New Ecological Options for the Management of Horticultural Crop Pests in Sudano-Sahelian Agroecosystems of West Africa

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Abstract

The agroecological approach to agroecosystem management relies on two pillars: vegetational diversification and soil biological activity enhancement. Although crop pests and their natural enemies may be diversely affected by measures derived from these principles, those generally result in increased agroecosystem resilience vis-à-vis both aerial and soil pests. Earlier studies by ICRISAT and CIRAD and their partners in West Africa showed the potential of the implementation of these principles for the management of some major pests of both staple food and horticultural crops, and their limitations for others, notably in the water-saving and income-generating systems mixing cereals, legumes, and high-value crops currently promoted in the Sudano-Sahelian zones, such as the drip irrigation-based African Market Garden (AMG) and the water harvesting-based Bio-Reclamation of Degraded Lands (BDL) systems. Pigeon-pea showed potential for trap-cropping tomato fruit worm (TFW) on okra, while Andropogon grass was dismissed for such management of stem-borer on pearl millet, and mixed results were obtained with castor bean and other potential trap crops for panicle-feeding bug management on sorghum. The results presented highlight the potential for mobilizing either aerial or soil-bound biological processes for managing fruit flies (FF), the main pest of grafted jujube tree, and leaf worm, the main pest of the Moringa tree, for sustainable production of these two major crops (in BDL and AMG systems, respectively), without having to rely on synthetic pesticide sprays. Studies on the social acceptability of the proposed management options (e.g., pigeon-pea in okra-based BDL) are also underway. The potential of the Jatropha shrub grown as a live-fence around these systems, either for its top-down effects or via the use of its extracts in an assisted push-pull strategy, is discussed. These studies on targeted pathosystems serve the dual purpose of finding solutions to local problems and contribute more globally to the design of pest resilient agrosystems.

INTRODUCTION

The agroecological approach to agroecosystem management, and more particularly its application to pest and disease management, relies on two pillars: vegetational diversification and soil biological activity enhancement. Although crop pests and their natural enemies may be diversely affected by measures derived from these principles, those generally result in increased agroecosystem resilience vis-à-vis both aerial and soil pests (Deguine et al., 2008).

Earlier studies by ICRISAT and CIRAD and their partners in West Africa showed the potential of the implementation of these principles for the management of some major pests of both staple food and horticultural crops, and their limitations for others, notably in the water-saving and income-generating systems mixing cereals, legumes and high-value crops currently promoted in the Sudano-Sahelian zones, such as the drip irrigation-based African Market Garden (AMG) (Pasternak et al., 2006) and the water harvesting-based Bio-Reclamation of Degraded Lands (BDL) (Pasternak et al., 2009) systems.

Pigeon-pea (*Cajanus cajan*) showed potential for trap-cropping tomato fruit worm (TFW) *Helicoverpa armigera* on okra (*Abelmoschus esculentus*), while Andropogon grass (*Andropogon gayanus*) was ruled out for such management of stem-borer (*Coniesta ignefusalis*) on pearl millet, and mixed results were obtained with castor bean (*Ricinus communis*) and other potential trap crops for panicle-feeding bug (*Eurystylus oldi*) management on sorghum (*Sorghum bicolor*) (Ratnadass et al., 2009a).

Besides annual staple food and vegetable crops, several perennial crops may assume key roles as high-value crops, both for nutritional value and income generation. This is notably the case of *Moringa oleifera*, which is the preferred indigenous leaf vegetable in Niger (Abasse et al., 2007), being cultivated in traditional gardens, and in ICRISAT-promoted AMG (while the related species *M. stenopetala* is promoted in the BDL system). Major constraints faced by the farmers are insect pests on Moringa leaves, particularly a leaf-feeding Pyralid worm whose attacks can be devastating during the nine months of the dry season (Gamatie, 2001; Mayaki, 2008).

This is also the case of the grafted jujube tree *Ziziphus mauritiana*, known as Apple of the Sahel, whose fruit suffer high infestation by fruit flies of the species *Carpomya incompleta* (Rhousseini, 2005). In both cases, farmers have no other choice but to either sustain dramatic pest damage, or spray harmful insecticides, with negative impacts on human and environmental health.

On the other hand, other perennial plants can serve as service plants with a pest regulation role in the above-mentioned agroecosystems. This is the case of pigeon-pea, of which some cultivars can be cropped as perennial field hedges (Daniel and Ong, 1990), and of Physic nut (*Jatropha curcas*) that, besides its production as a substitute to diesel oil, is grown as live hedges to combat erosion, or as live fences to protect market gardens from domestic animals (Openshaw, 2000).

Studies were conducted in 2009 and 2010 at Sadoré, Niger (13°15’N; 2°17’E), both at the ICRISAT research station and in a women farmers’ field in the neighbouring village, with a focus on perennial plants, either as crops to be protected from pests in an ecological manner, or as multipurpose service plants to facilitate such pest regulation on crop plants in Sudano-Sahelian agro-forestry systems.

MATERIALS AND METHODS

Studies on Moringa Tree (*Moringa oleifera*)

In December 2009, we conducted a survey on four Moringa trees at the ICRISAT AMG at Sadoré that consisted of collecting and counting all pre-imaginal instars of leaf-feeding worms both in the canopy and around the tree trunk under the canopy, by digging and sieving the 0-15 cm layer of sand.

We then used these larvae in a laboratory experiment with no replications, where large larvae collected from either leaves or sand, or small ones from leaves were provided either fresh leaves and sand, or leaves alone, or sand alone. Leaves were replaced by fresh leaves every second day and the experiment stopped and results recorded after a week, when all larvae had pupated on some treatments, or had died without pupating in other treatments.

Pupae obtained were kept in the laboratory for adult emergence, and the adults were killed, dried and identified.

Studies on Jujube Tree (*Ziziphus mauritiana*)

Four fruit fly trapping/baiting experiments were conducted to investigate the potential of the “assisted push-pull” strategy to manage jujube fruit flies.

In January 2009, we placed nine bucket traps filled with brewery waste (provided by Braduni SA, Niamey) in a fruit fly-infested jujube orchard. Brewery waste bait was prepared as described by Rousse et al. (2003). It was heated at 100°C until the first boiling signs in order to eliminate as much alcohol as possible, then gently cooled at room temperature, and diluted at 50% v/v with tap water.

In September 2009, we placed two MacPhail traps filled with GF-120 (Success Appat® provided by Dow AgroSciences, France) in traps near a jujube orchard.

The same month, we also used the spot spraying technique (Vayssières et al., 2009), to spray two trees on the border line of a five-year-old orchard, on which no chemical treatment of any kind was applied before and during the experiment. The orchard contained three trees of cultivar 'Umran', three trees of 'Ben Gurion', and three trees 'Kaithly'. The bait spray was applied on the foliage of the 'Umran' and 'Kaithly' trees neighbouring the 'Ben Gurion' trees. Inter-row spacing was 4 m and inter-tree spacing on the row was 5 m.

This bait spray was applied with a HD400 (Micron® sprayers LTDA, Bromyard, UK) manual sprayer using a conventional conical nozzle calibrated to deliver droplets of 2-6 mm from a spray mixture of 1.0 L of water and 0.1 L of GF-120.

To collect the flies that would have ingested the bait, we placed two white linen sheets at the tree base, thus forming a 3×3 m square, and collected intoxicated flies for three days after spraying.

Both damaged and undamaged fruits of all the three 'Umran' and 'Kaithly' trees of the border line were then harvested and counted. Damaged fruits were incubated in the laboratory in containers with the bases filled with sand, and fruit fly adults were identified after emergence.

Data (percent damaged fruit) were analyzed using the ANOVA module of XLSTAT (Addinsoft, 2009), comparing three levels of distance from the sprayed tree, namely the sprayed tree itself, the neighbouring tree, and the tree located two trees away, using the cultivars as replications.

In June 2010, we sprayed part of the foliage of two mango trees, cultivars 'Amélie' and 'Brooks' of an eight-year-old orchard with maturing mango fruits, and also placed white linen sheets under the sprayed part with the same objective as above, and made the same observations on intoxicated flies.

Studies on Potential "Service" Perennials

1. Pigeon-Pea. On the Sadoré-village BDL system, where 50 women farmers were allocated 200 m^2 plots for fruit tree (Apple of the Sahel) or leaf-vegetable tree (*Moringa stenopetala*) cultivation in half-moons, surrounded with okra in zaï holes, we provided some of them with seeds of annual pigeon-pea, cultivar 'ICPL 87' for cultivation as a border line, instead of roselle (*Hibiscus sabdariffa*) or sesame (*Sesamum indicum*) that they would normally have grown, with a view to both assessing its effectiveness as a trap crop for TFW management and its social acceptability. Observations on okra infestation by TFW and fruit yield were made on six pigeon-pea-bordered plots and compared with three unbordered controls.

2. Physic Nut Tree. The entomofauna of the Jatropha plantations at Sadoré was surveyed in June 2009, using a sweeping net held beneath the shrub branches that were shaken. Collected insects were then preserved in 70% ethanol vials (adults) or kept in aerated plastic containers to be reared in the laboratory until adult emergence (for immature instars).

In addition, funnel traps (AgriSense BCS Ltd.), half-filled with water and liquid detergent and baited by *Helicoverpa armigera* pheromone dispensers provided by Biosystèmes France SARL), were placed in the vicinity of both Sadore-village BDL and one of the Jatropha plantations on the ICRISAT station. Catches were recorded bi-weekly.

RESULTS AND DISCUSSION

Studies on Moringa Tree (*Moringa oleifera*)

The leaf-defoliating *Lepidoptera* species was preliminarily identified as *Noorda* sp. (?*blitealis*) by the French National Museum of Natural History in Paris (J. Minet, pers. commun., 2010). A formal confirmation is awaited. This, however, confirms earlier identification at the Natural History Museum of the University of Oslo, Norway (L. Aarvick, pers. commun., 2009).

The Moringa tree survey, conducted in December 2009 in the ICRISAT AMG at Sadore, showed that, during the day, there were as many *Noorda* sp. individuals of immature stages in the canopy as there were in the sand beneath the trees, although there were respectively more young instars in leaves and more old instars in the sand. No pupa was found in the canopy, while several pupae were found in the sand (Table 1).

In the laboratory experiment, we found that optimal pupation and minimal mortality were observed when larvae (either old ones from either leaves or sand, or small ones from leaves) were provided both fresh leaves and sand, while only large larvae pupated when provided sand alone, and pupation rate was low when either large or small larvae were provided leaves alone (with no actual pupation in the leaves).

These results suggest that *Noorda* sp. larvae require both leaves and sand to complete their development, and that they not only pupate in the soil beneath the Moringa tree, but that at least larger larvae move down to the ground and climb back to the tree probably at the hottest part of the day and at the cooler night time respectively. This confirms earlier observations (Mayaki, 2008).

Studies on Jujube Tree (*Ziziphus mauritiana*)

Results of the three bait trapping/spot spraying experiments where fruit flies were observed/caught are presented in Table 2. In the other experiment with GF-120 in traps near the jujube orchard (September 2009), no fruit fly was observed/caught.

Although a single individual of *Carpomya incompleta* was intoxicated by the GF-120 spraying, this was probably accidental and does not constitute an attractive effect. Actually, *C. incompleta*, which is specific (monophagous) to jujube, seems to be strongly repelled by GF-120 spraying, while *Ceratitis cosyra*, which is more polyphagous, is attracted and killed (alongside, although to a lesser extent, *Bactrocera cucurbitae* and *Dacus* spp. known as pests of cucurbit crops). *C. cosyra* was also the only fruit fly attracted by brewery waste-baited traps.

It was also found that, as a bait in traps (at high concentrations), GF-120 was not attractive for any species. This complies with other reports mentioning a repellent effect of ammonium acetate at high concentrations (Yee and Chapman, 2005).

This repellent effect was probably at play on *C. incompleta*, as suggested by the observation of percent damaged fruits on GF-120-sprayed trees compared to the trees located respectively in their immediate vicinity of two trees away (Table 3).

Studies on "Service" Perennials

1. Pigeon-Pea. The Sadoré village BDL was free of TFW infestation and damage. No *H. armigera* adult moth catch was recorded during the survey period. On the other hand, leaf-damage by *Syllepte derogata* caterpillars was observed on okra. Mean fresh okra fruit yield in the six pigeon-pea-bordered plots was 3,216±93 kg/ha, not significantly different from that of the three unbordered control plots in which the yield was 3,383±204 kg/ha.

Thus, whatever it provides, its service as a trap crop for TFW or not, pigeon-pea also produces grains without irrigation during most of the dry season.

2. Physic Nut Tree. Studies on Jatropha entomofauna at Sadoré did not reveal the presence of major horticultural crop pests. Notably, *H. armigera*, that was mentioned as a pest of this species in Asia (Dadang et al., 2007), was not found, although a total of 38 *H. armigera* adult moths were caught in the trap neighbouring one of the plantations during the survey period.

Larvae of a *Phycitinae*, whose adult moth resembles *Pempelia morosalis* (Shanker and Dhyani, 2006), was found to cause significant damage to young plants, resulting in dead hearts, along with the leaf-feeding Castor Semi-Looper (*Achaea* sp.) (which has been reported as an occasional pest on tomato).

CONCLUSIONS

The results of the presented studies highlight the potential for mobilizing both aerial and soil-bound biological processes for managing leaf worm, the main pest of the Moringa tree, and fruit flies, the main pest of grafted jujube trees and, for sustainable production of these two major crops (particularly in AMG and BDL systems, respectively), without having to rely on synthetic pesticide sprays.

Preliminary results on the biology and behaviour of the Moringa tree leaf-feeding worm (*Noorda* sp.) suggest the testing of a non-drying insect glue as a physical barrier to hamper upward movements of larvae on tree trunks. However, care should be taken not to hamper regulation by natural enemies such as ants.

Also, soil management via enhancement of natural enemy activity or mechanical control of pupae and larvae, are other potential options. If substitution methods for control are sought, given the toxicity of the compounds used so far by farmers, e.g., DDT which has been reported to be used in Niger (Gamatie, 2001), and, to a lesser extent, Cypermethrin (Mayaki, 2008), the use of *Bacillus thurigiensis* toxins, or neem extracts could be considered.

Our results suggest that GF-120 could be used both as a repellent to protect Jujube trees from the fruit fly *C. incompleta*, but also as an attractant to protect other fruit tree species likely to be damaged by *C. cosyra*. On the other hand, this "win-win" strategy can only be applied to fruit tree species flowering at the same time as Apple of the Sahel. It cannot for instance be used for the highly fruit-fly-susceptible Marula plum (*Sclerocarya birrea*) which is also evaluated in the BDL system. However, it could be used for citrus or annona trees known to be hosts for *C. cosyra*, and in irrigated orchards due to their water requirements. Of course, care should be taken to respect recommended dosages which were largely exceeded in our study (recommended dose per 1000 m^2 used for just two trees, that is 2×4×5 m = 40 m^2, i.e., 25 times the recommended dose). This strategy can be combined with "assisted" push-pull using neem extracts on the same trees, or in the case of jujube tree, using less preferred cultivars. On the other hand, to reduce carry over, as *C. incompleta* pupates in the soil, sanitation (disposal of fallen fruits) and soil management may apply to this pest as it does for *Noorda* sp. on Moringa.

With regard to pigeon-pea, an option to optimize its trap cropping efficiency would be to grow a perennial cultivar (either in rainfed or irrigated system) in order to have it flower before the main crop (including tomato in AMG). Such cultivars could also be pruned to provide both fire wood and N-rich biomass in the main plot, while also acting as bird perches, thus helping natural control of caterpillars by birds.

The role of Jatropha fences as a source of predators (by provision of floral food sources or alternate preys, or as bird perches), remains to be documented. On the other hand, as with neem tree (*Azadirachta indica*), Jatropha kernel extract can be used as botanical pesticides. Promising results on its potential use for TFW control were obtained (Ratnadass et al., 2009b). Neem tree could also be considered as a service perennial for Sudano-Sahelian horticultural systems, since it is commonly grown as a windbreak around mango orchards. As with Jatropha, on the one hand, its role as a live fence providing extra food sources to predators of horticultural crop pests has not been evaluated as yet, and on the other hand, neem kernel or leaf extracts can be used as natural pesticides or repellents in an "assisted" push-pull strategy.

Future research thrusts include the characterization of food webs for optimizing the introduction of crop and service plants into horticultural systems, both temporally and spatially, to maximize regulation of crop pests while minimizing the use of chemical pesticides. These studies on targeted pathosystems serve the dual purpose of finding solutions to local problems and via their genericity, to contribute more globally to the design of pest resilient agrosystems. For instance, it is probably due to its high specificity, as with *D. longistylus*, that does not make *C. incompleta* a good candidate for direct management by GF-120 spot spraying.

Also, studies on pigeon-pea trap cropping management of TFW damage on okra are part of a case study targeting a polyphagous pest with a high dispersal ability, which is itself part of a study of the impact of plant species diversification (PSD) on pests and diseases encompassing a broad range of specificity and dispersal ability levels. From the combined analysis of these pathosystems we expect indicators and decision rules which will help develop mechanistic models for predicting the impact of some modes of PSD deployment on diseases/pests with similar life-history traits (Ratnadass et al., 2010).

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Tables

Table 1. Distribution of *Noorda* sp. immature stages on four *Moringa oleifera* trees at Sadoré AMG (December 2009).

Immature stage location	On leaves	In the sand
No. immature stages per tree	8.0±8.08	7.25±5.31
% small larvae	34±28	10±20
% pupae	0	19±28

Table 2. Abundance of fruit flies recorded in three baiting experiments at Sadoré.

Baiting experiments	Fruit fly species				
	Carpomya incompleta	*Ceratitis cosyra*	*Dacus ciliatus*	*Dacus vertebratus*	*Bactrocera cucurbitae*
Brewery waste in traps in jujube orchard (Jan. 2009)	0	+++	0	0	0
GF-120 as spot sprays in jujube orchard (Sep. 2009)	+	+++	+	++	+
GF-120 as spot sprays in mango orchard (Jun. 2010)	0	++	+	0	0

0: not recorded; +: 1 individual recorded in total; ++: 1<no. individuals<10; +++: >10 individuals.

Table 3. Effect of spot spraying with GF-120 of *Ziziphus mauritiana* 'Umran' and 'Kaithly' on fruit fly (*Carpomya incompleta*) damage (Sadoré, Niger, 2009).

Location/sprayed tree	% damaged fruits
Two trees (8 m) away	68 a
One tree (4 m) away	53 b
Sprayed tree	38 c

Means followed by the same letter are not significantly different (Newman-Keuls test) at P=0.05.