A journey towards pest management

Prof Hannalene du Plessis

Unit for Environmental Sciences and Management, North-West University

"…science today should aim higher, surpass knowledge as its final goal and reach for wisdom" (Peeter Müürsepp).

World hunger has increased by 150 million since 2019 to 828 million people in 2021. Asia (425 million) and Africa (278 million) were the worst affected continents in 2022. It is therefore doubtful that the world will reach its global target of Zero Hunger by 2030. In addition, the global population is estimated to reach almost 11 billion people by 2100. It is and will always be an enormous challenge to provide food for all of humanity. Scientists from many disciplines are working towards this one common goal. For example, plant breeders breed for higher yield or wider adaptability in terms of drought or flooding, while soil scientists attempt to improve soil quality and develop sustainable soil management practices. However, yield improvements that result from the good efforts of all the improved crop varieties and farming practices can be nullified by the damage caused to crops by pests and diseases. My contribution to this effort as a researcher in agriculture, specialising as an applied entomologist, is in the focus area of integrated pest management (IPM). The aim of my research and contribution to this field lie in maintaining pests at tolerable levels by using and combining different pest control tactics.

Integrated pest management is "an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. It is therefore a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that consider the interests of, and impacts on producers, society, and the environment. The tasks to be undertaken is firstly the correct identification of the pest, followed by monitoring of the pest populations and assessing the damage caused. The lowest population density of a pest that will cause economic damage; or the amount of pest injury which will justify the cost of control (economic injury level) should either be known or determined. The control tactics to be used are presented in the IPM pyramid. Integrated pest management is a bottom-up approach. based on preventive measures and the reduction in use of chemical control. Therefore, at the base of this pyramid is preventative tactics, e.g., good sanitation of crop fields and greenhouses. This is followed by physical-mechanical control where pests are controlled physically, e.g., planting of traps crops or mechanical removal of larvae from plants (hand picking). Biological control is the use of living organisms to suppress pest populations. Chemical control should be applied as the "last line of defence" when a pest reaches the economic threshold level (ETL). The ETL is the pest density at which management action should be taken to prevent an increasing pest population from reaching the economic injury level. This is the lowest number of insects or amount of injury that will cause yield losses equal to the insect management costs. Since the aim of IPM is to reduce the overreliance on, and use of chemical control, this control tactic appears at the top of the pyramid. When chemical control has to be applied, products that are less hazardous to the environment, e.g., repellents and microbials should always be considered first, before applying more toxic, conventional pesticides.

Late in 2016 and early in 2017, two very important invasive pest species were recorded for the first time in South Africa. These were the Fall armyworm (FAW), *Spodoptera frugiperda* and the tomato leafminer, *Phthorimaea absoluta*. Invasive species hold great socio-economic and ecological importance in agriculture globally. A recent estimate of the economic cost associated with invasive insects globally, accounts to 70 billion US$ per year. Invasive arthropods threaten human health, jeopardize food supplies, endanger native species, cause economic losses, and disrupt ecosystem functions. Since invasive arthropods are dispersed beyond their native ranges, they escape population-regulating predators, parasitoids, and pathogens.

Before being able to develop an IPM strategy for control of the FAW, many unknowns had to be addressed, which could only be achieved through research. Fall armyworm populations consist of two morphologically indistinguishable strains adapted to different host plants. The corn strain (C-strain) prefers to feed on maize, cotton, and sorghum, whereas the rice strain (R-strain) is more associated with rice and several pasture grasses. These strains have different genetic backgrounds, mating behaviour, pheromone compositions and host-plant adaptation, which influences the decision-making process of an IPM system. To address these unknowns, we determined the possible source of the initial infestation and the strain composition of FAW in South Africa, in collaboration with scientists of the United States Department of Agriculture (USDA). Through genetic analyses, Florida and the Caribbean regions were determined to be the most likely origins of the African infestations. We also found that the African infestation represents a novel interstrain hybrid population and the magnitude and extent of FAW natural migration in Africa is more limited than expected.

The pest status of FAW is influenced by its ability to persist permanently within an area. Since this pest originated from a tropical/subtropical region, it lacks an overwintering phase, such as entering diapause when climatic conditions become unfavourable. It was therefore unknown whether FAW could survive the climatic conditions in South Africa, especially the cold winters. If not, its pest status could change from a persistent- to a seasonal or an occasional pest. In collaboration with a research team from CSIRO and the University of Australia, I modelled the Ecoclimatic Index (EI), which describes the potential suitability for persistence and the Growth Index (GI), which describes the suitability for population growth, using the CLIMEX model. I determined that only a few isolated geographical areas within South Africa and which do not overlap with the main maize production area, are suitable for persistence of this pest. However, I also determined that the ecoclimatic conditions in the main production are suitable for growth and development of pest populations if they invade these regions on an annual basis. This means that the pest can persist in restricted areas, e.g., the subtropical lowveld area, from where it can move into commercial maize production areas during the summer months. The CLIMEX modelling I did form the basis of all prediction models on FAW ecology in Africa and is widely used internationally. It was, for example used to describe the invasions of this pest into Asia and Australia and to model its expected invasion and distribution in Europe.

FAW moths are strong flyers and can fly up to 100 km per night, adding to their quick dispersal to areas outside of where persistent populations occur. To determine their ability to survive under the climatic conditions in South Africa it was also important to know the lower temperature thresholds for egg and larval development and the ability of larvae and moths to withstand short periods of cold spells. I determined the lower temperature threshold for eggs to be 13 °C and for larvae, 12 °C. Larvae do therefore not survive short cold spells of below 5 °C. Moths are more tolerant, but will die during short cold spells of lower than 2 °C. This further explains the restricted areas suitable for overwintering and persistence of this pest in South Africa.

Although the chemical composition of pheromones are very species specific, two species of moths, the FAW and false armyworm, *Leucania loreii* were caught in pheromone traps used for monitoring of this pest. Moths flutter in the buckets used as traps and in this process lose the scales and distinctive patterns on their wings which is used to identify moths in trap catches. Traps are widely used for FAW monitoring in South Africa. Technicians used by the private sector to count trap catches are in most cases not trained to do moth identifications which leads to inaccurate data on moth numbers. To support the wider research community, I developed an easy-to-use key for accurate identification and monitoring of the pest, by using hind wing markings instead of the forewing markings which are generally used. This identification key is since used widely in the agricultural sector.

While conducting field work at a research station in Mbombela, we came across a FAW egg batch from which very small parasitoids (body length ± 0.5 mm) emerged. Due to a lack of hymenopteran taxonomists in South Africa, these wasps were sent to the Centre for Agriculture and Bioscience International (CABI). The parasitoid was identified as *Telonomus remus*, the main egg parasitoid of the pest in the Americas. This finding made headlines in the scientific community throughout the world since other research groups were at that time considering this parasitoid for introduction into Africa for biological control of FAW. This finding then sparked an Africa-wide search for the parasitoid, which was then found in East, Southern and West Africa. It was previously released in South Asia and the Americas and found its way unnoticed into Africa. Following these discoveries, the parasitoid was collected and is currently reared in mass by the International Centre of Insect Physiology and Ecology (icipe) in Kenya for large scale releases in that country.

FAW is known to be resistant to Genetically Modified (GM) Bt crops and to several insecticide groups in the Americas. The susceptibility of FAW larvae to single-gene and pyramid Bt maize, as well as to selected insecticides were investigated to provide base line data and to inform insect resistance management programs in South Africa. South Africa is the only African country where Bt maize has been planted on a commercial scale since 1998/99. Bt maize controls the two stemborer species, the African stemborer, *Busseola fusca* and the Spotted stemborer, *Chilo partellus*. We investigated the efficacy of two Bt maize events *viz*. the single-toxin (Bt1), and the pyramid toxin event (Bt2), for control of FAW in South Africa and found moderate survival of FAW on the single-toxin event (Bt1), indicating the importance of resistance monitoring in future. The effective control provided by the pyramid toxin event (Bt2), is an important finding that can assist governments, academics, and policymakers in enhancing the acceptance of GM maize in other African countries, where FAW persist year-round.

Chemical control is usually considered as the first line of defence against an invasive pest, providing a quick fix to pest pressure. It was, therefore, no surprise that many insecticides received emergency registration for control of FAW in South Africa, soon after its invasion. The susceptibility of larvae from a research station where the pest is continuously controlled with insecticides, was evaluated during 2021 and in 2022. What was interesting, is that the concentration needed to kill 80% of the population (LC_{80}) exceeded the recommended label rate for only three of the registered insecticides. However, in the following year, the LC_{80} of all three of these products were higher, and control failure is now expected with pyrethroid insecticides only.

To summarise, in terms of the IPM pyramid and control tactics – what was the contribution of these findings? FAW cannot survive the low winter temperatures in South Africa's main maize production area. Without an overwintering phase, all life stages still present by wintertime, will be killed. Each season, moths migrate from the overwintering areas to crops planted in summer, "down scaling" the pest from a persistent- to a seasonal or an occasional pest. Larval infestation from moths arriving from the sub-tropical and tropical overwintering areas, are currently effectively controlled by Bt maize and most of the insecticides currently applied in South Africa. Due to insecticides not been applied frequently to control FAW in the main maize producing area of South Africa, biological control agents are not negatively affected, and they further contribute to control of this pest. Area-wide damage is therefore not as severe in South Africa compared to the tropical regions of the continent.

In this second part, I will demonstrate why it is important to move from low levels of IPM to higher levels where more management tools are integrated, with the aim of eventually managing pests at a regional level. Two of the most important vegetable crops in the world is potato, cultivated in more than 150 countries resulting in a yield of more than 359 million tons, and tomato that is cultivated in more than 170 countries with a total yield of more than 187 million tons. Sustainable potato and tomato production is therefore critical for future food security and social sustainability.

Sustainable production of these two crops is, however, threatened by two invasive insects, *viz*. the potato tuber moth (PTM), *Phthorimaea opercullela* and the tomato leafminer, *Phthorimaea absoluta*, commonly known as *Tuta.* The PTM was already present in South Africa before 1900. It mostly causes economic damage to potato tubers but can also occur on other solanaceous crops such as tomato. The tomato leafminer, is a recent introduction, which was reported for the first time in South Africa in 2016. It prefers tomato but can also damage the above ground parts of potato plants. *Tuta* is a devastating pest of tomato, feeding in all above-ground plant parts, *viz*. the leaves, stems and fruit and can cause up to 100% yield loss.

Chemical control is the most widely used and, in many instances, the only control tactic applied for control of PTM and *Tuta*. Application of pesticides is the most common control tactic in low-level IPM systems which focuses only at the field-level. The outcome of such an approach is insecticide resistance evolution. Since the first report of insecticide resistance in 1920, 597 species of insects evolved resistance to 336 insecticides. The presence of insects in a population, which are resistant to the mode of action of a specific insecticide group, can result in survival of these individuals after insecticide exposure. As a result of continued insecticide application, the proportion of these resistant insects increases compared to that of susceptible individuals and the population becomes increasingly difficult to control. To conduct insecticide resistance management (IRM), insecticides with different modes of action, should be rotated, and should therefore be available to farmers. Base line susceptibility testing of *Tuta* was conducted in 2017 and no resistance to the insecticides registered for its control in South Africa, was found. Since then, resistance to several insecticides evolved.

Susceptibility testing of PTM populations from six locations in the potato producing area to four insecticides were also conducted. Low susceptibility of PTM to these insecticides was detected, and as a result, control failure with insecticides from three of the four insecticide groups is currently expected.

In South Africa, tomato and potato crops share the same planting areas, the same invasive pest species complex and to a large extend, the same insecticides for control, not only for these two species, but also for various other insect species in this complex, *viz*. white flies and *Liriomyza* flies. All these pests are heavily controlled with insecticides in South Africa.

I have sampled thousands of PTM and *Tuta* larvae and reared them in our rearing facilities. We have never reared any parasitoids from eggs, larvae or pupae sampled in tomato fields from anywhere in South Africa. However, PhD students of mine in Sudan and Kenya sampled various predators and parasitoids from open-field tomato crops. They then rear and release these parasitoids as part of their IPM programs. The absence of parasitoids in South African tomato crops, can be attributed to the overreliance on insecticides. It is continuously sprayed, also killing the biological control agents. Tomato and potato production in South Africa is currently in troubled waters. In the words of Zalucki *et al*. (2009): Producers need to “move away from a ‘Sample, spray and pray’ (SSP) approach, which is the dominant form of IPM in most crops”.

Development and adoption of IPM strategies that integrates various management tools at local levels (Level 2 IPM), but preferably level 3 IPM is needed to address these pests at landscape level. It is urgently needed to ensure sustainable production of potato and tomato in South Africa. For example, the emphasis needs to change from individual fields (Level 1), not only to farm level (Level 2) but preferably to landscape level (Level 3). The mobility of insects over large distances and the variety of host plants/crops emphasizes the need to think more holistically. This will need organised societal contributions to the IPM decision-making process, e.g., organised involvement of farmers associations. Since third-level IPM features attention to environmental and societal costs and benefits in the making of pest management decisions, the focal ecosystem may be a community (second-level IPM), or it could be a more extensive entity such as an ecological region. Third-level IPM also involves integrated **crop** management. The potato/tomato production threat by PTM and *Tuta*, requires moving from first to third-level IPM. It therefore requires, in the words of Peeter Müürsepp: “a step-up from knowledge to wisdom”.