuring the host status for plant parasitic nematodes (Jenkins, 1964). We have also measured the capacity of cover crops to host natural enemies with observation in the field (insect survey).

Measurements of Cover Crop Characteristics

With our multi criterial method, we have preselected and assessed seven species of cover crops from three families, mainly *Fabaceae* (*Neonotonia wightii* 'Cooper', *Pueraria phaseoloides*, *Chamaecrista rotundifolia* 'Wynn') and *Poaceae* (*Brachiaria decumbens*, *Cynodon dactylon*, *Paspalum notatum* 'Common'), but also *Convolvulaceae* (*Dichondra repens*) that may be of interest for banana and citrus orchard cover cropping. According to the literature, these species have a wide range of growth characteristics, in terms of maximal biomass, leaf area index, nitrogen content, and optimal radiation requirements for their growth. Each species was grown in a plot in pure stand of 20 m^2 area. The soil was a nitisol derived from volcanic (andesitic basalt) ashes. We used the recommended densities that provided a uniform and fast growth to cover the soil. No fertilizer was added during the experiment. Irrigation was provided only during the first two weeks to ensure optimal plant emergence. We have measured dry biomass at 8^{th}, 13^{th}, and 22^{th} week after sowing. Biomass of the entire shoot of the plant was measured using three samples of 0.625 m^2 (0.25 by 0.25 m) per plot. Aliquots of plant samples were dried at 60°C for 48 h and weighed.

RESULTS AND DISCUSSION

Elaboration of the Multi Criteria Selection Grid (Fig. 1)

We have combined all our selected criteria according to the different types presented above (regulation and market constraints, coverage factors, biodiversity conservation and technical compatibility).These were organized in different steps (Fig. 1) according to the systems constraints and objectives and to priority decision rules. The multi-criteria grid was completed, using first literature data (steps/criteria 1 to 4), then field trial data (step/criteria 5 to 7) and prototypes data (last step 8).

Application to Seven Species

We have applied our multi criteria evaluation grid to seven species of cover crops (Table 1). *P. phaseoloides* fitted all the criteria excluding volubility, which was considered non-acceptable for both systems. *C. rotundifolia* and *D. repens* did not satisfy the coverage factors criteria for their low coverage index associated with low biomass. *B. decumbens* was characterized by a high biomass that should lead to an important competition with the main crop for mineral resources. This first analysis showed the difficulty to find cover crop species that satisfy both the need of covering the soil, which need a fast and sufficient development, and the technical suitability, which often needs a more moderated development. In our case, *C. dactylon*, *P. notatum*, and *N. wightii* complied these criteria and thus have turned into promising species to intercrop with banana plantation or orchards. The allelopathy of *C. dactylon* have led to the rejection of this species. Among these species, two of them, *N. wightii* and *P. notatum*, were suitable both for banana plantation and citrus orchards and have been introduced in prototypes.

In citrus orchards, grasses characterized by a high covering index associated with a low biomass production, were selected but natural enemies hosting services were poor. Other suitable species or a mixture of species have to be identified to provide better ecological regulation of pests or to improve pollination through bee hosting. In banana fields, grasses have been intercropped too, but nitrogen competition has been identified and evaluated, as a key criteria in maintaining high banana yield (Boodey et al., 2004). The evaluation of the *N. wightii* suitability is in progress, but we are still looking for more suitable species, i.e. perennial, with low volubility and low nutrient demand and/or nitrogen symbiotic fixing properties.

Limit of the Method

We have implemented a multi-criteria grid using data acquired in a field trial. These data should be complemented, especially for biodiversity measures according to field conditions and the method proposed by Simon et al. (2010), to measure the natural enemies in different soil and climate conditions.

Another point that we should assess is the nutritional competition between the main crop and the cover crop. Beside classic nutritional status measurements, we could take into account the crop's ability to proceed to symbiotic fixation of atmospheric nitrogen, which can reduce the potential nitrogen competition between the cover crop and the main crop.

CONCLUSION

Our multi-criteria grid could be used as a generic tool to combine all the sought criteria, integrating the services and the agronomical requirements of the cover crops and the constraints of a cropping system.

But the ideal cover plant probably does not exist, because some of the constraints and the function to be considered are sometimes incompatible. Mixing species and relay cropping of cover crops could also be a successful way to adapt the cover crop management to the high number of constraints for integrating cover crops in banana systems and citrus orchards. As a conclusion, we have shown that the concept of an ideal cover plant should be implemented, perhaps combining a more efficient mixed cover system (grasses mixed with nitrogen fixing plants).

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Tables

Table 1. Targeted values of selection criteria for orchards and banana systems, and application to seven species of cover crops.

	Coverage factors			Technical compatibility					Biodiversity conservation		Overall suitability
	Establishment rate	Capacity to be perennial	Covering rate	Mowing or maintenance requirements	Volubility	Foliage height (cm)	Persistence after mowing or walking	Shade susceptibility	Hosting pests	Hosting natural enemies	
Target value for											
Orchard (O)	fast	high	high	no	low	50	high	inter-row : high under-canopy : low	no	yes	
Banana (B)	fast	high	high	no	low	30	high		no	yes	
B. decumbens	fast	high	high	~~high~~	no	~~>>50~~	high	medium	no	no	NC
C. dactylon	fair	high	medium	~~high~~	no	<30	high	medium	no	no	O
P. notatum	fast	high	high	low	no	≈ 30	high	low	no	no	O+B
P. phaseoloides	fair	high	high	~~high~~	~~high~~	~~>50~~	medium	low	no	ND	NC
N. wightii	fair	high	medium	medium	medium	≈ 30	Low	low	no	ND	O+B
C. rotundifolia	fair	low	fair	-	no	~~50~~	~~No~~	medium	ND	ND	NC
D. repens	~~low~~	~~low~~	~~low~~	-	no	5	~~Low~~	medium	ND	ND	NC

ND: Not determined.
NC: Not compatible.
☒: Cripping criterion.

Figures

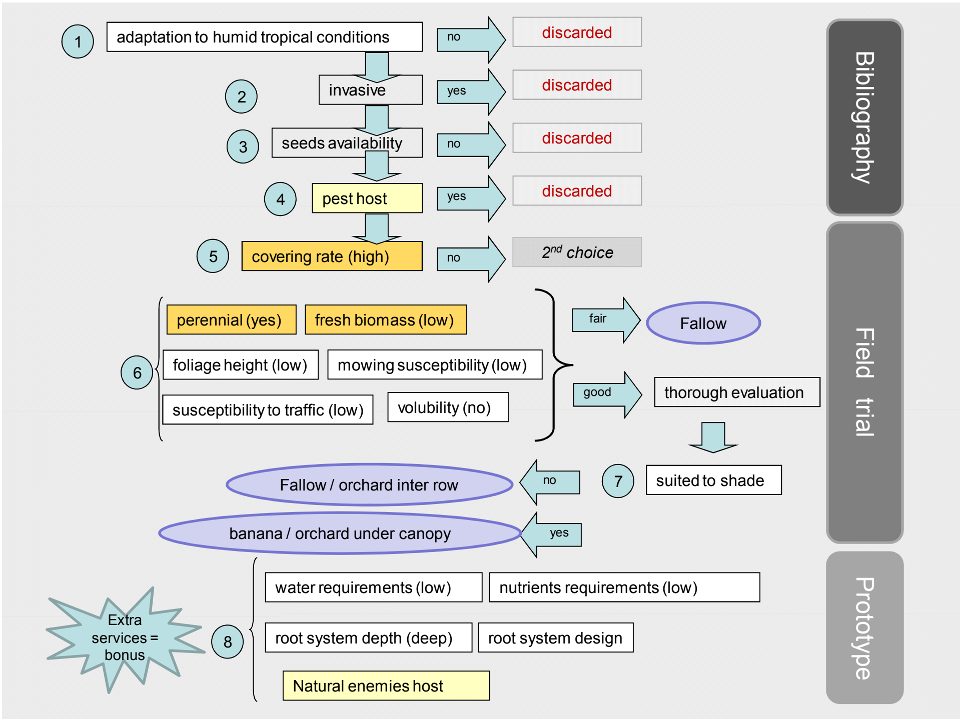

Fig. 1. General scheme of our multi-criteria selection grid. The numbers indicate the steps (1 to 4: bibliography data; 5 to 7: field trial data; 8: prototype data), the criteria types are mentioned as following: ☐: regulation and market constrains; ☐: technical compatibility; ☐: biodiversity; ☐: coverage factors. ⇨ indicates the assessment result; ○ indicates the mode of cover crop integration in the prototype.