Incorporating plant species diversity in cropping systems for pest and disease risk management

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Introduction

Farmers, particularly in the tropics, are faced with considerable phytosanitary risks often resulting in (i) food insecurity and reduced income (ii) adverse effects of pesticide use on human health and on the environment, and (iii) export restrictions due to strict regulations imposed by importing countries concerning quarantine pests and maximum limits on pesticide residues. This high vulnerability to crop damage by pests and diseases is mostly observed in modern intensive agroecosystems and attributed to over-simplification of the systems (Tilman et al., 2002). On the basis of the foregoing, it was hypothesized that the resilience of intensive agroecosystems can be increased by making their traits match those of natural biodiverse ecosystems, or of certain low-input, diversified, traditional agroecosystems (Lewis et al., 1997; Dawson and Fry, 1998; Jackson, 2002).

This can be achieved by using an agroecological approach, specifically by conserving or introducing plant diversity in agroecosystems at different spatial and temporal scales (Nicholls and Altieri, 2004; Ferron and Deguine, 2005; Deguine et al., 2008). In addition to agronomic benefits (Malézieux et al., 2009), and risk mitigation/alleviation in several respects (e.g. climatic events, price fluctuations), introducing vegetational diversity in agrosystems may lead to different pest and disease regulation processes.

Integrating selected plant species diversity in agroecosystems can reduce the impact of pests and diseases through several causal pathways, either individually or in combination (Ratnadass et al, 2012), namely 1) resource dilution and stimulo-deterrent diversion for pests; 2) disruption of the spatial cycle; 3) disruption of the temporal cycle; 4) allelopathy effects; 5) general and specific soil suppressiveness against soil-borne pests and diseases; 6) crop physiological resistance; 7) conservation of natural enemies and facilitation of their action against aerial pests and pathogens; and 8) direct and indirect architectural/physical effects (Fig. 1). However, knowledge on plant species diversity effects on pest and disease control is still very incomplete. Controversies regarding these effects exist, indicating that there is a need for clarifying the mechanisms and processes at play, particularly for tropical crops.

As of 2008, CIRAD and its partners have been implementing the Omega[3] project (Box 1). The project examines how pest and pathogen populations and their impacts are affected by the introduction of spatial and temporal plant species diversity in cropping systems. The aims of the project are (i) to gain knowledge on ecological pest and disease regulation processes that can be mobilized for the improvement of pests and diseases control and (ii) to generate tools and methods for the design and evaluation of novel pest and disease-resilient cropping systems.

Several biological models are studied at different spatial scales over a range of life history traits of the noxious organisms (Box 1, Fig. 2). Some of the results obtained from three of these biological models are presented below: white grubs on upland rice at the metric scale, mirids and cocoa trees at the field scale, and coffee berry borer at landscape scale.

Allelopathic effects of cover crops on white grubs/black beetles on upland rice in conservation agriculture cropping systems (Madagascar)

In Madagascar, a growing demand for rice resulting in increased pressure on inundated lands has favored the cultivation of upland rain-fed rice on hill slopes. Due to the instability of the ecosystem, this type of agriculture cannot meet the objectives of both sustainability and high yields if conventional tillage is used, particularly due to high erosion risk. Conservation agriculture cropping systems, based on no-till and permanent soil cover with dead or live mulch, have opened up new prospects for upland rice.

However, attacks by larvae (white grubs) and adult (black beetles) of Dynastid beetles (particularly *Heteronychus* spp.) are a major constraint to upland rice, particularly in the Central Highlands of Vakinankaratra. Conservation agriculture management, depending on the situation, can either aggravate or reduce damage, when compared to conventional tillage (Ratnadass et al., 2006).

Fodder radish (*Raphanus sativus)* showed promise for white grub control. The rice+fodder radish system was consistently the least damaged by white grubs in the field, and had considerably decreased white grub populations. Overall macrofauna diversity and abundance was not reduced, and the systems actually promoted diversity and abundance of ecosystems engineers like earthworms and ants (Rabary et al., 2011). Studies in laboratory-based mesocosms confirmed these results by showing that the rice+fodder radish system was the least damaged by *Heteronychus plebejus* and *Heteroconus paradoxus*. Moreover, incorporation of *R. sativus* residues around rice seeds significantly reduced damage by *Heteronychus bituberculatus*. In microcosm studies, fodder radish was found to have biocidal activity on *Heteronychus arator rugifrons* and *H. paradoxus*.

Shade trees to fight mirids in cocoa stands in Cameroon

In Africa, cocoa is traditionally grown in multi-strata and diversified agroforestry systems, where cocoa tree canopies are joined up and form a thick layer of foliage shaded by the canopy of neighbor trees. However, currently in West Africa, cocoa is increasingly grown in unshaded plantations, proven to be more productive especially when full sunlight is combined with fertilization (Wessel, 1985). However, such practices present certain risks for smallholder cocoa producers since unshaded “pure” cocoa plantations are often highly damaged by insect pests and consequently require intensive phytosanitary protection. Mirids (*Sahlbergella singularis* and *Distantiella theobroma*), the most harmful of these pests, cause varying degrees of damage to the cocoa tree, leading to premature ageing of plantations and sometimes to the death of trees when chemical protection is inadequate.

When compared to full sun plantations, traditional systems have proven to be significantly less damaged by mirids (Entwistle, 1972). A recent publication reports that mirid populations of traditional cocoa systems in Cameroon are often restricted to cocoa trees exposed to the sun through shade canopy breaks (Babin *et al.*, 2010). Indeed authors showed that *S. singularis* populations were highly aggregated in "mirid pockets" of 20 to 30 adjacent infested cocoa trees. Moreover, mirid pockets were usually located in those areas where sunlight transmission to cocoa trees through the shade canopy was the highest. An explanation could lie in the fact that full sun cocoa may provide mirids with more food resources than in shaded conditions, allowing more intensive mirid outbreaks and which could lead to irreversible damage of cocoa trees.

Over the last few years, there has been a growing interest worldwide in agroforestry, since these cropping systems offer numerous advantages with respect to food security and income source diversity for smallholders, biodiversity conservation, soil preservation and pest and disease control (Avelino *et al.*, 2011)

The foregoing gave rise to the idea of using plant diversification in cocoa agroforestry systems as a pest management strategy which should lead to a decrease in chemical input needs. Unfortunately, things are never that simple: excessive shade, by modifying microclimatic conditions, can increase the severity of cocoa diseases, particularly Phytophthora pod rot. In Cameroon, black pod rot (caused by *P. megakarya*) causes considerable production losses and entails regular fungicide sprayings, putting a serious strain on farmer financial resources. Some species causing Phytophthora pod rot diseases as well as mirids can live on other host plants (forest trees for example), which may provide an alternative source of infestation for cocoa plantations. Consequently, plant diversification in cocoa production should be scientifically-founded on the basis of a better knowledge of the tradeoffs between cocoa productivity, income diversity and ecosystem benefits linked to pest and disease management.

Landscape context effects on coffee berry borer in Central America

Disease and pest attack intensities are mainly determined by the effects at plot level of interactions between the host plant, the pest or the pathogen, the physical and biological characteristics of the plot, and crop management (Zadoks and Schein, 1979). However, crop pest and disease attack intensities can also vary under the influence of landscape context which can provide habitats for pests, pathogens, vectors and natural enemies, and facilitate their immigration into adjacent plots. The degree to which the landscape facilitates movements between resource patches is a measurement of landscape connectivity. Epidemic risks can therefore be reduced by limiting landscape connectivity for noxious species (Holdenrieder et al., 2004; Zadoks, 1999), and conversely by increasing it for natural enemies.

Landscape effects on pests and diseases have been mostly highlighted for temperate crops. However, promising landscape effects have been recently reported for the coffee berry borer, *Hypothenemus hampei* (Coleoptera: Curculionidae), in Costa Rica (Avelino et al., 2012). These authors showed that coffee berry borer abundance in coffee plots was positively correlated to the proportion of coffee area in the landscape at a distance of 150 m around the plots. Negative correlations were obtained with other land uses, specifically forest, pasture and sugar cane. Coffee berry borer is a coffee specialist; large extensions of connected coffee areas probably increased the possibilities for flying individuals to find new coffee berries for colonization. The latter is especially important after the coffee harvest, when coffee berries are rare. The logical consequence was an increased survival during the post-harvest period and higher infestations the following harvest. On the contrary, by fragmenting the landscape with land uses different from coffee, the survival of the pest was reduced. The strongest effect was recorded when forest patches were present, which was suggested to act as a barrier to coffee berry borer movement.

However, the authors also found higher incidences of coffee leaf rust, a coffee disease caused by the fungus *Hemileia vastatrix*, in coffee landscapes fragmented with pasture, possibly because this landscape structure promotes wind turbulence which is necessary for spore release. These results demonstrate that what is conceived as a barrier for one species may be conducive for another. It is therefore necessary to take into account the whole crop pest and pathogen complex to ensure efficient management. In this case, fragmenting coffee landscapes with forest patches was suggested to limit coffee berry borer abundance without favoring coffee leaf rust.

These findings clearly illustrate the importance of plant species diversity at landscape level for managing pest and disease risks, and the high vulnerability to pests and diseases of homogenous coffee landscapes.

Conclusions

We have described some promising plant species diversity effects on tropical crop pests and diseases. Our examples illustrate the complexity of the mechanisms underlying these effects. It appears that beneficial effects against one pest or disease may be accompanied by unwanted effects, as an increased incidence of another pest or disease. This confirms that more knowledge is needed, and indicates that the whole agroecosystem has to be considered when analysing the effects of vegetal biodiversity in order to minimize possible adverse effects and maximize the overall performance of the system.

BOX 1

The Omega3 project, named after a French acronym which in English stands for "*Optimizing Ecological Mechanisms of Pest and Disease Control for Sustainable Improvement of Agroecosystem Productivity*" (http://omega3.cirad.fr/index.php/en) aims at studying the effects of the planned introduction of plant species diversity in agroecosystems, as a potential alternative to conventional practices based on pesticide use.

Several biological models are under study (Fig. 2):

1. At a metric scale, we study the effects of sanitizing plants with allelopathic or biocidal properties on soil borne species such as white grubs (*Coleoptera: Scarabaeidae*) and Striga (*Striga asiatica*) on upland rice in Madagascar as well as on bacterial wilt (caused by *Ralstonia solanacearum*) on tomato in Martinique.
2. At field level, we study several management methods of mirid bugs (*Hemiptera: Miridae*) and black pod rot (caused by *Phytophthora megakarya*) on cacao in Cameroon by intercropping cocoa trees with other perennial plants using different spatial designs. We also study the luring effects of trap plants, combined with either (i) barrier effects and conservation biological control on tomato fruitworms (*Helicoverpa* spp) and whitefly (*Bemisia tabaci*) on vegetable crops in Martinique and Niger and, (ii) a food attractant

associated with a biological insecticide on fruit flies (*Diptera: Tephritidae*) attacking cucurbit crops in La Réunion.
3. At the landscape scale, the effects of landscape context on the incidence of coffee leaf rust (caused by *Hemileia vastatrix*) and abundance of coffee berry borer (*Hypothenemus hampei*) are studied in Costa Rica.

With a view of genericity, the "pathosystems" studied are positioned according to an *a priori* typology based on (i) the life-history traits the most amenable to manipulation by plant species diversity (namely specificity and dispersal ability), (ii) plant species diversity scales (namely from the soil, field to landscape level), and (iii) deployment modalities (namely via conservation agriculture, horticultural and agroforestry cropping systems) (Fig. 2).

Improving our understanding of the mechanisms that govern the effects of plant species diversity on pests and pathogens should enable us to explain how, where, and when exceptions to the principle of their positivity/efficiency are likely to occur. This understanding will help to optimize vegetational diversification and to develop sustainable agroecosystems based on enhanced ecological processes of pest and disease control.

Case studies on rice, cocoa and coffee we are reporting here, alongside those on horticultural crops, are expected to provide decision-making rules to set up mechanistic models contributing to the predictability and reliability of the suggested plant species diversity-based techniques.

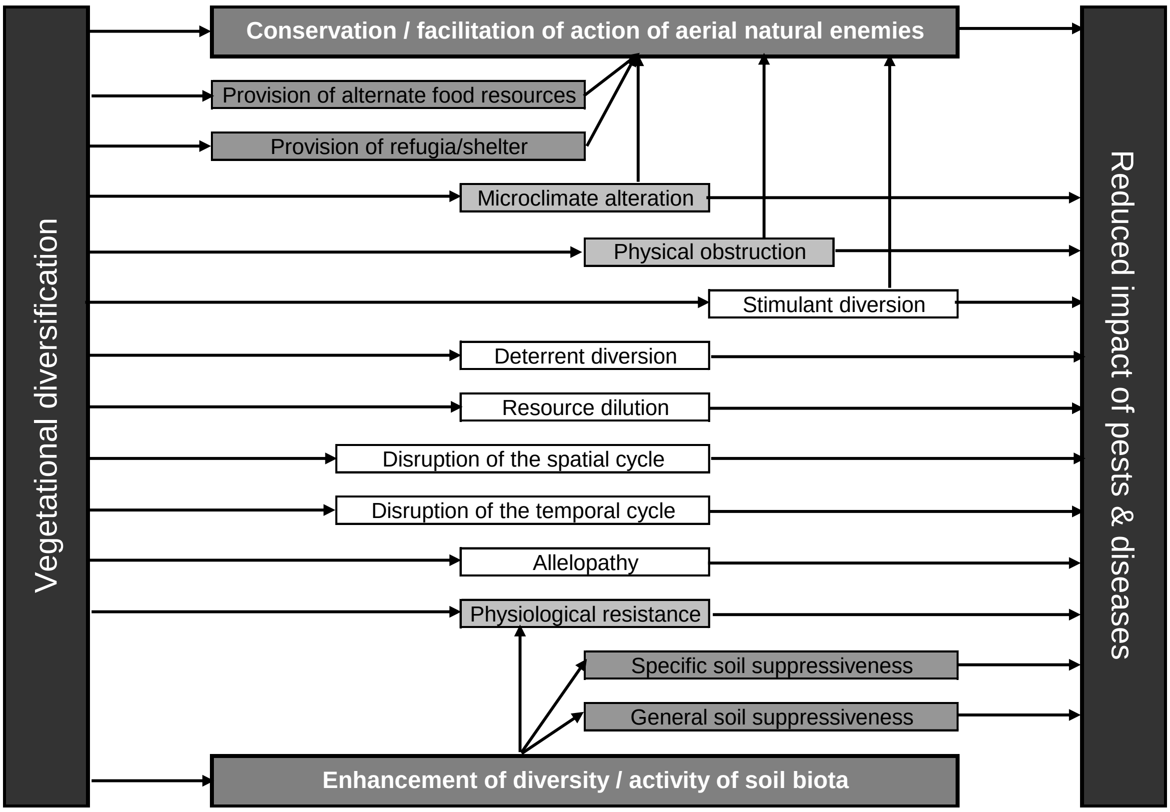

Fig. 1. Major pathways for reducing the impact of pests & diseases via the introduction of plant species diversity in agroecosystems (from Ratnadass et al, 2012 with courtesy of Agronomy for Sustainable Development, open access at http://www.springerlink.com/content/4n88745260j1r721/)

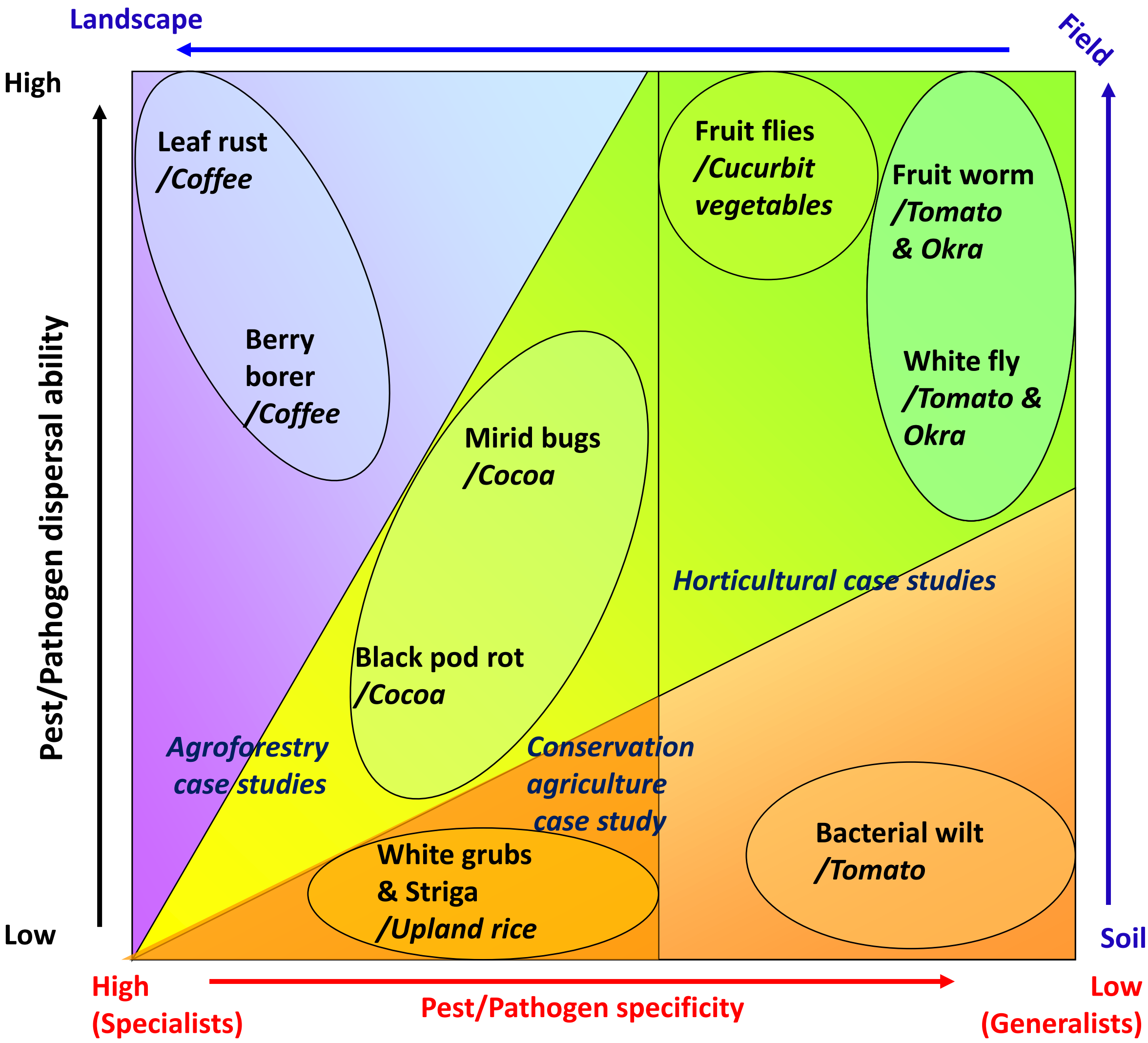

Fig.2. Omega[3] project case studies positionning, as a function of scale levels at which plant species diversity modalities & effects translate and to life history trait-based typology of pests and pathogens

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