Chapter 9:

Consolidated, overall report

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Introduction

Late blight (caused by *Phytophthora infestans*) infects both foliage and tubers and is the most devastating disease affecting organic and conventional potato production in the EU. Copper-based fungicides are 'considered to be traditional organic farming practices' and usually, but not always effective, and use is restricted by national legislation and/or organic certification standards.

Replacement of copper-based fungicides with other methods for disease control is a priority in EU organic farming policy. This reflects concerns about potential toxic effects of copper-based fungicides on plants, beneficial soil and other organisms, biodiversity and human health and that their use is not compatible with the underlying principles of organic farming. They were due to be prohibited for use in organic farming from March 2002 (EU Regulation No. 2092/91). However, the ban was delayed because of the increased risk of disease damage and losses of profitability for organic producers in the medium to long term without effective alternative control methods in place. A maximum application of 8 kg of elemental copper/ha/year was imposed for annual crops until the end of 2005, decreasing to 6 kg per year thereafter. (Regulations may be changed at any time as viable alternatives are developed or if approval for use of copper-based fungicides is withdrawn on safety grounds under the EC Review programme for existing active substances).

On average, organic potato crops treated with copper-based fungicides for late blight control yield about 25% more than untreated ones because the foliage is protected and the growth period extended for about 2 to 4 weeks (and tuber blight may also be reduced). This additional growing period and hence extra yield is worth between 15 and 45 million EUROS per year to EU organic-potato growers (calculated on the basis of 10000 ha of organic potato production, a tuber growth rate of 0.5 t/ha/day and a price of 270 EUROS/t). Without these fungicides or effective alternative control methods, this income would be lost and threaten the economic viability of organic potato production and/or whole organic farming businesses (especially those which rely heavily on the income from potato crops) in many areas of the EU. Since EU policies are aimed at supporting an expansion of organic production, a replacement for copper containing and other chemical fungicides is urgently required to avoid such consequences. In addition, any increase in late blight incidence on organic farms resulting from poorer control could also influence blight epidemics in neighbouring conventional farms and threaten conventional production systems.

An integrated systems approach to late blight management in organic systems that eliminates or reduces the need for copper-based fungicides could solve these problems. Such an approach should integrate use of (i) resistant varieties, (ii) agronomic strategies (iii) alternative treatments and (iv) optimise their effectiveness by utilising existing blight forecasting systems and aim to maximise synergistic interactions between these components.

Aims and Objectives of the research programme

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.

Objectives were:

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

The effect of the EU Regulation No 2092/91 ban on the use of copper-based fungicides in organic potato production was difficult to predict because of the lack of reliable data for organic potato production in different regions of the EU. Therefore, detailed information was required about: (i) blight incidence and resulting yield losses (ii) blight management strategies currently used and (iii) the potential socio-economic impact of the ban on copper-based fungicides on EU organic potato production and its competitiveness in an international market. An initial, comprehensive survey was conducted in seven European countries (CH, D, DE, F, NO, NL, UK) in 2001, relating to the 2000 cropping year, to provide this information.

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

Suitability of potato varieties with race specific (highly effective resistance based on R-genes) and race non-specific resistance (partial resistance/tolerance) as part of a blight management strategy has mainly been evaluated in conventional crops reliant on synthetic fungicides for protection. Such results may not be directly applicable to organic systems because overall resistance may be influenced by other components of the production system apart from the disease control regimes, such as differences in nutrient availability to the crop which may affect variety ranking order. Another major issue is breakdown of resistance resulting from growing the same resistant potato varieties frequently in the same geographic area leading to new races or more aggressive strains of *P. infestans*.
Field assessments were made of:

- (i) agronomic and economic suitability of a range of varieties for organic potato production in different areas of the EU
- (ii) race structure and aggressiveness of local *P. infestans* populations (to assess the risk for breakdown in variety performance in different EU-regions)
- (iii) potential suitability of varieties for within field diversification strategies to prevent/delay blight epidemics

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

Blight epidemics can be prevented or at least delayed by growing potato varieties with different forms of resistance in mixtures or alternating rows. Intercropping rows or beds of potatoes with other crops that can provide physical barriers for spore dispersal is another approach. However, there may be increased costs associated with the establishment, harvest and processing of crops grown in these systems. Effects of these three diversification strategies on late blight incidence and crop yield and quality were assessed in different EU countries.

4) Optimisation of agronomic strategies for the management of late blight

Other agronomic strategies may reduce or evade crop infection with late blight such as:

(i) effective methods of removal of volunteer/groundkeeper potatoes which are a primary source of *P. infestans* inoculum.
(ii) crop planting dates, seed densities and irrigation schedules (to avoid periods of high blight pressure in the growing season and influence yield irrespective of blight infection).
(iii) fertility management regimes (to avoid susceptibility or increase resistance to late blight and influence yield irrespective of blight infection)
(iv) methods and timing of defoliation (to maximise yield while avoiding tuber infection)

By assessing and seeking to optimise these treatments, the aim was to develop "locally adapted" agronomic management systems for late blight in EU-organic potato production.

5) Development of alternative control treatments to copper-based fungicides, which comply with organic farming standards

Alternative treatments against fungal pathogens include microbial antagonists, plant and compost extracts that have direct antifungal effects or stimulate competitor micro-organisms and/or induce resistance via "plant strengthening" activities. However, information about such treatments for late blight control in the field is limited. Alternatives including microbial preparations, plant, seaweed and compost extracts and other materials that might be adopted in commercial crops for late blight control were assessed.

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

Directed, air-assisted and electrostatic sprayers give more complete and uniform spread of active ingredient on leaves than conventional, overhead hydraulic machines. Consequently, reduced rates of copper-based fungicides and other materials may be used. This could reduce releases of copper into the environment and also reduce costs (alternative treatments are more expensive than copper-based fungicide). However the more sophisticated application equipment is more expensive than the standard. Application methods were compared and also the efficacy of reduced inputs and different formulations of alternative and copper-based fungicides (i.e. less than 8 or 6kg/ha/yr). This was in case the current derogation to apply reduced doses (but with further reductions below the current 6kg/ha/yr of elemental copper limit), were extended until effective alternative treatments are registered and licensed for commercial use.

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

The systems approach to late blight management involves integrating components of variety resistance, agronomic practices and/or novel treatments. Through survey and laboratory and field evaluations, the Blight-MOP project identified the major components with potential to contribute to an effective disease management system in the absence of copper-based fungicides (or with much reduced doses). Some have direct effects on the onset and severity of disease; others advance tuber-bulking so that an acceptable marketable yield can be achieved before infection results in the death of the crop.
The physical and financial performance of crops grown with an increasing numbers of individual component strategies to provide an integrated late blight management system was assessed on MODEL (Research) Farms in the seven participating countries. On commercial or LINK farms, optimised blight management systems were compared with existing systems. This approach was designed to construct blight management systems that are customised /

adapted to organic production systems in different regions of the EU and beneficial to growers, consumers and the industry as a whole.

The Blight-MOP programme

The Blight-MOP consortium included 13 partners from 7 European countries (CH, D, DE, F, NO, NL, UK) representing a range of environmental conditions and approaches to potato production in organic systems. Commercial growers were closely involved by providing information, sites and facilities for field experiments. Additional inputs were received from advisors, certifying authorities, processors, retailers and potato industry organisations.

1) SOCIO-ECONOMIC IMPACT & 'STATE OF THE ART' BLIGHT MANAGEMENT

The economic impact of late blight in organic production systems varies between countries and regions of the EU because of different climatic and market conditions, potato varieties used and agronomic techniques. Consequently, the impact of a ban on copper-based fungicides for late blight control and hence overall farm incomes will also vary. To quantify this, a survey was made of economic variables, agronomic techniques, late blight incidence and late blight management systems and their efficacy in organic potato crops. The survey was conducted in Denmark, France, Germany, Netherlands, Norway, Switzerland, and United Kingdom and related to crops grown in 2000 on 118 farms. Survey data, in combination with field trials' results were used to make cost/benefit (margin over cost) analyses of current and 'optimised' late blight management systems later in the research programme. This approach helped to quantify the economic importance of blight in different regions of the EU under various scenarios, notably after the ban on copper fungicides has been implemented and to provide a focus for the target efficacy/activity of blight management and treatment systems to be developed in the project.

The area of organic potato production increased between 1998 and 2000 in all countries (ranging from 11% in Denmark to 89% in Norway). Yields varied from 15t/ha in Norway to 30t/ha in Switzerland, the Netherlands and United Kingdom and on average were 50 to 80% of conventional yields. Farm gate prices for organic potatoes were between four and one and a half times higher than for conventional. However, premia varied between countries and seasons and occasionally, organic potatoes were sold through the conventional market. Further expansion of organic potato production was predicted by experts, but associated with decreasing profitability. Consumers are interested in the system of production (priorty 1) and demand for organic food is expanding but price is an issue for many (priority 2). And they are also interested in variety (priority 3). Organic and conventional growers use different varieties and the choice for organic systems is often a compromise between robustness in production and market acceptability.

Organic producers in Germany, Switzerland and United Kingdom considered their potato crops to be relatively profitable, but those in Norway, Netherlands and especially Denmark that profitability was unsatisfactory. Surprisingly, subjective assessments of profitability were not directly correlated with yield or farm-gate price.

Late blight was serious in 2000 in Netherlands, Germany and United Kingdom followed by Norway, France, Switzerland and Denmark. Between 1996 and 2000 some growers did not suffer losses due to late blight but impact varied from year to year. At least 70% of growers in Germany, Netherlands and United Kingdom experienced losses every year. In most countries, organic growers were criticized by conventional growers concerned about the prevailing levels of blight infection in their organically grown crops.

National legislation prohibits use of copper-based fungicides in Scandinavian countries (Norway and Denmark) and the Netherlands (with exception in 1998) and state and label organizations set a limit to quantities used in Switzerland (4kg/ha) and Germany. In France and the UK, use was unrestricted until 2001.Copper use was then limited in the EU by EU regulation 2092/91 to 8kg copper/ha/year until 31 December 2005 and 6kg copper/ha/year thereafter and is subject to further reduction or withdrawal. In the Netherlands, defoliation of potato crops is compulsory as soon as late blight incidence exceeds 5% of leaf surface infected.

Between 1996 and 2000, copper was used at least once by 60% of German, 65% Swiss, 80% United Kingdom and 100% French organic growers (and 45% of Dutch growers in 1998 with exceptional permission of the authorities) and never in Norway or Denmark. Some French and United Kingdom growers had used 16kg/ha, most used <7kg/ha. Swiss growers applied 2 to 4kg/ha and German growers generally < 2kg/ha.

Thirty to sixty % of growers had used alternatives to copper-based fungicides selected from a range of about 40 products and preparations but with very limited success.

Overall, if the copper ban is introduced, about two-thirds of growers (including Denmark and Norway where use is already prohibited) expected no change in organic potato production, one third a decrease (mainly amongst countries where copper can be allowed up to the EU defined limit) and less than 3% an increase. However, 11% of Dutch farmers predicted an increase, possibly to compensate for decreased production and considered that in this scenario, there would be an opportunity to expand their markets.

The contribution of agronomic and regional disease pressure on the overall success of organic potato enterprises was assessed objectively. Data analysis revealed that early planting and harvest, defoliation, use of increasing levels of copper-based fungicide application use of more resistant varieties contributed to the success of achieving higher ‘gross yields’. Most of these factors, together with the intensity of fertilizer input contribute to N-use efficiency and crop profitability. These production factors are mainly under the grower’s control and therefore account for some of the differences in performance between farms. The implications are that some growers do not fully exploit currently available production technology and have potential to stabilize and improve yields simply by adopting existing production strategies and this was revealed by the grower interviews as well as by the data analysis. They would benefit by :

- Planting early and chitting or pre-sprouting seed to bring tuber bulking forward and produce an acceptable yield before blight attacks
- Use a fertility management strategy that supplies sufficient nutrients (nutrient supply is generally sub-optimal in organic systems)
- Growing resistant/robust varieties
- Protecting crops efficiently

In practice, the extent to which these strategies can be included on the farm may be limited. For example, growing resistant varieties may be an effective strategy to manage late blight but will be limited if there is limited acceptance by the market. Soil fertility management affects yield directly and also crop susceptibility to late blight. There were consistent reports that nutrient deficient plants lacking in vigour were more susceptible to disease, possibly because of physiological imbalances. However, exploiting yield and improved resistance benefits will be limited if fertility inputs are in short supply and needed for other crops in the rotation as well as potatoes.

Most growers farming according to organic standards were not primarily motivated by expectations of high levels of farm income. Over 70% listed non-economic motives first including the desire to produce healthy, safe food (priority 1), conserve natural resources (priority 2), live and work in harmony with nature (priority 3), leave a viable farm for the next generation (priority 4). Economic motives such as high or reasonable income, achieving good market prices for products, retaining farm ownership although ranked less important that the environmental and food quality ones, were of second or third importance. This suggests that the altruistic motives maintain priority for a long as economic viability is maintained. Concerns of consumers about food safety in Europe are seen as a major opportunity to expand and develop organic food production but expansion and increased supplies could put pressure on premiums and prices and are seen as a threat and/or challenge to the future of organic farmers.

The survey indicated that:

- Region-specific optimization and integration of technologies should lead to a substantial improvement of yields and yield stability in organic potato production
- Copper has been a key component of organic potato production systems
- A ban on copper in the absence of effective alternatives could be expected to destabilize organic potato production by decreasing the production area and market supply
- There are key factors for successful potato production that need further development, exploitation and evaluation under various regional conditions
    - Crop resistance management strategies
    - Agronomic strategies
    - Soil fertility management
    - Novel crop protection strategies
- No fully successful production strategies are currently available that can be adopted into current potato management systems to solve all problems
- Further efforts to improve the efficacy of the key factors are worthwhile: any improvement will contribute to security of production and supply and decrease dependency on copper-based fungicides
- There are tremendous differences in performance of potatoes in organic cropping systems under similar environmental conditions and scope to improve productivity on some farms, simply by implementing current ‘state of the art’ technology
- Distribution of existing know-how and novel technologies will increase the success of organic potato production considerably

Blight-MOP aimed to address the key factors involved to address the major issues and to disseminate the know-how and novel techniques to fully exploit the benefits.

2) VARIETY PERFORMANCE

Assessment of variety performance in different EU regions and organic production systems:

Resistant varieties are an important component of an integrated disease management strategy, but the suitability of many for organic production in different EU regions is unknown. Whilst variety evaluation trial data from conventional agriculture is comprehensive, it may be of limited usefulness for organic cropping because the ranking order of variety performance may differ between conventional and organic production systems. Therefore, resistant varieties should be evaluated within organic rotations in different regions of the EU to assist variety choice. This would also help to formulate appropriate within field diversification strategies with varieties (grown in mixtures or alternate rows) with different types/ levels of resistance.

Experiments were designed to determine whether growing more resistant varieties is a promising strategy to eliminate or reduce the need for applications of copper-based fungicides in organic potato production. The potential reduction of foliar blight infection at local and regional level gained from substituting a currently grown variety with a new, more resistant one was assessed and compared with the effect of a copper-based fungicide. Resistance of selected varieties to foliar and tuber blight and their yield under organic growing conditions were assessed in Switzerland, France, England and Norway in 2001 and 2002. In each country, five 'novel' test varieties were compared with a standard or reference pair of varieties (Bintje – susceptible and Sante – resistant) and with two other varieties popular in organic production in that specific country. In addition, the effect of copper fungicides was assessed for all varieties in the United Kingdom, which ranged from very susceptible (Bintje) to highly resistant (Sarpo Axona, Sarpo Mira, Sarpo Tominia).

It was clear that in all four countries, some of the new potato varieties were much less susceptible to foliar and tuber blight than most of the varieties currently grown: Appell, Derby, Innovator and Naturella in Switzerland; Derby, Eden, Escort and Naturella in France; Sarpo Axona, Eve Balfour, Lady Balfour, Sarpo Mira and Sarpo Tominia in England; N89-1756 and N92-15138 in Norway. However, they are only commercially viable in organic farming if their agronomic characteristics e.g. adaptation to local climate; freedom from physiologically caused quality defects; resistance to major pests and diseases and tuber characteristics e.g. shape, size, skin finish, storage and culinary or processing properties, are comparable or superior to those of the varieties that are currently grown for the organic market sector. However, acceptability of any variety may vary from country to country and also from region to region within a country.

In the UK, copper-based fungicides (the only effective fungicides currently permitted for blight control in organic agriculture) reduced foliar blight and yield on average by between 20 and 30%. However there were no significant effects on tuber blight. In the UK 2001, the most resistant varieties were Sarpo Axona, Sarpo Mira and Sarpo Tominia and these showed very low levels of foliar blight infection even where copper oxychloride was not applied so that applying copper-based fungicides to them gave virtually complete control. In practice, the limited benefits of using copper-based fungicides in such highly resistant varieties would be difficult to justify. However as copper-based fungicides are inexpensive, some growers may be reluctant to dispense with them unless forced to do so because they insure against the risk of disease in all varieties. Longer term, it is desirable to grow organic potatoes without copper-based fungicides to meet the demands for their elimination. In the short term however, where severe blight pressure is the norm, limited use of copper-based fungicides may be necessary until other, effective blight management practices are available.

The implications of these results would seem to be the same for all countries – growing more resistant varieties offers a significant reduction of late blight incidence and less need for fungicide treatments. However, the extent to which this can be achieved depends primarily on their market acceptability and availability of organically produced seed of these varieties. Nevertheless, taking Switzerland as an example, it was estimated that assuming resistant varieties require 0 to 33% of the copper-based fungicides used to protect currently grown susceptible varieties, an overall reduction of 16.5 to 50% of copper fungicides could be achieved by growing them instead of susceptible varieties to the maximum extent that the market could absorb. This represents a major opportunity to substantially reduce copper inputs. Growing varieties with better blight resistance than those grown currently which require little or no protection with copper fungicides - seems desirable in organic cropping systems and the trend should be encouraged. However, this strategy alone is unlikely to eliminate the need to use copper-based fungicides but should be further improved by combining it with other component strategies in an integrated system.

Varieties with different levels of resistance to late blight were included in several other experiments in the research programme to test for interactions with other component strategies such as the agronomic strategies and their performance in alternating rows and variety mixtures. The more resistant varieties were consistently more robust than susceptible ones. However, it was clear that growing early but susceptible varieties such as Nicola and Charlotte (which are also popular with consumers) can be a useful component strategy in organic systems to produce reasonable marketable yields and profitable crops. They bulk earlier than more resistant but later maturing varieties and so may produce an acceptable yield before blight infection occurs. Planting early and chitting or pre-sprouting seed further enhances their earliness. However, because such varieties are more responsive to applications of copper-based fungicides than more resistant ones (i.e. there is a variety x copper based fungicide interaction), growers may be reluctant to stop applying them for fear of losing their crops to late blight

Clonal diversity, race spectrum and aggressiveness of *P. infestans* populations found in organic production units in different areas of the EU:

With the predicted increase of organic potato production in Europe, and a preference for growing more late blight resistant potato varieties (encouraged by results reported in the previous section), it is of strategic importance to assess the risk of possible shifts in regional/national late blight populations towards increased pathogenicity that can be linked with a shift towards the growing of more resistant cultivars. The chance of infection and disease progress is affected both by varietal resistance and by the genetic make-up of the pathogen. Plant-RI (NL) assessed the late blight populations collected in the field from a susceptible (cv. Bintje) and a moderately resistant (cv. Santé) cultivar in the variety evaluation experiments made in 2001 in France (F), Norway (N), The United Kingdom (UK) and Switzerland (CH). Isolates of the late blight populations were characterized using neutral DNA markers, virulence testing and aggressiveness assays. This made it possible to compare their diversity and pathogenicity, and test whether isolates collected from Santé were more pathogenic (virulent and/or aggressive) than those from Bintje. Insight in the pathogenicity traits of these populations could help to identify potato varieties that are best suited for use in organic systems in these countries.

Isolates from the 4 countries were fairly complex, but less so than the population found in the Netherlands. Clearly, populations of *Phytophthora* collected from the four countries differed in virulence spectrum and race complexity. However, no difference in race complexity could be related to the two cultivars (Bintje and Santé) from which the isolates were collected; indicating that no population sub-structuring based on virulence is to be expected when more susceptible varieties are replaced with more resistant ones. These results suggest no significant shifts towards increased pathogenicity are to be expected when more resistant potato cultivars are grown on a wider scale as a component of an integrated late blight management system in organic systems. However as future shifts towards virulence to new R-genes bred into new cultivars (e.g. Biogold), cannot be predicted on the basis of these results, they should not be excluded. To minimize the risk of resistance breakdown and its adverse consequences, growers should further diversify within a season wherever possible, by using varieties with genetically different resistance.

3) DIVERSIFICATION STRATEGIES

Diversification can make an important contribution to plant protection as a potential component of an integrated systems approach. Rotation is the traditional diversification method, but a different approach is to grow mixtures of varieties and species within a field. Mechanistic effects such as distance, barrier and microclimatological effects and complex ecophysiological interactions such as competition, induced resistance and allelopathy may reduce disease pressure. Previous work has shown that late blight development in susceptible varieties can be reduced by growing them with varieties with different types and levels of resistance in alternating rows or in random mixtures or intercropped with different species that are unaffected by late blight.

Alternating rows:

Late blight infection in susceptible varieties has been shown to be reduced and their yields increased significantly by growing these varieties in rows alternating with other varieties displaying a partial (non-race specific) resistance to the pathogen. Potential mechanisms include: physical barrier to inoculum dispersal caused by rows of resistant plants; progressive adaptation (during the course of the epidemic) of the pathogen genotypes to one or the other variety used in the association, thus restricting pathogen movement between varieties; compensatory growth effects between varieties. However, performance of potato varietal associations has not been assessed with different densities of partially resistant and susceptible varieties or with mixtures of partial and complete resistance (mediated by undefeated, race specific R-genes). Better knowledge and understanding of the underlying mechanisms for improved performance of such “associations” and influence of environmental conditions is required to improve their reliability. Field experiments investigated the 3 potential mechanisms by i) modeling the spread of late blight epidemics in pure and associated plots. ii) measuring variety-specific adaptation of *P. infestans* genotypes to determine to what extent any observed temporal adaptation of the pathogen population structure contributes to the performance of associations in controlling late blight. iii) quantifying competition between varieties in associated crops which may account for yield benefits that are independent of the effect of associations on disease control.

During two consecutive years (2001 and 2002) in Brittany, France, Bintje, Desiree and Naturella showed no significant disease reduction in alternating rows of contrasting varieties compared with pure (single variety) stands irrespective of the type of resistance used, whether they were grown in single or twin rows. Disease on the highly susceptible variety (Bintje) was reduced in alternating rows while the moderately susceptible variety (Desiree) suffered more disease in combination with Bintje, but the highly resistant variety (Naturella) was unaffected by alternating rows. There were no yield effects indicating that either the three varieties were very similar in competitive ability or the 75cm distance between rows was large enough to reduce competitive interactions.
Similar results were obtained in Denmark in both years with the varieties Kuras (highly resistant), Danva (moderately resistant) and Oleva (susceptible). There were no competitive interactions when mixed or significant reductions of late blight in the susceptible variety grown alternately either partial (non-race specific) or race specific resistance varieties.

However in 2001, late blight infection was significantly delayed by about a week in the highly resistant variety Kuras (with high race-specific resistance) when alternated with the susceptible variety Oleva after the adjacent rows of Oleva were killed off by leaf blight. Yields were increased possibly due to the competitive advantage of the resistant variety following death of the foliage of the susceptible variety and/or changes in microclimate that benefited the resistant variety. Such an effect was absent in 2002 however.
In France, pathogen populations differed according to host genotypes. Isolates virulent to Naturella (possessing the R2 resistance gene) were recovered almost exclusively from this cultivar, and proved weakly aggressive on Bintje (susceptible) or Désirée (partially resistant). Isolates collected from Bintje were most aggressive on both Bintje and Désirée. There was no clear indication of a strong correlation between pathogenicity characteristics and AFLP fingerprints. These patterns were similar in collections made over the two successive years.
It seems that alternating rows of susceptible and resistant potato varieties have a limited potential to control late blight in environments highly conducive to the disease, but may help manage the evolution of pathogen populations for virulence and aggressiveness.

Variety mixtures:

Much evidence shows that development of air-borne pathogen epidemics can be significantly restricted with variety mixtures with as few as three or four different forms of resistance. The mechanisms involve spatial separation of plants carrying the same resistance genes, barrier effects and induced resistance (i.e. plant A induces resistance in its neighbour B by plant A allowing the persistence of a pathogen race which is virulent to A, avirulent to but resistance inducing in B). The latter two mechanisms should play a greater role when plants are mixed within rows than when planted in alternating rows. However, improvements in disease control in mixtures must be weighed against additional costs for separating the varieties prior to sale or restricted marketing opportunities
Variety mixtures were tested in the United Kingdom (UK) and Germany (D) between 2001 and 2003 to investigate growing mixtures of potato varieties as a diversification strategy for the management of late blight. In the UK, five varieties with differing resistances were grown in all possible mixtures and pure stands in two differently sized plots. Susceptible or moderately resistant varieties suitable for commercial cropping were infected to similar extents in mixtures and pure stands. In two of three years, infection in variety Sante (moderately susceptible variety) was slightly less when mixed with Cara (moderately resistant), but Cara was unaffected. Mixing a late blight immune/near immune partner (Tominia) with either Cara or Sante reduced disease in these latter two varieties. Mixtures of varieties did not suppress disease to an extent exceeding that provided by the average of the resistance of individual components/varieties within the mixture. Larger plots were more infected than small plots but the disease progressed more rapidly in small plots whilst planting density had no effect. Cara yielded better in mixtures than expected, demonstrating positive combining ability whereas Appell performed worse than expected, showing negative combining ability. The combining ability of other varieties depended on their companion varieties. Mixtures improved yields by about 5% compared with the yields of individual components (indicating better resource use). Cara's advantage improved as the number of varieties in the mixture increased but Sante yielded progressively less (other varieties showed no response) and for Cara the relative benefit of mixtures over varieties was affected by plant density.
In Germany (D) in 2002 and 2003 – Agria and Simone (white skinned) and Laura and Rosella (red skinned) were grown in pure stands and four mixtures of a red and white skinned variety either following grass/clover or wheat to study effects of nutrient availability on late blight and plant-plant interactions. Yields were less after wheat but severity and rate of infection was less (but not significantly) following wheat than grass/clover. Effects of mixtures on disease were small compared with pure stands but the Laura-Simone mixture (these two varieties represented the upper and lower ends of the susceptibility spectrum) was

most effective, especially under low disease pressure after wheat than grass clover in both years. Whilst mixing varieties did not affect overall yield, the least competitive variety in the mixture produced fewer oversized and more undersized tubers than in pure stand. Competitive interactions between varieties were similar in both years and were unaffected by nutrient availability.

As with alternating rows of different varieties, on the basis of these results it seems that substantial advantages are unlikely to occur in terms of reductions of blight infection, especially if disease pressure is severe. However, there may be some yield benefits with certain mixtures due to improvements in resource use that are not related to blight infection. Growing mixtures on a commercial scale would provide a number of practical challenges in growing, harvesting, grading, storage and marketing.

Intercropping:

Separation of single or multiple potato rows/beds by suitable crops of a different species should restrict late blight infection and hence improve yields by reducing the amount of susceptible plant tissue per unit area (dilution), providing a barrier against spore dispersal and modifying the microclimate. Intercrops such as wheat should significantly delay the spread of blight and increase yields compared with shorter crops such as clover and the barrier effect should increase as the strips of wheat get wider. Resistance type (race-specific or race-non-specific) of the potato variety will probably influence the epidemiological interactions in diversified stands.

Effects of intercropping potatoes with either cereals or grass-clover on late blight severity and yield of two potato varieties were studied from 2000 to 2002 in large-scale field experiments in Germany. Orientation of the plots to prevailing winds (either parallel with, or perpendicular to the main wind direction) and effects of plot size (3 x 10 m in 2000 and 6 x 18 and 6 x 36 m in 2001 and 2002) were also investigated. Intercropping had no effects on late blight in 2000, but increasing plot size and distance between plots significantly reduced it in 2002. Reductions were highest in plots planted perpendicular to the wind grown next to grass-clover. Yields of potatoes in rows directly adjacent to cereals were invariably significantly reduced in all three years because of competitive effects.

Effects of the cropping strategy did not interact with variety. In 2000, the susceptible variety Secura was much more severely infected with late blight than the more resistant variety Simone, but yields were very similar indicating that as far as yield is concerned in an organic system, early bulking might be more important than resistance. Lack of correlation between AUDPC and yield in 2002 can be explained by the very dry spring which impeded the mineralization of organic matter in the soil resulting in much reduced nutrient supply to the crop. Thus, nutrient limitation rather than disease was responsible for the reduced yields.

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. In addition, potato yields will also be affected by competition between different varieties in the stand and from different barrier species. Therefore, in order to utilize diversification strategies effectively, reactions of different varieties to competition from other companion varieties and species have to be determined to identify varieties suitable for this approach. A useful additional breeding objective for organic farming would be to improve the competitive ability of varieties in mixed, diversified stands: weed suppression and use of limited resources for growth would be an additional benefit. Reduction in disease pressure from diversification in a potato cropping system may be dependent upon the size of the plots or beds of the different varieties and species. The most effective sizes may be much larger than experimental plots.

4) **AGRONOMIC STRATEGIES**

Agronomic practices (other than using resistant/tolerant varieties) may avoid, delay or reduce the incidence and/or severity of late blight by affecting physiological age, the onset or rate of tuber bulking, canopy size, plant to plant interactions, micro-climate within the crop and disease susceptibility. As such they are important components of integrated "locally adapted" agronomic management systems for late blight in EU-organic potato production.

Volunteer removal strategies:

Potato volunteers that survive over winter and grow spread late blight to newly emerging crops. Pigs excavate and eat volunteer tubers and recycle nutrients via their excreta but may damage soil structure. In the Netherlands sows (2001) and finishing pigs (2003) removed volunteer potatoes very quickly and effectively following harvest. However, this was offset by adverse effects: many of the pregnant sows in 2001 aborted after consuming volunteer tubers (but there was no conclusive proof that the potatoes were the cause): meat quality of the finishing pigs in 2003 was reduced substantially: soil was compacted in the top 6-18cm causing establishment problems in the succeeding cereal crop. Whilst 'rooting' pigs control volunteers extremely well, the risk of adverse effects mean that it cannot be recommended unconditionally. In any case, this option will be restricted to a relatively few farms with access to pigs and a suitable soil type.

Position in the rotation re: fertility building grass/clover crops:

Crop rotation is a crucial element of soil fertility management strategy (although there are also crop protection benefits). In organic rotations, potatoes are grown once every four to seven years and usually follow grass/clover or a cereal crop that is grown immediately after grass/clover to benefit from the previous build up of fertility. Resistance to late blight may be influenced by soil and hence plant fertility status. Fertility will be higher immediately after a grass/clover ley than after a cereal and whilst this may lead to higher yields the crops may be more susceptible to blight. On the other hand, nutrient deficient crops lacking in vigour may also be more susceptible to disease. In either case, there are likely to be differences between varieties and, changes during the growth period with respect to blight resistance. The effects of the position within the rotation (and hence different nutritional levels) of potato-varieties with different bulking times on late blight infection, yield and quality were assessed in Germany and the Netherlands in 2002 and 2003. Potatoes followed directly after a fertility building crop of grass/clover or Lucerne, or after wheat or barley following a grass/clover pre-crop.

Results from Germany confirmed the major effect of fertility on crop performance, highlighting that if varieties are to achieve their full yield potential under organic conditions adequate nitrogen supply is of paramount importance. Pre-crop grass/clover (rather than a cereal) was an effective way of building up the nitrogen supply and therefore the potential for a high yield. Achievement of levels of fertility sufficient to meet the demand for unrestricted growth should be given higher priority than the risk of late blight infection. Pre-crop species had no significant effect on the severity of infection but it was greater in potatoes after grass/clover. This was

attributed to more conducive micro-climatic conditions in the foliage rather than the nutritional status of the crop *per se*. Variety had the biggest effect on late blight infection: Simone, a later bulking and less susceptible variety than either Nicola or Rosella, had consistently lower symptoms. Copper fungicide treatment had a greater beneficial effect in susceptible than more resistant varieties. These results were similar to those from the variety evaluation trials mentioned previously.
Where the duration of crop growth is limited by high disease pressure and susceptible varieties such as Nicola are grown, adequate supplies of nitrogen to match crop demand over the growing season is of crucial importance for yield. Later bulking varieties, which tend to be more resistant to late blight, may compensate for delayed bulking because of a longer duration of crop and tuber growth, during which more mineralised nitrogen becomes available to keep pace with demand.
Results from the Netherlands were similar although the varieties were different and Lucerne was a pre-crop rather than grass/clover. Late blight was slightly greater after Lucerne than after wheat in 2002, but with compulsory defoliation at low levels of infection, the disease had no effect on yield, although Lucerne gave a slight but insignificant yield increase compared with wheat. As in Germany there were large effects of variety on blight infection dependent upon the level of resistance and hence tuber yield. In 2003, there were no differences in levels of late blight infection between the fertility treatments but there were differences between varieties. The very dry and hot seasonal conditions in 2003 coupled with the a high level of basal fertilisation with slurry prior to ploughing out the pre-crop for potatoes meant that crop performance was more limited by water shortage than by nitrogen deficit, and no pre-crop or fertilisation effects were evident.

Results of this series of experiments to assess effects of position in the rotation (re: fertility building grass/clover crops) with respect to late blight infection and crop performance indicated that the combination of site-adapted varieties grown on soils with enhanced fertility should form the foundation for potato cropping in organic systems. These are important agronomic measures which coupled with others that promote early crop development such as pre-sprouting or chitting of seed tubers and early planting can help to eliminate or at least considerably reduce the need for copper fungicide treatments. This principle is one which deserves much greater emphasis than it has received in the past.

Effect of animal manures and N:K ratios:

Balanced fertility management and high levels of available K are thought to increase resistance of potatoes to fungal diseases. With N however, high inputs may decrease blight resistance by giving a dense canopy with a micro-climate that encourages the disease whilst nutrient-deficient plants under stress may also be more susceptible to infection despite their small tops. However, more information is needed to clarify responses. Irrespective of possible effects of nutrient supply on disease, fertility is an important determinant of potential yield yet many potato crops in organic systems receive relatively limited inputs of nutrients and some are deficient (occasionally for N and often for K). Optimising fertility management and utilisation of applied nutrients is therefore a major agronomic objective in potato production. In particular, balancing losses due to increased blight infection with gains from improved growth is critical.

Effects of different 'organic' fertilisation regimes and interactions between N and K supply on foliar and tuber blight resistance, disease development and tuber yields were studied in the UK from 2001 to 2003. Field sites/soils had been under organic soil management for different periods. Complementary pot trials from 2001 to 2005 had similar objectives. Effects of tuber planting depth on tuber blight and levels of soil microbiological activity and water supply on crop response to different fertility management regimes were also investigated. Fertility treatments had no effect on blight infection in either Sante (resistant) or Nicola (susceptible) but affected yield. On a long-established organic site, cattle-manure-based compost outperformed chicken-manure pellets by about 40% in yield terms. The reverse occurred in sand culture in the pot experiments. Differences in water-soluble nitrogen contents and microbial activity between the field soil and sand were probably the reason. Contrary to suggestions in the literature, neither applied K level, nor N:K ratio affected blight infection. However, the form of the 'organic' fertility input (uncomposted dairy cattle farmyard manure, cattle-manure-based compost or commercially prepared organic fertiliser from chicken manure) affected yield independently of effects on blight infection. Cattle-manure-based compost (at 85 and 170kg/ha N) increased yield significantly compared with chicken manure fertiliser pellets in a long-term organic site. High, inherent biological activity leading to efficient mineralisation of nutrients from cattle-manure-based compost may have been involved. When weather was very dry in August 2003, late blight was suppressed and there were no treatment effects. At Nafferton, total tuber yield was unaffected by type and level of fertility input but at a less fertile site that was irrigated, chicken manure pellets were most effective because they contained more soluble mineral N than dairy cattle compost or manure. Magnitude of effects on tuber yield was dependent upon soil fertility (and probably the level of soil microbial activity) and soil moisture availability.

In the pot experiments basal fertiliser type (cattle-manure-based compost or chicken-manure pellets) affected both foliar blight (although significantly in only in one of the 3 pot trials) and tuber yields (in all trials). Blight was lower in cattle manure based compost treatments than where chicken manure pellets were used. At similar total N-input levels, chicken manure pellets always gave significantly higher yields than manure based compost. These results conflict with the results from field trials on long established organic farms trials where manure based composts always gave higher yields than chicken manure pellets probably due to their higher biological activity. Where the substrate had low biological activity (sand), a combination of organic-matter-based (e.g. compost) and water soluble N-inputs (e.g. chicken manure pellets) was better for yield. Liquid fertilizers based on pine or seaweed extracts and fish emulsion had no effects on late blight infection of leaves or tubers. Depth of planting of the mother tuber had no effect on tuber blight incidence.
In 2005, in the absence of late blight infection, well watered plants supplied with 170kg/ha N from chicken manure pellets gave yields almost double those of water-stressed plants with no supplementary fertility inputs. Applications of either manure-based compost or chicken manure pellets at 85 and 170kg/ha N significantly increased yield by 14 and 26% compared with the unfertilised control. However, doubling the fertility inputs from 85 to 170 kg/ha N did not significantly increase tuber yield with manure-based compost but gave a significant increase with chicken manure pellets. With full irrigation, chicken manure pellets invariably gave higher yields than farm-yard-manure based compost, averaging 12%. Yields of all treatments were higher

where water was in adequate supply. In these experiments, most effects of soil microbial activity or ‘inherent fertility’, organic manure type, level of nitrogen input and irrigation were additive. Whilst results from this experiment did not support the hypothesis that the best type and level of organic manure to apply depends upon the water supply and microbiological activity of the soil, the underlying principles are sound. The concept deserves further comprehensive testing over a wider range of situations covering a range of organic cropping systems on different soil types and with different histories. Fertility management that is optimized to a particular crop and situation to fully exploit the soil’s microbiological activity would ensure that valuable inputs of nutrients, that are often restricted in supply in organic systems, are utilized to best effect.

Overall, evidence suggested that the type and level of fertility input may affect yield by direct effects on crop and tuber growth because severity of infection with late blight did not appear to be increased as fertility input increased. The message is clear - fertility management is a key determinant of potato crop performance in organic systems and growers should focus on fertilising for yield not for managing late blight.

Planting date and seed tuber chitting:

Tuber bulking starts earlier with early planting and/or chitting (pre-sprouting) of seed tubers compared with late planting and/or the use of unchitted seed tubers.Consequently, early-planted crops grown from chitted seed should achieve a higher yield than late-planted crops grown from unchitted seed before infection leads to destruction of the canopy. Experiments evaluated this strategy in organic production systems for varieties with different blight susceptibility ratings, in different regions of the EU with different blight pressure without copper-based fungicides.

In the UK and the Netherlands from 2001 to 2003, crop responses to pre-sprouting (chitting) and early planting depended to a large extent on local conditions, over which the grower has limited control. In 2002 in both the UK and the Netherlands, early planting gave significantly higher yields than late planting for Nicola (susceptible) and Sante (resistant) Valor (moderately resistant) and Lady Balfour (highly resistant). Yield differences between planting dates depended on 1) when planting began 2) the interval between planting dates 3) the time at which late blight infection necessitated crop defoliation. These factors affected the length of growing season. When planting was late and the difference between the dates small, as in 2001 in the UK, yield effects were small. When the season was longer because weather suppressed blight, as in the Netherlands in 2003, there were no differences either: late planted crops had time to catch up with the early planted ones which senesced sooner. The early planting started and finished bulking and was defoliated before the late planting which continued to grow and accumulate yield. Chitting had similar yield effects to early planting. Fully chitted seed advanced tuber bulking leading to higher yields in 2002 in the Netherlands and in late planted Valor in the UK. Chitting effects were smaller when the growing period was longer, either because weather was unfavourable for late blight as in the Netherlands in 2003, or the variety was resistant e.g. Lady Balfour in the UK in 2002. In the UK in 2001 when planting was late and blight-infection started relatively early, it was more severe in late-planted Sante (the more resistant variety) but in 2002 the reverse happened with the resistant variety Lady Balfour. However, in the more susceptible varieties, Nicola in 2001 and Valor in 2002 in the UK and in both experiments in the Netherlands, there were no differences in blight infection that were related to planting date. Chitting also had no effects on late blight infection in the Netherlands, but in 2003 it was less severe in late-planted Lady Balfour in the UK. These observations are difficult to explain, reflecting the complex control and variation of blight resistance in potatoes throughout their growth.

Clearly, the results confirm that agronomic practices such as planting date and chitting which result in an earlier onset to tuber bulking are a useful component in a blight management strategy, but the effect is indirect. Benefits of early planting and/or sprouting on yield depend on the length of the growing season prior to blight infection. If blight is late, later planted or non-chitted seed may grow on and outyield early planted or chitted seed that senesce sooner. With early blight infection, more advanced treatments show to advantage. Timing of blight infection is impossible to predict accurately, therefore, early planting and pre-sprouting help to insure against the disease effects in organic production systems.

Plant configuration and spacing:

Periods of high humidity and prolonged leaf wetness encourage blight. These conditions may be affected by plant population and configuration which affect canopy structure and microclimate. Widely spaced plants with an open, well-aerated canopy should be less susceptible to blight infection than denser crops but effects on yield and tuber size-grading and hence marketability must also be considered. Effects of plant density and configuration and spacing on blight infection in varieties with different levels of resistance (Nicola (susceptible) and Sante (resistant)) were tested in 2001and 2002, in the UK and Netherlands. Populations tested were 33000, 44000 and 89000 plants/ha in two or three row beds in the UK and ranged from 38000 to 75000/ha in ridges either 75cm or 90cm apart in the Netherlands. These populations cover the commercial range for the production of large, baking potatoes at the lower population and small salad potatoes at the highest population. Invariably, there were no effects of plant population or configuration (bed arrangement or distance between rows) on the onset or rate of foliage blight infection or on tuber blight (which was rare). Very severe blight in the UK in 2001may have prevented effects although differences in canopy cover and structure with the different plant populations tested may have been too short-lived to be effective. Reports in the literature where plant population and spacing have decreased severity of blight infection refer to configurations that would not be used commercially and adverse yield and tuber size grading effects would far outweigh any beneficial effects on blight. Therefore, there is strong evidence that manipulating plant population and configuration in either conventional or organic crops has no beneficial effects in terms of late blight management, but is a most important technique for controlling marketable yield.

Irrigation regimes:

Potatoes are very sensitive to water supply and shortages decrease yield and quality (tuber size and shape, specific gravity and common scab infection) and so they are a priority crop for irrigation. However, both rainfall and overhead irrigation can encourage late blight infection because they increase humidity and the periods of leaf wetness and this risk must be taken into account. The major challenge is the same in both conventional and organic cropping systems: to balance the potential for lower yields with limited irrigation (i.e. the cost) with the potential for reduction in blight infection (i.e. the benefit). Irrigation strategy needs to optimise water use and hence crop response whilst minimising periods of favourable conditions for the development of blight infection. This requires application of irrigation water according to accurate assessments of crop demand under prevailing meteorological and soil conditions provided by monitoring equipment ('soil moisture meters') or predictive models rather than with cruder estimates.

In France in 2002 and 2003, an irrigation regime based on 'optimised, water input was compared with 'normal' practice (based largely on previous experience) and an unirrigated or 'rainfed' treatment in a dry area where irrigation of potatoes is a priority. All treatments were applied to a susceptible and a more resistant variety. In 2002 late blight infection was minimal and unaffected by water supply but irrigation improved yield by about 50% in both Charlotte (significantly) and Sante (not significantly) and tuber size grading compared with natural rainfall. Most noticeably, decreasing irrigation applied from 174 to 93mm did not significantly reduce yield or size grading benefits. In 2003, late blight infection reached up to 80% of leaf area infected in Charlotte (susceptible), but irrigation did not increase infection compared with the unirrigated controls. Irrigation improved both total and marketable yields but the optimised treatment was no better than the usual treatment. In this area of France (and other areas and countries where water stress develops), irrigation is essential to achieve high marketable yields. These can be achieved with reduced applications of water where a scheduling mechanism is used, apparently without much risk of increasing late blight infection.

Defoliation strategies:

Defoliation (destruction of the foliage by physical, chemical and thermal methods) reduces the risk of tuber blight infection which lowers marketable yield and provides a major source of inoculum that causes infection in newly emerging crops in the following year. Timing, method and prevailing environmental conditions all affect the performance of defoliation. Experiments made in the United Kingdom in 2001 & 2002 investigated effects of time and method of crop defoliation on tuber blight using methods allowed in organic production: burning with a propane gas-burner, mechanically defoliating the tops with a flail and a combination of burning and flailing, compared with an untreated control. Treatments were applied to varieties with different levels of tuber blight resistance and at low and moderate and levels of infection. Some included irrigation immediately after defoliation to simulate rainfall and wash zoospores from the treated foliage into the soil.
Yields and tuber size grading were largely unaffected by time or method of defoliation but yields were higher where defoliation was omitted. Because only moderate levels of tuber blight developed in both 2001 and 2002 irrespective of the resistance of the variety, it was not possible to draw firm conclusions about the efficacy of the different treatments for reducing tuber blight and improving marketable yields. In 2001, all defoliation methods reduced sporulation potential of the stems to a similar degree compared to the undefoliated control with no effect on the duration of 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). The simplest and cheapest method of defoliation i.e. flailing may suffice

but this needs to be tested further where conditions are more conducive to the development of tuber blight. If flailing is followed by foliage regrowth, risk of infection may be greater than for treatments involving burning with a propane-gas burner unless further passes with a flail are made. Leaving the tops to be killed off completely by late blight presents the greatest risk of tuber blight infection and serious losses of marketable yield and crop profitability.

5) ALTERNATIVE TREATMENTS AND APPLICATION AND FORMULATION TECHNOLOGY

Alternative control treatments that are acceptable in organic cropping systems and reduce or eliminate need for copper-based fungicides yet maintain crop yields and economic performance are highly desirable. Biologically-based treatments may have direct antifungal effects, or stimulate competitor microorganisms and/or affect the plant via resistance inducing/"plant strengthening" activities. Some may act as foliar feeds However, there are few reports of successful control of late blight with such alternatives. Few of them have been evaluated in the field and a limited amount is known about their specific modes of action or compatibility in mixtures. Formulation and application methodology, application rates, timing and frequency must also be considered as they may improve their efficacy, minimise the amount of the control agents required and avoid possible development of resistance by the pathogen to the control agents.Biological Control Agents (BCAs) such as compost extracts (CEs), plant and seaweed extracts (PEs), micro-organisms (MOs) and commercial products (CPs) were compared in some instances with different rates of copper fungicides, some at a much lower rate than the then prevailing limit of 8kg elemental copper/ha/year. In total, approximately 100 'alternative' treatments were tested between 2001 and 2004 under different seasonal conditions in laboratory, glasshouse and field environments. Effectiveness of copper-based fungicides at increasingly lower rates was also investigated as a short to medium term solution to the problem until alternatives are available that are fully effective.

Compost, Seaweed, Plant and 'Animal-based' extracts:

Some compost, seaweed, plant and 'animal-based' extracts have previously been reported to suppress late blight development in leaf bioassays when applied to potato leaves. These effects may be due to direct antifungal or resistance inducing/plant strengthening effects and they may act as 'foliar feeds', but the exact mechanism is unclear and little is known about their effectiveness.

Experiments in Denmark (D) and the United Kingdom (UK) were designed to determine and quantify the effectiveness of compost extracts made from cattle manure (D and UK); cattle slurry (D); horse manure (D); municipal and domestic greenwaste (UK) at different stages of the composting process. Extracts made from composted cattle manure, greenwaste and household waste showed no effects of fungicidal activity in a leaf bioassay or in the field in the UK. Copper oxychloride was effective and markedly better than the sulphur + copper sulphate product. In Denmark, in the bioassays, compost extracts suppressed late blight as effectively as copper oxychloride, but the effectiveness declined with age of the compost. Autoclaving the oldest composts prior to extraction gave some improvement in efficacy indicating a chemical rather than biological effect. The promising results shown in the leaf bioassays were not reproduced in the field, possibly because of limited persistence on leaves. In 2003, an additive (potassium oleate) was mixed with cattle deep litter compost extract as a wetter to improve the contact and persistency. Potassium oleate alone delayed 50% leaf blight infection by about a week: combining it with the autoclaved compost extract with the additive gave a few further days protection. This increased yield by about 10% compared with the untreated control, but a copper based fungicide at one third the recommended rate increased yield by almost 40%. Compost extracts gave no control of late blight: neither did seaweed, brassica or pine extracts,   chitin (animal-based) and fish emulsion, whereas copper oxychloride consistently gave the best control of foliage blight and highest yield.

Micro-organisms:

Micro-organisms were tested for effects on the late blight pathogen at BBA (D) and Agroscope FAL (CH). These included bacteria, fungi and yeasts, including some from collections kept by Research Institutions, Plant Pathology Units etc. and some as commercial products e.g. MBI600®, Serenade®, Sonata®, Trichodex®, Polyversum®. At BBA (D) in laboratory-based assessments, *Xenorhabdus bovienii* and *Pseudomonas putida* bacteria showed significant effects against *P. infestans* when applied close to the time of infection, but many other micro-organisms, including MBI600® were ineffective. Timing of application of the micro-organisms to the leaves relative to inoculation with *P. infestans* influenced their efficacy and in general, the closer the better. Most combinations of micro-organisms with other micro-organisms or plant extracts were compatible offering the possibility of improved effectiveness due to additive or synergistic effects and some improvements over single treatments were observed. In potted plants grown in open greenhouse and under field conditions, Serenade® (a *B. subtilis* preparation) and the bacterium *Xenorhabdus bovienii* gave good levels of control of *P. infestans* even under conditions that were favourable for the growth of the pathogen but unfavourable for the growth of the micro-organisms. With *X. bovienii*, there was a cumulative effect of repeated applications leading to improved control of late blight and this might be further improved by adding a wetting agent or combining the micro-organism with other effective treatments.

Mineral and Miscellaneous preparations:

Mineral (e.g. stone meal, sulphuric clays such as Mycosin®, clay minerals) and 'miscellaneous' organic and inorganic preparations were tested at Agroscope FAL Mycosin and similar preparations were effective under low to moderate but not high disease pressure. Some miscellaneous preparations were effective in the laboratory but not in the field, probably because of poor persistency.

Application and formulation technology:

Directional spraying penetrates more deeply into the canopy and covers leaves and stems more effectively than a conventional, overhead sprayer and therefore may reduce dose per application or the number of applications required. In 2002 and 2003, field trials in the UK tested the effects of applying different biologically-based preparations (compost extracts, plant extracts) *Bacillus subtilis* (BioM8) and copper-based fungicides (copper oxychloride and copper sulphate + sulphur) with either a conventional overhead application or a directed (drop-leg sprayer). The method of application had no effect on the efficacy of any treatment although general observations of the deposition of copper-based fungicide treatments confirmed that coverage of the foliage by the drop-leg sprayer was superior to that of the conventional, overhead boom sprayer. In 2003, very hot and dry weather conditions suppressed late blight infection making it impossible to draw any useful conclusions about the treatments (but the more uniform coverage of the drop-leg sprayer was evident again). Despite the potential improvements from directed (drop-leg) and air-assisted spraying, conventional overhead boom sprayers are most commonly used and this is likely to continue for reasons of cost and simplicity. In any case, it was clear that for late blight, the 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.

Formulation of alternatives to copper-based fungicides may influence their effectiveness by improving persistency and rainfastness. At Agroscope FAL, some of the alternatives were formulated with surfactants or wetters/spreaders (e.g. Tween 20; CereNat E30) but no improvements were observed. Clearly until effective alternatives are identified, progress with developing the best application methods and formulations will be limited.

Copper-based fungicides:

None of the wide range of alternatives tested gave an acceptable level of late blight control and few were any better than untreated controls. Copper-based fungicides were effective in the field provided they were applied at the right time. Copper oxychloride was the compound most frequently used at rates and frequencies ranging from the (then) maximum permissible upper limit of 8 kg/ha/year of elemental copper down to 1.0 kg/hectare/year, extending the life of the foliage by about one week to three weeks. However, effective control of late blight did not always increase total or marketable yields especially if tuber bulking had already slowed down or stopped before significant infection occurred, but it may have given protection against tuber blight. However, there was no clear relationship between the level of foliage blight and tuber blight and tuber blight infection was very low (<1% by weight or number) even when foliage blight was very severe. This makes it difficult for organic growers in particular to decide when to defoliate their crops to be confident of minimising tuber blight infection.

The Blight-Mop programme evaluated a very comprehensive range of possible alternatives to copper-based fungicides. Disappointingly, no effective alternatives were found and the authors are unaware of any from other investigations. Therefore, at least in the short to medium term until there is a discovery, an integrated strategy for late blight control including the use of low doses of elemental copper, applied according to a Decision Support System (DSS), may be a way forward. Of course, this would only be applicable in those countries and by certifying authorities that permit use of copper fungicides.

6) INTEGRATED SYSTEMS APPROACH: DESIGN AND FIELD EVALUATION OF NOVEL BLIGHT MANAGEMENT SYSTEMS

1. EVALUATION OF INDIVIDUAL COMPONENT STRATEGY EFFICACY:

Table 1 summarizes the major characteristics of each component strategy tested between 2001 and 2003 for their potential contribution to an integrated management system for late blight. An overview over each component strategy follows.

Table 1: Summary of the major characteristics of the component strategies.

Name of strategy	Is the strategy promising?	Notes on the applicability
A) varieties	Very promising (for some varieties)	Immediately applicable (but new varieties become available continuously)
B) alternating rows	Promise for limited reduction of foliar blight	Ideal combinations not yet developed
C) intercropping	Promise for limited reduction of foliar blight	Not yet fully developed
D) variety mixtures	Promise for limited reduction of foliar blight	limited to special cases at present
E) planting date	Promise for limited yield increase	Potential already exploited to a large degree
F) chitting	Promise for limited yield increase	limited by practical considerations such as labour requirements
G) defoliation	Promise for limited reduction of tuber blight	mainly limited by availability of equipment
H) fertilization	Promise for significant yield or quality increase	immediately applicable
I) rotation	Promise for some yield or quality increase	depends on crop rotation
J) foliar sprays & microbial inocula	No clear, experimental proof of efficacy	- - -
K) volunteer removal	No clear, experimental proof of efficacy	- - -
L) planting configuration	No effect within reasonable densities	- - -
M) irrigation	Promise for significant yield or quality increase	limited by availability of water & equipment
N) compost extracts	No clear, experimental proof of efficacy	- - -
O) microbial antagonists & plant extracts	No clear, experimental proof of efficacy	- - -
P) application equipment	Promise for limited reduction of foliar blight	limited by costs for investment
Q) alternative sprays	No clear, experimental proof of efficacy	- - -
R) low dosage of copper	Promise for similar protection against foliar blight with lower copper use	immediately applicable

A) Varieties
Replace existing varieties with a new more blight tolerant/resistant variety.

- Implications for production, storage and processing for different markets must be considered.
- Introduction is a lengthy process of because of national/ recommended list requirements; market and producer familiarisation process; seed multiplication. Depending on the genetics of resistance of the new variety, the risk of breakdown of resistance varies.
- Promising varieties were available in all countries. Widespread adoption would contribute to drastic reductions of foliar and/or tuber blight infections.

B) Alternating rows
Two or more varieties are planted in alternating rows or alternating beds of two, four or more rows.

- Most effective under low disease pressure with alternating varieties showing different types/level of resistance to late blight.
- Practical/organisational/mechanisation constraints. Varieties should be compatible for fertilisation needs, harvesting time etc.
- Not yet fully developed for practical application.

C) Intercropping
Beds or potato ‘fields’ of different size and/or orientation are separated by barriers composed of other crop species, such as clover or wheat.

- Most effective under low disease pressure.
- Practical/organisational/rotational/mechanisation constraints
- Not yet fully developed for practical application. Combinations with other row-crops e.g. maize may have potential.

D) Variety mixtures
Two or more varieties are planted at random in an intimate mixture within each row.

- Similar to the strategy of alternating rows, but closer association between components. Expected to be somewhat more effective.
- Practical/organisational/mechanisation constraints. Varieties should be compatible for fertilisation needs, harvesting time etc.
- Major limitation is unacceptability of mixed variety lots for most purposes by the trade but may be acceptable on a small scale or where separation is possible.

E) Planting date
Earlier planting leads to earlier tuber bulking, possibly leading to a higher yield before blight attacks.

- Risk of cold (frost damage) and/or wet weather and limited slow mineralisation and N-availability in some springs.
- Most growers use this strategy. Therefore, it has relatively little potential for further improvement.

F) Chitting/pre-sprouting seed tubers

Chitting seed tubers brings tuber bulking forward, possibly leading to a higher yield before blight attacks (and therefore similar in effect to earlier planting). May have effects on susceptibility to blight

- Major limitations: additional labour requirement; possible damage with fully automatic planters
- Standard practice in some countries and for some growers. Therefore, it has relatively little potential for further improvement in these situations.

G) Defoliation strategy

Defoliation with a propane gas burner kills blight mycelia and blight-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.

- Burning localized infected patches of the crop may slow down the epidemic. Burning infected fields reduces tuber blight.
- Major limitations: availability of defoliation equipment; cost of gas. Environmental concerns (use of fossil energy) are also important in some areas.
- Combined flailing/burning effective as burning alone, but less gas required.

H) Optimized fertilization regime

No direct effects on foliar blight evident, but optimized fertilization regimes have major effects on yield and quality.

- Major limitations: availability of manure on the farm; environmental legislation and organic standards.
- Nutrient availability to the potato crop also depends on rotation and weather, (which affects mineralization.)
- Fertility management is usually/should be optimized in view of yield effects rather than blight control.

I) Position in rotation

Rotational position has effects on yield via nutrient supply/availability and soil structure set by the preceding crop, but no direct effects on blight susceptibility.

- 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 are at risk of tuber diseases and pests such as *Rhizoctonia solanii*, drycore, wire worms.
- 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.

J) Foliar sprays & microbial inocula

Use of foliar sprays or microbial inocula for direct control of late blight.

- Although this approach is effective in some crops, its effectiveness against late blight of potatoes has not been demonstrated under field conditions.

K) Volunteer removal

Potato volunteers following harvest are a important source of disease inoculum and can be reduced by grazing pigs on harvested potato fields.

- 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.
- Because this method reduces the sources of inoculum in the following year, its effects are not evident. With the limitations, this method is unlikely to be adopted accepted by many farmers.

L) Planting density and configuration

Planting density and an optimized planting configuration alter crop structure, and thereby influence microclimate and blight.

- Only very low plant densities reduce blight (lower than commercially acceptable limit).
- Planting configuration is usually designed to optimize tuber size for specific markets, and facilitate mechanisation. Planting density influences seed requirement/ha, which is a major variable cost of production.
- To be effective on late blight, planting densities and configurations outside 'normal' commercial practice are required. Consequently, this is not a feasible component strategy.

M) Optimized irrigation regime

Optimized irrigation regimes must avoid long periods of leaf wetness (to avoid blight infection), as well as periods of drought (to ensure good yield and tuber quality). Therefore, these regimes vary considerably for wet and dry regions.

- Major limitations: availability of water and of irrigation equipment; equipment must be removed before all cultivation measures can proceed; high labour requirement.
- Most improvements in yield and quality can be achieved with irrigation on farms which currently do not irrigate. However, not all farms have water available and can afford irrigation equipment.

N) Compost extracts

Use of compost extracts for direct control of late blight.

- Although reported to be effective in some crops, its 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 need to 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.

O) Microbial antagonists & plant extracts

Spraying antagonists or plant extracts for direct control of late blight.

- Sprays showed efficacies up to 70 % and 45 % in glasshouse and semi-field trials, but efficacy was low in the field. 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.

P) Spray application equipment

Underleaf spraying technology leads to a more uniform cover of the canopy with plant protection products. For compounds with contact action in particular, e.g. copper-based fungicides, this improves efficacy.

- Major limitations: high equipment costs, particularly if the existing spray equipment does not need replacement; underleaf sprayers treat fewer rows than standard equipment, increasing labour requirement; risk of damage from spraying droplegs when the canopy is closed; need to adjust dropleg spacing according to crop row width which may necessitate frequent adjustments to accommodate crops other than potatoes.
- In a preliminary trial, air assisted sprayers gave similar coverage to underleaf sprayers. Whilst they lack the disadvantages described above, they are even more expensive.

Q) Alternative sprays

Spraying alternative, commercially available or novel products for direct control of late blight.

- Major limitations: choice of potential products is tightly restricted by the Regulation on organic farming 2092/91 EEC.
- Within this limit, no products with good efficacy were found. Therefore, this strategy has no practical application at the moment and requires further research and development.

R) Low dosage of copper

Copper fungicides are applied at lower dosages, resulting in a lower total usage of copper. At the same time, the timing of application is optimized by the PhytoPRE or other, similar decision support systems.

- With this strategy, 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).
- 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.

Several of the component strategies examined are **not (yet) applicable in practice** e.g. intercropping, variety mixtures, foliar sprays & microbial inocula, volunteer removal, planting configuration, compost extracts, microbial antagonists & plant extracts and alternative sprays. Some are not sufficiently effective at present and some e.g. alternating rows, variety mixtures, very low plant populations and wide spacing, present considerable practical challenges although effects on marketability of the crop are a major constraint. For these reasons such methods are unlikely to be adopted by a majority of organic farmers unless these problems are overcome. Among strategies which are **applicable in practice**, several groups can be distinguished. Those 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 **aspects other than blight,** particularly with regard to crop performance. However, these will only be adopted, if their overall impact is beneficial and the advantages will only be realised by growers who do not already use these techniques.

Defoliation strategy and specialised application equipment can make a useful contribution to the blight management strategy. Some farms have already invested in the necessary equipment and adopted this strategy, but for other farms, the cost of the investment would be difficult to justify on the basis of the level improvement in blight protection. Spraying lower dosages of copper than used currently could be widely practiced, but concerns of growers that reduced dosages of copper might not be sufficiently effective 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. Some of the more easily applicable strategies are **already widely used in current practice** on certain farms or in certain regions including 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.

In conclusion, each of the component strategies will be useful and applicable under a specific set of circumstances, but not under others. The challenge to organic growers and their advisors is to identify those particular component strategies within the currently used late blight management system that are not used at present and can therefore be introduced; that are used at present but can be optimised; that are used at present but are ineffective and can be replaced with effective alternatives. 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.
The field tests of optimised blight management systems were designed to address this challenge.

2. FIELD TESTS OF OPTIMISED BLIGHT MANAGEMENT SYSTEMS:

Efficacy of optimised, regionally-adapted blight management systems were validated in field trials in seven countries in 2004: CH, NL, DK, NO, UK, FR, DE. In each country, experiments were carried out on 1 MODEL (Research) farm and 4 LINK (Commercial farms).

On MODEL farms an "additive trial" design was used with treatments comprising combinations of 1, 2, 3, 4 or 5 components strategies. Component strategies (CS) were sequentially added to the currently used late blight management system (CULBMS) i.e :

1. CULBMS
2. CULBMS plus CS1 (predicted to have the highest impact)
3. CULBMS plus CS1 and CS2 (predicted to have the 2nd highest impact)
4. CULBMS plus CS1, CS2 and CS3 (predicted to have the 3rd highest impact)
5. CULBMS plus CS1, CS2, CS3 and CS4 (predicted to have the 4th highest impact)

6. CULBMS plus all strategies predicted to have an impact on late blight in WP 7.1.

On LINK farms an optimized system was compared with the currently used late blight management system (CULBMS). The optimized system was adapted to each farm's CULBMS and needs, and was therefore different for each farm i.e.:

1. CULBMS
2. CULBMS plus all strategies predicted to have an impact on late blight

LINK farms were widely spread over the countries, and included farms with differing potato management systems.

Foliage and tuber blight were assessed and the physical and financial performance of the 'optimised' blight management systems, taking account of materials, machinery and labour costs to provide cost /benefit analyses.

On the MODEL farms, different component and integrated strategies had different effects from country to country in terms of the most 'profitable system. In some cases, the benefits were due to improvements in blight control and hence higher marketable yields achieved. In others it was because of improvements in output (Euros/ha) caused by higher marketable yields and/or reduced costs that were not necessarily related to differences in blight infection or control. In Switzerland, introducing a more resistant variety (changing from Agria to Naturella) had the biggest effect, mainly by reducing foliar blight. In the Netherlands, lower planting density had the biggest effect, by reducing seed costs and increasing returns with no effect on blight infection. In Denmark, early planting had the biggest effect by increasing returns from higher yields that were achieved before damaging blight infection occurred. In Norway, chitting/pre-sprouting had the biggest effect by increasing marketable yield. In the United Kingdom, copper-based fungicides had the biggest effect, by reducing foliar blight. In France, yields were unusually low and the results have to be interpreted with care. Here, as in Switzerland, the change to a more resistant variety (from Charlotte to Eden) had the biggest effect, mainly by reducing foliar blight. In Germany the change in rotational position had the strongest effect, mainly by increasing marketable yield. On the LINK farms, the effects of 'optimised' systems were variable. In Switzerland, the optimized system reduced foliar blight in all cases yet the margin over cost of the improved system was better on only one LINK farm (it decreased it on three farms, due to lower marketable yields of the optimized system). In the Netherlands, the optimized system led to higher margins on two out of four farms with substantial differences between treatments in foliar blight, marketable yield, returns and costs. In Denmark, the optimized system improved the margin on one farm with major treatment differences in marketable yield. In Norway, the optimized system improved margins on all four farms, mainly due to better marketable yields. In the United Kingdom, the optimized system improved margin on all four farms, due to a significant reduction in foliar blight and/or better marketable yields. In France, the optimized system improved margin on three out of four farms. Treatments affected mainly foliar blight and/or marketable yield. In Germany the optimized system did not improve margin, mainly due to the higher costs of the improved system.

Success of integrated strategies was influenced by differences between and within countries in potato crop management and performance in organic cropping systems, the impact of late blight and growers' attitudes to the disease. On all MODEL farms, at least one of the experimental treatments gave better financial results than the currently used management system. This demonstrates that the approach of improving management systems is promising and that in most cases there is scope for improvements of the current management system. Improvements did not always work via the same mechanism. In Switzerland, France and the United Kingdom, the improvements were caused by a reduction in foliar blight attributable to the new strategy. In Norway, Germany and Denmark, increases of marketable yield and hence output that were not associated with decreased blight infection were responsible. In the Netherlands, costs were reduced as a result of lower seed rate leading to increased output.

LINK farm results must be interpreted more cautiously because treatments were not replicated, but the large plot sizes and the wide geographic distribution of the farms allow valid conclusions on practical applicability of the selected strategies. 16 of the 28 LINK farms (57 %) achieved a higher margin with the optimized system than the currently used management system. Of these, improvements could be attributed to reduced foliar blight on 7 farms, increased marketable yield on 8 farms and increased returns on 1 farm.

Whether improvements were possible depended on several factors:

- Level of sophistication of potato management systems varied greatly between farms and consequently, the potential for improvement.
- Variation from background factors that are characteristic of a specific area or farm may be very difficult or impossible to control and have a significant or over-riding effect on performance of the potato crop. This means that farms from different parts of a country could give quite different results, even though similar treatments were applied. For example, within a country, 2004 was a good year for the crop on some LINK farms where the optimized system improved margins, but this was not the case for others. Where there is an underlying problem e.g. with tuber quality, this needs to be resolved before the potential advantages of the new system can be fully realised. Under such circumstances, short-term optimization of the management system was not effective. In other cases, the optimized system may be beneficial in theory, but prove not to be in practice because an unanticipated problem (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.

With the possible exceptions of highly resistant varieties and use of copper-based fungicides (for which there are several potential limitations), no individual technique or component strategy was effective enough for the management of late blight when applied as a sole treatment. However, some were found which can contribute to a reduction of late blight as part of an integrated management system. By combining a range of component strategies both additive and synergistic effects may operate, but negative interactions between component strategies that result in more severe infections and decreased margins must be avoided. We believe that this 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 may be appropriate until they become redundant or are withdrawn. Improving the entire potato management system is demanding, because it requires a detailed analysis of the current system, good knowledge of alternative strategies, their strengths and weaknesses and applicability in different situations. This approach differs fundamentally from the conventional approach to plant protection which relies heavily on synthetic pesticides: it also requires considerably more flexibility from the farmer. At the community level, such an approach requires the combined efforts of researchers, advisory and extension services and farmers to communicate the relevant information utilising technical publications in farmers' journals, the internet, workshop presentations, on-farm demonstrations and conferences to stimulate and support uptake of the technology. This needs to be further disseminated at national, regional and farm levels, with the emphasis on sound and up-to-date knowledge, that can be translated into improvements in crop management and performance, not only for organic systems of production, but also for conventional. The farmer may acquire this knowledge by himself from the sources of information described above, or with the aid of advisory and consultancy services.

The experiments gave proof of concept for the systems management approach to address the problem of late blight control in organic systems directly by decreasing infection and/or by improving resource use and hence crop performance to mitigate the effects of the disease. Practical implementation requires the potato management system of each farm to be optimized individually. Certainly, there is no unique blueprint that is universally applicable. Further fine-tuning is likely to require on-farm experimentation and possibly some further applied research to develop some of the less advanced strategies and ensure that the optimum strategy is identified and selected for a specific situation. Achieving the optimum system is a challenge, which is likely to take several years in most cases. Whether or not a given component strategy is useful on a specific farm, and acceptable to the farmer depends on a multitude of factors, such as soil properties, local weather and the economic conditions, the availability of alternatives and possible conflicts between potatoes and other crops on the farm. However, any optimized system will be transient because of continual changes in technological, political, climatic, environmental and economic conditions that demand constant re-evaluation and modification of current, 'state of the art' systems.

Most of the Research Institutes involved in the Blight MOP project work closely with farmers. Their communication strategies and advice should help to translate and implement the results into commercial practice. Better management of late blight infections caused by *Phytophthora infestans* that is less dependent on copper-based fungicides will help to 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.