Examples of coping strategies with agrometeorological risks and uncertainties for Integrated Pest Management$^{\$}$

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Abstract

The paper outlines some approaches for coping with the agrometeorological risks and uncertainties associated with integrated pest management, based on the Australian experience with wheat and canola. The need to understand the linkage between climate and pest cycles is discussed, as is the need to include factors relating to local farming practice and farm economy in the risk assessment process. Areas for further study, such as the relationship between macro- and microclimate, and the timing of pesticide application, are outlined. A major focus of Australian research is the optimisation of natural controls relating to informed planting strategies, and the minimisation of pesticide application through the prediction of climatic influences, in the interests of sustainable and cost effective control of disease agents. Some epidemiological and risk-management perspectives for building capacity to support this concept are outlined.

Introduction

Some risks in the agricultural sector are unavoidable while others can be managed. Agrometeorological risks in the farming sector include the temporal and spatial variability of rainfall, temperature, evaporation and, in climate change scenarios, atmospheric carbon dioxide levels. While such factors may impact directly on plant growth and development they can also exert an important indirect effect by influencing the life cycles of plant diseases and pests. In addition they may have a profound influence on attempts to control such pests, as is seen when an unexpected rainfall event causes dilution or early hydrolysis of a surface pesticide, or when hail damage opens the way for mould, bacterial or insect attack. Integrated pest management (IPM) must take into account such risks if crop damage is to be minimised. The implications of agrometeorological risk studies in countries such as Australia offer not only local perspectives on IPM but also provide information for improved crop profitability, natural resource usage and agricultural sustainability in other countries, where a critical relationship between crop success, regional food security and human survival may exist.

The capacity of an individual farming enterprise to carry out IPM depends largely on their given financial and economic situation. A business with a high level of debt may only have capacity for low cost management options, such as the planting of disease-resistant varieties and routine pre-crop disease control, while a business that is leveraging and expanding its asset base may be able to cope with higher cost management options, such as the introduction of new crops or rotation of crops to preserve the long-term status of the land (Lloyd Kingham, NSW DPI, personal communication, 2006). Given these differences in ability to cope, perception of risk may vary considerably with level, type and location of enterprise.

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Global climate change will inevitably present a challenge to those engaged in agroclimatic risk modelling in the interests of IPM. Agribusiness units most at risk are likely to be those already stressed as a result of factors such as land degradation, salination and ecological change. Local economic setting must also be taken into account when estimating possible impacts. In countries with a low level of agricultural industialisation, many units may be based on low capital investment resulting in short-term land use policies, while in industrialised countries units may exist at the other extreme, having over-capitalised on items such as dedicated irrigation systems, slow-growing cultivars and on-site processing facilities. Units at both ends of this capitalisation spectrum may, however, be economically marginal in terms of climate change, with increased reliance on state subsidy, off-farm income, or secondary industry support. Such situations do not offer much leeway for farming sustainability through IPM in areas where climate change may be accompanied by increased disease occurrence or pest invasion.

One way to cope with risk has traditionally been through the use of insurance, although agricultural economists are becoming increasingly skeptical about insurance as a regionally-sustainable risk management strategy. Some crop insurance, however, may enable an enhanced ability to apply IPM in special situations. For example, an agrometeorological risk that can be insured against in Australia is hail. Hail can cause wound sites which allow pathogens to breach external defences and gain access to plant tissues, resulting in exacerbation of initially superficial damage. In such cases insurance indirectly allows for a measure of protection against microorganic degradation and pest damage. Only farmers in a stable or growing financial situation may, however, be able to afford this luxury (Lloyd Kingham, NSW DPI, personal communication, 2006).

Australian crops of wheat and canola have a local advantage in that the full potential spectrum of destructive pathogens have not yet been established through assiduous quarantine control and an integrated agricultural management system. In some cases, pathogens found in Australia offer less virulent or aggressive forms than those found elsewhere. Pathogenicity generally relies on a subtle interplay between genetics and external biotic and abiotic factors operating within local ecosystems. Abiotic factors may include farming practice, soil differences, seasonal characteristics or climatic conditions.

The expenditure on integrated control is supported by studies which show that when incursion of an exotic pest occurs or a new variety evolves locally, the result is considerable loss to the industries concerned, with reduction of both quantity and quality of a crop. Furthermore, there is an indirect cost associated with environmental damage resulting from the need to apply additional pesticide (White 1983; Zadoks and Schein 1979). Where epidemic threats are anticipated, contingency planning can enable the use of proactive or less extreme intervention, resulting in reduced pest damage, pesticide use, and ecological impact (Murray and Brennan 2001).

Two climate-sensitive diseases of Australian field crops are stripe rust of wheat and Sclerotinia rot of canola, both having a high risk-ranking in the list of Australian crop diseases (Murray and Brennan 2001). Stripe rust of wheat is estimated to cause on average a loss of about US$ 142 million per annum (Brennan and Murray 1998), while stem rot has been reported as causing a loss of about US$ 37 million, even though the study period was considered to be agrometeorologically favourable (Hind-Lanoiselet 2006).

In terms of the gross economic production value, wheat is the most important crop in Australia, attracting a large share of public funds for research and development. A substantial part of those funds is raised from production levies that are matched by government funds, then disbursed by bodies such as the Grains Research and Development Corporation (Brennan and Murray 1998). Research carried out in terms of this and other funding has already identified the importance of agrometeorological risk assessment (Huda et al. 2004; Wallace and Huda 2005).

The current paper uses some of the Australian research into climate sensitive diseases, in particular wheat and canola, to present some thoughts on the approaches needed for coping with the risks and uncertainties associated with IPM. A perspective on future considerations in this area is also given.

Crop Diseases - Stripe rust in wheat and Sclerotinia rot in canola

Stripe rust in wheat is caused by *Puccinia striiformis* f.sp. *tritici* (Figure 1). Infection and growth is favoured at temperatures between 12 to 15°C, with increasing time required at lower and higher temperatures. At ideal temperatures (12 to 20°C), the cycle from spore infection to new spore production takes about 12 to 14 days, given susceptible plants and sufficient humidity. In the warmer months up to 2 cycles of the disease can occur per month (Murray *et al*. 2005).

Figure 1. Stripe rust on wheat (photo, Paul Lavis)

Sclerotinia rot is caused by *Sclerotinia sclerotiorum* (Lib.) de Bary (Figure 2). Sclerotia (asexual resting propagules) remain viable for many years in the soil. When weather conditions are favorable, the sclerotia germinate to produce apothecia (sexual fruiting bodies) (Le Tourneau 1979; Morrall and Thomson 1991). Apothecia produce thousands of air-borne ascospores that can be carried several kilometres by the wind (Brown and Butler 1936; Schwartz and Steadman 1978). Spores that land on canola petals may lodge in the lower canopy of the crop during senescence at the end of flowering. Germinating spores use the petal as a source of nutrient, produce a fungal mycelium that grows and invades the canola plant. Germination and infection are enhanced by wet weather during the flowering period (McLean 1958; Rimmer and Buchwaldt 1995).

Sclerotinia is a monocyclic disease in Australia in keeping with the flowering periodicity of canola, although in some parts of New South Wales (NSW) where a summer-irrigated crop is grown, two cycles may occur in one year (Hind-Lanoiselet, unpublished data, 2006).

Figure 2. Sclerotinia stem rot on canola (photo, Tamrika Hind-Lanoiselet, NSW DPI)

A potentially sustainable way of controlling crop diseases is the breeding of resistant plants, although to optimise control other management strategies such as fungicide use and good land management practices have to also be used. The latter can include crop rotation and general crop hygiene (Murray and Brown 1987). The incorporation of multiple disease management strategies reduces the chance and hence severity of attack and limits fungicide use which in turn reduces the risk of the pathogen acquiring resistance to the fungicide. Conventional breeding has, however, not always been successful at producing resistant plant varieties, as can be seen until recently with attempts to breed resistance for *S. sclerotiorum* into canola (Buchwalt *et al*. 2003). Even when resistance for a pathogen such as stripe rust has been successfully bred into a variety for several decades this can be overcome by the introduction of a new stripe rust race as occurred in Western Australia in 2002, with spread of rust to the eastern Australian states by 2003 (Murray *et al.* 2005).

When plant resistance cannot be relied on for the level of pathogen management required, other management strategies such as fungicide application are generally used (Sansford *et al.* 1995). Routine seasonal application of fungicides is, however, not profitable as procurement and application costs are high, and disease incidence varies greatly with year, region and locality (Sansford *et al.* 1995; Twengstrom *et al.*1998). A major consideration is the potential removal or dilution of fungicides by early or unexpected rains, and in this regard short-term climatic modeling is highly desirable. The result of climate-pest models only take on meaning when interpreted in terms of broader risk management considerations.

Models can range in complexity from a simple set of anecdotal rules applied by the subsistence farmer to complex, computer-based models as that constructed by researchers in collaboration with state departments. The simplest models are likely to be based on relatively simple causal or "push-pull" relationships (deterministic) whereas complex models are likely to be based on webs of such relationships involving a large number of agrometeorological factors and confounders, with ability to take into consideration the chance of each causal factor potentiating with time, or in terms of some spatial distribution (probabilistic).

All models offer a predictive dimension, giving opportunities for anticipating and hence limiting crop damage. Some use early warning systems, such as changing weather patterns, to allow for early, corrective action (proactive models), whereas others rely on the onset of disease as an action trigger (reactive). The latter models are likely to be of limited effectiveness in controlling damage, hence the need to explore new data and methodologies which can be effectively used in modelling for proactive disease management (Gugel and Morrall 1986; Zadoks 1984). A cornerstone of epidemiological modelling is the collection of relevant local data for disease occurrence and related risk factors, from which risk management models can be developed to allow for a range of actions based on the excedence of limit values within an predetermined data range. (Abawi and Grogan 1975; Last 2001)

Implications for technology transfer

A preliminary step to breaking the epidemic cycle of disease in plant populations is to identify strategic intervention points in the life cycle of the agent. This requires a thorough knowledge of characteristics relating to the crop or plant population itself (host), the pathogen (disease-causing agent) and the place in which the disease occurs (environment). While epidemiological study based on these characteristics can yield great insight as to the establishment and continuation of disease in plant populations, observations may be very specific to time and place and for this reason great circumspection is required when transferring conclusions and hence control strategies from one region to another.

Agrometeorological factors may vary considerably, as evidence when early European farming traditions were first imported to Australia. The intensive cropping system used on European farms and originally imported into Australia and other Asia-Pacific countries has been found in many cases to be unsuitable in terms of available area and soil characteristics. Disease control for intensive horticulture may also be unsuitable for broad acre field crops, for example the practice of liming soil to pH 7.0-7.5 to control clubroot (*Plasmodiophora brassicae*) of Brassica *spp*. (Donald *et al.* 2003).

The large scale migration from Europe to Australia from the early 19th century brought farmers into contact with semi-arid and arid environments for the first time. The response was to perceive drought as a symbolic national enemy, and to attempt technological solutions to solve the "drought problem" with extensive economic support. A better approach might be to accept that certain areas of the land are simply unsuitable for certain types of agriculture (Royal Geographical Society of Queensland 2001).

Relevance of specific technologies also changes with time. Tillage was traditionally used in Australia to reduce the incidence of soil borne diseases including *S. sclerotiorum*, but improved conservation practice suggests that zero tillage is desirable in conserving soil moisture, reducing erosion and limiting costs (Kharbanda and Tewari 1996; Paulitz 2006). Furthermore, a number of studies on conventional and no-till systems have not found significantly different levels of disease incidence (Paulitz 2006).

To support place-sensitive technology transfer throughout the Asia-Pacific region, Australia is developing a range of generic modeling and intervention strategies which will be validated at selected sites in the region. An important component of this ongoing research thrust, however, is the securing of funding from regional agencies to augment support which the Australian government is prepared to commit to such a project.

In exchange for such investment Australia offers a range of research experience relating to an integrated monitoring system which sees regularly updated fact sheets for disease control distributed to farmers throughout State Agriculture Departments (such as the NSW Department of Primary Industries, http://www.dpi.nsw.gov.au), based on modelling studies supported in government and universities by funding bodies such as Grains Research Development Corporation (http://www.grdc.com.au).

Resource allocation for risks

A rational allocation of resources for the control of plant diseases is based on the potential economic losses which they may cause. This applies both at individual level, when a grower decides whether or not control of a particular disease is financially warranted, and at the national level, when funds are apportioned to research, risk communication and disease control. As the disease spectrum and economic environment change with time, estimates of disease losses need to be based on current data, if resource allocation is to be optimised (Brennan and Murray 1998).

In countries where primary industries are in an early stage of development, farmers may have little income and may rely on loans at high interest rates for input investments, and for crop protection. When there is crop failure due to high climatic variability, as may result in droughts, farmers with low financial capacity may loose their entire investment. Ultimate outcomes are not only economic; farmers in India have been reported to perceive this as personal failure and widespread anguish with high rates of suicide have been recorded (Sivakumar 2000). In Australia the suicide rate in male farm owners is about twice the crude national average for males in all sectors, despite the fact that in Australia several organizations provide farmers with financial assistance when extreme weather conditions have resulted in severe challenges, such as drought and floods.

Such assistance includes income support from Centerlink, interest subsidies from the Rural Assistance Authority, advice and funding for developing a business plan and succession planning from the Farm Help Program, and funding for establishment of a farm Environmental Management System (EMS) from various state agencies. In order to further the mental health and wellbeing of farmers in NSW, Australia, a blueprint has been developed to improve access to mental health services, including counselling, crisis lines and the teaching of coping skills (NSW Farmers Association 2005).

While applied IPM is likely to remain a technological area, resource allocation within a risk management framework needs to involve interdisciplinary collaboration if the very real threats to the mental and physical health of those engaged in farming as primary industry are to be addressed.

Supportive Decision-Making Tools

A decision support tool called RustMan was developed for stripe rust of wheat in the 1990s. RustMan estimates the likely impact that stripe rust will have on wheat yield and the benefits from spraying to control the disease. RustMan uses results derived from field experiments at Wagga Wagga and Yanco from 1984-1987, with the addition of current information on the reaction of wheat varieties to the races of stripe rust in Southern and Central NSW. Estimates require the input of average weather conditions occurring over one agricultural season (Gordon Murray, personal communication, 2006).

Sufficient macroclimatic data has now been collected for the development of a similar tool for Sclerotinia rot on canola although the higher impact of post-treatment climatic variation demands a longer-term forecast record.

Effectiveness of decision-making tools

The effectiveness of decision making tools depends on their ability to predict and to facilitate risk management or mitigation, with subsequent assessment of outcome (Meinke and Stone 2005). Some points relating to this effectiveness are:

- Farmers are only able to respond and adapt to climatic conditions, they cannot expect the model to assist them to manage or mitigate the climatic event itself,
- Adaptation or 'responsive adjustment' as risk ameliorating strategy, must be targeted and may be complex,
- The proactive dimension in risk amelioration is important if damage is to be minimised,
- Outcomes need to be seen in practical terms if individual and societal benefits through improved risk management practices and better targeted policies are to be optimised.

Importance of Experimental Observation

Hind-Lanoiselet *et al.* (2004, 2006) demonstrated the importance of rainfall distribution in relation to disease development, having observed that in years with low rainfall and high temperatures Sclerotinia rot is not a limiting factor for crop development. In such years the application of fungicide had impact on early disease but no ultimate impact on yield (Figure 3). Such findings suggest that in similar years finances can be directed away from this problem to be used more productively in other areas, with the proviso that this practice is not rigidified so as to prevent successful financial re-targeting in subsequent growing seasons.

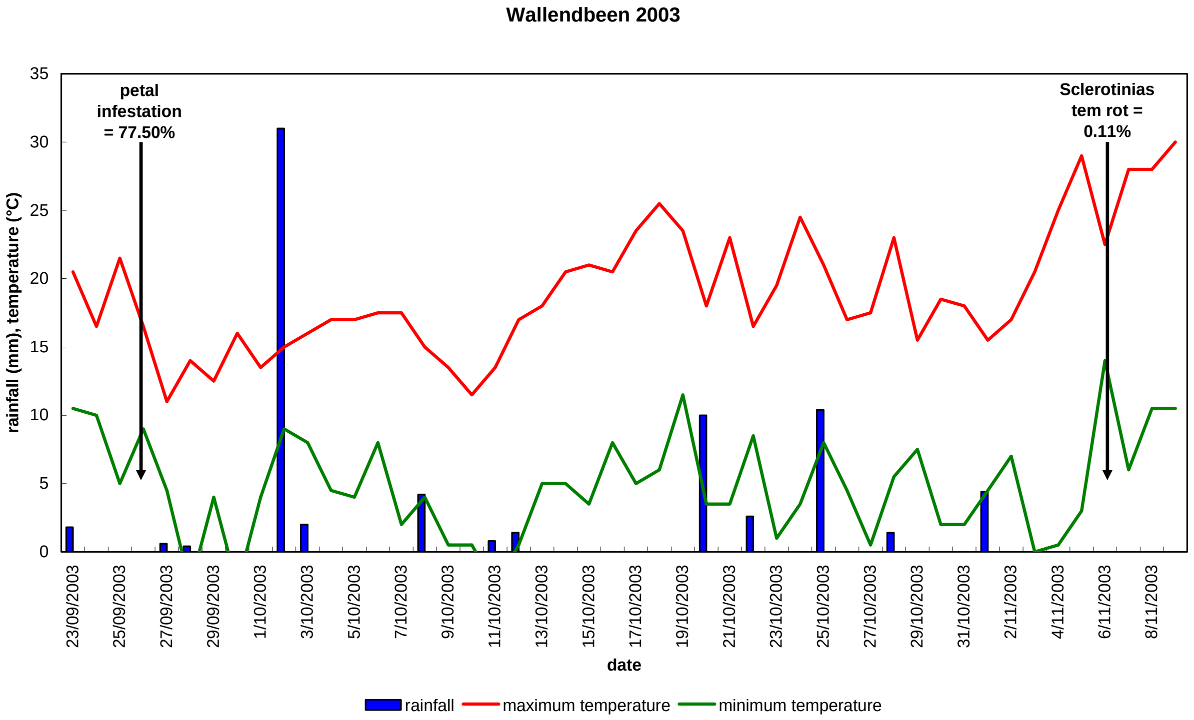

Figure 3. Incidence of *S. sclerotiorum* at 20% flowering on canola petals and disease incidence before harvesting after a dry finish at a trial in Wallendbeen in 2003

Desirable level of complexity

A management tool should only include easily obtained information and results should be relatively simple for the user to interpret. Complex tools based on advanced modeling need to clearly communicate the data for general stakeholder use. The economic component needs to be included as part of a risk-benefit framework which only encourages the use of fungicide when it is likely to enhance profitability.

Economic balance in control

Due to the sporadic nature of stem rot it is uneconomical to apply fungicides routinely, although to be effective they need to be applied before the plant becomes infected. In Australia, growers are advised to consider the current price of both chemical and canola to determine the viability of Sclerotinia control before applying a fungicide (Hind-Lanoiselet and Lewington 2004, and Hind-Lanoiselet et al. 2005). The following table is used to help determine the level of Sclerotinia infection that would justify a fungicide application (Table 1).

Table 1. Returns from the use of Rovral fungicide for Sclerotinia control.

Rovral	yield loss (t/ha)	On Farm Price Canola ($/tonne)													
% yield loss	at 2 t/ha potential	$270/t	$280/t	$290/t	$300/t	$310/t	$320/t	$330/t	$340/t	$350/t	$360/t	$370/t	$380/t	$390/t	$400/t
5	0.1	-$55	-$54	-$53	-$52	-$51	-$50	-$49	-$48	-$47	-$46	-$45	-$44	-$43	-$42
10	0.2	-$28	-$26	-$24	-$22	-$20	-$18	-$16	-$14	-$12	-$10	-$8	-$6	-$4	-$2
15	**0.3**	-$1	$2	$5	$8	$11	$14	$17	$20	$23	$26	$29	$32	$35	$38
20	0.4	$26	$30	$34	$38	$42	$46	$50	$54	$58	$62	$66	$70	$74	$78
25	0.5	$53	$58	$63	$68	$73	$78	$83	$88	$93	$98	$103	$108	$113	$118
30	0.6	$80	$86	$92	$98	$104	$110	$116	$122	$128	$134	$140	$146	$152	$158

Note: Net returns from Sclerotinia control for each fungicide are based on a 2 t/ha potential yield and chemical and application costs of $82/ha for Rovral, and a rule of thumb that yield loss = 0.5 (disease incidence).

The data in the tables show that:

- A yield loss of 10% to 15% would be required to break even and justify using the fungicide
- A 10% yield loss would represent 20% stem rot in the crop
- A 15% yield loss would represent 30% stem rot in the crop, a high disease level

The RustMan support tool can be profitably used before the rust is seen so that farmers can make early decisions (Gordon Murray, personal communication, 2006). In reality the software is typically not used until the disease has taken hold at which point effective management may not be possible. This delay is exacerbated by the limited stock and thus appreciable waiting time for fungicide. To improve this situation RustMan needs to be used early on in the assessment and to facilitate this relevant output information needs to be effectively communicated through one of the public access web sites or by electronic mail.

Towards the Future

Agriculture in Australia has shown considerable capacity to meet challenges through farm management practice, appropriate crops and cultivars selection, technologies to increase water use efficiency, and pest control. Global warming, however, poses a much greater and broader challenge and current financial resources may be inadequate. Dissention about the potential outcomes of global warming are problematic. While the agricultural impacts of drought and floods of specific duration and intensity can be estimated, some parts of Australia may, in fact, experience improved conditions as a result of longer growing seasons, fewer frosts, higher rainfall (northern Australia) and increased atmospheric carbon dioxide (Australian Greenhouse Office 2006).

A future trend in climate prediction is likely to be in the area of macroclimate forecasting, with medium range weather forecasts (3-10 days) being increasingly used in operational farm management decisions. There is increasing capacity to integrate seasonal climate forecasts, medium range weather forecasts and historical climate information, to enhance the availability and accuracy of data to be included in proactive decision making. In crop protection there have been simultaneous advances in describing the relationships between plant diseases and crop microclimate, such as those relating to field temperature and leaf wetness.

Further research is, however, urgently required to explore relationships between macroclimate (climate of a region) and microclimate (climate immediately within and surrounding a plant canopy), and this will require improved collection of microclimate and local disease incidence data. Recent work in Australia suggests the value of such information in risk and opportunity-management decision making (Wallace and Huda 2005; Huda et al. 2004).

Epidemiology and risk assessment will undoubtedly play an increasing role in anticipating the complex interaction between climate and disease. In its broadest sense, epidemiology is “the study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to the control of health problems” (Last 2001). While originally developed as the science of disease control in human populations (*demos* being Greek for “the people”), epidemiological approaches are today fundamental to disease control in the agricultural sector.

A basic concept in traditional epidemiology is the Host-Agent-Environment (HAE) disease model which in its simplest form is represented by a triangle as shown in Figure 4.

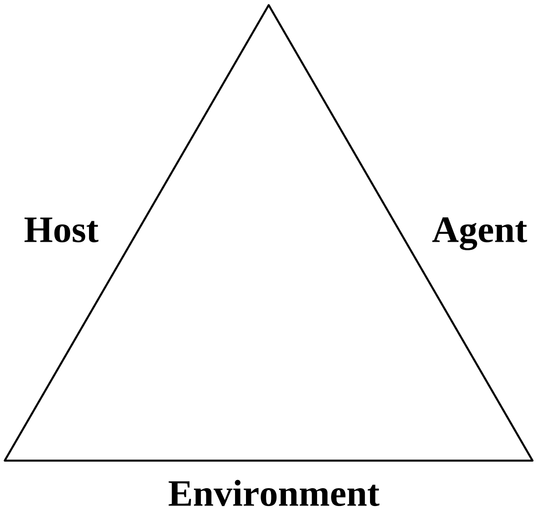

Figure 4. The Host-Agent-Environment disease triangle

The model proposes that for a disease to exist, all three co-factors must be present. In the case of the fungal diseases discussed in this paper, these factors include:

- Host (crop) factors: plant species and variety, time of planting, crop rotation, general crop hygiene, coexistence of other pathologies.

- Agent factors: mould types present, load and viability of infectious forms, state of spore activation.

- Environment factors: climate (including macroclimate, microclimate and seasonal change, weather immediately following fungicide or pesticide application, hail damage and relative humidity), insect damage, sunlight duration, presence of atmospheric gases including carbon dioxide, and acid-forming gases, soil factors (macronutrients, micronutrients, salinity and iron sulfides), irrigation factors (volumetric and qualitative, application technique, leaf runoff, soil pooling, nutrient residue on leaf), availability, type and application of fungicide, and agricultural practice.

Some plant epidemiologists have suggested the addition of a fourth factor, time, to the model (forming a "disease pyramid") to take into account the temporal process of disease development (Stevens 1960; Van der Plank 1975). The authors, however, view time not as a single, independent variable but as integral to each of the three base variables, because of the need to consider distinct and complex time-series when developing probabilistic risk-factor distributions for a range of polycyclic processes in risk modeling (Zadoks and Schein 1979).

Epidemiology is not only a study system but one committed to the management of problems. The term "coping strategies" in this chapter title relate to an Australian commitment to view crop disease control not only as a theoretical field but as a field of endeavour aimed at securing sustainable regional economic, social, ecological and health outcomes. The centrality of integrated plant production and pest control in achieving food security with limited environmental impacts has been clearly identified by major international organisations (Food and Agriculture Organisation 2005; Unnevehr and Hirschhorn 2000).

Good risk assessment alone is powerless to bring about change unless operating within a framework for sound and intersectoral risk management. This is particularly true where a project must bring together a number of countries in collaborative effort to ensure effective regional risk management.

At a recent workshop in Hyderabad it was proposed that an integrative model proposed by Derry, et al. (2006) be used to guide an Asia Pacific Network research project into Asia-Pacific regional climate and disease risk management (Figure 5).

Figure 5. Risk management model (Derry et al. 2006)

The model facilitates early identification of climatic hazard or change likely to impact on agricultural security in terms of epidemiological realities (stage 1). Proactive risk assessment (stage 2) incorporates the consideration of existing climate/crop-disease models and the possible development of downscaled models on the basis of local epidemiological records and observed agricultural practice. In practical terms this stage is already under development in Australia, with models relating to disease frequency and impact being investigated. Risk assessment information communicated to government and farming organisations enables the fine-tuning of policy (stage 3), to encourage proactive and cost-effective epidemiological and economic interventions (stage 4). Examples are the application of fungicide during a period of expected high humidity with suitable temperature range for mycotic growth, or the avoidance of fungicidal leaf treatments prior to a period of predicted rainfall, when wash-off can occur. Developing systems for monitoring changes in crop health status following intervention (stage 5) provides feedback for the further fine-tuning of policy and interventions.

It should be noted that the overall process is a cyclic one, with a potential starting point at any one of the five loci. Thus there is no “correct” place to start, and all meaningful work can be “banked” at a relevant point within the conceptual framework. Effective intersectoral and multi-staged communication of risk lies at the hub of the model, which will involve the development of communication pathways and a common dialogue between scientists, managers and communities. The current WMO workshop is seen to provide opportunities for such collaboration on a regional level.

In terms of the model some envisaged policy-related strategies are:

- The assistance of agricultural development by anticipating short-term climatic variations, in order to improve economic yield, and hence security relating to food supply with positive outcomes on socioeconomic conditions and population health

- The provision of a suitable framework for policy modification in the anticipation of important, short-term climatic change, enabling the incorporation of proactive intervention in agricultural practice

- The exploration of new approaches to managing crop diseases and the application of pesticides and herbicides to ensure economic use, and prevent overuse, as an important component in human health and aquatic ecosystem protection

- The encouragement of multilateral agricultural risk communication and dialogue between all stakeholders in the agrometeorological process

Conclusions

In addressing risks and uncertainties for integrated pest management, Australian researchers have concluded that more needs to be known about the complex relationships between climate and pest cycles relevant to local place. In this regard, collaborative activity is required between scientists, risk managers, government and local farmers to determine best practice approaches for addressing pest management, with the aim of achieving economically-sound and ecologically-sustainable outcomes.

Research results relating to Sclerotinia rot in Australian canola and stripe rust in wheat offer useful practical findings for the development of pest management systems elsewhere. A major focus of Australian research is the optimisation of natural controls relating to informed planting strategies, and the minimisation of pesticide application through the prediction of climatic influences, which can in turn lead to optimal effectiveness in the control of disease agents. Technology transfer is, however, a highly specialized area which has resulted in errors in the past, and which must therefore be treated with circumspection.

The relationship between macro- and microclimate, and the effects on the cycles of disease agents, needs special attention if quantity of applied pesticide is to be minimised, while optimising disease control outcomes.

While improvements in meteorological and crop-pest monitoring and modeling will remain important, a sound understanding of local economic, ecological and social realities is essential if the effectiveness and accountability of interventions is to be assured.

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