CGIAR

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Emerging Themes in Agroecosystem Health and Food Safety

Chairman:	Dr Paula Bramel *International Institute of Tropical Agriculture (IITA), Nigeria*
Session Organiser:	Dr Braima James *International Institute of Tropical Agriculture (IITA), Benin*
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IPM contributions to the achievement of Millennium Development Goals of halving hunger and poverty

B James
International Institute of Tropical Agriculture, BP 08-0932, Cotonou, Benin
Email: b.james@cigar.org

P Bramel
International Institute of Tropical Agriculture, PMB 5320, Ibadan, Oyo State, Nigeria

A Lagnaoui
The World Bank, Washington, DC, USA

E Erisgen
CropLife International, Avenue Louise 143, 1050 Brussels, Belgium

C Asiabaka
Federal University of Technology, Owerri, Nigeria

Introduction

Growing populations of rural and urban poor farmers face serious production constraints from pests and inappropriate plant protection practices which reduce agricultural profitability. Integrated pest management (IPM) approaches have reversed pest impacts on livelihoods, and MDGs provide an investment strategy for such an approach to fight hunger and poverty. MDG 1 has two targets to halve the proportion of people whose income is less than $1 a day and suffer from hunger. IPM impacts on MDG 1 concurrently contribute to "ensure environmental sustainability" (MDG 7), reduce child mortality (MDG 4) and improve maternal health (MDG 5). The CGIAR Systemwide Program on IPM (SP-IPM) increases the quality and usefulness of IPM research and outreach (James *et al.* 2003) in ways that promote achievement of MDGs.

IPM contributions to MDG 1

Depending on locality, high priority biotic stresses affecting crops include the parasitic weed *Striga* spp for cereal and legumes on marginal soils, maize streak virus, maize sheath blight, cereal stem borers, tropical whiteflies, cassava mosaic virus, and legume pod borers. SP-IPM partners integrate IPM science into breeding strategies to provide high yield varieties that assure sustainable food supply. Crop management is essential for the varieties to fully express their potential. In the highlands of Peru, for example, the Andean potato weevil (*Premnotrypes* spp.) can wipe out the food and commercial value of staple potatoes in localities with intensive production on small plots without crop rotation. CIP-promoted entomophagous fungi *Beauvaria brongniartii* has reduced losses from 50% to 5% with an net benefit of $12m by 2020 in two pilot villages. CIMMYT and IITA elucidate species diversity of plant parasitic nematodes (PPN) and provide biological nematicides against the sedentary PPN *e.g., Heterodera* and *Meloidogyne* and migratory PPN *e.g., Pratylenchus* spp. and *Scutellonema bradys*. In Banana production, Bioversity International and IITA promote post-harvest field phytosanitary measures in combination with resistant varieties against banana weevil (*Cosmopolites sordidus*) and root feeding nematodes leading to 70% increases in yield. In maize, ICIPE's "push and pull" technology suppresses striga seed bank in soil whilst Napier grass distracts stem borers to increase yields by at least 30%.

Alien invasive species are a particular problem in sub-Sahara Africa (SSA). CGIAR/NARS collaboration on classical biological control strategies has shown notable impacts on livelihoods of rural small-holder communities (MDG 1) and environmental quality (MDG 7) in the continent. IITA-led activities have halted and reversed losses in cassava productivity by 90-95% with savings estimated at US$8m to US$20 where the alien invasive cassava mealybug (*Phenacoccus manihoti*) was controlled; and by 80-95% with savings of US$2m where another introduced pest cassava green mite (*Mononychellus tanajoa*) was controlled. Similarly, towards MDG 7 target 2 to "increase the proportion of population with sustainable access to an improved water source," biocontrol of floating water weeds has cleared water ways for fishing and navigation by at least 36%.

SP-IPM partners actively search for biopesticide alternatives to chemical pesticides. For example, collaborative research by CABI, IITA and NRI-UK had led to commercial production of *Metarhizium anisoplieae* var *acridium* to limit environmental degradation associated with massive aerial applications of insecticides to reduce acute hunger due to periodic locust invasions in SSA and Central West Asia and North Africa. Similarly, CIP, ICRISAT and IITA have developed indigenous strains of fungal and viral entomopathogens into biopesticide candidates for the management of Andean tuber moth in potato, pod borers of grain legumes, and leaf feeding caterpillars of vegetables in Latin America, Asia and West Africa. Amongst newly discovered botanicals, CIAT indicates promising effects of Finotin, a plant protein extracted from seeds of the tropical forage legume *Clitoria ternatea*, against a wide range of pests that damage field, forage and fruit crops. World Bank's Pest Management Plans and Crop Life International's stewardship program have potential to integrate biopesticides as complements to chemical control programmes.

Malnutrition, diseases and poor growth are aggravated by poor quality foods which cause dietary deficiency of protein and other nutrients. For example, aflatoxin poisoning aggravates *kwashiorkor* in children, retards growth and development, undermines immune systems and increases the risk of liver cancer. Additionally, aflatoxin contamination in excess of 20 ppb serves as trade barrier. Post-harvest IPM is therefore critical to MDG 1, MDG 4 targets "to reduce child mortality and under-five mortality by two-thirds", and MDG 8 target on trade promotion. To complement food quality management strategies developed by CIMMYT, ICARDA, ICRISAT, and IITA, IITA and it partners promote use of 'atoxigenic' strains of the fungus *Apergillus flavus* in biocontrol of aflatoxin.

Conclusion

Incautious agricultural practices can threaten natural 'life support' systems enabling pests to disrupt agricultural sustainability. Given the substantial economic importance of pests, the long-term IPM gains will impact positively on MDG 1 to reduce hunger and poverty whilst improving health of rural and urban poor (see IPM research briefs). The value adding technologies require supporting policies and institutions to boost profitability.

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IPM research briefs: http://www.spipm.cgiar.org/Brief/IPM%20research%20briefs.htm

Importance of soil health to sustainability of staple crop production systems

A Yahyaoui
International Center for Agricultural Research in the Dry Areas (ICARDA), ICARDA-CIMMYT Wheat Improvement Program (ICWIP), PO Box 5466, Aleppo, Syria
Email: a.yahyaoui@cgiar.org

J M Nicol
Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Ankara, Turkey

D Coyne
International Institute of Tropical Agriculture (IITA), PO Box 7878, Kampala, Uganda

S Kelemu
Centro Internacional de Agricultura Tropical (CIAT), Colombia

K Makkouk
International Center for Agricultural Research in the Dry Areas (ICARDA), PO Box 5466 Aleppo, Syria

Soil health is a major component in improving crop production and maintaining sustainability agro-ecosystems which improved livelihoods for resource poor farmers.

The soil environment is a complex mixture of organic and inorganic matter that includes thousands of different species, the vast majority of which are still undescribed. It has been estimated that, worldwide, the value of these ecosystem services provided by the soil biota in agricultural systems may exceed US$ 1,500 billion per year. The soil is thus a dynamic living resource that forms the basis of sustainable agriculture, as well as the physical support for almost all other human activities. Soil-borne pests can cause heavy yield loss, often by preventing development of healthy root system leading to low average yields of these crops in developing countries.

Plants grown on marginal, usually low fertility soils are less vigorous and more prone to attack by a wide range of pests amongst which soil-borne pests feature prominently. Losses due to soil-borne pests are recognized as an important factor in reducing crop yields, but often poorly quantified. The severity of soil-borne pests appears to be increasing, in the tropics often as a consequence of increasing human population pressures that bring about changes in cropping pattern, with more marginal production becoming subject to increasing edaphic and climatic stresses that typically predispose crops to pests attack. The importance of interaction with environmental factors (like soil fertility and moisture) in the occurrence and dynamics of soil-borne pests is reflected in this document by an approach that has sub-projects grouped by agro-ecological zones.

Soil organisms are not merely inhabitants of the soil, but are essential components of it, contributing to fundamental ecosystem processes such as carbon, nutrient- and water-cycling, as well as contribute significantly to soil aeration and drainage. The world's major staple crops are the cereals including wheat, maize and rice and in other region grain legumes. The soil is thus a dynamic living resource that forms the basis of sustainable agriculture, as well as the physical support for almost all other human activities.

CGIAR 2

Many of the world food staples in developing countries are grown in soils which do not promote a high level of ecological activity due to the cropping systems and associated farming practices. As a result soil borne pathogens and pests (SBPPs) can cause heavy yield losses in many agricultural systems from banana/plantain to root /tuber crops and also broad acre cereals and legume systems by preventing development of healthy root system.

Despite the importance of the SBPPs, not much attention has been attributed to this group of pests, in parts because of the greater technical difficulty in investigating them, and partly perhaps because they are 'out of site, so out of mind'; however, sp-IPM recognizes the perpetual threat of soil pests to world's staple food crops.

This paper will further highlight the importance of soil health and soil pathogen and pests on the well being of the farming communities in key tropical and dryland cereal systems.

The underground revolution: importance of soil borne pathogens in marginal cereal production systems of West Asia And North Africa

J M Nicol
International Maize and Wheat Improvement Center, Ankara 06511, Turkey
Email: j.nicol@cgiar.org

A Yahyaoui
International Center for Agricultural Research in the Dry Areas Aleppo, Syria

H Eleckcioglu
Çukurova University, Faculty of Agriculture, Adana, Turkey

N Bolat, A Bagci, E Donmez, M Avci, M Karacam
Turkish Ministry of Agriculture and Rural Affairs, Anatolian Agricultural Research Institute, Eskişehir, Bahri Dagdas International Agricultural Research Institute, Konya. Central Field Crops Research Institute, Ankara, Turkey

B Tunali
Ondokuz Mayıs University, Kurupelit, Samsun, Turkey

Introduction

Wheat is a food staple in many developing countries. In West Asia and North Africa (WANA) region, wheat production is characterized by low rainfall, monoculture cereal fallow systems. Soil borne pathogens (SBPs) of economic importance in wheat production in West Asia and North Africa (WANA) region and other rain-fed wheat production systems of the world are cereal cyst nematodes (CCN) *Heterodera spp.*, root lesion nematode (RLN) *Pratylenchus spp.*) and the root rotting fungi crown rot (CR) *Fusarium spp.* and common root rot (CRR) *Bipolaris sorokinana* (Chakraborty et al, 2006,, Nicol and Rivoal, *in press*, Nicol *et al.*, 2007, Tunali, *in press*). Many of the soils of the WANA region are characterized by soils with low organic matter, poor soil structure and micro nutrient deficiencies.

These features combined with sub-optimal moisture and SBPs increase the stress on plant health and exacerbate yield losses. There is a need investigate aspects of pathogen distribution, biology and impacts of SBPs within the context of soil health management in wheat cropping systems.

SBP research in marginal cereal systems

SBP research in Turkey is built on two primary IPM methods including host resistance and conservation agriculture (crop rotation and tillage) in order to fully understand the control of SBPs within the context of soil health and sustainability. The ongoing research has ascertained that SBPs are widespread in Turkey with 75% and 40% of soil samples containing CCN and RLN respectively (Nicol and Rivoal, *in press*). In more than 25% of cereal crown samples from the country, one or more of the dry land root rot pathogens CR and CRR were found (Tunali, *in press*). Similar results have been obtained in other parts of Syria, Iran and Tunisia within WANA region. SBPs have also been recorded causing significant yield losses in Turkey where several years' field experiments demonstrate loss of up to 37% caused by CCN (Nicol and Rivoal, *in press*, Nicol *et al.*, 2007), and 26%

caused by CR and CRR (Nicol et al., 2007, Tunali, *in press*). The population dynamics of CCN are being studied to understand economic threshold densities for damage, and in line with prior knowledge that water stress increases the economic importance of SBPs.

The management of SBPs has focused on use of genetic resistant crop varieties, and more than 30 sources of resistance have been identified and utilized in national and international breeding programs against CCN, RLN and CR (Nicol *et al.*, 2007). In addition more than 20 sets of genetic resources for resistance have been shared with national partners in WANA region. Conservation agriculture (CA) practices are explored as integral components in the IPM approach. Rotating wheat with non-host crops has been an effective method to reduce infestation levels of CCN and RLN. Tillage management practices (no-till, chemical fallow) had significantly differential reactions for CCN and RLN in a wheat/chickpea continuous and fallow system. Some bacterivore nematodes (indicators of soil health) were positively correlated with reduced tillage practices. Soil health aspects of organic matter and pH, were unaffected by either crop rotation or tillage management.

Conclusion

Interdisciplinary research is required to address the various IPM research and implementation challenges posed SBPs. International organizations such as CIMMYT and ICARDA play a pivotal role with their national program partners and Advanced Research Institutions to generate, share and utilize information for the benefit of the global community.

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Occurrence, distribution and research situation of cereal cyst nematode in China

D Peng, D Zhang
State Key Laboratory for Biology of Plant Diseases and Insect Pests, Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, China
Email: dlpeng@caas.net.cn

J M Nicol
International Maize and Wheat Improvement Center, ICARDA-CIMMYT Ankara, Turkey

S Chen
Institute of Plant Protection, Hebei Academy of Agricultural Sciences, Baoding, China

L Waeyenberge, M Moens
Crop Protection - Institute for Agricultural and Fisheries Research, Merelbeke, Belgium

H Li
College of Plant Protection, Henan Agricultural University, Zhengzhou, Henan, China

W Tang
Department of Plant Pathology, China Agricultural University, Beijing, China

I T Riley
South Australian Research and Development Institute(SARDI), Urrbrae, Australia

Introduction

China is the world's largest wheat producer with more than 120Mt of wheat produced per year and average yields around 4 t/ha. The cereal cyst nematode (CCN, *Heterodera avenae*) was first reported from Hubei province in the centre of China in 1987, and now it has been reported in at least nine provinces in high frequencies including Henan, Hebei, Beijing area, Inner Mongolia, Shanxi, Qinghai, Anhui and Shandong. The area of wheat production in these provinces is about 20 million ha, representing about two thirds of China's total wheat production, with average yields range from 3-6 t/ha depending on agroecologies. Preliminary results with common Chinese wheat cultivars in the three provinces (Anhui, Henan and Hebei) indicate significant yield increases with the application of the nematicide aldicarb (Temik®) in the order of 10-40% similar to reports from Australia, France, India, Turkey and USA (McDonald, Nicol 2005)). CCN's widespread distribution in key wheat producing provinces of China, and the preliminary yield loss data demonstrate significant losses, this pathogen is considered as a major biotic constraint to China's wheat production.

CCN distribution, population density and yield loss

CCN population density in China is high compared to other countries where the nematode has been reported to cause economic damage in wheat (Peng *et al*, 1996)). Survey results from 1998-2005 indicate the incidence CCN and abundance varied greatly from province to province. CCN incidence averaged 98.4%, 63.7%, 92.6% and 72.7% in Hubei, Beijing, Hebei and Henan respectively. CCN population density measured as eggs/g soil ranged 0.6 - 45 from 126 samples, 36 - 96 from 124 samples, 21 - 150 from 108 samples and 9 - 12 from 22 samples in Hubei, Beijing, Hebei and Henan areas respectively. Recently, samples from drier provinces of Inner Mongolia, Qinghai and Shanxi were found to contain CCN.

caused by CR and CRR (Nicol et al., 2007, Tunali, *in press*). The population dynamics of CCN are being studied to understand economic threshold densities for damage, and in line with prior knowledge that water stress increases the economic importance of SBPs.

The management of SBPs has focused on use of genetic resistant crop varieties, and more than 30 sources of resistance have been identified and utilized in national and international breeding programs against CCN, RLN and CR (Nicol *et al.*, 2007). In addition more than 20 sets of genetic resources for resistance have been shared with national partners in WANA region. Conservation agriculture (CA) practices are explored as integral components in the IPM approach. Rotating wheat with non-host crops has been an effective method to reduce infestation levels of CCN and RLN. Tillage management practices (no-till, chemical fallow) had significantly differential reactions for CCN and RLN in a wheat/chickpea continuous and fallow system. Some bacterivore nematodes (indicators of soil health) were positively correlated with reduced tillage practices. Soil health aspects of organic matter and pH, were unaffected by either crop rotation or tillage management.

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The health and capacity of vegetative seed systems in sub-Saharan Africa: developing a pro-poor CGIAR strategy to harness new technologies and conserve biodiversity

C Staver, R Markham
Bioversity International, Parc Scientifique Agropolis II, 34397 Montpellier, France
Email: c.staver@cgiar.org

T Dubois, P Bramel, C Herron, M Ayodele
International Institute of Tropical Agriculture, Uganda, Tanzania and Nigeria

M Fregene
Centro Internatiocional de Agricultura Tropical, AA 6713, Cali, Colombia

I Barker, P Gildemacher
Centro Internatiocional dela Papa, Apartado 1558, Lima 12, Peru

Vegetatively propagated crops (VPCs) are crucial to hunger reduction and improved livelihoods in Sub-Saharan Africa (SSA). Cassava is the most important source of calories; bananas and plantains are both a food staple and a fruit; yellow-fleshed sweet potatoes offer nutritional benefits and potato is both a food and cash crop in highland areas. Farmers grow other VPCs such as yams, taro and tannier, both for food and for sale.

The vast majority of farmers depend on informal seed systems to meet their planting needs. For potatoes which represent the best studied VPC seed system in SSA, certified seed represents only about 1% of the total seed supply. Local seed systems offer numerous advantages for rural communities. Local seed is low cost and convenient, with a focus on preferred and locally adapted cultivars. Planting material for VPCs is often difficult to transport over long distances, being bulky and perishable, except with specialized handling. Local seed is also available even in regions distant from markets (Thiele 1999). However, local VPC seed systems may not provide clean planting material and may even contribute to the propagation of seed-borne diseases which are particularly numerous for VPCs:

Key pests and diseases transmitted in planting material of VPC in SSA
Bananas/plantains: *Cosmopolites sordidus*, nematodes, *Fusarium oxysporum pv. cubense*, *Xanthomonas campestris pv. campestris*, BBTV, BSV, sudden death virus
Potatoes: PLRV, PVY, *Ralstonia solanacearum*, *Phthorimaea operculella*
Cassava: *Colletotrichum gloeosporioides*, *Xanthomonas manihotis*, AECMV, ACMV, EUCMV, CBS, FS
Sweet potatoes: SPCSV, SPFMV, SPMMV,SPCFV,SPLCV, *Cylas* spp, *Alternaria* spp
Yams: DAV, CMV, DbBV, DaBV, YMV, *Colletotrichum gloeosporioides, Erwinia amylovora*

While breeding programmes, IPM and agronomic practices are more crop- and location-specific, seed systems for VPCs have commonalities calling for a cross-crop approach. Pilot programmes with virus-resistant cassava varieties, sweet potato, tissue culture banana plants and potato seed selection offer lessons for a broader, more robust seed system initiative. The four international centres engaged with VPCs, in conjunction with other international partners such as FAO and IAPSC-AU, are leveraging their crop-based expertise to develop innovative approaches that will make clean, low-cost, superior germplasm available to rural communities.

Certain seed-borne pests and diseases can be addressed through farmer learning. Positive selection of vigorous, symptom-free potato plants as seed, piloted by CIP and KARI in Kenya, increased yields by 30% and was adopted by 28% of farmers. For banana and plantain, peeling and hot-water treatment of suckers, macro-propagation and micro-corms, easily promoted in farmer field schools, can reduce seed-borne problems and crop losses.

The successful promotion of new cultivars and the management of certain seed-borne diseases require that the formal and informal seed systems be linked. The mechanisms and appropriate degree of linkage depend on how quickly the clean seed degenerates or is re-infected, the economic yield gap between clean seed and seed from informal sources, and the degree of market integration of the community (Thiele 1999). Building on this perspective, this incipient working group of the SP-IPM proposes a number of actions.

Descriptive and diagnostic tools of informal VPC seed systems can build on methods used in studies of true seed (Jarvis et al. 2003; Sperling 2000). For VPCs in SSA, formal systems are extremely under-invested. Simple checklists are needed to inventory regulatory mechanisms for internal and cross border seed movement, laboratory capacity to test seed quality and standards for public and private tissue culture operations. An actor-oriented approach drawing from innovation systems analysis may offer useful possibilities for identifying key capacities and linkages in the formal system.

All the CG centers responsible for VPCs have piloted clean seed delivery mechanisms for elite varieties. These experiences will be analyzed to identify common infrastructure needs for advanced laboratory protocols such as detection of viruses and bacteria, and for initial multiplication of elite, clean lines. This analysis, supported by characterization of zones by crop-specific threats to seed system, should lead to more effective investment and training.

A joint FAO/CGIAR project is under way to develop Quality Declared Seed protocols and standards for local seed producers of the major VPCs. These will take into account the primary disease problems, field, nursery and laboratory requirements, and monitoring procedures to meet minimum standards. The development of these standards will allow the identification of commonalities for follow-up actions. In parallel to this, a review of successful approaches to small private-sector seed multipliers and cooperative community seed associations in Ethiopia, Uganda, Kenya and Ghana will contribute guidelines for strengthening this link from the formal to the informal system.

A final issue for innovative VPC seed systems in SSA will be mechanisms to recycle unique local crop diversity, that has been contaminated and its value reduced by disease problems, through cleaning and elite multiplication back to rural communities – a challenge that can only be addressed through advanced science and collaborative, learning-based implementation.

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Putting agro-biodiversity to work: the cowpea story

M Tamo, G Goergen, C Agboton
International Institute of Tropical Agriculture (IITA), BP 08-0932, Cotonou, Benin
Email: m.tamo@cgiar.org

R Srinivasan
The World Vegetable Center (AVRDC), PO Box 42, Shanhua, Tainan 74199; Taiwan

Introduction

Cowpea, *Vigna unguiculata* Walpers is the most important grain legume in West Africa, where, unfortunately, yields are threatened by a complex of insect pests and diseases. Among them, the pod borer *Maruca vitrata* (Fabricius) (Lepidoptera, Crambidae) and the cowpea aphid *Aphis craccivora* Koch (Homoptera, Aphididae) have been the object of intensified studies concerning the relationship between biodiversity and ecological functions of their respective natural enemies (Tamò *et al.*, 2003).

The cowpea pod borer, *Maruca vitrata*

Several parasitoid species have already been reported to attack *M. vitrata* larvae in different parts of the World. In West Africa, the most important ones are braconids such as *Phanerotoma leucobasis* and *Braunsia kriegeri*. However, their contribution in controlling *M. vitrata* populations is considered minor, even on wild occurring alternative host plants, e.g. *Pterocarpus santalinoides* and *Lonchocarpus sericeus* (Arodokoun *et al.*, 2006). In Asia, Huang *et al.* (2003) have recorded three braconid wasps (*Apanteles taragamae*, *Bassus asper* and *Dolichogenidea* sp), three ichneumonids (*Trichomma* sp., *Triclistus* sp. and *Plectochorus* sp.) and two unidentified tachinid flies from Taiwan.

The two tachind flies were subsequently identified as different sexes of the same species, *Nemorilla maculosa*, a larval-pupal parasitoid. Among the parasitoid diversity, *A. taragamae* (with up to 63% parasitism) and *N. maculosa* (with about 40% parasitism) were found to be the most promising biological control candidates against *M. vitrata* in West Africa. IITA has already imported *A. taragamae* from Taiwan in 2005 and conducted a series of pre-release studies, to ascertain host range, host finding capacity, and reproductive biology in view to optimize the mass rearing.

Based on the outcome of these studies, experimental releases were carried out in Benin and Ghana, on patches of natural vegetation comprising major host plants such as *P. santalinoides*, *L. sericeus* and *Pueraria phaseoloides*. Field studies to assess establishment have been initiated in both countries.

In West Africa, *M. vitrata* larvae were found to be infected by a Cypovirus, but its sublethal character was considered to be of little importance in the natural regulation of the pest populations. However, a new, hitherto unknown nuclear polyhedrosis virus (NPV) was discovered to infect *M. vitrata* larvae in Taiwan in 2004. This NPV was subsequently characterized at AVRDC in collaboration with Southern Taiwan University of Technology, Taiwan (Lee *et al.*, 2007). This is the first world record of a NPV infecting *M. vitrata*, and was named as MaviMNPV. Few NPV formulations have already been produced using MaviMNPV and they are currently under field evaluation at AVRDC. IITA imported this MaviMNPV in 2006 for studies under controlled experiments in Benin. Preliminary observations indicate a high potential of the virus as a biopesticide candidate against *M. vitrata*.

The cowpea aphid, *Aphis craccivora*

In spite of good sources of resistance against the cowpea aphid, this pest remains an unsolved problem throughout the cowpea cultivation areas in Subsaharan Africa. Repeated surveys to identify major natural enemies of *A. craccivora* in Benin, Ghana, Niger and Nigeria have revealed the total absence of hymenopterous parasitoids attacking this pest (Soukossi, 2001, unpublished results). In view of the multitude of *A. craccivora* parasitoids found elsewhere, such as *Trioxys* spp. (Hymenoptera, Braconidae), (e.g. in Pakistan and India), which are reported to control this pest in a variety of environments and on different crops (Singh and Agarwala, 1992), there could be a potential 'off the shelf' biological control project, as it has been the case for the successful introduction of *Trioxys pallidus* (Haliday) in hazelnut orchards of Oregon.

This biocontrol effort should further be integrated with available HPR, in the hope to obtain synergistic effects on the reduction of the aphid populations. The cowpea aphid is originating from the Mid-East – South Central Asia, where is very seldom recorded as reaching pest status. Over a dozen of hymenopterous parasitoids have been identified attacking this pest, with peak parasitism levels in the field of up to 65%. Considering that here are no parasitoids at all attacking this pest in Subsaharan Africa, any introduction of climatically adapted strains is believed to be able to reduce aphid numbers below the damage levels. Combined with HPR affecting aphid populations in a synergistic manner, this approach should provide the cowpea farmer with a better management option than solely relying on chemical pesticides.

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Functional agrobiodiversity in potato-based production systems - its monitoring and use

J Kroschel, N Mujica, V Canedo, J Alcazar
International Potato Center (CIP), Apartado 1558, Lima 12, Peru
Email: j.kroschel@cgiar.org

Introduction

In developing countries in the Tropics and Subtropics, potato (*Solanum sp.)* has a high yield potential but low yields are common and mostly attributed to pests. Without control, losses can reach more than 70% in the field and up to 80% during storage. Major pests are three species of the potato tuber moth complex (PTM, *Phthorimaea operculella*, *Symmetrischema tangolias* and *Tecia solanivora*), Andean potato weevils (APW, *Premnotrypes suturicallus*, *P. vorax* and *P. latithorax*) and leafminer fly (LMF, *Liriomyza huidrobrensis*). The unilateral use of pesticides to protect the potato crop against these pests greatly contributes to the production costs of potatoes. Moreover, insecticide sprayings pose tangible risks to human health, contribute to environmental contamination and often lead to secondary insect pests in the absence of natural enemies. In addition, most farmers in developing countries lack the knowledge and equipment necessary to obtain good results using chemical pesticides. The International Potato Center (CIP) is looking for safer alternatives to replace toxic chemicals and anticipates a widespread impact on poverty reduction, food security, human health and environmental protection through the development and adoption of Integrated Pest Management (IPM) by focusing on five main areas of basic and applied scientific research: (i) Ecosystem research in potato-based agro-ecosystems; (ii) Pest severity, population ecology and phenology modeling; (iii) Conservation/enhancement of natural enemies and biocontrol; (iv) Assessment of communication and behavior of insects; and (v) Participatory research and training. Hence, within its IPM research, CIP applies and tests ecological concepts and principles to the design, the development and management of sustainable agricultural systems. This research should lead to a better understanding and designing of strategies for conservation and enhancement of natural enemies to stabilize agroecosystems to counteract insect pests. In this paper we present recent results of monitoring and using functional agrobiodiversity for developing sustainable potato-based agricultural systems in the Andean highlands and Peruvian coastal lowlands.

Methodological approach

Research is done to understand ecological phenomena and food webs and to produce an inventory of insect communities in potato agroecosystems. The research assesses herbivore/natural enemy and plant interactions and interrelationships, related to landscape fragmentation and complexity and farmers' practice, and their effects on functional diversity and the exchange of species among different habitats. Survey instruments are used to study pest and natural enemy abundance and distribution in different agroecosystems. Experiments are laid out in landscapes covering a gradient from extremely simple and structurally poor (<10% of non-cropped area) to complex and structurally rich landscapes (>50% non-crop habit). Studies are made in conventional farms using pesticide-treated and -free plots or on organic farms. Different insect-sampling methods are tested and used. Parasitoids are reared from different life stages of pests collected during the vegetative period or attracted through direct weekly exposure of pests' eggs and larvae. Evaluation includes statistics and the use of diversity indices, parasitism rates, etc.

Case I: Potato-based systems in Peruvian coastal lowlands

Leafmining flies of the genus *Liriomyza* are important pests in cropping systems along the Peruvian coast. A total of five *Liriomyza* species (*L. huidobrensis*, *L. sativae*, *L. graminivora*, *L. commelinae*, *Liriomyza* sp.) were identified from 27 vegetable crops: The most dominant species was *L. huidobrensis* collected from 23 crops. *L. sativae* was second. On average, 29.5% parasitism was registered by 63 parasitoids belonging to seven families: Eulophidae (29 sp.), Braconidae (11 sp.), Pteromalidae (8 sp.), Eucolidae (1 sp.), Elachertinae (6 sp.), Mimaridae (2 sp.) and Chalcidoidea (6 sp.). The endoparasitoids *Halticoptera arduine* (48.2%), *Chrysocharis flacilla* (19.5%), and *Chrysocharis caribea* (8.0 %) as well as the ectoparasitoid *Diglyphus websteri* (8.7%) were most abundant. *H. arduine* was not only the most effective parasitoid but also parasitized all leafminer species in 25 crops. Maize (*Zea mays* L.) is only affected by *L. graminivora* but hosting 6 parasitoid species affecting *L. huidobrensis*. A higher diversity of leafminers, with a total of 12 species, and parasitoids (50 morphotypes) was observed at field borders, which are characterized by a higher floristic richness. Interestingly, mainly non-crop Agromyzidae species were found with *L. sabaziae* as the most abundant one (58.7%); however, seven weed species with *Stellaria media* as the most important one are host plants of *L. huidrobrensis*. In contrast, we found special weed-leafminer interrelationships: *Malva parviflora/Calycomyza malvae*, *Galinsoga parviflora/L. sabaziae* and *Sorghum halepense/Cerodontha dorsalis*, which are parasitized by not less than 19, 18, and 15 parasitoid species.

Conclusion: The high diversity of parasitoids supports the assumption that leafminer flies are of neotropical origin. We are testing strategies to take more advantage of the richness of parasitoids by increasing their efficacy through adapted cultural practices (e.g. enriching the weed community at field borders or intercropping maize) and the development of other IPM components (e.g. biocontrol). The parasitoids identified are potential candidates for classical biocontrol of *L. huidrobrensis* in other countries and regions.

Case II: Potato-based systems in Peruvian Andean Highlands

At altitudes of more than 3,200 m a.s.l. 2-4 applications of highly toxic insecticide is common farmer practice to control APWs. In this region, PTMs are mainly considered a storage pest. We found that insecticide applications mainly affects its target but with no significant effects on soil beneficial insects (ground beetles, Carabidae, rove beetles, Staphylinidae) monitored in pitfall traps. Without APW control, other pests (e.g. flee beetles, *Epitrix* sp.) get more abundant and damaging on potato. With malaise traps no differences in number of pests and beneficial insects could be established in pesticide-free and non-free fields, but higher numbers of hover flies (Syrphidae) were found in structurally poor agro-ecosystems. However, in structural rich landscapes pest abundance and damage was generally lower. At this altitude, parasitism is in general low and no clear differences could be established between structurally poor and rich or pesticide-treated and -free systems. Parasitism rate of *Copidosoma koehleri* (Encyrtidae) on PTM was only 0.005% and only individual specimens were found of the family Braconidae, Ichneumonidae and Tachinidae.

Conclusion

Structurally richer landscapes in the Andean highlands showed little floristic diversity, which does not support many beneficial insects for agricultural pests. In contrast, plants of the families Asteraceae and Brassicaceae at field borders, which are important pollen sources for beneficial insects (Braconidae (1 sp.), Coccinellidae (2 sp.) Ichneumonidae (1 sp.), Nabidae (1 sp.), Sphecidae (2 sp.), Syrphidae (6 spp.), Tachinidae (3 spp.), and Vespidae (2 spp.), could be promoted to augment natural control.

Functional biodiversity for sustainable management of African rice gall midge in lowland rice-based systems

F E Nwilene, O Ajayi, T A Agunbiade
Africa Rice Center (WARDA), Ibadan, Nigeria,
Email: f.nwilene@cgiar.org

O Youm, A Togola
Africa Rice Center (WARDA), Cotonou, Benin

M N Ukwungwu
National Cereals Research Institute (NCRI), Nigeria

D Dakouo
INERA Station de Farako-Ba, Bobo-Dioulasso, Burkina Faso

S I Kamara
Rokupr Rice Research Station, Freetown, Sierra Leone

A Hamadoun
IER/CRRA, Sikasso, Mali

Introduction

The African rice gall midge (AfRGM), *Orseolia oryzivora* Harris & Gagné (Diptera: Cecidomyiidae) is a serious insect pest of rice in rainfed and irrigated lowland systems in Africa. The larvae are stalk borers of rice at vegetative growth stages and cause rice leaves to grow into tubular galls called 'silver shoots' or 'onion leaves' that prevent panicle from bearing grains. Heavy yield losses (45-80%) due to AfRGM have been reported in farmers' rice crops from endemic locations in Africa. Because of this biotic constraint, the intensification practices of lowland rice farmers are unsustainable. There is an urgent need to prevent the pest-induced crop losses and ensure food security and poverty reduction in Africa. Amongst IPM approaches being explored against AfRGM is the integration of available midge-tolerant varieties with natural biological control through habitat management. Understanding inter-specific relationships in agro-ecosystems and the roles these species play in crop protection are essential to the development of sustainable IPM strategies. Pending availability of high yielding rice varieties with durable resistance to AfRGM (Nwilene et al., 2002), this study explored biodiversity as a functional principle of pest (AfRGM) management.

Functional agrobiodiversity studies

Two natural enemies attack AfRGM – the endoparasitoid *Platygaster diplosisae* and the ectoparasitoid *Aprostocetus procerae*. The parasitoid populations build up slowly to become effective at the end of the season. Why are these large and diverse natural enemy populations unable to contain AfRGM early in the season before rice crops are destroyed? *Orseolia bonzii* which infests *Paspalum scrobiculatum*, a common weed in rice agroecosystems, is distinct from AfRGM (Nwilene et al., 2006), and is an alternative host for the two main parasitoids of AfRGM (Williams et al., 1997; Nwilene et al., 2007). The delay between the destruction of *P. scrobiculatum* and appearance of AfRGM populations on rice crop means that the large majority of the parasitoids from *O. bonzii* die before AfRGM are available. Field studies were undertaken in southeast Nigeria to ascertain if management of *P. scrobiculatum* (leaving *Paspalum* plants undisturbed) on a strip of land 1m or 2m wide round the edge of rice crop for the first few weeks after rice is transplanted might significantly increase parasitoid carry-over into the crop. Three midge-tolerant varieties – BW 348-1, Cisadane, Leizghung and a susceptible check, ITA 306 were evaluated for their reaction to gall midge damage. The effect of *Paspalum* densities at 1, 2, 3, and 4 per m^2 and a control was measured at 21, 42 and 63 days after transplanting.

Results

The susceptible variety ITA 306 had higher AfRGM damage compared to the other varieties. Damage in all the four varieties decreased with an increase in *Paspalum* density but was inversely related to the crop growth stage, resulting in slightly higher damage in younger plants (21 DAT) than in older ones (63 DAT). The results showed that the varieties differed in their response to *Paspalum* density, as reflected in yield effects. For instance, with four *Paspalum* plants per m^2, at 63 DAT, grain yield increased by as much as 414% in Leizhung compared to 204% and 269% in BW 348-1 and Cisadane, respectively, and 168% in the susceptible ITA 306. There was a positive correlation between *Paspalum* density and percent parasitism ($r_x = 0.83$). A simple intervention to increase the carry-over of parasitoids at maximum *Paspalum* density gave better control of gall midge damage and higher grain yield than the control treatment without *Paspalum*.

Conclusion

It is concluded that the combination of beneficial organisms, tolerant varieties and habitat management suppressed AfRGM, restored nature's balance, and resulted in increased rice yields. It is also concluded that some practical realities need to be considered before recommending habitat management strategies to farmers. These include: (i) will habitat management require more work and resources? (ii) how can habitat management strategies be incorporated into current rice growing area? (iii) how can farmers be motivated to adopt habitat management tactics? and (iv) are farmers really better off in the long term by using habitat management? Factors such as seasonal labour, capital and land availability are likely to be major determinants of ability to adopt habitat management strategies and could be investigated as a follow-up study.

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Potential changes in the distributions of the potato tuber moth, *Phthorimaea operculella* Zeller, in response to climate change by using a temperature-driven phenology model linked with geographic information systems (GIS)

M Sporleder
International Potato Center (CIP), ICIMOD, Khumaltar, Kathmandu, Nepal
Email: msporleder@cgiar.org

J Kroschel, R Simon
International Potato Center (CIP), Av. La Molina 1895, Lima 12, Peru

Introduction

The potato tuber moth (PTM), *Phthorimaea operculella* Zeller, (Lepidoptera: Gelechiidae), which probably originated in tropical mountainous regions of South America, has become a cosmopolitan pest of potatoes and other solanaceous crops. This highly invasive pest causes significant crop losses in almost all tropical and subtropical potato production systems in Africa, Asia and Central and South America. It has a large climatic range although activity increases with temperature. While PTM can be of economic significance in temperate regions, including New Zealand, southern Europe, and in the southwestern USA, cold and long winters generally restrict its development reducing its pest status. Historically, population development is limited by the 10°C annual isotherm in both the southern and northern hemisphere. During recent decades, however, the climate on earth has clearly become warmer, especially in the northern hemisphere. The mean temperature in Europe during the past century has raised 0.8ºC, displacing isotherms about 120 km northwards on average. This global warming, which is very likely due to increasing anthropogenic greenhouse gas concentrations, is projected to continue. It has been recognized that the increase of temperature would allow the spreading of insect species northward and upward due to faster development. Depending on temperature, PTM develop several overlapping generations per year and thus populations comprise individuals of mixed life stages. Due to its high growth potential, multivoltinism and absence of diapause the specie seems to be highly sensitive to temperature changes. The objective of this study was to assess the potential changes in the distributions of PTM in response to global warming using a temperature-based phenology model linked with GIS.

Materials and methods

A generic temperature-driven phenology model developed for PTM (Sporleder *et al.*, 2004), which has been validated both in the laboratory and the field (Keller 2003), was used to predict the species' responses to climate change on a global scale. Primarily, the phenology model was coupled with interpolated daily temperature data (WorldClim; the data are described in Hijmans *et al.*, 2005) to predict pest phenologies worldwide at a spatial resolution of 10 min ($18.6 \times 18.6 = 344$ km^2 at the equator). Three spatially referenced pest risk indices displaying the risk of establishment, numbers of generations per year, and an activity index were computed on a worldwide scale. Resulting risk maps revealed well the present distribution and pest activity of PTM in the world (Sporleder *et al.*, 2007). In the present study, to predict the species' responses to climate change, similar maps were generated for two scenarios of climate change using an atmospheric general circulation model (GCM), described by Govindasamy *et al.* (2003), to forecast global climate for the year 2050 and 2080.

Results and discussion

The GCM projected more pronounced temperature increases in temperate regions, specifically of the northern hemisphere, as well in mountainous regions of the tropics and subtropics (from 30°N to 30°S). It was predicted that expansion northwards and to higher altitudes, especially in tropical regions, of PTM may occur. As an example of a temperate region of the northern hemisphere, in the Columbia River Basin of Washington and Oregon, the average annual temperature of about 12°C is likely to increase by 2-3°C by 2050. In this region, PTM populations are largely controlled by low winter temperatures but with substantial numbers of over-wintering pests after mild winters as observed in 2003. Hot summers allow a rapid population increase which surpasses control thresholds. The modeling study revealed that the number of generations per year would increase from 4.4 to 4.8 and 5.4 for temperature increases of 1 and 2°C, respectively. The activity of the moth during the vegetative growth period of potatoes would increase 2.4 and 5.7-fold. As an example for a tropical mountainous area, in Hunancayo, Peru (3300 masl), where the average annual temperature today is also about 12°C, temperature is predicted to increase by 1-2°C by 2050. In this region, in which PTM is considered a pest of stored potatoes, daily temperature fluctuations are higher than the within-year temperature fluctuations. An average temperature rise of 1 or 2°C would increase the number of PTM generations per year from 3.3 to 3.7 or 4.2, while moth activity would increase 6.9 or 61-fold. The global boundaries for PTM could shift about 400-800 km north in the northern hemisphere and several 100 m in altitude in tropical mountains. PTM activity is likely to increase in all regions where the pest prevails today. The amount of projected warming varies between global climate models and there still remains a considerable range of climate sensitivity that limits the assertions of the present modeling study. Global warming will increase the intensity of extreme weather events and change the amount and pattern of precipitation that will alter PTM population development in different ways. The potential expansion of area with PTM transmission will be important for future examination.

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Implication of climate change on trans-boundary rust diseases

A Yahyaoui
International Center for Agricultural Research in the Dry Areas (ICARDA), ICARDA-CIMMYT Wheat Improvement Program (ICWIP), PO Box 5466, Aleppo, Syria
Email: a.yahyaoui@cgiar.org

R P Singh
Centro Internacional de Mejoramiento de Maiz y Trigo(CIMMYT), Apdo. Postal 6-641, 6600 Mexico

Z A Pretorius
Department of Plant Sciences, University of Free State, Bloemfontein 9300, South Africa

M Hovmoller
Faculty of Agricultural Sciences, University of Aarhus, Forsohsvej 1, Dk-4200, Denmark

T Fetch
Agriculture Canada, Winnipeg, Manitoba, Canada

C Welling
Plant Breeding Institute, University of Sydney, Australia

W Khoury
AGP-Food and Agriculture Organisation (FAO), Rome, Italy

S Rajaram
International Center for Agricultural Research in the Dry Areas (ICARDA), ICARDA-CIMMYT Wheat Improvement Program (ICWIP), PO Box 5466, Aleppo, Syria

Cereal rust diseases continue to be among the most devastating plant pathogens globally. The wheat rust (stem rust, yellow rust, and leaf rust) pathogens are able to multiply within susceptible crops and associated grass weeds, and are capable of both local and long distance dispersal in continental wind movements. Each of these pathogens exists in a range of pathogenic variants ('races, also known as 'strains' or 'pathotypes') which are continually subject to evolutionary forces of mutation and selection giving rise to new variants.

These variants, or races, are capable of overcoming current resistance in cultivars and are considered as the most important factor in the development of rust epidemics in East Africa and elsewhere. Wheat stem rust is among the most serious diseases of wheat worldwide and represents a major and immediate threat to wheat production in the East Africa and the Near East regions. The occurrence of stem rust race (TTKS) labeled as Ug99 shows the great danger for important yield losses on the currently grown wheat cultivars.

Historical records show that virulent stem rust races occurring in Africa were able to reach Australia, presumably on high altitude winds. Yellow rust virulence on the resistance gene Yr 9 that occurred in Kenya in the mid 1980's caused great yield losses in Near Eastern countries in late 1980's as well as in Pakistan and Nepal during the early 1990's

This combined with migration of new races with different virulence phenotypes and enhanced aggressiveness can create new areas of adaptation and epidemics. An example has been warmer temperatures adaptation of stripe rust (*P. striiformis*) that has lead to wheat stripe rust spread not only in Southern and East Africa but also to wheat growing areas along the Mediterranean cost in North Africa. Global climate changes will have far-reaching consequences on crop diseases in the non-tropical drylands. The adaptive potential of plant pathogens may prove to be one of the most important predictors of the magnitude of climate change effects. A rise in temperature would contribute to an increase in the number of generations for diseases would increase, adding another layer of complexity.

Global climate changes will have far-reaching consequences on crop diseases, such as the wheat rusts in the non-tropical dry-lands as well as other temperate areas. The adaptive potential of plant pathogens such as the rusts may prove to be one of the most important predictors of the magnitude of climate change effects. The spatial and temporal distribution, survival and proliferation of cereal rusts (*Puccinia* spp) will be affected by a rise in temperature in association with changes in rainfall patterns and native grass and voluntary host plants infections during the off-season. Climate affects the pesticides used to control and/or prevent disease outbreaks: the intensity and timing of rainfall influence pesticide persistence and efficiency; temperature and light affect pesticide persistence through chemical alteration. Most analyses show that in a warmer climate, diseases may become more frequent than currently and may expand their geographical range, resulting in increased use of agricultural chemicals with accompanying health, ecological and economic costs.

Climate imposes a major change in the over-wintering and over-summering patterns of this rust fungus in the region. The scaling up of trans-boundary rust fungal pathogens from individual infections to epidemics and broader impacts has been felt on several instances, a good example of which is the de novo spread of Ug99 race of *Puccinia graminis* f. sp. *tritici* (www.globalrust.org).

Currently, there is no coordinated framework for acquiring and sharing data on incidence, severity, and genetic composition of rust infections in the developing world. The emergence of Ug99 and related derivate races in east Africa, and the subsequent spread of this race to Yemen highlight the need for such a framework. The data-driven quantification to predict the likely path of Ug99; or the probability, magnitude, and human security impacts of potential rust epidemics are currently impossible. The Global Rust Initiative (GRI), primarily through the efforts of ICARDA, CIMMYT, USDA-ARS (CDL-Minnesota), and Agriculture Canada (Winnipeg-Manitoba) have deployed nurseries (trap nurseries) of specialized genetic stocks that enable the detection of specific virulences in prevailing populations of rust spores. These 'trap' or 'sentinel' nurseries are a key component of an early detection system. GRI efforts have also increased awareness of the life cycle of stem rust in many developing countries.

Careful monitoring of movement of these airborne pathogens and understanding the new epidemiology would be steps in a strategy to understand and deal with the effects of global climatic changes as they occur. This would provide tools to enhance resistance/tolerance to biotic stresses that would lead to improved and sustained crop productivity.

Global monitoring of cereal rust movement

A Yahyaoui
International Center for Agricultural Research in the Dry Areas (ICARDA), ICARDA-CIMMYT Wheat Improvement Program (ICWIP), PO. Box 5466, Aleppo, Syria
Email: a.yahyaoui@cgiar.org

D Hodson, R Ward
Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Apdo. Postal 6-641, 6600 Mexico

K Cressman
AGP-Food and Agriculture Organisation (FAO), Rome, Italy

E De-Pauw
International Center for Agricultural Research in the Dry Areas (ICARDA),PO Box 5466 Aleppo, Syria

Rusts have been recognized as the most important diseases of wheat since the Roman times. The three wheat rusts, stem or black rust (*Puccinia graminis tritici*), leaf or brown rust (*P. recondita tritici*), and stripe or yellow rust (*P. striiformis*) are extremely prevalent wherever wheat is grown. These rust fungi produce spores very abundantly that are carried by wind for short or long distances. Records of very long-distance transport over thousands of kilometers by high-altitude winds are very common. The speed of rust reproduction is a key factor for epidemics to develop and the rate or reproduction depends on the prevalent environmental conditions and the susceptibility of the wheat varieties planted Epidemics result in severe crop losses that can reach 80% in severe cases. The cereal rust pathogens known as stem rust (*Puccinia graminis* fsp *tritici*), stripe rust (*Puccinia striiformis*), and leaf rust (*Puccinia triticina*) are the most important biotic constraints to cereal production (and food security?) worldwide. Rusts are air-borne pathogens with their contaminating spores disseminated by wind. Historical information shows records of wind borne spores moving across continents, although shorter distance movements are more common – often within distinct pathozones (or epidemiological regions). In recent years, a virulent strain of wheat stripe rust (*Puccinia striiformis*) referred to as Vir.Yr9, occurred in East Africa in 1986 and reached South Asia in 1993 following wind patterns. Vir.Yr9 caused important yield losses in many countries along its path and even complete crop failure at some locations. In 1999 a new strain (race?) of stem rust (*Puccinia graminis* fsp *tritici*) occurred in Uganda, hence we now known as Ug99 (www.globalrust.org). This stem rust race is expected to follow the same pathway as the stripe rust VirYr9. Ug99 represents a much greater threat than Virulence Yr9, as an estimated 80% of current global wheat varieties are susceptible.

Ug99 has spread in east Africa and in 2006 jumped the Red Sea with confirmed reports in Yemen. Due to the complexity of wind currents and cropping patterns around the horn of Africa, its further spread remains uncertain. The wheat rust (stem rust, yellow rust, and leaf rust*)* pathogens are able to multiply within susceptible crops and associated grass weeds, and are capable of both local and long distance dispersal in continental wind movements. Long distance transport may annually occur across the North American Great Plains (800 km) and from the western region of Australia to New Zealand (7-5,000km).

Long distance spread is influenced by latitude and by local and global (predominantly west to east) wind patterns. Generally, spores move west to east due to the winds resulting from the rotation of the earth. Well documented examples of the long distance spread of cereal rusts in the last half century were: 1) The occurrence of barley yellow rust in South America and its further spread, including to North America; 2) The introduction of a highly aggressive wheat stripe rust race to California and its northward (Pacific Northwest), southward (Mexico) and eastward spread including its establishment in the Great Plains where stripe rust previously was of no consequence; wheat stripe rust from eastern Africa to the South Asia, 3) The recent (2002) introduction and spread of a new wheat stripe rust race in Western Australia and its airborne movement to eastern Australian states and presumably New Zealand; 4) The gradual spread of *Yr9*-virulence in wheat stripe rust from eastern Africa to the South Asia. The prospect of a stem rust epidemic in wheat in Africa, Asia and the Americas is real and must be stopped before it causes untold damage and human suffering.

With the long distance travel of rust spores, it is only a matter of time until Ug99 reaches across the Arabian Peninsula and into the Near East, Mediterranean region; and possibly eastern Europe (particularly the Balkan region, Ukraine etc.), Russia, and the central Asia countries, South Asia and eventually East Asia, Australia, and the Americas. In order to alleviate/stop the threat of Ug99 and to avoid/limit the development of more complicated races of trans-boundary wheat rusts; there is an urgent need to develop a global tracking system of cereal rust diseases and eventually establish an early global warning and decision support systems that would permit to avoid tremendous crop losses, that could not be sustained by poor resource farmers in Africa nor by corporate farmers that would have to revert to use of chemicals that would not only increase the production cost but would also impact the environment. The development of GIS maps similar to those developed for locust monitoring would allow the development and implementation of a global warning and decision support systems that permits timely planning of control measures and targeted management of the rust diseases

Publicly accessible GIS environmental data (wind, temperature, moisture, etc.), will provide a range of actors with the means to answer pressing questions which affect the insecurity that wheat rusts like Ug99 will introduce to world food production. Question which will be tractable include:

- Where are Ug99 and its derivatives likely to go next?
- Where are the likely self-perpetuating 'epidemiological zones' for stem rust in today's world; and what level of gene flow can be expected among those zones?

An international consortium – the Global Rust Initiative – is now working on monitoring, surveillance and early-warning of cereal rusts. Key elements include; the integration of field surveys, improved knowledge of predominant air flows and spore deposition, cropping patterns and crop calendars. The aim is to determine the probable pathway of further spread of Ug99 and allow better preparedness of countries along the pathways of the deadly rusts. These crucial global monitoring efforts are described. Accurate knowledge on predominant wind currents and spore movements during different periods of the wheat growing season could be of great value to the world community.

Bio-safety of transgenic crops to non-target organisms

H C Sharma, M K Dhillon
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India
Email: H.Sharma@cgiar.org

M Tamo
International Institute of Tropical Agriculture (IITA), BP 08-0932, Cotonou, Benin

One of the major concerns of transgenic crops is their effects on the non-target organisms. The information that pollen from *Bt* corn causes toxic effects on larvae of the monarch butterfly, *Danaus plexippu,* atttracted lot of attention regading the biosafety of transgenic crops to the non-target organisms. However, Wraight *et al.* (2000) did not observe any relationship between mortality of *Papilio polyxenes* and pollen deposition from transgenic maize on its host plants. Several studies have now shown that there is no affect of *Bt* corn pollen on the monarch butterfly.

Interaction of transgenic crops with predators

There are no adverse affects of *Bt* transgenic crops on the generalist predators. However, long term field studies with larger sample size should be conducted to understand the interaction of transgenic crops with the predator abundance under field conditions. *Chrysoperla carnea* larvae were detrimentally affected when fed on *Spodoptera littoralis* reared on maize expressing *cry1Ab* gene (Dutton *et al*., 2002). However, no significant effects on survival and development were observed in *Hippodamia convergens* fed on *Myzus persicae* reared on potatoes expressing *Bt* toxins. There are no apparent effects of transgenic cotton on the relative abundance of predatory spiders, *Clubiona* sp. and *Neoscona* sp., coccinellid, *Cheilomenes sexmaculatus*, and the chrysopid, *Chrysoperla carnea*. However, the abundance of spiders, coccinellids and chrysopids was quite low in insecticide protected plots towards end of the cropping season (Sharma *et al*., 2007).

Interaction of transgenic crops with parasitoids

The effects of transgenic crops on the natural enemies vary across crops and the cropping systems. Some of the variation may be due to differences in pest abundance between the transgenic and the non-transgenic crops. The activity of *Cardiochiles nigriceps* - a parasitoid of *Heliothis virescens*, is not influenced by the transgenic plants. There is no effect of transgenic maize on parasitization of the European corn borer, *Ostrinia nubilalis* by *Eriborus tenebrans* and *Macrocentrus grandii*.

There is a significant reduction in cocoon formation of *Campoletis chlorideae* – a larval parasitoid of *H. armigera*, when the later is fed on artificial diet containing *Bt* toxins Cry1Ab and Cry1Ac at the LC_{50} and ED_{50} levels. However, there is no effect on post-embryonic development and fecundity. Significant reduction in cocoon formation was also recorded when the *H. armigera* larvae were fed on leaves of transgenic cottons before and after parasitization (Sharma *et al*., 2007).

However, no *Bt* toxins were detected in parasitoid cocoons, suggesting that reduction in cocoon formation was largely due to early mortality of the *H. armigera* larvae. There are some adverse affects of transgenic crops on the host specific parasitoids.

However, the adverse affects of transgenic crops may still be far lower than those of the broad-spectrum pesticides, which virtually kill all the natural enemies in the ecosystem.

Interaction of transgenic crops with fauna and flora in the rhizosphere

Genetically engineered crops may affect the fauna and flora in the rhizosphere, but long-term significance of any of these changes is unclear. No effects have been detected in culturable bacteria, fungi, protozoa, and nematodes from the *Bt*-maize fields. Under field conditions, the microflora of *Bt* transgenic potato plants has been observed to be minimally different from that of chemically and microbially treated commercial potato plants. There are no significant differences in mortality or weight of earthworms (*Lumbricus terrestris*) in soil planted with *Bt*- and non-*Bt* maize. *Bt* toxins have been detected in the gut and casts of earthworms, which are cleared in 2 to 3 days after being placed in fresh soil.

Conclusions

Natural enemies play an important role in suppressing pest populations. To ensure a sustainable deployment of transgenic insect-resistant plants, it is important that they are compatible with other control methods, including biological control. Therefore, there is a need to understand the effects of transgenic crops on the target and non-target insect pests, and the beneficial natural enemies under laboratory and field conditions.

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Consultative Group on International Agricultural Research (CGIAR) research-for-development agenda on mycotoxins for enhanced food safety and trade

R Bandyopadhyay, A Menkir
International Institute of Tropical Agriculture, PMB 5320, Ibadan, Oyo State, Nigeria
Email: r.bandyopadhyay@cgiar.org

S Asaad
International Center for Agricultural Research in the Dry Areas, Aleppo, Syria

T Ban, D Bergvinson, D Jeffers, J Murakami, R Ortiz
Centro Internacional de Mejoramiento de Maíz y Trigo, (CIMMYT), Apdo. Postal 6-641, 6600 Mexico

K Hell, B James
International Institute of Tropical Agriculture, BP 08-0932, Cotonou, Benin

P Lava Kumar, S N Nigam, H D Upadhyaya, F Waliyar
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India

Introduction

Mycotoxins are highly toxic metabolites produced by a number of fungi especially in drought-prone environments, unseasonably rainy environments, or high moisture at pre-crop harvest, harvest, and storage. The toxins, e.g. aflatoxins, deteriorate food quality, are barriers to international trade, pose serious risk to health, and have caused several deaths in Africa and Asia.

Human poisoning by aflatoxins occurs through consumption of contaminated maize and legumes. Nearly 4.5 billion people suffer food-borne toxins, especially in the developing world (Williams *et al.*, 2004). The chronic incidence of aflatoxin in diets is evident from presence of the toxin in human breast milk in West Africa, Sudan, Thailand, and the United Arab Emirates, and in umbilical cord blood samples in sub-Saharan Africa. Children exposed to aflatoxin may be stunted, underweight (Gong *et al.*, 2004), and more susceptible to infectious diseases. Immunologic and nutritional effects of aflatoxin highlight the probability that the six top WHO risk factors as well as the risks of liver cancer are modulated by aflatoxin (Williams *et al.*, 2004). Furthermore, farmers need greater capacity to comply with international sanitary and phytosanitary regulations in order to participate in global markets in which food safety concerns are high.

Response by Consultative Group on International Agricultural Research (CGIAR)

In order to provide mycotoxin management options that ensure food safety for health and wealth among producers and consumers, IITA, ICRISAT, CIMMYT, and ICARDA, in partnership with advanced research institutes and national programs, conduct strategic, applied and adaptive research on aflatoxins in maize, groundnut, sorghum, cashew, cassava, yams chips, pistachio, almonds, and chili peppers; *Fusarium* toxins in maize, wheat and sorghum; and ochratoxin in cocoa and cashew (Ortiz *et al.*, in press). Genetic enhancement (both through plant breeding and biotechnology) (Menkir *et al*, 2006), biological control (Bandyopadhyay *et al.*, 2005), habitat management, integrated mycotoxin management (http://www.aflatoxin.info), risk assessment (Bandyopadhyay *et al.*, in press), institutional capacity development, public awareness (James *et al.*, in press) and networking (http://www.globalfusarium.org) are among the tools used by the CGIAR centers to combat the mycotoxin problem worldwide. A well-coordinated inter-institutional research partnership is required to further enhance these initiatives in developing countries.

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Designing more effective training in agro-ecological crop and pest management in bananas and plantains: an electronic learning resource

C Staver, R Markham
Bioversity International, Parc Scientifique Agropolis II, 34397 Montpellier, France
Email: c.staver@cgiar.org

Farm households grow *Musa* (banana and plantain) under a wide range of climate and soils. In each situation they face specific problems, including how to manage pests, diseases and plant nutrition which are influenced by weather variability. In recent decades new pests have been introduced and certain existing pests have been favoured by changes in cropping practices. Over the same time period, prices for agricultural products have fluctuated wildly, while new markets have also opened. Due to all these factors, farmers make crop and pest management decisions under extreme uncertainty.

To use new techniques more effectively, synchronise cropping systems with ecological processes and fine tune crop management to local and often variable conditions, farmers need to strengthen their skills in observation and agro-ecological analysis. A farm household which is more observant, which experiments more, which asks more questions, which keeps better records and which is better informed is better prepared to make decisions for planning and managing crops under conditions of variability and uncertainty. Development projects with a *Musa* component often lack training materials for non-formal adult education and depend on field technicians with limited formal education in *Musa*, a crop unlike annual or tree crops. This suggests a need not only for farmer training materials, but also materials for field technicians in a format conducive to participatory learning.

Bioversity International is developing a learning resource for training and education in *Musa* agro-ecology and pest management which combines an introduction to the agro-ecological principles of the crop and a format for developing a location-specific curriculum. The format, referred to as 'participatory group learning and experimentation by crop stage', draws on the experiences of farmer field schools as adapted to the needs of a group of NGOs and research organizations in Nicaragua (CATIE 2003).

The approach incorporates: multiple crop fields as a learning laboratory; learning exercises which strengthen ecological knowledge of the crop, pests, the food web and the agro-ecosystem; simple scouting methods for observation of crop, pest, and system indicators; group discussions at key moments in the crop cycle; and knowledge testing tools. In the first meeting prior to crop planting, farmers discuss pest and crop problems and their experience with different practices, prioritize critical problems and possible alternative practices for testing, and identify indicators for evaluating the group's progress. Farmer volunteers establish experiments and complete scouting procedures in their fields and report back at later meetings. In each of the four to five meetings during a year-long cycle, farmers analyze recently planted fields and fields in first, second, and later harvest cycles. In this way, the multi-year crop can be studied during a single year. In the final meeting, the group of farmers reviews the results of their experiments, analyzes their management decisions during the cycle in relation to pest levels and crop development and retest their knowledge of the *Musa* ecosystem based on similar themes to those in the initial meeting. The meeting concludes with the identification of practices for scaling up and of themes for more experimentation and further training (Staver 2005).

The web-based resource has five sections: 'why an agro-ecological learning approach?', 'an introduction to the *Musa* agro-ecosystem', 'factors in *Musa* growth and productivity', 'managing *Musa* pests agro-ecologically', and 'tools and methods for agro-ecological learning'. Each section is illustrated with photographs and diagrams. The section on pest agroecology presents information pest-by-pest by crop stage, identifying the climatic and biological factors which favour or suppress pests. A similar format reviews alternative management practices and their agro-ecological basis. The last section presents examples of learning curricula for specific zones. It also reviews seven steps which a group of trainers and scientists can use to develop the curriculum for farmer participatory group learning and experimentation for their own conditions:

1) define production zones by agro-climatic conditions and production technology used;
2) prioritize the diverse problems which farmers face in improving yield or enhancing the value of their crop while reducing risk and costs;
3) identify the key changes to moving from the current situation to the improved situation (skills of farmers, skills of extensionists, availability of specific technologies, research);
4) organize available information by stage of crop which is most relevant to farmer decision making with particular emphasis on the type of farmer targeted by the project;
5) for each key moment in the crop cycle, identify skills and alternative technologies which farmers are to test out on their own farms;
6) develop learning activities for each meeting which motivate and equip farmers to act;
7) review final plan and prioritize activities according to the time available.

The curriculum design is a first approximation, made more robust with mechanisms for modifying content during the process itself and for monitoring outcomes and impacts that can be used in upgrading the design for future learning cycles. The training facilitation group can begin to modify the initial design after the diagnostic farmer meeting by reviewing the results of the test of farmer knowledge, analyzing the problems and priorities and adjusting the proposed activities for the next meeting. After each meeting the extensionists and trainers meet to review progress and modify the approach and content for the following meetings. The trainers and extensionists should visit a few farm households in their fields between each meeting. In these visits they can contact other members of the household, not just the person coming to the farmer meetings. By the end of the participatory farmer group learning and experimentation process, the training group will have numerous inputs to monitor the effectiveness of their work, including the farmers' attendance at meetings, pre- and post-training farmer knowledge testing, farmer experiments and learning exercises on-farm, and the farmers' scaling up of useful practices.

These materials are available on a web site (http://platform-agro.inibap.org/index.html) which includes a technical bibliography and an open format to upgrade available materials by the incorporation of additional pests and project experiences from around the globe.

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Entertainment-Education and pest management

K L Heong
International Rice Research Institute, Los Banos, DAPO 7777, Metro Manila, Philippines
Email: kheong@cgiar.org

M M Escalada
Visayas State University, Baybay, Leyte, Philippines

N H Huan
Plant Protection Department, 28 Mac Dinh Chi St., Ho Chi Minh City, Vietnam

The use of the entertainment-education (E-E) framework to produce a soap opera series to create favourable attitudes and change practices in rice pest management was evaluated in Vietnam. The framework was applied through a multi stakeholder participatory process involving research, extension, local government and media. To facilitate educational content accurately and seamlessly weaved into the drama, a team of technical experts and scriptwriters, called 'turtles and peacocks', was established. An audience analysis (n=605) was initially conducted. A typical farm family was identified to serve as the model and a 'creative document' with descriptions of the family, home surroundings, common activities and a map was developed. The 'turtles and peacocks' paid regular visits to this family to learn about their activities, behaviour and common local words used to be able to write the scripts. Results of the audience analysis, the creative document and the experiences of the farm visits were resource materials for the drama design workshop where stakeholders developed the title of the soap, drama characters, story lines and broadcast times. The soap opera was named 'Chuyen Que Minh' or Homeland Story. Two techniques from the Sabido soap opera development methodology, the "character map" and "values grid" were used to develop the characters and educational messages incorporated into the scripts.

The soap opera was launched in Vinh Long town hall on 7 July 2004 by the Vice Minister for Agriculture and Rural Development. Between July 2004 and December 2005, 104 episodes were broadcast over the Voice of Ho Chi Minh City and Voice of Vinh Long. The series featured three sets of characters, those who were positive towards IPM practices, those that were negative and a transitional group. Conversations were developed between these sets of characters, discussing the pros and cons of pest management practices. The main character was transitional who eventually changed beliefs and practices in the series.

A message design workshop was held to develop a strategy, materials and activities to promote the new drama series. A poster, a leaflet, TV and radio spot announcements, and a launching ceremony were developed. All the support materials were pretested before they were finalized and mass produced. In parallel with the drama broadcasts, three additional on-the-ground activities were organized. Radio clubs, where farmers gathered together once a month to listen to previous episodes and discussed the stories and educational issues, were organized. Quiz competitions were organized weekly and a 'meet the actors' day was held in the Vinh Long town hall.

Three surveys were conducted to prepare, monitor progress and evaluate its effects; the audience analysis, the baseline or pre-test survey and the post-test survey. The pre-test post-test no control group experimental design was used to assess the effects of the soap.

Prior to developing the questionnaire for each survey, the authors conducted focus group discussions to gather materials to structure and frame the questionnaires. The questionnaires were prepared in English, translated into Vietnamese and pretested.

Changes in seed, fertilizer and pest management practices

Farmers reported about 31% reduction in insecticide sprays in the wet season from a mean of 1.89 to 1.30 sprays per season, about 9% reduction in seed rates used, from a mean of 210.3 to 191.8 kg/ha and about 7% reduction in nitrogen used, from 95.6 to 88.6 kg/ha. There were also slight reductions in the use of potassium and phosphorus but these were not significant. Yields reported were significantly different, mean of 4.75 to 5.12 t/ha in the pre and post test respectively. More farmers in the post-test (30.3%) reported not using any insecticides at all than in the pre-test (17.5%).

Changes in attitudes favouring practices of reducing insecticides and nitrogen

Fewer farmers (63.5%) believed that "all insects are bad" in the post-test than in the pre-test (79.1%). There were also significant reductions in percentage of farmers believing that insecticide sprays had to be applied in the first 40 days after sowing (from 79.8% to 47.6%) and that leaf damages would mean loss in yields (from 59.2% to 38.3%). On the other hand more farmers believed that pesticides can affect their health, from 61.6% to 86.1%. More farmers in the post-test believed that reducing seed rates from 150-200 kg/ha to 80–100 kg/ha would result in the same yields. Farmers also modified their beliefs that nitrogen would produce healthier crops.

We used stepwise multiple regression analysis to explore which variables had more influence on farmers' insecticide use The final model of three variables was statistically significant ($F = 72$ $p < 0.001$) but accounted for only 15% ($R^2 = 0.15$) of the total variation. Of the 3 variables, farmers' beliefs that spraying in the first 40 days after sowing was not necessary and that pesticides would affect human health, accounted for ~ 45% of farmers' sprays (ß coefficients were 0.332 and 0.119 respectively). This implies that the drama episodes that focused on these two messages along with the interpersonal communication support from the radio listeners groups may have contributed more towards farmers' insecticide use changes than other messages.

The study showed that the E-E soap opera contributed positively to changes in farmers' beliefs and practices. The 1500 fan mail expressing their interest in the soap opera content reinforced the influence of the soap opera. Coupled with the extensive reach of the radio drama and from the focus group discussions the authors had had with farmers, it was evident that the soap opera had contributed to the changes observed. The participatory process and E-E tools had been useful in facilitating distillation of scientific information to be built into the drama to educate, entertain and motivate listeners. The 'turtles and peacocks' partnership had been vital and can serve as a platform to transform technical information to motivate change. Other important components in the process were the series of on-the-ground support activities, such as radio clubs to provide technical support, advice and discussions. The launching day, drama publicity, radio quizzes and 'meet-the-actors' day were important in popularizing the drama. In most developing countries radio will remain the principal medium for communication. These are readily available, inexpensive, portable, and can have wide reach, even in very remote areas. It has high potential to be the vehicle for IPM, new agricultural ideas and technologies.