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Ecological engineering: from concepts to applications

Choosing cover crops to enhance ecological services in orchards: a multiple criteria and systemic approach applied to tropical areas

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Abstract

Conventional agriculture is based on a high level of chemical inputs such as pesticides and fertilisers, leading to serious environmental impacts, health risks and loss of biodiversity. Pesticide reduction is a priority for intensive agricultural systems such as orchards. Reintroducing biodiversity in single crop systems can enhance biological regulations, and contribute to reduce the use of chemicals and to provide additional services such as run-off and erosion control. In tropical wet areas, weed control is difficult to manage without herbicides especially when orchards are not located in easily mechanised areas and when labour force is costly. Cover plants can be easily introduced in orchards and could be efficient in weed control and other functions. Based on this assumption, we developed a specific approach for the choice of adapted cover plants in single crop orchards to control weeds and provide additional ecological services. The approach was undertaken on citrus orchards in the French West Indies.

A multicriteria evaluation grid was built to select an "optimal" cover crop. In both Martinique and Guadeloupe, 202 species were first selected in the local flora, and tested on vegetative characteristics. Specific criteria were secondly defined relating to seed availability (limitation of alien species introduction), farm constraints and regulations (no invasive species). Specific features were then determined according to the agronomic potential and ecological services for an optimal cover plant. Criteria included weed control, the ability to control runoff and erosion, water and nutrient competition, pests and natural enemies hosting capacity. The whole evaluation grid combines data from literature, expert assessment and experimental measurements.

Optimum cover crop functional groups were defined according to agrosystem and associated objectives. In Guadeloupe, a participatory approach led first to the selection of Fabaceae (*Neonotonia wightii*) characterized by high auxiliaries hosting services. These services were assessed using a bio-indicator (family of phytoseiidae). In Martinique, the need for a high covering index associated with a low production led to the selection of grasses: *Urochloa mozambicensis* and three *Paspalum* species.

The multicriteria grid can be used as a generic tool to select cover plants and can be easily adapted to apply to various cropping systems. Its use for banana cropping system is currently in progress. However, the concept of an optimal single cover plant remains difficult to achieve and the elaboration of a multi-specific cover system is often required to reach the desired efficiency.

Keywords: agro ecological services; cover plants; innovative practices; multi criteria selection grid

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1. Introduction

In conventional horticulture, the level of chemical inputs such as pesticides and fertilisers is high, leading to serious environmental impacts [1], health risks [2] and loss of biodiversity [3]. In the European Community, the reduction of pesticide use is a priority for intensive agricultural systems such as orchards [4,5]. Reintroducing biological diversity in single crop cropping systems can enhance biological regulations [6,7] and hence contribute to control the bioagressors in the agrosystem [8], to reduce or eliminate the use of chemicals [9] and to provide additional services such as run-off and erosion control [10].

Weed control is one of the most significant constraints that producers face in tropical wet environments. It requires, in most cases, large quantities of herbicides as weeds are hard to control in integrated production systems [11]. How can weeds be managed in orchards with minimal herbicide use? Maintaining weeds as a free ground cover, i.e. natural vegetation, results in high orchard management constraints and high competition with the crop [12]. The most obvious way to control a ground cover is by mechanical mowing or by brushcutting, but these mechanical practices become difficult when orchards are located in sloping or rocky areas and when labour force is costly [13]. We hypothesised that introducing selected cover plants, i.e. planned biodiversity, can efficiently control weeds in orchards. In order to test this hypothesis, we set up a method to choose the cover plants species that achieve specific criteria and combine functional ecological traits and agronomical characteristics. The aims were to promote bioregulations, to decrease the use of pesticides and, more generally, to provide ecological services, even if the biodiversity of the system is reduced compared to orchards with natural cover.

Our cover crop selection scheme was based on a systemic approach, attempting to find an ideal type of cover crop integrating specific functional traits [14,15], taking into account ecological, agronomical and socio-economical constraints and objectives. Our approach consisted of a grid construction structured by different selection steps according to specific criteria. The ranking and conditions within the selected criteria were defined with the producers for orchards in the selected areas according to the targeted agronomic and ecological services sought for the innovative cropping system and specific farm constraints (such as labour). When this multicriteria assessment was fruitful, our final aim was to enhance and design innovative cropping systems that include cover plants as a component. Our general approach is detailed in Fig. 1.

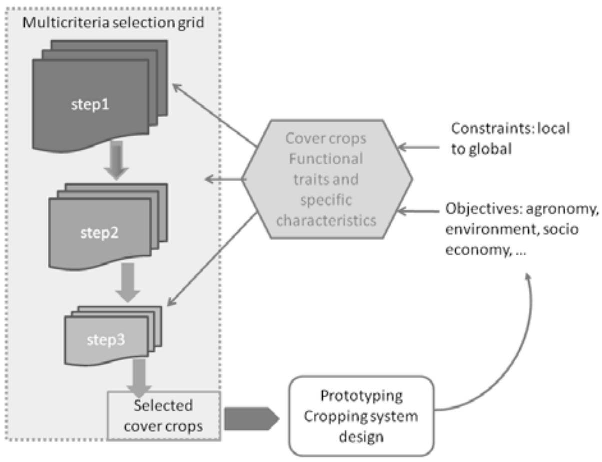

Fig. 1. General approach to select and integrate cover crops in cropping system, applied to orchards in tropical wet area

2. Materials and methods

2.1. Multicriteria grid construction

Potential cover crops were screened according to 3 successive steps (Fig. 2). Each step proceeded in binary choice: if the criteria objective was achieved, the cover crop was selected for the next step, if not it was rejected off the grid. Criteria are based on previous research, experts' assessment (scientists, technical staff and producers), agronomical experiments, and eco-physiological measurements. Core material, i.e. potential plant biodiversity, was taken from the floristic inventory/stocktaking of the area [16] that identifies 3200 plant species in both Guadeloupe and Martinique, the Tropical Forages database [17] that identifies 180 species of tropical cover crops and the AFRIS FAO website [18] that characterizes cover crop species.

The first screening step of the grid consists in a selection on vegetative characteristics: plant height (<50cm), capacity for re-growth (fresh biomass/ha 30days after mowing), covering capacity (covering rate normalized by CEB (Commission des Essais Biologiques) [19] and perenniality (ability to maintain on the long term). The perenniality was considered as an important objective because in an orchard the aim is to achieve a permanent cover crop during several fruit tree cycles and to avoid annual seedling operation.

The second step integrates criteria of practicability: seed availability (market access), regulations (non invasive species only) and specific farm constraints (labour demand, labour cost, …).

Step 3 of the selection takes into account the desired ecological services: capacity for weed competition (% cover / soil covering rate after sowing), N fixing properties (nodules presence and activity), potential auxiliary or pest hosting (ecological family trait), and biomass production (fresh biomass/ha). To implement step 3 of the selection grid, experiments were carried out both in Guadeloupe and Martinique (detailed in *2.2.*). The criteria ranking could differ from one cropping system to another, according to the sought objectives.

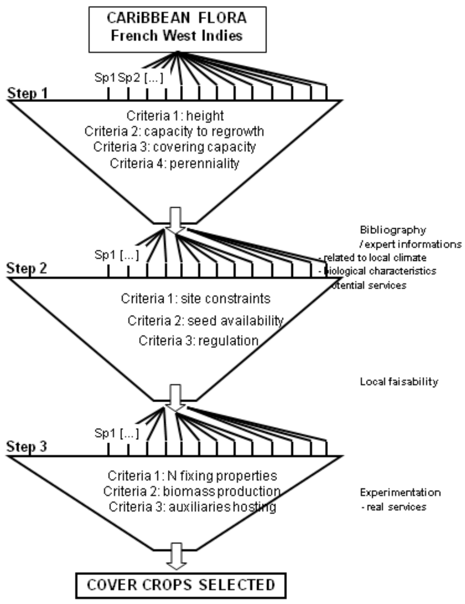

Fig. 2. Multicriteria selection grid with the detailed screening steps for orchards

2.2. Multi criteria grid use

We tested two different agro-ecological environments: a tropical area with a dry season of 3-5 months and non mechanized citrus orchards in Guadeloupe (Le Bouchu, Vieux Habitants) and a tropical wet area with mechanized citrus orchards in Martinique (Rivière Lézarde, Saint Joseph).

The global objectives of the introduction of cover crops in both situations were to compete with weeds but not with productive trees, to reduce or eliminate herbicide use and to facilitate orchard management (vehicle traffic and impact on soil, N symbiotic assimilation, auxiliary hosting, …).

2.2.1. Guadeloupe experiment

To implement step 3 of the selection grid, field trials were first conducted in 2007 in Guadeloupe, at the CIRAD experimental station, (Station "Le Bouchu", Vieux-Habitants, Guadeloupe, 16°03' N 61°45' W, altitude 24 m) (fluvisol, FAO classification; 2.5% organic carbon (OC); distribution of particle size: 34% clay, 23% silt, 43% sand). The climate is tropical with an annual rainfall average of 1000 mm and a dry season from January to April. Seven cover crops (Table 1) were assessed in individual plots (3 m x 3 m, with 3 replicates) from September 2006 to August 2007. The best plant was selected according to its weed control efficiency and its adaptability to environmental conditions (tolerance to dry season). The weed control efficiency was assessed through recovery rate dynamics and ability to compete with weeds, which was expressed by species richness. When species richness is high, weed control is poor. Recovery rate was estimated visually; it was assumed to be a surface equivalent to the vertical projection of the above ground parts of the plants onto the ground surface and was expressed as a percentage [19].

2.2.2. Martinique experiment

To implement step 3 of the selection grid, an experiment was conducted in 2008 Martinique, at the CIRAD experimental station (Station "Rivière Lézarde", Saint Joseph, Martinique, 14°39' N; 60°59' W, altitude 52m) (andic nitisol FAO classification, 3.2% organic carbon (OC); distribution of particle size: 66% clay, 13% silt, 16% sand). The mean annual rainfall is 2400 mm with a dry season from February to April.

Issued from step 2, 24 cover crops were assessed in individual plots (2.5m x 2.5m, with 3 replicates) from April to December 2008. Green biomass and the covering rate 70 days after sowing were measured to account for the competition with citrus and weed control: when green biomass is high (> 20T/ha) competition with trees is high, when recovery rate is low (cover percent < 55%) weed control is poor. We also measured the capacity of cover crop to regrow after mowing (fresh biomass 30 days after mowing, T/ha), its final height (cm), the root biomass (total fresh biomass T/ha) and the root depth. These parameters were used to assess other functional or agronomical traits: the ability of the herbaceous stratus to resist to mowing (and thus its perenniality) and to support vehicles and human traffic in the orchard, and the species' performance in improving soil structure and mobilizing deep soil nutrients for the main crop.

3. Results and discussion

3.1. Step 1

The 3200 species of Caribbean flora [16] were screened in step 1 according to their ecological adaptability (temperature), their perenniality and their height (< 50cm). 202 species were thus considered as potential cover crops for our objectives. We completed this first step with criteria from the Tropical Forages website [17] and with information from the AFRIS FAO web site [18]. Crossing references and experts' information led to the selection of 63 species in Guadeloupe and 80 species in Martinique, mainly grasses and legumes (from *Fabaceae* and *Poaceae* species in particular). The selected species were herbaceous and perennial plants, which were described as long-term pasture (>4 years), by their stem habit (creeping, prostrate), and their ecological adaptation (temperature, shade environment and soil pH requirements).

3.2. Step 2

Seed availability on the international market led us to screen in the field the behaviour of 24 species in Martinique (13 Fabaceae, 10 grasses, 1 Convolvulaceae), and 7 species in Guadeloupe (6 Fabaceae, 1 grass) taking into account the cover crop management and farm constraints (no mechanical control) (Table 1).

Table 1. Selected cover crops for orchards in both Guadeloupe and Martinique, end of step 2, in bold common species

Guadeloupe	***Martinique***
Fabaceae	
Arachis pintoi. Krapov. & W.C. Greg	*Aeschynomene americana* L.
Desmodium adscendens (Sw.) DC.	*Alysicarpus ovalifolus* (S. et Th.)Leon
Desmodium intortum (Mill.) Urb.	*Centrosema pascuorum* Mart. ex Benth.
	Chamaecrista rotundifolia (Pers.) Greene
	Crotalaria juncea L.
	Crotalaria spectabilis Roth
	Dichondra repens J.R.Forst. et G.Forst. *(Convolvulaceae)*
	Macroptilium bracteatum (Nees & Mart.) Marechal & Baudet
	Pueraria phaseoloides (Roxb.) Benth.
	Stylosanthes capitata Vogel
	Stylosanthes guyanensis (Aubl.) Sw
Macroptilium atropurpureum (DC.) Urb.	
Neonotonia wightii (Wight & Arn.) J.A. Lackey	
Stylosanthes hamata (L.) Taubert	
Poaceae	
	Brachiaria decumbens Stapf.
	Buchloe dactyloides (Nutt.) Engelm.
	Paspalum notatum Flüggé *cv Common*
	Paspalum notatum Flüggé *cv Pensacola*
	Paspalum wettsteinii Hack.
	Urochloa mozambicensis (Hack.) Dandy
Cynodon dactylon (L.) Pers	

3.3. Step 3

The objective was to maximize services and minimize competition between the cover crop and citrus trees. In Guadeloupe, step 3 consisted in the test and selection of cover crops according to their ecological and agronomical adaptability to water stress (dry season resistance) and weed control capacity (Fig. 3). The high capacity to control weed and the ability to endure drought led to the selection of *Neonotonia wightii*.

In step 3 in Martinique, the assessment of the 24 species led to the selection of four grass species (*Urochloa mozambicensis* and 3 *Paspalum* spp.) and 3 legumes (2 *Macroptilium* spp. and *Centrosema pascuorum*). These cover crops were selected according to their agronomical performances: low biomass production combined with a high covering rate, leading to low competition with citrus and good weed control (Fig. 4).

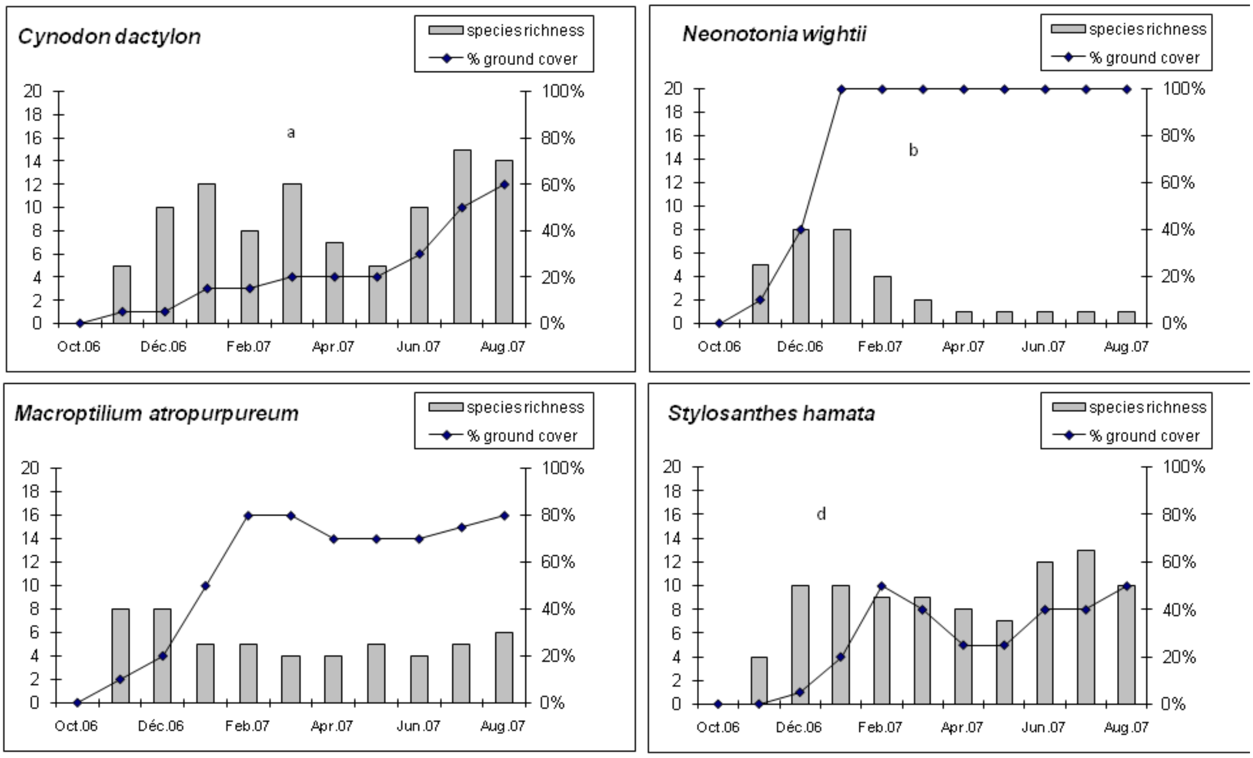

Fig. 3. Four cover crops evaluation in field trial in Guadeloupe: (a) *Cynodon dactylon*, (b) *Neonotonia wightii*, (c) *Macroptillum atropurpureum*, (d) *Stylosanthes hamata*. Grey bars: species richness (number of present species); black line: cover rate (%). (b) was the selected cover crop

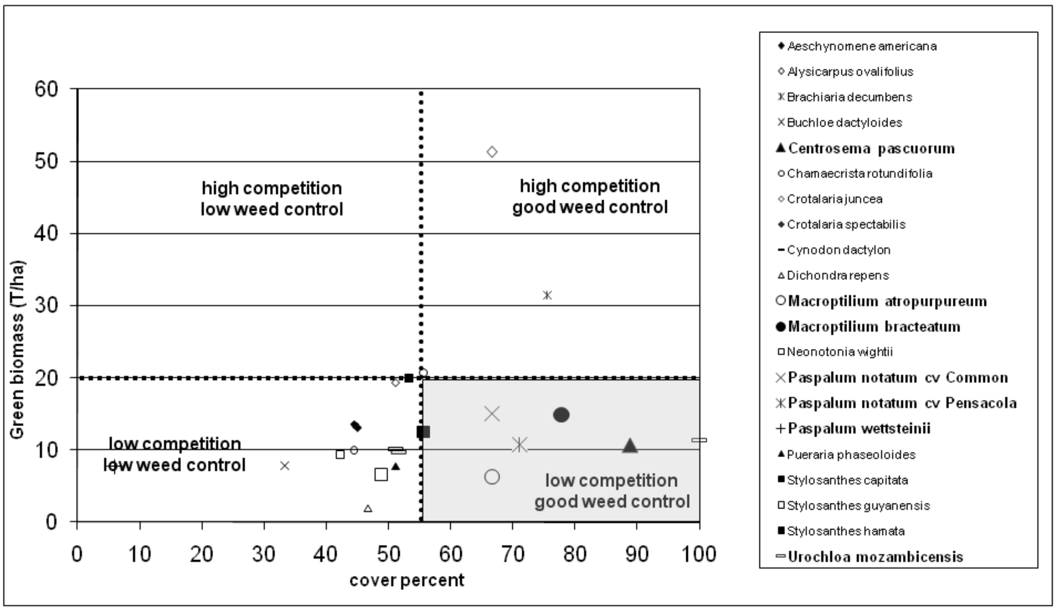

Fig. 3. 24 cover crops assessment with experimental measurements in Martinique: covering rate (%) and green biomass production (T/Ha), the grey area is the cover crops selection area

3.4. Selected cover crops

The multicriteria grid led to the selection of two main families: Fabaceae (legumes) and Poaceae (grasses). Both families can control weeds with limited herbicide application. Fabaceae have a quick germination of seeds, are attractive for auxiliaries, and can potentially fix N if N is low in soil and if adequate rhizobium is present. However, they are very sensitive to trampling. Poaceae provide a deep and robust root system which aids in run-off control, good weed control, carrying capacity for vehicles, the potential to uptake minerals from the deep soil, and aids in soil structure improvement. However, the competition with the main crop for water and mineral fertilizers is high and they are not attractive for auxiliaries or pollinators.

The main differences between the two selection sites were due to the experts' appreciation and local constraints that could explain the different issues.

4. Perspectives: Prototyping and cropping system design (Fig. 1)

The final aim of cover crop selection was their introduction in adoptable and eco-efficient cropping systems.

In Guadeloupe, the selected cover crop, *N. wightii,* has been introduced in mandarin and orange orchards in a participative process [20]. The cropping system prototype, which consists of cover crop associated with citrus trees, is compared to natural cover cropping management with regular and moderate herbicide applications (Glyphosate). *N. wightii* suppressed efficiently weeds after 4 months but the establishment period has been facilitated with a selective herbicide (Fluazifop p butyl) 2 months after planting. Pesticide use has been reduced but not eliminated and sustainability assessment is in progress. The main service, weed control, has been sought as well as auxiliary hosting, in particular Phytoseideae, that controls citrus pests (*Phyllocoptruta oleivora*, and *Polyphagotarsonemus latus*)[21], but the integration of all the others secondary services was not successful. For example, N fixing was not measured in our conditions.

In Martinique, prototyping is in progress with *Paspalum notatum* cv. Common, but this herbaceous stratum is being colonized by more aggressive grasses like *Brachiaria humidicola* arriving from neighbouring fields or from seeds already present in the soil. Colonization is also observed by aggressive climbing dicotyledons (*Mikania* *micrantha*, Asteraceae, or *Momordica charantia*, Cucurbitaceae). Therefore, herbicide has been applied to the tree line and hand removing of the most aggressive weeds has been found to be necessary.

The implementation of a ground cover must be considered as an investment in the long term, and must be managed as carefully as the trees: stale seedbed technique, no-tillage technique, hand spot application of herbicide, and hand removal of some weeds must be used to achieve a good covering system.

Next, prototypes will be developed, using a multi-specific composition of the herbaceous part of the cropping system, mixing legumes and grasses.

5. Conclusions

Our multicriteria selection grid is a generic and adaptive tool for perennial and semi-perennial crops. It is currently also being used in banana cropping systems, resulting in different choices of cover crops.

Introducing cover crops in orchards could be a good way of ecological engineering for weed control and thus reduced herbicide use. We adopted a systemic approach in the cover crop selection process, considering at the same time the main objective (weed control) and other agronomical and ecological services. Our results showed that the concept of an ideal cover plant has to be implemented in relation to the services potentially sought for the cover crop functional groups. When we applied our multi criteria assessment grid, the final number of cover crop species was very low and all the services we sought were not obtained. The most restrictive criteria in our grid were seed availability and regulation requirements. It is very important to take in account the fact that imported cover crops can potentially become invasive species. Thus, the consideration and use of local species (endemic or naturalized) should be preferable for further cover crop selection/cropping system design.

A single cover crop is not enough to cover all the functional traits we focused on, thus mixing of several families and species may prove to be a more efficient cover system in orchards: legumes for N fixing properties and auxiliary hosting and grasses for run-off control, soil structure improvement and field traffic. The efficiency of new cropping systems including multi-specific cover crops may be also improved with the design of specific spatial arrangements within families: legumes located under the citrus canopy and grasses in the inter row.

Future studies will use the same framework and multicriteria assessment grid to combine different controlled mixed covers using both native and non-native plants in order to address all agronomical and ecological services and promote global agro-ecological functioning and regulations in orchards while excluding herbicide use.

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