THE CHALLENGE OF CHEMICAL CONTROL AS PART OF INTEGRATED PEST MANAGEMENT

U. Gisi\textsuperscript{1,2} and A. Leadbeater\textsuperscript{2}

\textsuperscript{1} University of Basel, Institute of Botany, 4056 Basel, Switzerland
\textsuperscript{2} Syngenta Crop Protection AG, Schwarzwaldallee 215, 4058 Basel, Switzerland

SUMMARY

The interactions network for Integrated Pest Management (IPM) consists of five major elements: crop plants (species and cultivars), pest populations, environment (climate, soil, habitat), consumers and economy. Of special importance in this context is the economy-pest population interaction with aspects such as the implementation and cost-benefit relationship of pest control strategies. The challenges for crop protection in targeted IPM addresses aspects such as globalisation, climate change, reinforced plant protection policies, consumer demands for safe food and reduction of risks to human health and environment. It has become increasingly difficult for growers to control crop diseases. Genetic resistance of crop plants towards diseases has been in many cases short-lived and GMOs have only limited success for disease control and acceptability. With more intensive cropping, new diseases, new races and more aggressive pathotypes of diseases may arise. All these changes require chemical control measures to prevent economic disaster, since reliance on genetic resistance, biological control and cultural techniques have been insufficient. Intensive use of chemical control measures has in turn led to its own challenges, including resistance to pesticides. The sustainable use of pesticides to prolong their effectiveness and usefulness to growers is key, and the implementation of resistance management strategies an essential part of this.

Key words: crop protection, diseases, fungicides, pest populations, pest control, resistance.

INTEGRATED PEST MANAGEMENT: INTERACTIONS NETWORK

Integrated Pest Management (IPM) programmes have become the major strategies in modern crop protection since many years. They are mostly based on empirical approaches addressing the exploitation of short term solutions. However, the scientific background of today’s IPM programmes is largely missing. Upcoming challenges for crop protection include aspects such as globalisation, climate change, reinforced plant protection policies, consumer demands for safe food and reduction of risks to human health and environment. Research on IPM should ideally combine disciplines such as biology, biochemistry, molecular biology and genomics, agronomy, agro-ecology, climatology, and socio-economy. The central focus on pest populations (pathogens, insects and mites, weeds) is driven by interactions between them and four major elements: (i) crop (host) plants and cultivars, (ii) environment (climate, soil, habitat), (iii) consumers, and (iv) economy (interactions pentagon, Fig. 1). Major pests under European conditions include species of 

Host plant (cultivar)-pest interactions. Pests cause typical symptoms on host plants such as fungal structures (spores, mycelia, pustules, fruiting bodies), leaf spots, die-back, rot, defoliation, discolouration, damping-off, wilting, insect galls, wounds, insect feeding damage. Plants may react to pests with a range of defence responses such as hypersensitive reaction (HR), hypertrophy, cankers, malformation, scab, induced resistance. Symptomatology can be used to diagnose the causing pests and decide on the most suitable control method. Compatible interactions (disease symptoms) are in most cases based on the classical gene-for-gene relationship between virulence (avirulence) genes of the pathogen races and resistance genes of the plant cultivars. Conventional and molecular plant breeding programmes yield cultivars with varying degrees of resistance (horizontal, vertical resistance) which, after a certain time of exposure, may select for new pathogen races with different virulence structure.
Environment (climate, weather, soil, habitat)-pest interactions. As all biological processes, the development of pest populations is dependent on climatic conditions such as temperature, humidity, leaf wetness, day length. Together with plant genes, climatic factors are the main drivers for the selection of “new” races (pathotypes, genotypes) which may express altered fitness, competitiveness and aggressiveness properties as compared to “older” races which may be gradually replaced in epidemics by the new races. This evolution progresses often within clonal populations, but sexual recombination can fix the new traits and enlarge the genetic diversity. However, new genotypes and new pathogen (and insect) species (“new-comers”) may also be imported by shipment and transport of infected plant material (tubers, plantlets, seeds, other “carriers”), which became more pronounced through globalization. IPM often takes advantage of climate-pest interactions by the development of prognosis systems and models.

Consumer-pest interactions. People working in agriculture (producers) and even more those not involved in agriculture but selling and consuming agricultural products (retailers, consumers) worry a lot about food quality (e.g. vitamins, taste), safety (products free of toxins produced by nature, e.g. mycotoxins) and residues (e.g. caused by pesticides). They want to eat “healthy” food and have to accept (and be aware) that “eco-friendly” products need a minimum of IPM measures (including pesticide treatments in order to be produced in sufficiently high quantity and quality. Official bodies, advisors and politicians bear direct responsibility for food safety (e.g. through well-timed registration of pesticides, adequate regulations of product uses, funding of certain production systems) and can influence both agricultural practices and eating habits of consumers.

Economy-pest interactions. For producers of agricultural goods, it is vital to have access to economically and ecologically safe solutions for pest control, and that these solutions can be implemented (e.g. legal aspects, cost-benefits, easiness and reliability of use). IPM is a combination of agronomic, biological, physical and chemical control strategies and often uses thresholds (disease level, insect density, forecasts) to choose the most effective measure and timing of applications.

CROP LOSSES CAUSED BY PESTS

All available statistics add up to clear consequences for future crop production: the world needs to grow more food from the available land and with the available water in a sustainable manner. The area of agriculturally productive land is likely to stay stable at around
1.5 billion ha; the population is likely to increase by about 80 million per year. Amongst the many threats to crop production on a worldwide basis is the damage to these crops caused by pests (including plant pathogens, insects/mites and weeds). Crop losses due to such pests have been calculated to be substantial, and crop protection techniques and products have been developed to reduce these losses and make crop productivity as high as possible. Estimates of losses in crop production worldwide have been published by Oercke (2006) for major food and cash crops.

Weeds are overall the most important pest group in crop production worldwide, but the incidence and impact of pathogens is also substantial (Table 1). Potential crop losses from pests include losses without physical, biological or chemical crop protection; actual losses comprise crop losses sustained despite the crop protection practices employed. Use of crop protection measures, which include chemical pesticides, obviously has not completely prevented crop losses, but they have significantly contributed to productivity and quality of produce worldwide. Crop yields would be around half their current levels if no crop protection measures were implemented. Even with crop protection, around a third of crop yields are still lost to weeds, diseases and insects. Crop yields will probably have to increase by around 50% on a global level by 2030 to ensure food security.

OPTIONS FOR THE CONTROL OF PLANT PATHOGENS

To protect crops from diseases, there are several crop production and protection options. Organic crop production is one of these options, but yields are in general lower than under conventional management. Cereal yields in organic production are typically 60-70% of those under conventional management although vegetable yields are often just as high as under conventional management (Offermann and Nieberg, 2000). Taking organic cereal yields at 60% of conventional systems, this equates to a requirement of about 67% more area to produce the same crop.

Plant breeding for disease tolerance (resistance), using classical, marker-assisted or GM approaches, is a very important tool in disease management programmes, and the use of plant varieties resistant to particular diseases has proved to be very effective (e.g. for wheat stem rust). It must be realised however, that the development time for successful new varieties is similar to that of a new chemical (8 to 12 years; AEBC, 2005). GM crops are well established in several parts of the world, most notably in North and South America, India and China, but their introduction has been more difficult in several other areas of the world, especially in Europe, because of consumer and environmental concerns.

There are only few examples of tolerance to important plant pathogens and none have been commercially introduced. It is probable that even if disease tolerance becomes successfully implemented in major economic crops such as cereals, potatoes or soybeans, these traits will themselves require protecting through the integrated approach of using chemical fungicides to avoid the tolerance breaking down.

Biological control methods can be effective in certain situations, most notably in the control of several insect pests with natural predators or “biopesticides” such as Bacillus thuringiensis. Biological control approaches do exist against a range of plant pathogens, and under “optimal” conditions can be successful (e.g. in greenhouses). Challenges to wide scale biological control of plant

<table>
<thead>
<tr>
<th>Crop</th>
<th>Attainable production (Mt)</th>
<th>Plant pathogens</th>
<th>Total crop pests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Potential</td>
<td>Actual</td>
<td>Potential</td>
</tr>
<tr>
<td>Wheat</td>
<td>785</td>
<td>16 (12-20)</td>
<td>10 (5-14)</td>
</tr>
<tr>
<td>Rice</td>
<td>933</td>
<td>14 (10-15)</td>
<td>11 (7-16)</td>
</tr>
<tr>
<td>Maize</td>
<td>891</td>
<td>9 ( 8-13)</td>
<td>8 (4-14)</td>
</tr>
<tr>
<td>Potatoes</td>
<td>518</td>
<td>21 (20-23)</td>
<td>14 (7-24)</td>
</tr>
<tr>
<td>Soybeans</td>
<td>245</td>
<td>11 ( 7-16)</td>
<td>9 (3-16)</td>
</tr>
<tr>
<td>Cotton</td>
<td>78  3)</td>
<td>9 ( 7-10)</td>
<td>7 (5-13)</td>
</tr>
</tbody>
</table>

1) Potential and actual losses are without and with crop protection, respectively
2) Figures in parentheses indicate variation among 19 regions
3) Seed cotton
pathogens in major agricultural crops however include issues with environmental robustness, a certain lack of reliability of disease control, limitations in production capacity (availability of product) and special supply chain requirements such as refrigeration.

The control of crop diseases with chemical fungicides has had a successful history for more than a century. They are integral to the production of crops in many countries of the world, resulting in increased yields and farmer income. Economic benefit studies have shown conclusively that without fungicides for control of plant pathogens, production of some crops would be impossible in parts of the world (Gianessi and Reigner, 2005; Cook and Jenkins, 1998; Cuthbertson and Murchie, 2003).

**REQUIREMENTS FOR THE USE OF FUNGICIDES**

The discovery and development processes for new fungicides by crop protection companies are quite complex and difficult because there is a wide combination of properties of the fungicide that need to be met:

- **Biologically efficient:** high selectivity (on target), fast action, optimal residual effect, good plant tolerance, low risk of resistance development.
- **User friendly:** low acute and low chronic toxicity, good formulation characteristics, safe packaging, easy application method, long storage stability.
- **Environmentally sound:** low toxicity for non-target organisms, fast degradation in the environment, low mobility in soil, no relevant residues in food and fodder, low application rate.
- **Economically viable:** good cost-profit ratio for the farmer, applicability in Integrated Crop and Pest Management, innovative product characteristics, competitive and patentable.

The search targets for new fungicides include elements such as a novel mode of action against key diseases and a low risk of resistance occurring. In fact, many of the new fungicides brought to the market recently are site-specific fungicides, acting against the pathogens at a single binding site in the biochemical pathway (e.g. sterol biosynthesis inhibitors like triazoles, respiration inhibitors like “strobilurins” and carboxamides, cellulose biosynthesis inhibitors like carboxylic acid amides). From a product safety point of view, this tends to be a good thing, especially if the target pathway is one that does not exist in mammals. However, from the consideration of resistance risk, and consequently the long-term sustainability of the product in the market, this might not be so favourable, depending on the nature of the mode of action, the pathogen biology and the genetic changes needed to adapt to the fungicide. Thus, major driving forces for the discovery of new fungicides are the appearance and/or increase in importance of new diseases (e.g. soybean rust caused by *Phakopsora pachyrhizi* in South America), the development of fungicide resistance and higher requirements for minimum residues and toxicological side effects (Leadbeater and Gisi, 2010). Modern crop protection products are well defined, extensively tested and proved to cause minimum risks to operators, consumers and the environment when used according to the manufacturers’ recommendations.

**FUNGICIDE RESISTANCE AND ITS MANAGEMENT**

An important part of the assessment of new (and current) fungicides is resistance risk and resistance management. Fungicide resistance happens when populations of target pathogens arise that are no longer sufficiently sensitive to a fungicide to be controlled adequately in the field (Brent and Hollomon, 2007). Resistance generally appears as a response to repeated use of a fungicide or to repeated use of chemically related fungicides expressing a common mechanism of antifungal action. Practical resistance to fungicides has proved to be quite common over the years for a range of fungicide classes, especially for inhibitors with a single-site mode of action (e.g. “strobilurins”, phenylamides, MBCs). Fungicide resistance is a major threat to the sustainability and longevity of a fungicide product in the market.

To further handle resistance management, the Fungicide Resistance Action Committee (FRAC, www.FRAC.info) was formed as a group of industry scientific experts to give use recommendations and to study the science of fungicide resistance. As a part of the work of FRAC, new and established fungicides are classified according to their mode of action and resistance risk (FRAC Code List). This grouping is recognised worldwide as a key basis for designing resistance management strategies. According to industry sales figures for 2006, sales of high to medium risk fungicides represent around 65% of the market value.

Resistance can successfully be managed today by the use of combinations of fungicides with different modes of action (e.g. high risk with low resistance risk fungicides). Key amongst these mixture partners are multi-site fungicides such as mancozeb and chlorothalonil. Combinations of fungicides in mixtures represent several advantages, for they: (i) are in most cases easier to handle and provide more reliable disease control than alternation or use of single products; (ii) contribute to delay resistance evolution; (iii) have a broader spectrum of activity against diseases than single products; (iv) often express synergistic interactions providing better disease control (at lower use rates) than single products. Well documented cases of synergistic interactions are mixtures of phenylamides combined with multi-site fungicides (Garibaldi et al., 1985; Gisi et al., 1985; Gisi, 1996). An effective resistance management for fungi-
cides is only possible if the discovery and development of novel modes of action of pesticides and a safe and effective diversity of products in the markets are maintained.

CONCLUSIONS

The challenges of feeding a growing world population have a high profile in the international press currently. Agricultural intensification will need to increase and also solutions will have to be found to resolve the issue of rapidly increasing commodity (food and feed) prices. Despite great technological advances in agricultural production over the past century, the “theoretical yields” of crops are not yet realised, and much more potential still exists for the optimisation of agricultural production. This optimisation will be achieved through further advances in agricultural production systems, including improvements in natural and genetically modified crop traits, and will continue to be dependent on new innovations in the area of chemical crop protection. Diversity in fungicides with regards to chemistry and mode of action is essential to ensure continued and increased crop production, control new threats arising and to manage fungicide resistance. Without such a diversity being available to the farmer in the future to use in integrated production programmes, the ability of the grower to continue in business and to produce sufficient food would be endangered.

REFERENCES


