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**Innovative Solutions to New Invaders:
Managing Agricultural Pests, Diseases and Weeds Under Climate Change**

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Innovative Solutions to New Invaders: Managing Agricultural Pests, Diseases and Weeds Under Climate Change

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Global agriculture is struggling to keep pace with increasing demands for food as human population increases and food preferences alter. Changes in temperature, greenhouse gas concentrations, precipitation patterns and radiation further challenge farmers. Insect and nematode pests, plant diseases and weeds are major constraints to crop production. Developing models to project the potential distribution and abundance of a pest species under various climate change scenarios is essential, and the Australian scientific community has been at the forefront with the development of CLIMEX and its application to modelling some of the world's worst weed species, such as the pan-tropical Asteraceae, *Chromolaena odorata*. CABI is developing tools to assist farmers in coping with these challenges. In West Africa, *C. odorata* promotes other crop pests, such as the polyphagous *Zonocerus variegatus* grasshopper. CABI has developed an efficacious mycopesticide, a formulation of *Metarhizium anisopliae* var. *acridum*, to prevent threats from increasing grasshopper and locust populations.

TREVOR NICHOLLS joined CABI in 2005 and has restructured the organisation to deliver clearer strategic focus and customer orientation, resulting in three consecutive years of operating profits and the elimination of a £7 million debt burden. Prior to joining CABI, his career covered 25 years experience of building international businesses in the life science industry, with a focus on genomics, in major pharma, biotech and academic clients. He has broad experience of initiating change and restructuring organisations, ranging from start-ups to FTSE 100/Nasdaq-quoted companies. Trevor holds a BA and DPhil in biochemistry from the University of York and diploma qualifications in marketing (CIM) and company directorship (IoD).

Climate change models project increased precipitation in parts of the humid tropics. In Central Africa, this will exacerbate yield losses, such as to fungal 'blackpod' disease on cocoa. Farmers currently use contact fungicides, but this strategy will become less efficacious with increasing rainfall. CABI and partners are identifying endophytes, such as *Trichoderma*, as biocontrol agents to deal with this threat.

Other pests will become more damaging as temperatures increase. Populations of banana root nematodes increase with increasing temperatures and cause greater root damage. Furthermore, some species will spread to higher altitudes at which they are currently absent. CABI's Global Plant Clinic advises farmers on how to minimise damage from such pests. These examples of CABI's work are described in more detail below.

Introduction

The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) confirmed many of the trends they had predicted in 2001. Atmospheric concentrations of greenhouse gases (CO₂, N₂O, CH₄) are continuing to increase. By the end of the 21st century, global average air temperatures are projected to rise by 1.8–4.0°C (IPCC 2007). This alters the hydrological cycle as the water-holding capacity of air increases by about 4% per degree Celsius. Boko *et al.* (2007) project increased rainfall in West Africa, although the distribution will not be even. Dry areas will become drier and humid zones wetter, resulting in more abrupt ecoregional transitions and closer isopleths. Similarly, since the 1950s, north-western

Australia has become wetter while southern and eastern areas have become drier (Smith 2004). However, there is disparity between different global models as projections depend on the extent to which feedback from vegetation changes is taken into account.

There is strong evidence that more extreme weather events will occur (IPCC 2007). According to an index based on the total dissipation of power over the lifetime of a cyclone, tropical cyclones have become more destructive in the last thirty years (Emanuel 2005; Man and Emanuel 2006). This has had notable economic impacts on tropical crops, including the devastation of the northern Queensland banana crop in 2006 by Cyclone Larry, and Hurricane Dean destroying bananas worth A\$300 million in Martinique in August 2007. Such disturbances, in tandem with increases in international trade, create a plethora of opportunities for pest introduction and favour rapid colonisers (r-strategists).

Over 70% of the world's food comes from just nine crops (rice, wheat, maize, potato, barley, cassava, soybean, sugar cane and oats), each of which is cultivated far beyond its natural range. The IPCC (2007) summarised 69 studies on the effects of higher temperatures on three of these: rice, wheat and maize (Fig. 1). While mild warming is projected to result in initial increases in crop yields in the temperate regions, when temperature increases exceed 3°C, yields will decline. Most disturbingly, any increase in temperature is projected to cause yield decline in the tropics, even for maize and rice, whose centres of origin are in or close to the tropics as they are already near the upper limits for optimum growth. These models do not take into account any increase in crop losses due to increased pest damage, and the effects of climatic change upon crop-pest relationships is largely unknown.

We will discuss three examples of CABI's work spanning the research–development spectrum: developing innovative methods to replace older control strategies that are less effective under climate change; technologies to control pests that are likely to be favoured by climate change; and the use of some commercial biopesticides to tackle pests whose range is expanding.

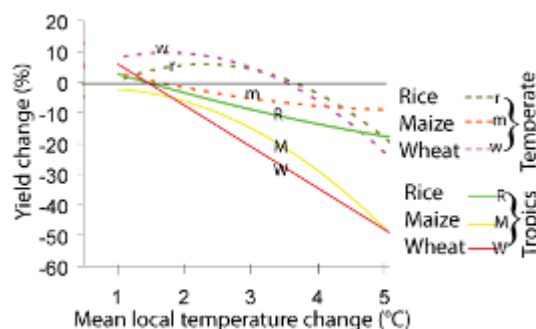


Figure 1. Effects of temperature change on yields of maize, rice and wheat grown in temperate and tropical conditions. Adapted by Norgrove from IPCC (2007), summarising 69 studies.

Novel biological control agents for cocoa blackpod disease

Theobroma cacao, the raw ingredient for chocolate, is an understorey tree, native to the forests of South America yet grown throughout the humid Tropics. World cacao production is about 3.5 million t y⁻¹, 90% of which is grown in Côte d'Ivoire, Ghana, Indonesia, Nigeria, Cameroon, Brazil, Ecuador and Malaysia, where millions of smallholder farmers depend on the revenue. Globally, some of the major constraints in cacao production are fungal diseases: blackpod caused by *Phytophthora*, predominantly *P. palmivora* and *P. megakarya*; frosty pod (*Moniliophthora roreri*); and witches' broom (*Moniliophthora perniciososa*). Witches' broom had devastating effects in Brazil in the 1990s. Globally, blackpod is the major biotic yield constraint, resulting in estimated losses of 450 000 t y⁻¹ (Bowers *et al.* 2001).

While *P. palmivora* is cosmopolitan, *P. megakarya* is not known outside Africa. It was first identified in Nigeria in the 1970s (Brasier and Griffin 1979) and is now common in Cameroon and Gabon. *Phytophthora megakarya* has been isolated from fruit of a native *Irvingia* sp. tree in ancient primary forest near the Nigeria – Cameroon border (Holmes *et al.* 2003) so it may have shifted host and be a new-encounter pathogen. *Phytophthora megakarya* has invaded Ghana (Kebe *et al.* 2002) and is now spreading west into Côte d'Ivoire, threatening the region's largest cocoa producer. *Phytophthora megakarya* sporulates more abundantly than *P. palmivora*. The soil-borne phase of the *P. megakarya* disease cycle causes root infection, maintaining a reservoir of inoculum during the dry season, releasing zoospores into the soil surface water

when rains start (Opuku *et al.* 2007). The soil is therefore the primary inoculum and disease tends to progress from pods at the bottom of the trunk and later into the canopy (Opuku *et al.* 2007).

Current control strategies include cultural methods, and fungicide use. Cultural methods aim to reduce inoculum and alter microclimatic conditions. Phytosanitary harvesting is the removal of mummified husks before the beginning of the rainy season and, thereafter, visibly diseased pods from the farm on a weekly basis. Other strategies are branch pruning, removing water shoots and eliminating shade trees. While phytosanitary harvesting and pruning can minimise yield losses from *P. palmivora*, these measures alone result in negligible yield in *P. megakarya*-infected areas (Opuku *et al.* 2000; Norgrove 2007a). Copper (I) oxide fungicides are applied using side-lever manual knapsack sprayers to treat trunks, pods and leaves up to 12 times per year. Alternative fungicides include contact cupric and copper hydroxide preparations, and the systemic potassium phosphonate, which is injected into the trunk and translocates in the xylem and phloem (Opuku *et al.* 2003). CABI and partners have been working together with cocoa farmers to promote more effective control methods, including rational fungicide use, improved sprayers and spraying techniques (Bateman 2004).

Yet projected higher temperatures, humidity or precipitation in some parts of the humid tropics, including the west African cocoa belt, will generally exacerbate yield losses as these factors promote fungal disease. For *P. megakarya* growth, temperatures above 26°C are reported to be sub-optimal (Brasier and Griffin 1979), so aggressiveness might reduce as climate change advances. However, higher precipitation will result in greater run-off of the fungicide, requiring either better formulations or more frequent spraying, further reducing profitability. So alternative control methods are necessary.

CABI, together with USDA and other partners, have been searching for endophytic *Trichoderma* fungi, plant symbionts that can protect their hosts from diseases through various mechanisms: competitive exclusion; antibiosis; induced resistance and mycoparasitism. *Trichoderma* spp. that exhibit these properties and colonise cocoa tissue are being collected, isolated and screened for potential as biocontrol agents (e.g. Bailey *et al.* 2008).

Dealing with greater pest pressure on *Musa* spp. through integrated pest management

Musa spp., comprising banana, plantain and highland banana, are grown by subsistence farmers across three continents within a diversity of cropping systems. *Musa* spp. are prone to pests and diseases, partially because genetic variability within the population is low. *Mycosphaerella fijiensis* (Morelet) fungus is the causal agent of black sigatoka, a major constraint to *Musa* production in lowland tropical humid areas. It originates from the Pacific, but is now prevalent throughout the tropics and can cause 40% yield loss due to incomplete finger-filling. Black sigatoka infection starts as dark streaks visible on the lower leaf surfaces, which form black lesions on both leaf surfaces and then become necrotic, destroying large areas of mature leaf tissue (Waller *et al.* 1993). It is spread by wind-dispersed ascospores (sexual) and conidia (asexual) and thus is beyond the control of plant quarantine measures. In upland areas, the less virulent yellow sigatoka (*M. musicola*) is more prevalent.

Musa spp. host a complex of root nematodes that destroy root tissue, increasing the risk of toppling, particularly after the bunch has emerged. *Radopholus similis* (Cobb) Thorne is the greatest cause of yield loss in *Musa* worldwide. The genus *Radopholus* is indigenous to Australasia (Sher 1968) yet is now cosmopolitan throughout the tropics. It is a pioneer root invader (Quénéhervé 1989) and can complete its life cycle without a soil phase. Infestation levels in the soil are lower than for other nematodes (Quénéhervé 1989) and populations within roots usually decline with time as *R. similis* is displaced by other nematode species (Bridge *et al.* 1995).

So what will be the impact of climate change on this suite of pests and consequently *Musa* yields? Black sigatoka may expand its range and spread to the highlands currently free of it and replace the less-virulent yellow sigatoka. *Radopholus similis* is sensitive to temperature and is currently absent at high altitudes and latitudes. In a global study, Fallas and Sarah (1995) compared growth of seven *R. similis* isolates from different parts of the humid tropics. They compared multiplication at 21°C, 24°C, 27°C, 30°C and 33°C, finding that the 30°C treatments had the greatest final population for all the isolates. In a similar study,

Pinochet *et al.* (1995) compared in-vitro reproduction at 16°C, 21°C and 24°C. They found that reproduction was greatest at the highest temperature and at 75 days after commencement, the final population was nearly 16 times greater at 24°C than at 21°C. In a field study in Central Africa, there was a significant positive relationship between root damage by nematodes and soil temperature (Norgrove and Hauser, unpubl.). Combining these data, within its current range, increases in temperature up to 30°C will result in increased nematode populations, greater root damage and more crop losses (Fig. 2). Increases in temperature at higher altitudes will permit *Radopholus similis* to survive and reproduce in areas currently free of it.

CABI's Global Plant Clinic promotes integrated pest management to farmers, including methods to reduce damage from *Radopholus* and other nematodes. These include using clean planting material, such as suckers that have been immersed in hot water, tissue culture plantlets or carefully pared suckers. Some nematode species survive and reproduce in old corm material so this should be removed from the field at the end of the crop cycle. For species that have a soil phase and can survive without their host, it is advised to use crop rotation with non-susceptible crops or to leave land fallow for at least three years.

Interactions between changing climate, weed distribution, insect pests and crop diseases

Chromolaena odorata, or Siam weed, is native to South America, invasive throughout the tropics and a serious weed in cropped fields, timber plantations and pastures.

CLIMEX_{TM} (Sutherst *et al.* 2007) uses IPCC models plus precipitation, vapour pressure and temperature data to project climate change surfaces for global weeds, including Siam weed. CLIMEX predicts that in Australia its potential range will extend south into coastal New South Wales by 2080, and in West Africa that the range will expand east to Central Africa and beyond (Kriticos *et al.* 2005). While there have been some biocontrol attempts in Papua New Guinea and in Ghana, this method is contentious in West Africa where many farmers perceive Siam weed positively as it outcompetes the more difficult-to-manage *Imperata cylindrica* (Norgrove 2007b).

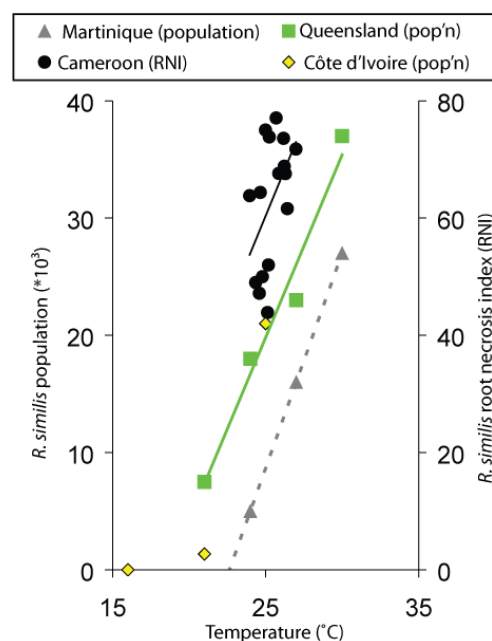


Figure 2. Temperature effects on *R. similis* populations and root necrosis indices in *Musa* spp. Data from a field study in Cameroon (Norgrove and Hauser, unpublished) and from controlled lab studies elsewhere (Fallas and Sarah 1995; Pinochet *et al.* 1995). Treatment means presented. All data significant at $P < 0.05$.

So while Siam weed may have some redeeming qualities, it has other complex impacts. It is an attractant for the African grasshopper *Zonocerus variegatus*, which sequesters the pyrrolizidine alkaloids of *C. odorata*, protecting itself from antagonists and increasing its population (Fischer and Boppré 1997). *Zonocerus variegatus* is polyphagous, defoliating maize, cassava and other food crops (Le Gall *et al.* 2003), particularly during the dry season. Increases in *Z. variegatus* populations have been linked with the increasing cover of Siam weed in West Africa. As well as being a pest in its own right, it transmits cassava bacterial blight, one of the major cassava diseases in the region.

In the 1990s, CABI developed the 'LUBILOSA' project which culminated in the formulation of Green Muscle_{TM}, a biopesticide now being produced commercially in South Africa. Green Muscle is highly effective against grasshoppers and locusts, including *Z. variegatus*. It is transmitted between individuals aided by their gregarious behaviour. This is one 'off the shelf' technology that could be used to manage this increasing problem which is exacerbated by both land use and climate change.

Conclusion

In the light of climate change, there is much uncertainty about abiotic changes in the environment. The interactions between these, crops and their pests are hard to predict. However, minimising crop losses in this period of food insecurity is essential. To adapt to this uncertainty and to reduce risk, while smallholder farmers in the tropics should be encouraged to adopt innovations that minimise losses and increase yields, they should still maintain the richness and diversity of their traditional cropping systems. Farmers currently change the mix of their cropping systems on an annual basis. For example, if the rains are late, they reduce their investment in three-month crops such as groundnut and maize and increase investments in crops such as cassava, the tubers of which can be left in the ground for a variable time. Conversely, if rains are early they will shift focus to the cereal and leguminous crops, which have a higher protein content.

CABI will continue with fundamental research, developing technologies and advising vulnerable farmers in their IPM choices in the light of the new challenges posed by climate change in our member countries. We will drive the sustainable agriculture and climate change agenda through our innovative approach of knowledge, research, capacity building and action at a local level.

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