Chapter 10:

Conclusions

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Blight-MOP's aim was 'Development of a systems approach for the Management of potato late blight in EU Organic Potato production in the absence of copper-based fungicides' to maintain yields and quality at levels currently obtained where copper fungicides are used.

1) Assessment of socio-economic impact of late blight and 'state of the art' blight management practices in EU organic potato production systems.

The survey of 118 farms in Denmark, France, Germany, Netherlands, Norway, Switzerland, and United Kingdom and relating to crops grown in 2000 concluded:

- Further expansion in organic potato production in the EU is likely because of increasing consumer demand linked to concerns about food safety, but profitability may decrease.
- Crop profitability and price premiums are variable from country to country and season to season. Expansion and increased supplies could put pressure on premiums and prices which is seen as a threat and/or challenge to the future of organic potato production.
- Most growers are primarily motivated by environmental, food quality and philosophical considerations rather than economic performance of the enterprises (at least as long as profitability is maintained).
- Late blight is a major problem for the majority of growers, but the seriousness and impact varies from year to year and region to region. Copper-based fungicides are relied upon in many cases for late blight control to maintain yields (which are ~ 50 to 80% of conventional yields) but inputs vary. National legislation prohibits their use in Scandinavian countries (Norway and Denmark) and the Netherlands (with exception in 1998) and State and organic certifying organizations set a limit to quantities used in Switzerland (4kg/ha) and Germany. Elsewhere, the EU regulation 2092/91 current limit of 6kg copper/ha/ year applies but in some countries e.g. Germany and Switzerland, about half this quantity is used on average. Between a third and two thirds of growers have used one or more of about 40 alternatives to copper-based fungicides, but generally, these gave little or no control of late blight.
- If an EU-wide ban on the use of copper-based fungicides is introduced, about two-thirds of growers expect no change in organic potato production, one third a decrease (mostly those allowed to apply up to the EU defined limit) and less than 3% expect an increase. A small proportion of growers are optimistic that a ban would give an opportunity to expand their markets.

- Variation in growers' efficiency in using inputs and agronomic techniques accounts for some of the differences in performance between farms. Some growers could stabilize and improve yields simply by adopting existing production strategies or improving efficiency where circumstances allow. Important strategies are:
  - Planting early and chitting/pre-sprouting seed to start tuber bulking early in the season leading to an acceptable yield before blight attacks
  - Fertility management to supply sufficient nutrients to achieve target yields (nutrient supply is generally sub-optimal in organic systems)
  - Growing resistant/robust varieties
  - Protecting crops efficiently from disease.

- Copper has been a key component of organic potato production systems. A ban on copper in the absence of effective alternatives could decrease production and market supply and destabilize organic potato production
- Region-specific optimization and integration of technologies should improve yields

and yield stability in organic potato production substantially

- Key factors needing further development, exploitation and evaluation under various regional conditions are
  - Crop resistance management strategies
  - Agronomic strategies
  - Soil fertility management
  - Novel crop protection strategies.
- No fully successful production strategies are currently available but increasing efficacy of the key factors will secure production and supply and decrease dependency on copper-based fungicides.
- Differences in performance of potatoes in organic cropping systems under similar environmental conditions are large. Some farms could improve productivity simply by implementing current 'state of the art' technology.
- Dissemination of know-how and novel technologies will increase the success of organic potato production considerably and exploit the benefits of the research programme.

2) Assessment of varietal performance in organic production systems in different EU regions and interactions with local blight populations.

VARIETIES	**Is the strategy promising?**	**Notes on the applicability**
	Very promising (for some varieties)	Immediately applicable (but new varieties become available continuously)

- **Resistant varieties are the most effective strategy for managing late blight in the absence of copper based fungicides and production levels could be maintained. Adoption would be highly dependent on marketability of the resistant varieties.**
- Continued breeding for resistance to both foliage and tuber blight and evaluation under organic systems of production is required.
- Reductions of ~ 16.5 to 50% of current levels copper fungicide applications could be achieved by growing them instead of susceptible varieties to the maximum extent that the market could absorb.
- Widespread adoption would contribute to drastic reductions of foliar and/or tuber blight infections: withdrawal of copper would stimulate rapid uptake of more resistant varieties
- Introduction can be a lengthy process. Breeding, seed multiplication, production, storage and processing for different markets must be considered for different countries and regions: initiatives to market them as 'ecologically-friendly' varieties may counteract market resistance.
- Shifts in regional/national late blight populations towards increased pathogenicity with more resistant cultivars in production seems unlikely although virulence to new R-genes bred into new cultivars cannot be ruled out completely.

3) Development of within field diversification strategies to prevent/delay blight epidemics

ALTERNATING ROWS	**Is the strategy promising?**	**Notes on the applicability**
	Promise for limited reduction of foliar blight	Ideal combinations not yet developed

- Lack of effect under conditions that are highly conducive to blight but may be effective under low disease pressure with alternating varieties showing different types/level of resistance.
- May help manage the evolution of pathogen populations for virulence and aggressiveness.
- Relative competitive ability of alternating varieties may affect yield if growth resources are exploited more efficiently.

• Major limitations: practical/organisational/mechanisation constraints. Adjacent varieties should be compatible for fertilisation needs, harvesting time etc. • Not yet fully developed for practical application.

VARIETY MIXTURES	Is the strategy promising?	Notes on the applicability
	Promise for limited reduction of foliar blight	Limited to special cases at present
• Similar to alternating rows, but with closer association between varieties, effectiveness may be better. • Relative competitive ability of alternating varieties may affect yield if growth resources are exploited more efficiently in mixed rather than pure stands. • Practical/organisational/mechanisation constraints and cost of separation if required. Varieties should be compatible for fertilisation needs, harvesting time etc. • Major limitation: unacceptability of mixed variety lots for most purposes by the trade but may be acceptable on a small scale or where separation is possible.		

INTERCROPPING	Is the strategy promising?	Notes on the applicability
	Promise for limited reduction of foliar blight	Not yet fully developed
• Most effective under low disease pressure as for alternating rows of varieties and variety mixtures. • Epidemiological effects of diversification strategies (alternating rows of varieties; variety mixtures; intercropping) are extremely dependent on the variety (level and type of resistance) used and spatial variation in disease pressure. • Orientation of rows relative to the prevailing wind and size of beds seems to be important. Most effective sizes may be much larger than experimental plots • Major limitations: practical/organisational/rotational/mechanisation constraints. • Not yet fully developed for practical application. Combinations with other row-crops e.g. maize may have potential but potato rows adjacent to tall crops suffer yield loss due to interspecific competition.		

4) Optimisation of agronomic strategies for the management of late blight		
VOLUNTEER REMOVAL	**Is the strategy promising?**	**Notes on the applicability**
	Effective removal decreases source of inoculum but no clear, experimental proof of efficacy	Extremely limited
• Pigs 'rooting' on harvested potato fields are very effective at removing volunteers • Major limitations: availability of pigs on the farms; labour requirement for fencing, moving sheds, fences and animals. Pigs may severely damage soil structure under certain conditions on some soil types and there may be animal welfare and meat quality implications. • Because of the limitations, this method is unlikely to be adopted by many farmers.		

ROTATIONAL POSITION	Is the strategy promising?	Notes on the applicability
	Promise for some yield or quality increase	Depends on crop rotation
• Rotational position affects marketable yield via nutrient supply/availability and soil structure set by the preceding crop, but has only small effects on blight infection.		

- Rotational position for potatoes is one component of the fertility management programme which provides the foundation for yield in organic systems irrespective of late blight considerations.
- Many growers have already exploited the potential of this strategy, but there is still potential to improve the rotational position and design in a many farms growing potatoes.
- Major limitations: crop rotation structure and the position available for the potato crop. Optimal position for potatoes may result in a less optimal position for another crop, e.g. cereals. Some crop rotation positions present risks of tuber diseases and pests such as *Rhizoctonia solani*, drycore, wire worms.

FERTILISATION	**Is the strategy promising?**	**Notes on the applicability**
	Promise for significant yield or quality increase	immediately applicable

- Optimised fertility management regimes using permitted manurial inputs (and rotational position) have major effects on yield and quality but not on late blight infection.
- Nutrient availability to the potato crop and magnitude of effects on yield also depends on rotation, weather (which affects mineralization), soil fertility, soil moisture availability and probably the level of soil microbial activity but interactions need further research and clarification.
- Fertility management should be optimized to exploit direct effects on yield through improvements in crop growth rather than to influence late blight infection.
- Major limitations: availability of manure on the farm; environmental legislation and organic standards.

<table>
<tr><td rowspan="2">PLANTING DATE AND SEED TUBER CHITTING</td><td>Is the strategy promising?</td><td>Notes on the applicability</td></tr>
<tr><td>Promise for limited yield increase</td><td>Potential already exploited to a large degree</td></tr>
<tr><td colspan="3">• Early planting and chitting bring forward tuber bulking, possibly leading to a higher yield before blight attacks, especially when the growing season is short.
• Effects of these treatments on crop susceptibility to late blight are difficult to discern.
• Most growers plant as early as possible so this strategy has relatively little potential for further improvement and chitting is standard practice in some countries and for some growers.
• Major limitations: risk of cold (frost damage) and/or wet weather and limited slow mineralisation and N-availability in some springs; additional labour requirement for chitting; possible damage to chits with fully automatic planters resulting in loss of effect.</td></tr>
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<table>
<tr><td rowspan="2">PLANTING DENSITY AND CONFIGURATION</td><td>Is the strategy promising?</td><td>Notes on the applicability</td></tr>
<tr><td>No effect within reasonable densities</td><td>- - -</td></tr>
<tr><td colspan="3">• Planting density and configuration alter crop structure, and so may influence canopy microclimate and blight incidence because of effects on humidity and duration of leaf wetness.
• Planting density and configuration is chosen primarily to control marketable yield by optimizing tuber size for specific markets e.g. large baking potatoes, small salad potatoes.
• Range of planting densities and configurations is limited by mechanisation requirements and soil type.
• Planting density influences seed requirement/ha, which is a major variable cost of production.
• Irrespective of the level of resistance of the variety grown, to be effective on late blight, planting densities and configurations outside 'normal' commercial practice are required. Only very low plant densities at wide spacings reduce blight (lower than commercially acceptable limit). Consequently, this is not a feasible component strategy.</td></tr>
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<tr><td rowspan="2">IRRIGATION</td><td>Is the strategy promising?</td><td>Notes on the applicability</td></tr>
<tr><td>Promise for significant yield or quality increase</td><td>limited by availability of water & equipment</td></tr>
<tr><td colspan="3">• Optimized irrigation regimes must avoid drought to ensure good yield and tuber quality but minimise periods of leaf wetness to avoid blight infection. Regimes vary considerably for wet and dry regions.
• Most improvements in yield and quality can be achieved with irrigation on farms which currently do not irrigate.
• Optimised irrigation strategies according to a scheduling system may reduce water requirement by up to 50% compared with ‘guess-work’ whilst maintaining yields, but apparently without much risk of increasing late blight infection
• Ideally irrigation should be restricted when the general conditions favour the development of late blight, both early in the season when applied for common scab control and later when applied for influencing yield and tuber size
• Positive effects of irrigation on yield far outweigh the risk of encouraging late blight infection.
• Major limitations: availability of water, irrigation equipment, labour and finance to cover investment and operating costs.</td></tr>
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<table>
<tr><td rowspan="2">DEFOLIATION STRATEGY</td><td>Is the strategy promising?</td><td>Notes on the applicability</td></tr>
<tr><td>Promise for limited reduction of tuber blight</td><td>Mainly limited by availability of equipment</td></tr>
</table>

• Defoliation (destruction of the foliage by physical, chemical and thermal methods) reduces risk of tuber blight depending on timing, method, prevailing environmental conditions and interval between defoliation and harvest. It is also used to prevent tubers becoming oversized. • Burning foliage with propane gas kills blight mycelia and spores. Flailing does not and may be less effective at destroying the foliage. Both methods are preferable to allowing the disease to kill the crop off. • Combined flailing/burning is as effective as burning alone, but less gas is required. • All defoliation methods reduce sporulation potential of lesions on the stems to a similar, but much greater, degree than in undefoliated crops. • The safe interval between defoliation and harvest (i.e. the time allowed for the foliage to completely die off and minimise risk of tuber infection before lifting the tubers) appears to be the same for all three defoliation methods • Burning infected fields reduces tuber blight and burning localized, infected patches of the crop may slow down the epidemic. • Flailing is the simplest and cheapest method of defoliation and may suffice but further tests are needed where conditions favour tuber blight. • Regrowth following flailing poses a risk of greater infection than where burning is done and repeated flailing may be necessary. • Major limitations: availability of defoliation equipment; cost of gas. Environmental concerns (use of fossil energy) are also important in some areas.

5) Development of alternative control treatments to copper-based fungicides, which comply with organic farming standards: e.g. foliar sprays and microbial inocula		
COMPOST EXTRACTS	**Is the strategy promising?**	**Notes on the applicability**
	No clear, experimental proof of efficacy	- - -
• Although reported to be effective in some crops, effectiveness against late blight of potatoes has not been demonstrated under field conditions. • Even if effectiveness was shown, concerns over hygiene, toxicology and possible effects on non-target organisms must be addressed. • This method is not yet developed to the stage of practical applicability. It is not clear which compost feedstocks and methods of preparing extracts should be used, and how often and at what concentration the extract should be applied. Consequently, labour and extraction equipment costs are not clear at present.		

MICROBIAL ANTAGONISTS & PLANT EXTRACTS	**Is the strategy promising?**	**Notes on the applicability**
	No clear, experimental proof of efficacy	- - -
• Sprays showed efficacies up to 70 % and 45 % in glasshouse and semi-field trials, but efficacy was low in the field, possibly because of limited persistency. From the present experiments, it cannot be concluded whether effectiveness under field conditions could be improved by altering the formulation, e.g. increasing UV protection or rainfastness with wetting agents. • Currently, products with adequate and consistent levels of effectiveness are unavailable for use in practice.		

ALTERNATIVE SPRAYS	**Is the strategy promising?**	**Notes on the applicability**
	No clear, experimental proof of	- - -

	efficacy	

- Commercially available or novel products for direct control of late blight must conform to the restrictions of the Regulation on organic farming 2092/91 EEC.
- No products conforming to the regulation with good efficacy were found although about 100 possible alternatives were tested. Therefore, this strategy has no practical application at the moment and requires further research and development.

6) Evaluation of novel application and formulation strategies for copper-free / alternative and copper- based late blight treatments

Name of strategy	Is the strategy promising?	Notes on the applicability
APPLICATION EQUIPMENT	Promise for limited reduction of foliar blight	Limited by costs for investment

- Underleaf spraying technology covers the canopy more uniformly with plant protection products, improving efficacy of compounds with contact action in particular, e.g. copper-based fungicides, compared with conventional overhead sprayers.
- Dose per application and/or the number of applications required may be reduced.
- Efficacy of foliar spray applications is far more dependent on optimum timing rather than method: if they have no effect on the pathogen, the method of application is irrelevant.
- Major limitations: high equipment costs (particularly if existing spray equipment does not need replacement); lower work-rate of underleaf sprayers; risk of damage from spraying droplegs; need to adjust dropleg spacing according to row width to accommodate crops other than potatoes.
- Air-assisted sprayers gave similar coverage to underleaf sprayers without most of the limitations described above, but they are even more expensive and overhead boom sprayers will continue to be the most popular for application of foliar sprays.
- Until effective alternatives are identified, progress with developing the best application methods and formulations as important components of a late blight management strategy in organic cropping systems will be limited.

LOW DOSAGE OF COPPER	Is the strategy promising?	Notes on the applicability
	Promise for similar protection against foliar blight with lower copper use	Immediately applicable

- Copper fungicides, even at reduced rates give far more effective control of late blight than current alternatives that comply with organic farming standards
- Copper fungicides applied at lower dosages result in a lower total input of copper whilst maintaining reasonable levels of efficacy, especially when timing of application is optimized by the PhytoPRE or other, similar decision support systems.
- Drastic reductions in total copper use were possible with only slight reductions in protection (5 – 35 %).
- We estimate that ca 2 kg/ha/year of pure copper are sufficient to protect potatoes (i.e. one third of the amount currently allowed by the organic regulation 2092/91 EEC). Most effective use may be achieved by applying low doses at the beginning of the spray programme and increasing them at later stages.
- This strategy is widely applicable that can contribute to a reduction of copper use, but will not result in its elimination.
- Major limitation: farmers' fear that reduced dosages of copper might not be sufficiently effective. This might be overcome by extension activities and demonstration trials, but the farmer's own experience will be the most important factor.
- A policy of progressively decreasing permitted levels of copper until they can be replaced with effective alternatives or are withdrawn would avoid devastating effects of a complete ban on the EU organic potato crop.

OVERALL

- When late blight infection is severe, currently available direct control methods (apart from varieties showing extreme disease resistance) in either organic or conventional systems of potato cropping, including synthetic fungicides, will have little or no effect. Relative effectiveness may improve under conditions of less severe disease pressure.
- **Strategies not (yet) applicable in practice** include intercropping, variety mixtures, foliar sprays & microbial inocula, volunteer removal, planting configuration, compost extracts, microbial antagonists & plant extracts and alternative sprays because:
    - they are simply not sufficiently effective at present
    - they pose considerable practical challenges for implementation e.g. with alternating rows, variety mixtures, very low plant populations and wide spacing
    - their application is constrained by the need to achieve market specifications.

  For these reasons such methods/strategies are unlikely to be adopted by a majority of organic farmers unless these limitations are overcome.
- **Strategies applicable in practice** to mitigate the effects of late blight involving a change or modification in agronomic practices e.g. varieties, chitting, and planting date, optimized fertilization regime, position in rotation and optimized irrigation regime, have major effects on crop performance (i.e. yield, tuber size grading, tuber quality). However, these will only be adopted, if their overall impact is beneficial and the advantages will only be realised by those growers who do not already use these techniques. Specialised equipment for defoliation and spray application may improve blight management strategy but may be too expensive or difficult to justify on the basis of the level improvement in blight protection for the majority of growers.
    - ***Applying lower dosages of copper than used currently could be widely practiced, but growers' concerns that these might give poor results may be a major constraint. This might be overcome by extension activities and demonstration trials, but the farmer's own experience will be the most***

important factor.

- **Strategies already widely used in current practice** on certain farms or in certain regions because they are easily implemented, include resistant varieties, early planting dates, chitting of seed tubers, defoliation strategy, optimized fertilization regime, position in rotation, optimized irrigation regime and low dosage of copper.
  - ***In these cases, the component strategy is already incorporated as a part of the currently used blight management system and cannot be further improved.***
- Each component strategy will be useful and applicable under a specific set of circumstances, but not others. The challenge to organic growers and their advisors is to identify:
  - useful component strategies that are missing from the currently used late blight management system and can therefore be introduced
  - those used at present but are ineffective and can be replaced with effective alternatives
  - those used at present but can be optimised.

The outcome is likely to be improved crop performance, either because of better blight control or because of enhanced growth leading to higher marketable yields, or because of lower costs or a combination of all three factors.

7) Integration of optimised resistance management, diversification, agronomic and alternative treatment strategies into existing organic potato management systems

- Different component and integrated strategies will have different effects from country to country and from farm to farm within a country. Consequently, the most 'profitable' system is unique to a specific situation. Increased profitability results from higher marketable yields and/or reduced costs. Benefits may be associated with improved late blight 'control' but may also be independent of disease effects and achieved by improving growth and hence yield, or by a combination of both processes.
- Relative success of integrated strategies between and within countries reflects differences in potato crop management and performance in organic cropping systems, the impact of late blight and growers' attitudes to the disease.
- The approach of optimising management systems is promising as there is scope in many cases for improvements of the current system depending on:
  - Existing level of sophistication of potato management systems and hence the potential for improvement which varies greatly from farm to farm
  - Conditions specific to an area or farm such as the local agro-climate or soil types which are very difficult or impossible to control, may have a significant or over-riding effect on the potato crop. This means that similar treatments applied to farms in different parts of a country could give quite different results (as borne out by the results on LINK farms in 2004)
  - Any major underlying problem at a particular location that is quite unrelated to late blight infection e.g. tuber quality, needs to be resolved before the potential advantages of the new system can be fully realised. Moreover, an optimised system may appear be beneficial in theory but not in practice if an unanticipated problem or costs (e.g. relating to harvest/handling/storage) counteracts the initial benefit
  - Stage of development of the component strategy and need for further improvement or adaptation to local conditions before success is assured.

- No single technique or component strategy **applied as a sole treatment** was effective enough for the management of late blight (except highly resistant varieties and copper-based fungicides).
- Certain combinations constituting an integrated management system provide additive or

synergistic effects that ‘control’ late blight infection or improve crop performance. Negative interactions must be avoided.

- An integrated management system is the most sustainable approach to stabilize yields of organic potatoes and to reduce or eliminate the use of copper fungicides in organic potatoes in the longer term.
- In the short to medium term, using lower doses of copper-based fungicides than currently permitted and are better targeted may be appropriate until they become redundant or are withdrawn.
- Improving the entire potato management system requires detailed analysis of the current system, good knowledge of strengths and weaknesses of alternative strategies and considerable flexibility.
- At community, national and farm level, success depends on researchers, advisory and extension services effectively communicating relevant, up-to-date information via technical publications, workshops, demonstrations and conferences to stimulate and support uptake of the technology for organic and conventional systems.
- On-farm experimentation and further research are required to:
    - develop some of the less advanced strategies
    - identify combinations of component strategies that interact positively; those that are ineffective or interact negatively and those that are not cost effective.
- There is no universal blueprint. The potato management system must be optimized for each farm individually to match soil properties, local weather and the economic conditions and avoid conflicts with other crops within the rotation.
- Achieving the optimum system is likely to take several years in most cases and will need to be re-evaluated and modified in the light of changes in technological, political, climatic, environmental and economic conditions.

- By working closely with farmers, Research Institutes and individuals involved in Blight MOP will facilitate the implementation of these results. Better management of late blight with less dependency on dependent on copper-based fungicides will sustain the production and profitability of organic potato growing in Europe for the benefit of all stakeholders and meet an important objective of EU organic farming policy. There may be additional benefits from applying principles to other crops grown in organic systems that receive copper-based fungicides.