ABSTRACTS:

Using chemical ecology in push-pull control of insect pests: from theory to implementation

Oral Presentations

In programme order

Session 6

The success of the push-pull system for controlling lepidopterous pests and parasitic striga weeds in small-holder cereal farming

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The 'push-pull' system (www.push-pull.net) effectively controls serious biotic constraints to cereal-livestock production in Africa, stemborers, fall armyworm, and striga weed, while improving soil health and biodiversity. It allows income diversification with sustainable livelihood components such as livestock farming. The companion cropping system makes smallholder farms more resilient often with a tripling of yields and has now been made more climate smart. It involves attracting stemborers with trap plants (pull) whilst stemborers and fall armyworm away from the main crop using a repellent intercrop (push). Chemicals released by intercrop roots induce abortive germination of the noxious parasitic striga weed. The companion plants provide high value animal fodder year-round, facilitating milk production. Furthermore, soil fertility is improved due to improved nitrogen fixation, carbon sequestration and phosphorus availability, reduced soil erosion and degradation. The technology improves gender equity and is appropriate for smallholders, and economical as it is based on locally available plants, not expensive external inputs. It fits well with traditional mixed cropping systems in Africa. The push-pull system has been adapted to drier and hotter conditions linked to climate change by identification and incorporation of drought tolerant companion crops. This climate-smart push-pull directly responds to rising uncertainties in Africa's rain-fed agriculture due to the continent's vulnerability to climate change. The new companion crops, *Desmodium intortum* and *Brachiaria* Mulato II hybrid, can withstand extended periods of drought stress with no water. To date push-pull has been adopted by over 250,000 smallholder farmers in 18 sub-Saharan African countries whose maize yields have increased from about 1 t/ha to 3.5 t/ha. Low-input technologies that address several production constraints and deliver multiple benefits are more relevant for African smallholder farmers but also proves useful lessons for agricultural systems in the developed world.

Deciphering the chemical ecology of push-pull intercropping system in mitigating fall armyworm, *Spodoptera frugiperda*, herbivory

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The Fall armyworm, *Spodoptera frugiperda*, is a serious invasive pest currently spreading across the world after having previously been confined to the Americas. Intercropping maize with companion plants in a push-pull system has been shown to substantially reduce *S. frugiperda* infestation, but the underpinning mechanisms are still unknown. We hypothesised that companion crop volatiles repel herbivores (push) while attracting natural enemies (pull). Plant volatiles collected from companion plants (*Desmodium intortum, Desmodium uncinatum* and *Brachiaria* Mulato II) were used in bioassays and electrophysiological recordings with *S. frugiperda* and key larval endoparasitoids (*Cotesia icipe* and *Coccygidium luteum*). Coupled GC-electroantennogram (GC-EAG) recordings from the antennae of *S. frugiperda* and both parasitoids *C. icipe* and *C. luteum* showed robust responses to aromatic and terpenoid volatile compounds from companion plants. In wind tunnel bioassays, moths made significantly fewer source contacts with maize volatiles when mixed with desmodium compared to maize alone. In no choice oviposition bioassays, while a significantly lower proportion of eggs was laid at the bottom of the oviposition compartment when *S. frugiperda* were positioned above companion plants, significantly more eggs were laid at the top of these compartments, indicating that female moths were repelled by the volatiles of the companion plants. The parasitoid wasps were attracted to the scent of both *Desmodium* spp. (intercrop) and the *Brachiaria* border crop in an olfactometer bioassay. Field experiments revealed that push-pull plots (*i.e.* maize intercropped with *D. intortum* and surrounded by *Brachiaria*) had fewer *S. frugiperda* larvae, lower damage and higher parasitism rate than monocropped maize. Our findings decipher the underpinning mechanisms of how push-pull companion cropping mitigates *S. frugiperda* herbivory in sub-Saharan Africa maize agroecosystem.

Keywords: Behavioural assays; companion crops; GC-EAG recordings; maize fields; oviposition; tritrophic interaction; volatile profiles.

‘Pushing’ towards a new IPM strategy. *Drosophila suzukii,* the search for effective repellents

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Drosophila suzukii is a worldwide pest that causes severe economic losses to producers of soft and stone fruit. It has a highly serrated ovipositor enabling it to lay eggs in ripening fruit. The summer morph *D. suzukii* are highly attracted to fruiting crops. Winter morph *D. suzukii* overwinter in woodlands and hedgerows surround crops and then disperse into fruit crops at the start of the growing season. These studies aimed to identify semiochemicals that elicit a repellent response in both the summer and winter morphs. Electroantennograms were used to determine if the *D. suzukii* antenna could detect the 14 chemicals. Laboratory bioassays found seven of the chemicals repellent to the summer morphs, and five chemicals were repellent to the winter morphs. Four chemicals caused a repellent response in both morphs. Semi-field trials in polytunnels were used to examine if the potential repellents could reduce the number of *D. suzukii* attracted to fruit held in traps compared to a control. Three of the four tested chemicals reduced the number of *D. suzukii* caught in traps and eggs laid in sentinel fruits. The final experiment was conducted in a strawberry crop and demonstrated, for the first time, two chemicals that reduced *D. suzukii* oviposition in fruit. The repellent chemicals offer an additional control strategy to the integrated pest management of *D. suzukii*.

Keywords: Crop protection; Push-pull; Spotted Wing Drosophila; *Drosophila suzukii*; Integrated pest management

New opportunities for a push-pull system in brassica crop production

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The diamondback moth (DBM), *Plutella xylostella* (L.) is the major economic pest of brassica crops in the tropics. Ongoing climate change has significantly exacerbated its pest status through e.g. short generation time, increased abundance, fecundity and metabolic activity translating into increased feeding and pest pressure. Control of this pest in Africa is generically achieved by deploying hard synthetic pesticides. However, several reports suggest pesticide resistance in DBM, likely triggering environmental, public health and sustainability concerns owing to pesticide overuse. However, rich vegetational diversity (intercrops), may help sustainably manage specialist pest insects through obscuring volatile cues used for host plant identification, physical obstruction, increased pest emigration, reduced chances of appropriate landing and making host crop plants less apparent- and -attractive. Thus, through the manipulation of habitats and host finding behaviour using natural host-pest semio-chemicals and aligning to Root's resource concentration and natural enemies' hypotheses, intercropping of brassica crops with plants that are rich in attractant and repellent volatiles could create a push-pull environment that may sustainably reduce DBM pest abundance and subsequent crop damage. Here, we propose the use of multipurpose plants in a push-pull system for the management of DBM in brassicas. Specifically, we propose Indian mustard, *Brassica juncea* L. (Czern). as an attractant crop and *Hyptis spicigera* Lam. as a repellent plant in a system that creates synergistic and complementary pest control effects. Use of multipurpose plants is highly sustainable through provision of other useful economic products e.g. human and livestock food (*B. juncea*) as well as livestock nutraceuticals (*H. spicigera*) and forms critical synergies in mixed crop-livestock production systems The results have huge implications in reducing the use of hazardous synthetic pesticides, improving public and environmental health as well as improving sustainability in smallholder African horticulture and mixed cropping systems.

Keywords: *Brassica juncea;* horticulture; *Hyptis spicigera; Plutella xylostella*; push-pull

Exploiting Push-Pull pest insect management by biotechnology

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The 'push-pull' system www.push-pull.net by a companion planting approach, effectively controls serious biotic constraints to cereal-livestock production in sub-Saharan Africa . This system fits well with traditional mixed cropping systems in Africa and has been adapted to drier and hotter conditions linked to climate change by identification and incorporation of drought tolerant companion crops. However, the push-pull control of the fall armyworm and striga weed now recommend use of elements of this technology for more industrialised production systems where expensive seasonal inputs have largely failed. Thus incorporating the chemical ecological tool by which the push-pull controls pests and weeds sustainably is of growing interest. In the push-pull, lepidopterous pests are pulled to naturally attractive trap plants whilst these pests, including the fall armyworm, are pushed away from the main crop using specific repellent intercrops. Key compounds in this process are known as the homoterpenes: (*E*)-4,8-dimethyl-1,3,7-nonatriene (DMNT) and (*E*,*E*)-4,8,12-trimethyl-1,3,7,11-tridecatetraene (TMTT). Recently it was demonstrated that the protein OsCYP92C21 is responsible for homoterpene biosynthesis in rice and the ability of rice to produce homoterpenes is dependent on subcellular precursor pools. By increasing the precursor pools through specifically subcellular targeting of expression, genetic transformation and genetic introgression, the biosynthesis of the homoterpenes DMNT and TMTT were enhanced in rice. The final introgressed GM rice plants demonstrated strong attractiveness, without damage, to the parasitic wasp *Cotesia chilonis* because of the enhanced homoterpene emissions compared to the wild type rice. Thus, the way is obvious for the biotechnological enhancement of this "push" trait directly in crop plants by GM or GE. Furthermore, the natural chemicals released by intercrop roots that result in abortive germination of the noxious parasitic striga weed have now been elucidated. The unique feature of these compounds is the addition of two *C*-linked glycoside groups onto the widely produced plant flavone apigenin and the *C*-glycosyl transferases partially characterised. Thus, the other major trait determining the striga weed control by the push-pull is close to exploitation by GM or GE. However, although these biotechnologies for delivering some aspects of the push-pull are becoming available it must be remembered that the low-input and thereby sustainable technologies of the push-pull that address several production constraints and deliver multiple benefits are more relevant for smallholder farmers in sub-Saharan Africa but also proves useful lessons for agricultural systems in the developed world.

Chemical interaction between the sugarcane spotted borer *Chilo sacchariphagus* (Lepidoptera: Crambidae) and a dead-end trap plant

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Sugarcane yield losses due to the sugarcane spotted stem borer, *Chilo sacchariphagus*, are reduced when plants of *Erianthus arundinaceus*, a close relative to sugarcane, are dispatched at the border of sugarcane fields. Previous studies concluded in a dead-end trap plant type of mechanism, since female borers preferentially lay their eggs on *E. arundinaceus* and the subsequently emerged larvae are unable to reach adulthood. We explored the chemical mechanisms involved in this plant-insect interaction. 71 compounds were identified through mass spectrometry in host and trap plant emissions at dusk (n=2x6). Among them, seven compounds, shared between the emissions of the two plants, elicited a significant electroantennographic detection in female borers (n=2x9, bootstrap $p<0.05$). This result suggests that *C. sacchariphagus* hardly distinguishes between the two plant species. In addition, the terpene (E)-β-ocimene was solely observed in *E. arundinaceus* emissions (bootstrap $p<0.001$), elicited a dose-dependent antennal response (n=10, Wilcoxon's rank sum test $p<0.01$) and an attraction of female *C. sacchariphagus* in Y-tube bioassays (n=13, bootstrap $p<0.001$). Our data suggest that a marginal sensory difference is sufficient to induce a preference for egg-laying between two plants with otherwise similar emission profiles. We will discuss the evolutionary implication of this mechanisms, and why we believe that it might result in long-term protection of the crops. This work was published in J Chem Ecol (2021). https://doi.org/10.1007/s10886-020-01240-z.

Keywords: Stem borer; Trap crop; GC-EAD; GC-MS; β-ocimene

Socio-economic issues of developing push-pull technologies

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Agricultural production in sub-Saharan Africa (SSA) does not match its people's food needs and contributes to environmental degradation. The food production system is limited by insect pests, parasitic weeds, aflatoxins, water stress, and climate change, which cause yearly yield losses worth over US$ 14 billion, and affecting livelihoods of >500 million people. Push-pull technology rebuilds sustainable local production systems, improves farm incomes, and contributes to food and nutrition in SSA, by increasing grain yields 3 to 5-fold, with minimum reliance on external inputs, and is more resilient and sustainable under changing climate conditions. The economic performance of push-pull technology has consistently shown benefit-cost ratios greater than those for other recommended cereal-cropping options or for farmers' traditional practices. The technology consistently posts higher factor productivity and yields with significant net economic gains. Push-pull has been disseminated and widely adopted by farmers in SSA. The main drivers of adoption of the push–pull practice are the farmers' need to control Striga, fall armyworm and stemborers, to increase cereal and livestock fodder yield, to control soil erosion, and improve soil fertility. Several dissemination pathways have been deployed: mass media, print media, and interpersonal pathways such as field days, farmer field schools (FFSs), farmer teachers/trainers, fellow farmers, and public meetings. Demonstrative pathways which catalyze interactive learning e.g., field days triggered have the highest impact on both the probability and intensity of push–pull adoption, followed by FFSs, and farmer teachers. Farmer-to-farmer extension models drastically increased awareness and adoption of the practice.

Keywords: adoption; Africa; dissemination; productivity; Push-pull

Controlling the Fall armyworm, *Spodoptera frugiperda,* using the push-pull system: an update

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The push-pull system for maize Lepidopteran stemborers is an important conservation biological control approach that protects crops from pest damage through semiochemically mediated insect behavioural manipulation. This manipulation is achieved by intercropping maize with companion plants that repel the pests and recruit parasitoid wasps together with peripheral companion plants that attract pests away from the maize crop. The recent invasion by the devastating maize pest fall armyworm, *Spodoptera frugiperda*, in Africa calls for urgent development of effective control strategies. Recent studies showed how the push-pull system, although originally developed for controlling *Busceola fusca* and *Chilo partellus*, substantially reduces crop damage. Here, I will give an update on the key semiochemically mediated mechanisms underlying the crop defence against fall armyworm within the push-pull system, and progress on the characterisation of volatile emission profiles for candidate trap plants for integration within the p

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Poster Presentations

In programme order

Poster Session 1

Chemical profile of non-volatile compounds from seeds, leaves and roots of *Crotalaria spectabilis*

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Crotalaria spectabilis (Fabaceae) is commonly used as a green manure for nitrogen fixation. Previous studies have shown that this plant produce, as secondary metabolites, several flavonoids and the toxic compounds pyrrolizidine alkaloids. In a field experiment using *C. spectabilis* as a border crop with maize, the results showed a significant decreased in population level of *Spodoptera frugiperda* larvae in maize. Therefore, the aim of this study was to identify the chemical profile of *C. spectabilis* to help to understand the chemical interaction between *S. frugiperda* and *C. spectabilis*. For this, roots and leaves of *C. spectabilis* plants with 45 days after germination and seeds were submitted to a liquid extraction using ethanol/water (8:2). After extraction, the material was filtered and submitted to HPLC (Flexar, Perkin Elmer) with a photodiode detector and LC-ESI-MS/MS analysis (Ekspert ultraLC 100 coupled to a TripleTOF 5600+, SCIEX). The LC-MS/MS data were submitted to the web-based mass spectrometry ecosystem called GNPS, to deconvolution of spectra and the identification of the compounds, that were conducted using the spectral fragmentation pattern comparison with the GNPS public library. The GNPS analysis of data identified 19 compounds among the seeds, roots and leaves samples. The major compound in the seeds was monocrotaline, followed by flavonoids and other pyrrolizidine alkaloids. The major compound in the roots and leaves are still being identified.

Keywords: chemical interaction; crotalaria; liquid chromatography; mass spectrometry; non-volatile compounds.

Olfactory background of stimulo-deterrent pest management strategy in the sugarcane-borer Eldana saccharina

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The African sugarcane borer (*Eldana saccharina*) is one of the most important pests of South Africa's sugarcane cultivation. The larval damage causes significant financial losses for farmers leading to unsustainable cultivation. The moth is indigenous to the wetland sedges of Africa, where it occurs in great abundances. One of the original hostplants of *E. saccharina* is *Cyperus papyrus,* but since then it has been reported that the moth feeds on various gramineous plants, most importantly sugarcane. The sensory adaptation behind the host shift from wetland sedges to sugarcane and behind the success of push-pull strategy is poorly understood. In our experiment, we collected and analyzed the volatile bouquet from the moth's original host plant, *Cyperus papyrus* and the invaded hosts such as two types of sugarcane varieties (N21 and 51NG146), as well as push-plant *Melinis minutiflora*. We pointed out physiological active volatiles from the volatile profiles on adult female and male moths by gas chromatography coupled electroantennography.

Keywords: *Eldana saccharina*; hostplants; plant volatiles; electrophysiology; push-pull strategy