Potato production in the “developing countries” is increasing significantly in production, acreage, and yields (http://www.cipotato.org/market/potatofacts/growprod.htm), making potato an important food staple for many people. Concomitantly, late blight caused by *Phytophthora infestans*, is a serious issue in these countries and to minimize crop losses due to late blight, effective management practices must be implemented. However, as variation among the great number of developing countries makes generalization practically impossible, for the most part, disease management strategies need to be adapted or developed on a country-by-country basis. The purpose of this paper is to summarize what has been done and what still lies ahead for potato late blight IPM in the developing countries.

**IPM and Ecological, Genetic, Economical Aspects**

Ecological, genetic, and economic aspects should be considered when implementing potato late blight IPM. Several developing countries are located in temperate climate zones, whereas many others are within subtropical or tropical areas. Environmental conditions influence the development of late blight epidemics, and management strategies should accommodate these different ecological conditions. The genetic aspects of both host and pathogen populations with their particular effects on disease development are now better understood and can be more carefully considered in management strategies. Also of importance are the economic issues involved with late blight management. In the developing countries, potato production ranges from a subsistence crop to large commercial fields planted with high-yielding cultivars intended for the chip industry and the likelihood of adoption and/or the appropriateness of management practices can depend on economic considerations.

**Ecological aspects.** Potatoes are grown in developing countries in an amplitude of ecological conditions. For developing countries with a temperate climate, strategies already established for the management of late blight in industrialized countries could succeed. To the contrary, simple importation of knowledge from temperate climates to tropical or subtropical conditions, where potato can be grown at low and high altitudes, could be disastrous as varying environmental conditions can differentially affect the disease development and management.

**Genetic aspects.** Populations of *P. infestans* in the developing countries range from panmitic with sexual reproduction, such as in Central Mexico, to strictly clonal as in many countries of Africa and South America. Two factors related to genetic aspects are important from the management perspective — the role of oospores as extra inoculum and the distinct ecological requirements of different pathogen lineages.

**Economic aspects.** In developing countries, the economic issue is more crucial to effective late blight management than in industrialized economies. Many resource-poor farmers use far less fungicide than is needed for reasonable late blight control. Despite this fact, chemical control is the principal measure used to reduce yield loss caused by the disease. Strategies that would help the decision making process could result in more efficient fungicide usage and better disease control.

To facilitate this discussion, plant disease control measures based on fundamental epidemiological principles will be presented and their contributions to late blight management in developing countries will be discussed. An epidemiological model of disease development over time will be considered. The model states that the final disease intensity is a function of the amount of initial disease plus an increment of disease development over time; algebraically, \( Y = Y_0 + r \cdot t \), where \( Y \) is the final disease intensity, \( Y_0 \) is the initial disease, \( r \) is the disease progress rate and \( t \) is time. For each of these components \( Y_0, r, \) and \( t \), the ecological, genetic and economical aspects will be considered and examples, where available, will be given.

**Epidemiological Basis of Late Blight Management**

**Reducing \( Y_0 \).** The initial amount of disease (\( Y_0 \)) is related to the amount of initial inoculum. The importance of initial inoculum to late blight epidemics varies according to ecological, genetic and economic issues. When

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considering the role of initial inoculum for disease development two categories should be analyzed: internal and external initial inoculum.

For many countries in the temperate climate zone, internal initial inoculum contributes to epidemics. Infected tubers, cull piles next to fields, or volunteer plants are potential sources from where inoculum could spread in potato fields (Zwankhuizen et al., 1998). Where a recombinant population is present, oospores can serve as primary inoculum (Strömberg et al., 1999) and also as an overwintering structure (Turkensteen et al., 2000). The absence of these significant sources of internal initial inoculum prevents disease initiation. Thus, management strategies based on sanitation (removal of cull piles, elimination of volunteer plants, etc.), and the use of healthy seed tubers could improve disease control in developing countries in temperate climates. In subtropical and tropical climates, internal initial inoculum does not seem to be as important and preliminary results suggest that survival of *P. infestans* in crop debris in subtropical climate is limited (Maziero, Maffia and Mizubuti, unpublished results). Internal initial inoculum may be important where sexual reproduction occurs and oospores are formed, but, to date, there are no reports of epidemics being started by oospores in developing countries in subtropical and tropical climates.

There is strong evidence that, contrary to what happens in the temperate zones, in most subtropical / tropical areas the external initial inoculum determines the onset of the late blight epidemics. Potato plants get infected in early stages and the spatial patterns of early infections in diseased fields are uniform (Garret et al., 2001). Also, in many of these subtropical or tropical areas, potato and/or tomato are grown in a continuous production system and overlapping crops are common. In these areas, presumably, the contribution of sanitation is not likely to be as important for disease management as the inoculum coming from other potato or tomato plants located in the surrounding areas. However, reducing the amount of initial inoculum in the field can contribute to reducing the amount fungicide used. Data from experiments carried out in Africa suggest that with sanitation (removal of diseased potato leaves) it is possible to reduce fungicide dosage and still have some level of disease control (Fontem, 1995). It is not known if this approach is economically viable.

**Reducing r.** For a typical polycyclic disease, such as late blight, the disease progress rate (r) determines the increase in severity. Reducing r is the main goal for disease management. The genetic aspects related to the rate of disease development are host resistance and the intrinsic ecological requirements of some genotypes of the pathogen. The contribution of host resistance in lowering r is well known and should be a common approach for effective late blight management in the developing countries. Regardless of environmental conditions, host resistance plays a major role in reducing crop damage. There are several potato cultivars resistant to late blight that are now part of production system in different parts of the world (Table 1).

Table 1. Examples of potato cultivars resistant to late blight grown in developing countries

<table>
<thead>
<tr>
<th>Region</th>
<th>Cultivars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andes</td>
<td>ICA Purace, Santa Catalina, Amarilis, Perricholi</td>
</tr>
<tr>
<td>Central America and México</td>
<td>Norteña</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>Cruza 148, Murca (Uganda II), Asante (Victoria)</td>
</tr>
<tr>
<td>South and West Asia</td>
<td>Kufri Badshah</td>
</tr>
</tbody>
</table>

Resistant cultivars can effectively suppress late blight development under favorable environmental conditions and high inoculum pressure. Comparative analyses of late blight intensity on susceptible cultivar Alpha and resistant cultivar Norteña illustrates how effective a resistant cultivar can be. At 40 days after emergence, disease severity was 100% and 4% in Alpha and Norteña, respectively (Grünwald et al., 2000). However, despite cultivar availability, usage is limited. The potato cultivars with considerable resistance to late blight are often not as productive and/or as good quality as the susceptible ones.

The genetics of the pathogen population can also affect late blight development. Considerable emphasis has been devoted to the distribution of the A1 and A2 mating types in the population of *P. infestans* worldwide. Perhaps more important for management purposes is the knowledge of how often and how much sexual reproduction contributes to late blight epidemics so that more efficient control strategies could be designed. For instance, where sexual reproduction occurs and oospores act as primary inoculum, growers should protect plants right after emergence. Systemic fungicide should be used much more carefully, because selection for fungicide resistance could occur more quickly.

The presence of isolates of both mating types does not necessarily imply a sexually reproducing population. In some countries there is only one clonal lineage (one mating type) and high host-specificity (Oyarzun et al.,
while in others countries of both mating types are present but the population also has a clonal structure and is highly host-specific (McLeod et al., 2001) (Table 2). High host specificity is a “barrier” to sexual reproduction when A1 and A2 genotypes are restricted to different hosts.

Table 2. Distribution of A1 and A2 mating types and Phytophthora infestans population structure in some developing countries

<table>
<thead>
<tr>
<th>Region</th>
<th>Country</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ethiopia, Kenya, Uganda</td>
<td>A1, clonal, host specific</td>
</tr>
<tr>
<td></td>
<td>Morocco</td>
<td>A1 + A2</td>
</tr>
<tr>
<td></td>
<td>South Africa</td>
<td>A1, clonal</td>
</tr>
<tr>
<td>Asia</td>
<td>Bangladesh, India, Korea, Nepal, Pakistan</td>
<td>A1 + A2</td>
</tr>
<tr>
<td></td>
<td>China</td>
<td>A1 + A2</td>
</tr>
<tr>
<td></td>
<td>Russia</td>
<td>clonal (Siberia) recombinant (near Moscow)</td>
</tr>
<tr>
<td>Latin America</td>
<td>Argentina, Brazil, Paraguay, Uruguay</td>
<td>A1+A2, clonal, host specific</td>
</tr>
<tr>
<td></td>
<td>Bolivia</td>
<td>A2, clonal, host specific</td>
</tr>
<tr>
<td></td>
<td>Chile, Ecuador, Peru</td>
<td>A1 clonal, host specific</td>
</tr>
<tr>
<td></td>
<td>Colombia, Costa Rica, Honduras, Panama, Venezuela</td>
<td>A1 clonal</td>
</tr>
</tbody>
</table>

Ecological conditions affect distinct stages of the pathogen life cycle of *P. infestans*, influencing late blight development. There is a considerable amount of data on the ecological requirements of *P. infestans* generated in temperate climates but information about environmental effects on late blight development in subtropical and tropical areas is limited. Ecological adaptation occurs and it would be reasonable to assume that the different stages of the pathogen life cycle could have developed different ecological requirements in warmer regions. At present, the strongest evidence points to the origins of *P. infestans* in the tropical highlands, making more plausible its adaptation to lowland areas or hot summer seasons. This is an interesting aspect of population biology that needs to be investigated. In the Andes some growers empirically achieve disease escape by planting more susceptible cultivars at higher altitudes, where the environmental conditions are less favorable for disease development.

When quantifying the effects of temperature on basic epidemiological components, major differences were detected between isolates of a lineage that affects potatoes (BR-1) and those of a lineage that are tomato adapted (US-1). Interestingly, there were differences in weather requirements between isolates of the same lineage depending on their origin; US-1 isolates from Brazil seem to be more tolerant to higher temperatures than those of the US-1 isolates from Northeast United States (Mizubuti and Fry, 1998). These differences can affect the applicability of forecast systems and of simulators. Validation in different areas with distinct ecological conditions and preferably over several growing seasons is necessary before adoption as management tools.

Besides temperature effects, topographical features can affect survival of sporangia exposed to solar radiation. At higher altitudes UV irradiance is higher and its effect on viability of pathogen propagules is more deleterious. The half-life of *P. infestans* sporangia at lower altitudes was estimated around 30 minutes (Mizubuti et al., 2000) while at highland tropics (2600 meters above sea level) the half-life was about 15 minutes (N. J. Grünwald, personal communication). Higher sporangia mortality combined with lower average temperatures in highland tropics would result in lower disease progress rates, but the lower rate of potato development extends the time for the host-pathogen interaction, which in turn leads to longer epidemics.
Epidemic duration should be considered when planning fungicide usage, because some products seem to have higher efficiency for slower epidemics (Mayton et al., 2001).

Economic aspects that affect disease development rate are related to management strategies: host resistance deployment and fungicide usage. Host resistance deployment is considered here as an economic aspect because of the lower marketability usually associated with resistant cultivars. Technically speaking, planting resistant cultivars can effectively reduce late blight damage. Economically speaking, for small to medium scale farmers and large-scale business (fresh market or chip industry) this practice is questionable for reasons related to processing and/or commercialization (consumer preferences, quality control, adapted machinery, etc.). An interesting alternative is the use of mixtures of resistant and susceptible cultivars. Apparently, for areas not very favorable to late blight development, disease intensity is reduced when cultivar mixtures are used (Garrett et al., 2001).

Fungicide use is the most effective measure for late blight control. Despite the fact that its use increases production costs, its efficacy in controlling the disease is appealing even to resource-poor farmers and fungicide use is a common practice in many developing countries. Health, environmental, and economic issues are stimulating better late blight management. Tools for better fungicide use vary from simple to complex and their adoption depends mostly on economics and the business scale; i.e. small farmers can't afford sophisticated decision support systems.

Simple strategies to optimize fungicide usage have been successfully conducted. Spray schedules have been modified according to the favorability of the environmental conditions and/or to the host resistance level. The water-bottle management scheme developed in the Andes, where the precipitation is measured and related to spraying times, is an example on combining low cost apparatus with grower's education for rational fungicide usage (G. Forbes and P. Oyarzun, unpublished data). A step further would be the use of more elaborate decision support systems. Validation of existing forecast systems must be conducted in the developing countries before they can be used as management tool. The contribution of these systems is highly variable and should be considered on a case-by-case basis. Modification of existing systems or development of new ones for specific environments are two options to improve the performance of decision support systems. Examples of these two approaches are the adjustment of severity values of Blitecast to be used in Morocco (Sedegui et al., 1999) and the development of a potato late blight forecast system JHULSACAST for Western Uttar Pradesh, India (Singh et al., 2000).

Reducing t. Another strategy capable of reducing the final disease intensity is the manipulation of the time the crop is exposed to the pathogen. Although, theoretically, many actions could be taken to reduce the time of host-pathogen interaction and thus, the duration of the epidemic, in practice manipulation of time is not easily implemented. There are few examples where this principle has been successfully applied to reduce late blight intensity. In the northwestern plains of India, late blight epidemics usually start after the second week of November. A series of field experiments were carried out to determine the effect of planting date — by changing planting date, plants can escape disease (the host is susceptible and the pathogen is present, but environmental conditions are not optimal). On average, planting in the last 10 days of September resulted in less severe late blight epidemics (Arora et al., 1999, Sekhon and Sokhi, 1999).

A genetic component that is linked with time is plant maturation. The positive relationship between maturation time and late blight resistance is well known (Umaerus and Umaerus, 1994). Ideally, an early-maturing potato cultivar with durable resistance to late blight would be a valuable asset to manage the disease in the developing countries. This is an area where plant breeders, plant pathologists and extension agents need to join efforts in providing growers a good cultivar with a management scheme that will contribute to reduce crop losses due to late blight.

Conclusions

Three points are of primary concern when evaluating the current scenario on late blight management in the developing countries. First, fungicides are widely used and are a tool that almost all growers rely upon to control the disease. Second, cultivar resistance should be more commonly utilized. Third, farmer education is crucial for better management of late blight.

On a short-term basis, optimization of fungicide should be considered as the most likely successful management practice. Growers in the developing countries are used to managing the disease almost solely based on fungicide applications. In many situations irrational use of chemicals results in serious economic, social and environmental problems. Epidemiological research should be fostered in the developing countries to optimize fungicide usage without compromising profit.
The use of resistant cultivars can benefit all types of growers – from subsistence farmers to large businesses normally associated with the chip industry. Nevertheless, one would expect that what all growers, regardless of type, would like to have is a resistant cultivar with excellent commercial features. Certainly, this constitutes a challenging issue that breeders have to face if expanded usage of resistance is to be achieved.

Finally, efficient late blight management in a near future can only be achieved with farmers’ education as part of a program. The lack of knowledge and reduced education levels impose major constraints on the understanding of plant disease management. Technology transfer and implementation are not easily accomplished. Thus, educational programs aiming at better late blight management in the developing countries should be a priority for funding agencies and research institutions.

**Literature cited**


