Chapter 5: Agronomic Strategies

Section 1: Volunteer removal strategies

Section 2: Position in the rotation re: fertility building grass/clover crops

Section 3: Effect of animal manures and N:K ratios

Section 4: Planting date and seed tuber chitting

Section 5: Plant configuration & spacing

Section 6: Irrigation regimes

Section 7: Foliar sprays and microbial soil inocula

Section 8: Defoliation strategy and timing

Section 9: Consolidated Report on Agronomic Strategies

Chapter 5: Agronomic Strategies

General Introduction

Agronomic techniques can be used as part of an overall integrated approach to late blight management. Some lead to an earlier start to tuber bulking and/or increase the rate so that an acceptable marketable yield is achieved before the disease results in death of the crop or deliberate defoliation by the grower to avoid infection of tubers. Others may affect the crop's susceptibility to disease or the rate at which the disease progresses because of effects on the microclimate within the crop canopy or have fungicidal effects (alternatives to copper-based fungicides are of particular interest in this respect). Development of effective agronomic strategies requires optimization and integration of a range of cultural methods with potential to affect crop infection with late blight which include:

Potato volunteer (groundkeeper) removal strategies; fertility management strategies (position in the rotation relative to the fertility building grass/clover crop phase; use of animal manures and manipulation of N:K ratios prior to planting); planting date and seed tuber chitting (pre-sprouting); plant configuration & spacing; irrigation regimes; defoliation strategies; foliar sprays and microbial soil inocula programmes.

Potato volunteer (groundkeeper) removal strategies: In areas with mild winters, potato volunteers (especially those emerging within potato fields - but also those emerging in neighbouring, non-potato crops) are an important primary inoculum source of *P. infestans*. Unfortunately, in organic production systems mechanical weed control and hand- weeding between potato crops is usually insufficient to reduce populations of potato volunteers to minimise the risk. A different approach is to put pigs onto land after the potato harvest as they are known to dig up and eat even relatively small potato tubers. In certain situations, this could be a useful alternative or an additional volunteer control strategy that would also contribute to fertility inputs. However, management may be difficult and the pigs may create greater soil disturbance and compaction leading to adverse effects on establishment and growth of the subsequent crop having implications for the cost/benefit ratio.

Fertility management strategies

Position in the rotation relative to the fertility building grass/clover crop phase:
Potatoes in organic rotations are most commonly grown immediately after grass/clover ("fertility building") crops or after a cereal crop which follows a grass/clover crop. This was confirmed by the survey reported in Chapter 2 – 40% of organic potato crops followed grass/clover and 40% followed cereals with only 20% following vegetables/roots and in most cases potatoes were grown at intervals of 4 to 7 years. Levels of available soil nitrogen immediately after a grass/clover ley are higher than after the subsequent cereal crop. Whilst this is thought to increase potato yields, it may also render crops more susceptible to blight. Resistance expression by potatoes may also depend on crop nutrient demand at different growth stages as well as soil fertility status. Since stages of maximum nutrient demand differ between early, mid, and late bulking potato varieties, this is likely to result in temporal differences between varieties with respect to blight resistance.

Animal manures and N:K ratio: According to the survey (Chapter 2) growers fully recognise the need to optimise fertility and that it is generally sub-optimal in organic cropping systems. This not only limits yield because of adverse effects on growth but also is believed to pre-dispose plants to late blight: a clear message was that 'weak' plants are more susceptible than well-fertilised, vigorously growing plants. Nitrogen may be limiting in many cases and also potassium to a greater extent, whilst phosphate is rarely, if ever, deficient. Cattle manure or slurry is the main fertility input and applied prior to planting but compost and other organic manures are sometimes used and occasionally applied as a 'top-dressing' post-planting. Permitted fertility inputs used in organic farming (e.g. animal manures, compost, legume crops) differ with respect to their effect on soil nutrient content, proportions of different nutrients and nutrient release during the growing season. The aim is to use such inputs to achieve balanced fertility management over the complete rotation to optimise production. In potatoes, crop yield and quality are improved by balanced fertility and one of the contributory factors is thought to be an increase in resistance to fungal diseases. Imbalances on the other hand, such as a lack of available potassium or excesses of readily available soluble nutrients (especially N) may result in increased susceptibility to fungal pathogens and the N:K ratio may be particularly important.

Planting date and chitting (pre-sprouting): Early establishment of crops (using early planting and/or chitting of seed potatoes) to extend the growing period prior to the appearance of late blight is used in several regions of the EU as a strategy to reduce yield losses due to late blight as shown by the survey results in Chapter 2. However, recent trials have shown that, in certain cases, chitted potatoes may suffer increased blight attack because the potatoes are physiologically older and more susceptible at the time of blight attack than non-chitted potatoes. Thus, chitting may not only affect the yield of the crop but also interactions between blight inoculum density and plant susceptibility. However, so far, this strategy has not been optimised for varieties with different degrees of blight susceptibility, or in regions with different blight pressure and in the absence of copper-based fungicides.

Planting configuration and spacing: *P. infestans* infection and spread is facilitated by periods of high humidity and prolonged leaf wetness within the crop canopy. Reductions in the planting density (planting configuration/spacing between rows and spacing within rows) can shorten the period of leaf wetness/high humidity because of better aeration and thus suppress blight development. However, decreasing planting density is likely to affect yield and tuber size grading, increasing the yield of larger tubers, which for maincrops may be more difficult to market although the problem of under-sized outgrades will decrease. The economical optimum for planting configuration and spacing will depend on variety (with moderately resistant varieties probably benefiting more than fully susceptible varieties from wider spacings), target harvest date and the onset and severity of late blight.

Irrigation regimes and the development of late blight, crop yield and quality: Overhead spray irrigation (which is increasingly used in organic production to improve yields and quality), like natural rainfall, wets the leaves and increases humidity in the crop and can encourage blight development if timed inappropriately. Optimum spray irrigation regimes should result in higher yields and better quality without increasing the problem of late blight infection. However, the effect of limiting the amount or frequency of irrigation to avoid or delay late blight infection must be balanced against potential limitations to yield associated with water shortage. Interactions between varieties with different resistance levels and irrigation regimes with respect to blight development and severity may be important. There could be less need to restrict water applications in more resistant potato varieties in which the pathogen often requires longer periods of leaf wetness for infection to occur than in more susceptible varieties and yields would be affected to a lesser extent.

Foliar sprays and microbial soil inocula: Seaweed extract preparations, compost extracts and mixed microbial fermentation products have been proposed as potential blight control treatments. In the survey, between 30 and 60% of the growers used alternative treatments from a list of about 40 different products, and their use in particularly popular in Switzerland. Reliable data on their efficacy and information about their mode of action are, however, not available, but they appear to have a lower efficacy than copper fungicides. They may have direct fungicidal effects on the pathogen or influence the resistance of the crop. However, as some of these products supply mineral nutrients (e.g. seaweed extracts) or are thought to improve nutrient supply to the plant via stimulation of soil microbial processes (e.g. EcoN), their potential effect on late blight may therefore be (at least partially) due to improved nutrition of the host plant.

Defoliation strategy and timing: Production of *P. infestans'* spores depends on the presence of live potato tissues. Consequently, defoliation is commonly used by growers to remove and destroy the tops before harvest to reduce the risk of tubers becoming infected by zoospores produced on the foliage. Indeed, this was the major reason given by growers surveyed for Chapter 2 for defoliation at some stage (normally during crop senescence, but sooner if blight infection came in early). The effectiveness of different defoliation methods (flailing and burning alone or in combination) permitted under organic farming standards to kill and/or restrict the production of spores will vary and be influenced to a large extent by prevailing weather conditions (in particular rainfall). Their capital, energy and labour requirements will also differ. The optimum method and timing for defoliation may have to be revised if copper-based fungicides are omitted from the blight control strategy.

Section 1: Volunteer removal strategies

Summary

Efficient destruction of volunteers (and potato dumps) is an important and primary component of an integrated late blight management system as it eliminates the most important source of the inoculum leading to infection of newly emerging crops. However, their control is more difficult in organic cropping systems than in conventional ones where total and selective herbicides can be used. Outdoor pigs are highly effective foragers and will eat potato tubers that are on the soil surface and can unearth buried ones providing an additional 'mechanical' means of control. Experiments were made in the Netherlands (NL) in 2001 and 2003 to evaluate the effectiveness of pigs for the removal of potato volunteers (groundkeepers) immediately following the harvest of the potato crop. Sows were used in 2001 and finishing pigs in 2003. Both types consumed volunteer tubers after a few days and virtually completely within one week, which equated to a stocking density of between 600 and 1000 'pig days' irrespective of the type of pigs (sows or finishers).

However, the effectiveness of this control method was offset by a number of problems: in 2001 many of pregnant sows used aborted their offspring following the experiment in the winter of 2001/2002. Whilst there was no conclusive veterinary evidence that consuming raw potatoes in the field was responsible, the risk was too great to accept. This risk was eliminated by using finishing pigs, but their meat quality was adversely affected (compared with pigs that had not been used to remove tubers from a potato field) resulting in a loss of 60 euros per pig. In addition, pigs' foraging activity resulted in poaching and soil damage/compaction that decreased establishment of the following cereal. Thus, whilst this method of volunteer control is extremely effective in relation to late blight management, not only is it limited in application because it depends on availability of pigs in autumn and soil type, but also because of potentially adverse effects on sow fertility, pig carcase quality and soil conditions.

Introduction

In areas with mild winters, potato volunteers, either emerging within potato fields or in neighbouring non-potato crops, present an important primary inoculum source for *P. infestans*. In organic production systems mechanical weed control and hand- weeding between potato crops in the rotation is often insufficient to reduce potato volunteers to a level where they do not pose a risk as a blight inoculum source. Specific mechanical methods are therefore often necessary to reduce volunteer populations. To some extent, these may be replaced by putting pigs onto land after harvest of potato crops. Pigs are known to dig up potato tubers including relatively small ones and thus could be used as an effective alternative or an additional volunteer control strategy. The use of pigs may have additional benefits (e.g. by providing additional fertility inputs as they forage), but a potential disadvantage is that they may also result in greater soil disturbance.

An experiment was conducted in the Netherlands by Louis Bolk Institute, which investigated the effects of different levels of foraging intensity in terms of 'pig-days per hectare' on the number of volunteer tubers remaining that could emerge in the next year.

Materials and methods

In 2001 a preliminary experiment using sows was set up as a randomised block trial, with three treatments (no pigs, 50 pigs/ha, 200 pigs/ha) in four replications. All plots were 10m wide x 20m long. In 2003, 20 finishing pigs were kept initially on a surface are of 2250 m^2 of a field immediately following the harvest of a potato crop. Every day the area available to the pigs was reduced by closing off an area of 75 m^2 at both ends of the area to increase foraging density from 89 - 1167 pig-days per hectare over the assessment period.

Results

In 2001 the sows ate all available potatoes in the plots within 3 days. After the third day (600 pig-days per hectare) as no food was left they started to break out onto new areas. Soil structure analyses indicated that the pigs caused a more compact structure in the top soil before winter, but in spring these differences had disappeared. In the spring of 2002 only 8 volunteers were found on 1728 m^2 (equivalent to 46/ha) and there were no differences between treatments. In the winter of 2001 - 2002 many of the sows that had been used in this experiment had abortion problems subsequently. Veterinary experts were consulted about these problems, but gave no conclusive answer whether this was the result of consuming raw potatoes during the experiment. Nevertheless, to avoid any possibility of such potential adverse effects, it was decided to use finishing pigs for the experiment in 2003 instead of pregnant sows.

In 2003 the finishing pigs ate all potatoes in the top soil within 8 - 16 days: after 8 days (967 pig-days/ha) the farmer had the impression that all remaining potatoes were consumed, and on this part of the experimental field only one potato was found at the final assessment of potatoes in the top soil (after 1167 pig-days/ha).The quality of the meat of the pigs that participated in the experiment was poorer than from other pigs on the farm and resulted in a loss of profit of € 60 per pig. Observations in spring 2004 of the farmer indicated structural damage to the whole of the experimental area caused by the pigs' foraging leading to poor emergence of triticale whereas it was good on other areas that had been free of pigs.

Discussion & Conclusions

Pigs can be very effective in removing potatoes that are left on the field after harvest. They are far more effective than other animals that will eat potatoes because pigs will root and dig them up from a considerable depth and not just from the surface. Both experiments showed that pigs were able to eat practically all potato groundkeepers within a reasonable time period following harvest and virtually eliminated the problem of volunteers overwintering to act as a source of late blight inoculum. However, possible risks of health problems when sows are used, meat quality problems when finishing pigs are used, and damage to soil structure limit the applicability of pigs as removers of volunteer potatoes.

Section 2: Position in the rotation re: fertility building grass/clover crops

Summary

In Germany, three potato varieties – Nicola, Rosella, and Simone, mainly differing in the time of initiation of tuber formation (early, middle, late, respectively) – were grown in a 3-factorial field trial for two years in 2 rotational positions i.e. after grass/clover and winter wheat (which had a grass/clover pre-crop) in order to induce a different fertility status through the nitrogen supply. Copper-based fungicide was used to control late blight. Nitrogen supply after grass/ clover was between 26 to 32 kg higher than after winter wheat. Although late blight severity was consistently higher after grass/clover the differences were not significant in both years. N-mineralisation rates in 2002 were below average due to unfavourable weather conditions in May and June. Thus, only in

2003 was the additional N-supply after grass/clover translated into significant yield increases. Although there were large differences in susceptibility of the varieties, especially in 2002 with Simone being most resistant, these did not result in corresponding differences in yield. Rosella significantly outyielded the other two varieties in both years. Copper fungicide treatment had a moderate but significant impact on disease severity in 2002 and 2003. However, yield increases due to copper fungicide treatment were only significant in the year 2003 by 1.9 t/ha. It is concluded that the combination of the fertility status of the site and varietal choice is an important system-based means of reducing yield losses due to late blight in organic potato production while the use of copper fungicides may not result in the desired yield effects.

In the Netherlands, two experiments were done in 2002 and 2003 using varieties Sante, Appell and Aziza in 2002 and Raja in 2003. In 2002, potatoes were grown immediately following spring wheat or lucerne and in 2003 following a pure-stand of barley or a barley crop undersown with barley. The fertility input was further modified by applying 20 cubic metres of slurry during the early part of crop growth to half of the plots: the remaining half of the plots received no additional fertiliser.
Nitrogen availability was very similar irrespective of pre-crop because of the high level of inherent fertility of the soils built up over a period of organic fertility management and basic fertilisation immediately prior to cropping, especially in 2003. However, in 2002, potatoes without additional slurry after planting, suffered a slight nitrogen deficit at the end of the growth period.
In 2002, potatoes after lucerne were more infected with late blight than after wheat but this did not affect the duration of crop growth nor the time at which the crops were defoliated (crops in NL must, by law, be defoliated at low levels late blight infection ~10% foliage infection). However, varietal differences in resistance to late blight were very obvious – Appell was markedly more resistant than Sante.
There were no significant effects of fertility treatments in either 2002 or 2003, or varieties in 2003, but in 2002, Appell gave about twice the yield of Aziza (approximately 30 t/ha compared with 15 t/ha).

Introduction

The impact of *Phytophthora* late blight on the yield and quality of organic potato production is highly variable. Yield losses may range from small or insignificant to total, complete loss. Yield-loss-relationships are mainly estimated under conventional conditions. In organic production, however, these measurements are still missing. The contribution of the nutrient supply to potatoes in organic production is often underestimated. In organic rotations, one- or two-years of grass/clover is needed as a nitrogen supplying part of the rotation. It is argued whether potatoes in organic production should be grown directly after grass/clover or only in the second year after grass/clover (i.e. usually after a cereal that may follow the grass/clover) as the quality of the potatoes is affected with respect to the nitrate and starch content. Möller (2002), however, showed that there is a close, highly complex interaction between the nitrogen supply, the whole growth period of tuber growth and the daily rate of tuber growth.

There are many reports that differences in nutrient supply to potato crops influence the susceptibility of the crop to *Phytophthora*. On the one hand it is reported that heavily fertilised crops are more infected by late blight, on the other hand many organic farmers report the opposite, i.e. that a weak, poorly fertilised crop is more susceptible. The impact of a *Phytophthora* attack is under certain circumstances of minor importance when the "right potato-variety" is supplied with an adequate amount of nitrogen released during the phase of main tuber growth between mid June until beginning/middle of July from previously accumulated reserves. In Germany, it was shown in 2001 with a number of varieties which had different bulking times, that early bulking varieties are better able to build up high yields in spite of a *Phytophthora* attack than late bulking and even more resistant varieties. In comparison it was also shown that the same varieties did not reach the same yield on a site following a pre-crop of wheat after grass/clover during the same period. However, during a phase of mild late blight these varieties were able to compensate for the delay. Therefore, in a systems approach of late blight control it is necessary to pay more attention to the supply of nitrogen in organic production. Field trials were set up 2002 and 2003 in Germany and the Netherlands to asses the effect of the position within the rotation of potato-varieties with different bulking times on the late blight attack. Potatoes were grown in two rotations i.e. directly after a fertility building crop i.e. grass/clover or lucerne or after wheat following the pre-crop grass/clover. The aim was to assess the effect of different nutrition levels on yield and quality of potatoes in organic production in view of increasing restrictions on the use of copper-fungicides.

GERMANY (D)

Material & Methods

Experimental site: The experiment was conducted in 2002 and 2003 under organic management on the experimental farm of the University of Kassel (central Germany) 8km NW of Witzenhausen, about 250m asl. Soils are deep loess soils.
A rotation trial was set up in 1999/2000 including two four-year rotations. Rotation 1 was grass/clover; potato; winter wheat; spring cereal. In rotation 2 the position of potatoes and winter wheat were exchanged to provide varying levels of nutrition for the potatoes. A total of 32 plots were arranged as a split plot design, with rotation as the main factor and subplots arranged within each main plot. The size per main plot was 22 x 60m, allowing for the arrangement of various subplots.

Plot arrangement: Each subplot was 10 rows wide by 10m. Row 1, 5 and 10 were edge rows, rows 2-4 were used for three sequential harvests and row 6-9 for final harvest (Fig. 1). Subplots were arranged in two long rows along the edges of the main plots to allow for sequential harvests from the outside in order not to disturb the parts of the plots to be used for final harvest. In 2002, all subplots were surrounded on both sides with two rows of the moderately susceptible variety Rosella. In 2003, the second surrounding row was planted with the susceptible cultivar Linda to provide for a more uniform inoculum pressure throughout the experimental area.

Treatments: Three varieties (Nicola, Rosella, Simone) were selected to be similar with respect to maturity (all middle early group, Bundessortenamt, 2002) but varying in bulking behaviour. Rosella and Nicola are moderately susceptible to late blight whereas Simone, as a late bulking variety, is less susceptible (Table 1).

Agronomic measures: All measures are summarised in Table 2. In 2002, with relatively warm and dry weather in early April, planting of the edge rows started on April 11 and April 23 for experimental plots. Unfortunately, unpredicted rains started in the middle of planting and lasted intermittently for about three weeks and planting could only be continued on May 15. This resulted in two replications planted on April 23 and one on May 15, while the main plot of one replication with pre-crop grass/clover was planted on April 23 and the main plot with pre-crop winter wheat on May 15. In 2003, all experimental plots were planted on April 15. Each variety in the two crop rotations were treated with copper hydroxide, 3 and 4 times with 0.5 kg/ha in year 2002 and 2003, respectively) on extra plots and compared to plots without copper fungicide treatment. (See Table 2)

Table 1. *Varieties and their properties used in pure stands and in four two-way mixtures with one red and one white variety per mixture*

Variety/Mix	Colour	Bulking[1]	Susceptibility[2]
1. Nicola	white	early	middle
2. Rosella (R)	red	middle	middle
4. Simone (S)	white	late	low

[1]Based on Möller, 2000 and own observation (Ann rep. MOP Feb. 2002)
[2]Based on own observations in 2001 at the same site

Fig. 1. Set-up of subplots within main plots.

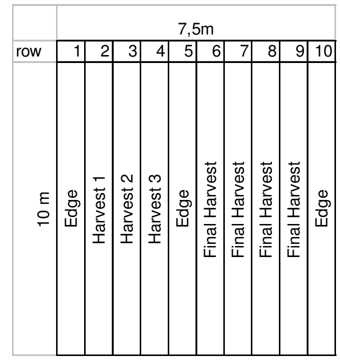


Table. 2. Agronomic measures in 2002 and 2003

2002	2003	Measure
24.10.01	15.1.	Ploughing in rotation 2 (pre-crop wheat)
16.2.	20.1.	Ploughing of grass-clover for rotation 1
11.4.	14.4.	planting of edge rows
23.4.	15.4.	planting main plots
15.5.	-	late planting main plots 2002[1]
18.5., 2.6. 26.6.	16.5.	Hoeing and hilling
2.7.	27.6.	sequential harvest 1
15.7.	08.7.	sequential harvest 2
29.7.	15.7.	sequential harvest 3
19.6., 26.6., 5.7.	24.6, 8.7., 15.7., 29.7.	Copper spraying (500g per application)
7.8.	-	sequential harvest (late planted plots 2002[2])
-	12.8	defoliation
16-19.9	25.-29.8	harvest

[1] One replication with pre-crop grass clover and two with winter wheat were planted late due to prolonged rainfalls (see text for explanations).
[2] Sequential harvests for the late planted plots in 2002 were started on the second date only.

Assessments: In 2002, soils were analysed prior to planting in mid-April and five more times from early June to late July. It became clear, however, that the main mineralization phase had been during late April and May. Therefore, in 2003, sampling times were adjusted starting in late March and adding two assessments in May. Due to extreme drought, no samples could be taken after June 20 in 2003. Nitrate-N (N_{min}) was determined in 0-60cm depth according to the standard assessment method of Schinner et al. (1998).

Growth stages were assessed regularly using the decimal code of Radtke et al. (2000) following the BBCH scale.

Plots were checked regularly until the beginning of the late blight epidemic. After this, disease was assessed twice weekly on 5 plants per plot for the pure stands and on ten plants per plot in the mixtures (five of each variety). Percent diseased leaf area was estimated, following the key of James et al. (1971).

For each sequential harvest, plants in one row were counted and harvested. Potatoes were separated by colour and into three size classes (Table 3). In 2002, the sequential harvests for the main plots planted on April 23 were conducted on July 2, 15 and 29, for the later planted plots dates were July 15, 29 and August 7 (Table 2). For the final harvest at least four rows were harvested and sorted by size classes.

Data analysis: All data were calculated using Excel and analysed with SAS (1986).

Because of the two separate planting times in 2002, in a first step, the replication data from 2002 were analysed separately for the two pre-crops to determine if there were replication effects that could be explained through planting time. Because these effects disappeared within a few weeks (see results section) the four replications were analysed together.

Cumulative disease severity was calculated as the Area under the disease progress curve (AUDC) using the following equation (Kranz, 1996):

$$AUDC = \sum_{i=1}^{n-1}\left(\frac{x_{i+1} + x_i}{2}\right)\left(t_{i+1} - t_i\right) \qquad (1)$$

where $\mathbf{x_i}$ = % infested foliage at assessment i, $\mathbf{t_i}$ = time (days) of assessment i, **n** = Number of assessments.

Data were analysed as well on a per plot basis as on a per variety basis. For the comparisons per variety, the yields per variety in the mixtures were compared to half the yield of that variety in pure stand. As each variety was present in two mixtures only the data sets on a variety basis consisted of three treatments only. The LSmeans in 2002 and the means in 2003 were compared using the statement pdiff or LSDs, respectively.

Results and Discussion

Climatic conditions

The weather was relatively cool and wet during the 2002 season and generally very unfavourable for potato development (Fig. 2). In contrast, in 2003, conditions were unusually dry and hot. From mid-May on almost every day temperatures rose above 20°C with many days above 30°C. The only substantial rain fell on May 31 when soils were already quite dry and most of the water evaporated quickly. Thereafter, there was virtually no more rain. Between April and August there was a total of only 200mm rainfall.

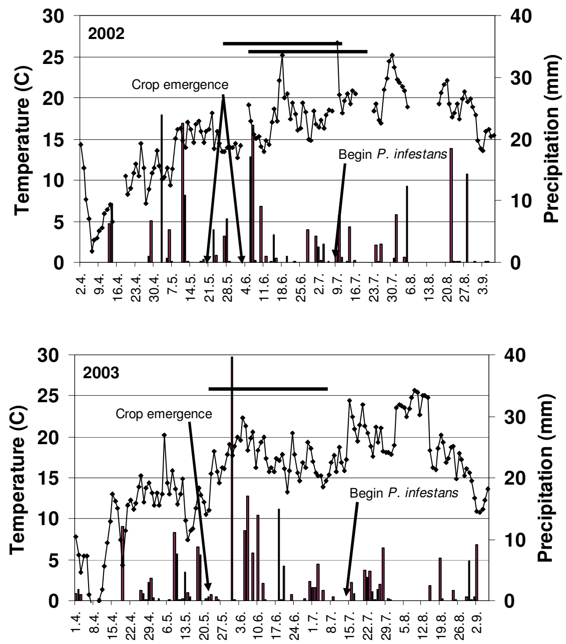


Fig. 2. Climatic conditions during the growing seasons 2002 and 2003. The date at which late blight was first observed is indicated with an arrow. The horizontal bars indicate the first six weeks of crop development after emergence.

Soil mineral N dynamics

In year 2002 the nitrogen mineralization was not typical. Due to the relatively cold weather conditions, there was no peak at the end of May / start of June as observed in other years including 2003. Therefore, the impact of the different pre-crops was not clearly differentiated although there was a slight difference between the curves in the plots after winter wheat or grass/clover (Fig. 3). At the end of April there was a clear distinction between the plots with pre-crop grass/clover (108 kg NO_3-N/ha) and wheat (94 kg NO_3-N/ha) in a soil depth of 60 cm. Thereafter, until the end of July the differences narrowed and even after June 20 in 2002, the N_{min} levels after grass/clover dropped below those of pre-crop winter wheat.

In year 2003, however, the impact of the different pre-crops on nitrogen supply was clearly discernible throughout most of the growing season. We observed a typical dynamic, very similar to 2001 but different to the atypical dynamics in 2002 (Fig. 3). At the end of March, the plots with pre-crop grass/clover already contained 60 kg NO_3-N/ha while with pre-crop wheat there were only 40 kg NO_3-

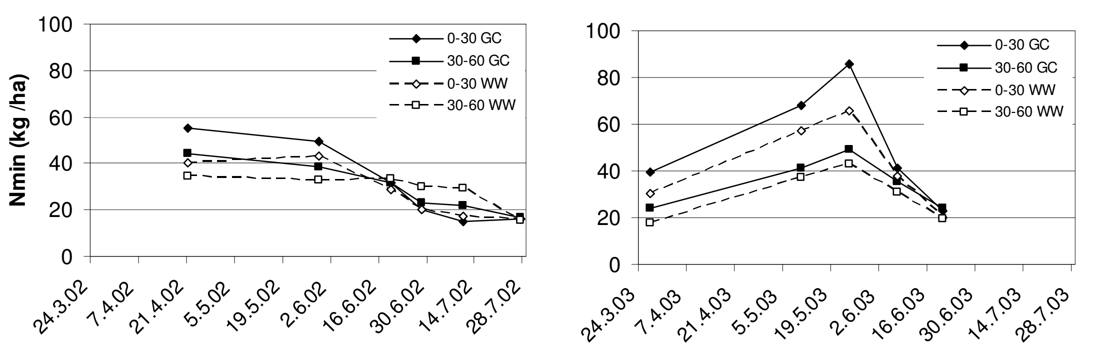


Fig. 3. Soil mineral N contents in kg/ha during spring and early summer in the main plots with pre crop Grass clover (GC, solid symbols and winter wheat (WW, open symbols) in 0-30 and 30-60cm depth in 2002 (left) and 2003 (right).

N/ha. Thereafter, until the last ten days of May mineralisation progressed up to a peak with 150 kg NO_3-N/ha after the pre-crop grass/clover and 107 kg NO_3-N/ha after winter wheat. Throughout June, soil nitrate was depleted by the crop to 20 kg NO_3-N/ha independent of the pre-crop. This is in contrast to the dynamics in 2002 but in line with the results from 2001.

Plant development and effects of planting time in 2002

Despite the three week break during planting in 2002, above-ground development of plants was surprisingly similar. The later planted potatoes emerged about two weeks after the early planted ones but all started flowering almost at the same time. Overall, there were no significant differences in above-ground development among the different main plots or varieties in both years (data not shown). Just like above-ground, below-ground the potatoes caught up rapidly in the later planted plots in 2002 (Fig. 4) and there was no effect of planting time on final yield (see below). Comparing early and late planted plots based on the respective first, second, and third sequential yields it was not possible to clearly differentiate the later planted main plots on the basis of yield.

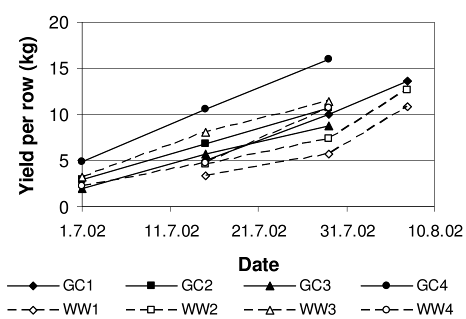


Fig. 4. Yield development (kg per 10 m row) in main plots 2002 after pre-crop grass clover (GC, solid symbols) and pre-crop winter wheat (WW open symbols). Three plots were planted late and sequential harvests were delayed.

Disease development and Gross Yield

In 2003, late blight first was observed in the experimental plots around July 15, about 10 days later than in 2002 (Fig. 2). Due to the cool weather conditions disease developed relatively slowly in 2002 with the last plants dying five weeks after the first disease was observed. In contrast, in 2003, disease did not progress beyond an average of 38% diseased leaf area in the worst case by August 5 2003 (Fig. 5). At that date, plants started yellowing due to early maturation in the hot and dry weather and disease assessments had to be stopped. Consequently, areas under the disease progress curves (AUDPC) were substantially lower in 2003 than in 2002 (Table 3). In both years the factor variety had the strongest impact on late blight development. Simone resulted in the lowest AUDPC but only in 2002 was the difference between Simone and the other varieties significant.

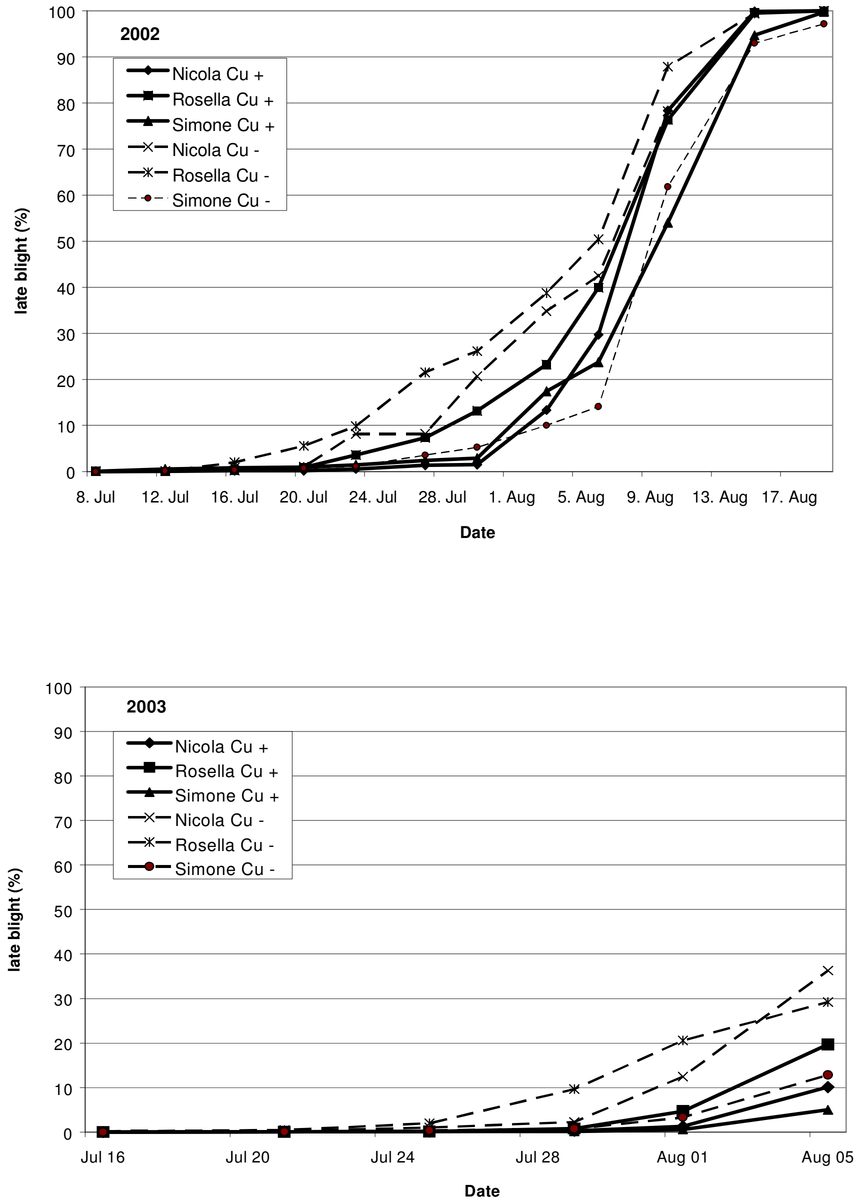


Fig. 5. Late blight development: dependence on variety and copper-fungicide application in 2002 and 2003.

Although we observed a considerable difference in disease severity depending on the pre-crop, the difference was not statistically significant. In both years copper-fungicide spraying resulted in significant differences ($p = 0.003$) in late blight severity (12% for 2002, 71% for 2003). We observed also tendencies of interactions between the factors copper-fungicide treatment and pre-crop and between the variety and copper-fungicide treatment ($p = 0.074$). Therefore, the reduction of the disease was most pronounced in treatments with more susceptible varieties such as Nicola and Rosella which clearly responded to copper-fungicide spraying, particularly when they were grown after grass/clover. There was not such a distinction when varieties were grown after winter wheat, most expressively shown with Simone. Thus, the results reveal that even under low disease pressure, late blight management is dependent on variety (susceptibility) and use of a successful direct control measure. The more yield potential is built up by a high supply of nitrogen, the more foliage will develop and the higher is the risk of foliage destruction by a stronger disease attack. However, this approach should be considered with respect to the yield and the economic efficiency.

However, the decrease in the disease severity due to copper-fungicide treatment resulted only in 2003 in a significant yield effect (+1.9 t/ha). The factors variety and pre-crop were more distinct but also the year had a strong impact on the yield development. The mean yield of the whole trial was 38 t/ha in 2003 while in 2002 the mean total yield was about half that at 18.6 t/ha. Although the weather conditions in 2003 were extremely dry, mean total yields at final harvest were significantly different, with 40.3 t/ha after grass/clover and with 36.2 t/ha after winter wheat, respectively. In 2002 the mean total yield was 50% lower and not significantly different between the pre-crops (Table 3). As in 2002, Rosella outyielded the other varieties with nearly 9 t/ ha over pre-crop and copper-fungicide treatment in year 2003. The factor variety had the strongest influence on the yield according to the F-value in the Anova. There was a significant interaction between copper-fungicide spraying and variety similar to the situation of the late blight attack. Success of copper-fungicide spraying depends on the variety (susceptibility) as Nicola was affected stronger in both rotational positions then the other varieties which are moderate or low susceptible to *P. infestans*. Copper-fungicide treatments resulted in a 4 t/ha increase of yield in Nicola and Rosella, while the yield of Simone was nearly independent of copper-fungicide treatment.

Table 3: Area under disease curve (AUDC) of *P. infestans* and yield of potatoes in the experiments of the years 2002 and 2003 in dependence of pre-crop, variety and copper treatment.

Pre Crop		Grass clover				Winter Wheat				Mean variety*	
		AUDC		t/ha		AUDC		t/ha		AUDC	t/ha
VARIETY	year	Cu+	Cu-	Cu+	Cu-	Cu+	Cu-	Cu+	Cu-		
Nicola	´02	1166	1466	16.3	20.6	933	1051	17.1	16.3	1134 b	17.6 b
	´03	50	160	39.8	36.6	69	98	35.7	31.5	94	35.9 b
Rosella	´02	1310	1584	23.5	21.8	997	1179	18.5	19.7	1268 b	20.9 a
	´03	14	195	46.2	45.3	13	154	43.1	39.3	94	43.5 a
Simone	´02	1045	1025	18.8	16.9	858	843	18.1	15.6	923 a	17.4 b
	´03	17	52	37.1	36.6	36	31	33.1	34.6	34	35.4 b

		Grass clover		Winter Wheat	
mean Pre Crop	year	AUDC	t/ha	AUDC	t/ha
	´02	1266 a	19.7 a	977 a	17.6 a
	´03	81 a	40.3 a	67 a	36.2 b

		AUDC		t/ha	
mean copper	year	Cu+	Cu-	Cu+	Cu-
	´02	1052 a	1191 b	18.7 a	18.5 a
	´03	33 a	115 b	39.2 a	37.3 b

* different letters indicate significant differences between treatments ($P \leq 0.05$, Bonferroni Test)

It was obvious that disease pressure had less of a strong impact on yield than had been expected. Under our conditions disease started after 10 July in both years of the experiment as well as in other years at our site and on farms up to 30 km away (See also Chapter 8 of this report). The disease development was fairly gradual so that the build up of tuber yield was not strongly affected by the disease. From the both years of the experiment, it may be assumed that the choice of the variety and its bulking characteristics were crucial for yield. For an acceptable yield, it is very important in organic farming to select a variety with an early bulking initiation, so that a relatively high yield is already built up by the time of the first late blight infestation. This is true even if the disease starts early and progresses rapidly. However, more disease tolerant varieties such as Simone might give a bigger benefit for the farmer's success.
Taking into consideration the results reported for the experiments made in Germany in Chapter 8, an adequate nitrogen supply is the most important aspect of potato growing under organic conditions where disease progress characteristics are similar to those at our site. Multiple regression analysis showed that late blight accounted for only about 30 % of the variation of yield (Finckh et al., 2005) while temperature sum (i.e. conditions for mineralization), nitrogen content 10 days after emergence and growth duration in total explain at least 73 % of the variation. In 2003 this was also demonstrated by the sequential harvests. The susceptible and moderately susceptible varieties Nicola and Rosella were able to build up a high yield by mid-July in plots after grass/clover as the nutrient supply was adequate and the varieties have an early and mid-early bulking initiation (Nicola 30 t/ha, Rosella 33 t/ha). At this time, yield of Simone, a later bulking variety, reached 28 t/ha. Also at this time, the biggest differences between yields following the different pre-crops were observed: following grass/clover the yields of Nicola, Rosella and Simone were 6, 3 and 2 t/ha higher than after winter wheat. The differences were similar at the final harvest.

The impact of the different pre-crops in terms of nitrogen content of the soil was clearly discernible during 2003. After a steady mineralization process, immediately following grass/clover soil contained 150 kg NO_3-N/ha at the end of May but only 100 kg NO_3-N/ha after the wheat pre-crop. Until the last sampling in June soil nitrate was depleted by the crop to a level of about 20 kg NO_3-N/ha independent of the pre-crop. As the fertility of a site has a major effect on yield, grass/clover as pre-crop was shown to be an appropriate way of building up the nitrogen supply and therefore the potential for a high yield.

There was no significant pre-crop effect on disease severity although there was a clear trend: disease severity was increased in the potato plots after grass/clover. It became clearer that the higher disease severity after pre-crop grass/clover more associated with the micro-climatic conditions in the foliage rather than the nutritional status of the crop. This was shown by supplementary trials which gave some evidence that there is a strong interaction between *P. infestans* isolates and each crop genotype and by the growing conditions of the host. No significant difference was observed between varieties, but the factor variety showed the strongest influence on late blight incidence and severity. The late bulking variety Simone had consistently lower symptoms clearly related to its lower susceptibility. Nevertheless, the beneficial effect of copper fungicide treatment was significant and the magnitude increased as varietal susceptibility increased (i.e. significant interaction between variety and copper). Although late blight attack was fairly mild during 2003 there were significant effects on yield. The factor variety (=susceptibility) had the strongest influence on the yield according to the statistical analysis. Independent of the pre-crop, Rosella's yield exceeded the other two varieties but responded quite markedly to the influence of the grass/clover. The interaction between variety and copper fungicide treatment is of major importance as it gives some indication of how farmer's growing decisions may be influenced. So far as variety choice is concerned, there are two main options: either to grow an early bulking variety such as Nicola, which can be more susceptible to late blight but produces an acceptable yield before infection stops bulking, or a late bulking, but more resistant variety such as Simone. The results suggest that farmers using copper fungicides can grow varieties such as Nicola or preferably Rosella, successfully. With this latter variety, there is less risk of losing yield potential which is set by its denser foliage and in the experiments, Rosella produced a satisfactory yield even without copper fungicide treatment. However, during the two years of experimentation, the late blight epidemic was relatively mild. The more resistant, but later bulking variety Simone built up a good yield without copper fungicide spraying and thus, represents varieties which could be grown on farms where the use of copper fungicides is not permitted. Clearly, results indicate that the combination of site-adapted varieties grown on soils with enhanced fertility should form the foundation for potato cropping in organic systems and this principle is one which deserves greater emphasis.

Conclusions

For potato production, an adequate supply of nitrogen which matches crop demand over the growing season is of crucial importance if varieties are to achieve their full yield potential under organic farming conditions. This is particularly important under high disease pressure (i.e. where the duration of crop growth is limited) and where susceptible varieties such as Nicola are grown. Later bulking varieties are able to compensate for the delay in bulking initiation as they are mostly more resistant to late blight and consequently have a longer duration of crop growth and tuber bulking. The nutrient management of the site and choice of varieties that are adapted to all conditions prevailing at the site are pre-requisites for successful organic potato production. These are important agronomic measures which together with others that promote early crop development such as pre-sprouting or chitting of seed tubers can help to overcome, or at least reduce considerably the need copper fungicide spraying.

References

FINCKH, M.R., SCHULTE-GELDERMANN, E., BRUNS, C. 2005: Challenges to organic potato farming: Disease and nutrient management, submitted to Potato Research

KRANZ, J. (1996) Epidemiologie der Pflanzenkrankheiten. Eugen Ulmer Verlag, Stuttgart,
MÖLLER, K. (2000) Einfluß und Wechselwirkung von Krautfäulebefall (Phytophthora infestans (Mont.) de Bary) und Stickstoffernährung auf Knollenwachstum und Ertrag von Kartoffeln (Solanum tuberosum L.) im Ökologischen Landbau. PhD Thesis, Technical University of München, Shaker Verlag.

NETHERLANDS (NL)

Materials and Methods

In the Netherlands in 2002 and 2003 two experiments were laid out, using the varieties Santé, Appell and Aziza (2002) or Raja (2003). The experiments were set up as a split-plot-design with four replications, with the preceding crop on the whole plots, and the variety and fertilisation treatments fully randomised as sub-plots. There were two preceding crop treatments (in 2002 lucerne and summer wheat, in 2003 barley with or without undersown lucerne), and two fertiliser treatments (no extra fertilisation, or 20 m^3/ha slurry, applied during early crop growth).
Weekly assessments included the number of stems per hectare, growth stages, percentage soil coverage, crop height, disease severity of late blight, yield (gross, net, size grades), underwater weight and tuber infection by late blight. Foliar late blight was expressed as the percentage leaf area infected, using the scale of James (1970). Nitrogen dynamics were modelled by the use of the NDICEA-model. Data were analysed using the statistical program Genstat.

Results

Nitrogen dynamics

Nitrogen availability was very similar for potatoes grown after the different pre-crops. For 2002 this can be explained by the fact that the spring wheat pre-crop was so poor that it was not harvested, so that there was no nitrogen take-off. In 2003 the basic fertilisation applied to the whole field before planting the potato crop was rather high, which may have obscured any differences in fertility created by the different pre-crops. In 2002, the plots without extra slurry fertilisation suffered a slight N-deficit (as predicted by NDICEA) at the end of their growth in 2002, but not in 2003, probably due to the high basic fertilisation.

Crop growth and late blight

In 2002 there seemed to be small differences in blight-infection between the 2 pre-crops: potatoes after lucerne had a higher infection than potatoes after wheat. However, this did not result in differences in the duration of crop growth, and defoliation occurred at the same time in July. On the other hand, variety differences in blight-infection were very clear: Appell was the most resistant and Santé the most susceptible. In 2003, there were no differences in levels of late blight infection between the fertility treatments other than between varieties.

Yield

Yield differences due to fertility treatments were small in 2002. Lucerne tended to improve yields, as did extra fertilisation, but only variety effects were significant (see Table 5.1).
In 2003 however, there were no differences between the yields of different treatments.

Table 5.1	**Yields 2002**	Lucerne		Wheat	
Slurry Application:		Yes	No	Yes	No
Appell	Net yield	38.2 [b]	34.3 [ab]	35.4 [ab]	30.3 [a]
	Net yield 40-65 mm	31.7 [b]	28.3 [ab]	30.3 [ab]	24.3 [a]
	% tubers 0-40 mm	16.49 [a]	16.32 [a]	13.64 [a]	18.46 [a]
Aziza	Net yield	20.85 [a]	19.71 [a]	21.29 [a]	19.07 [a]
	Net yield 40-65 mm	13.84 [a]	13.39 [a]	15.28 [a]	12.88 [a]
	% tubers 0-40 mm	33.37 [b]	31.94 [ab]	27 [a]	32.97 [ab]
Santé	Net yield	29.1 [a]	29 [a]	26.3 [a]	26 [a]
	Net yield 40-65 mm	22.8 [a]	22 [a]	21 [a]	20.6 [a]
	% tubers 0-40 mm	20.8 [a]	22.3 [a]	18.7 [a]	17.8 [a]

Discussion & Conclusions

In the experiments some effects of both pre-crop and extra fertiliser occurred in 2002, but not 2003.With lucerne and extra fertilisation there was a trend towards greater infection with late blight but also towards a higher yield, but effects were small and not significant.
The experiments were carried out in a practical farming situation, with a commercial fertilisation programme. The fact that in this situation, only minor effects on blight susceptibility and yield occurred may be due to the fact that the margins in which a farmer has to operate are small, and limited by soil and weather conditions. For example, in the very dry and hot season of 2003, combined with the rather high basic fertilisation the farmer gave, yields were more limited by water deficit than by nitrogen deficit, and as a result, no pre-crop or fertilisation effects could appear.

Section 3: Effect of animal manures and N:K ratios

Introduction

Experiments focused on optimising mineral fertiliser regimes for conventional potato production systems showed that both potato yield and late blight disease severity are affected by the levels and balances of macronutrients (especially N and K) supplied to the crop. However, little is known about the effects of different organic-matter-based fertility inputs on crop growth, yield and blight susceptibility in organic cropping systems. Balanced fertility management is thought to increase the resistance of potato crops to fungal diseases and high levels of available K are thought to increase blight resistance. With N however, the reverse is generally considered to be true: high levels decrease blight resistance and give a dense canopy with a micro-climate that favours the development of the disease. On the other hand, there are some that believe that nutrient-deficient plants which are under stress may also be more susceptible to infection even though they have small tops. Notwithstanding effects of fertility management on late blight infection however, nutrient supply is an important determinant of potential yield because it affects the size and longevity of the leaf canopy and hence the rate and duration of tuber bulking before the crop is defoliated either because of late blight or the need to remove the foliage of disease-free crops prior to harvest. Since many potato crops in organic systems receive relatively limited nutrient inputs, yield may be more adversely affected by the effects of deficiency on crop and tuber growth than on late blight infection. However, whilst nutrient input in organic cropping systems is often considered to be sub-optimal, the effects of ‘excessive’ inputs should not be ignored. These include delays to the start of tuber bulking and maturity leading to reduced yield, lower specific gravity and storage potential and increased risk of tuber blight infection. Clearly, optimising fertility management and utilisation of applied nutrients is a major agronomic objective in potato production, especially in organic systems, because of the large effects on performance. The balance between the potentially higher losses due to increased blight infection which may be a result of increased fertilisation and higher yields due to improved growth is critical.

The objectives of the field trials reported here, all of which were carried out in the United Kingdom from 2001 to 2003, were therefore:

(i) to quantify the effect of different fertilisation regimes on foliar and tuber blight development and tuber yields of potato
(ii) to identify the interactions of N and K supply from organic fertilisers on blight resistance and yields
(iii) to compare the impact of different fertility inputs (a) in sites/soils which had been under organic soil management for different lengths of time and (b) in different seasons

A series of complementary pot trials ran in parallel with the field trials from 2001 to 2005. All were carried in the United Kingdom at Close House Experimental station near Heddon on the Wall in the North of England. The objectives were broadly similar to those of the field experiments:

(iv) to quantify the effects of different fertilisation regimes and identify the interactions of N and K supply from organic fertilisers on foliar and tuber blight development and tuber yields.
(v) to investigate the relationship between planting depth of the mother tuber and infection of the progeny tubers with late blight (Although deeper planting may reduce the risk of tuber infections, there is little quantitative information).
(vi) to compare the impact of different fertility inputs and nutrient levels in soils with different levels of microbiological activity and water supply (Previous experiments in the series indicated that these edaphic factors were extremely important in determining the most appropriate soil fertility management programme to adopt for the potato crop in organic cropping systems).

a) FIELD EXPERIMENTS

Summary

In 2001, fertility treatments had no effect on blight development in either the resistant variety Sante, or the susceptible variety Nicola in either field or pot experiments. However, fertility treatment affected yield. In the field, crops treated with cattle-manure-based compost significantly outyielded those treated with chicken-manure pellets. The reverse was true in sand culture in the pot experiments. Inherent differences in microbial activity between the field soil and sand were thought to be responsible for these results.
Suggestions in the literature that the level of K applied to potato crops in the soil and to the foliage has an effect on blight infection were not borne out by results from experiments in either 2001 or 2002. Nor was there any evidence that the N:K ratio had an effect although wide ratios were achieved. On the other hand, the form of the ‘organic’ fertility input (uncomposted dairy cattle farmyard manure, cattle-manure-based compost or commercially

prepared organic fertiliser based on chicken manure) may affect yield even though blight infection may not be affected. In 2001, at the same level of N input (85 or 170 kg/ha N), cattle-manure-based compost increased yield significantly compared with chicken manure fertiliser pellets in a well-established, long-term organic site. This may have been due to enhanced fertility supply from cattle-manure-based compost as a result of the soil having a high, inherent biological activity. However, data was not available to test this, but the aim was to test the hypothesis in experiments in 2003. There is a suggestion that if fertility management is correct, potato tuber yields will be improved before blight infection leads to defoliation of the canopy and an end to tuber bulking.

In 2003, weather conditions were very dry in August and suppressed late blight infection. There were no effects of treatments on foliage blight at either site (Nafferton or Stockbridge Technology Centre –STC). At Nafferton, total tuber yield was unaffected by type and level of fertility input. On the other hand, at STC yields were higher with chicken manure pellets than with cattle-manure-based compost or uncomposted dairy cattle manure (FYM) at all levels of applied N (85, 170 and 250 kg/ha N). Yields were also highest and similar at the 170 and 250 kg/ha N level. This was probably because the site at STC was less inherently fertile (potatoes followed soybeans) than at Nafferton (potatoes followed a 2 year grass/clover ley). Furthermore, irrigation at STC in August may have improved availability of the higher level of soluble mineral N in the chicken manure pellets than in compost or dairy cattle manure. Clearly, even though fertility type and level did not affect infection with blight in any of the experiments, it seemed that the magnitude of effects on tuber yield was dependent upon soil fertility (and probably the level of soil microbial activity), weather conditions and soil moisture availability.

2001

The effects of type and level of fertility input and N:K ratios on the development of foliar and tuber blight and tuber yield of contrasting varieties

Materials and Methods

The experiment was carried out at Stanfield Hall Farm, Pickering, North Yorkshire. Plots of 3m x 10m were fertilised with either chicken-manure pellets or cattle-manure-based compost at 2 different input levels (equal to 85 or 170 Kg N per ha) and at various N:K ratios (by adding potassium sulphate in addition to chicken-manure pellets or cattle-manure-based compost) and details are shown in Table 5.2. Two potato varieties with different blight resistance levels (Sante–tolerant; Nicola–susceptible) were used and the plots were arranged in a randomised block design with 6 replicates per treatment. Foliar blight incidence was recorded at regular intervals after the first symptoms were detected (15 August 2001) (James, 1971). Potato haulms were destroyed when 95% of the foliage was destroyed by foliar blight. Crops were harvested in the second week of October and assessed for yield, tuber size distribution and tuber blight incidence.

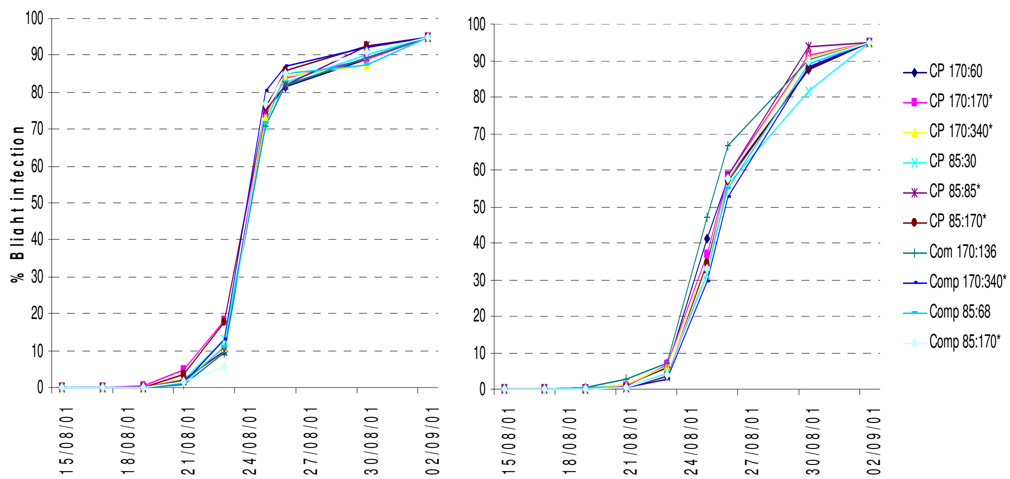
Table 5.2 Fertility inputs and N:K ratios

Fertility input	Nitrogen Levels kg/ha	Potassium Levels Kg/ha	N:K ratios
Cattle-manure-based compost (Com)	85 170	68;170 136;340	1.25:1;1:2 1.25:1;1:2
Chicken-manure Pellets (CP)	85 170	30;85;170 60;170;340	2.83:1;1:1;1:2 2.83:1;1:1;1:2

Results

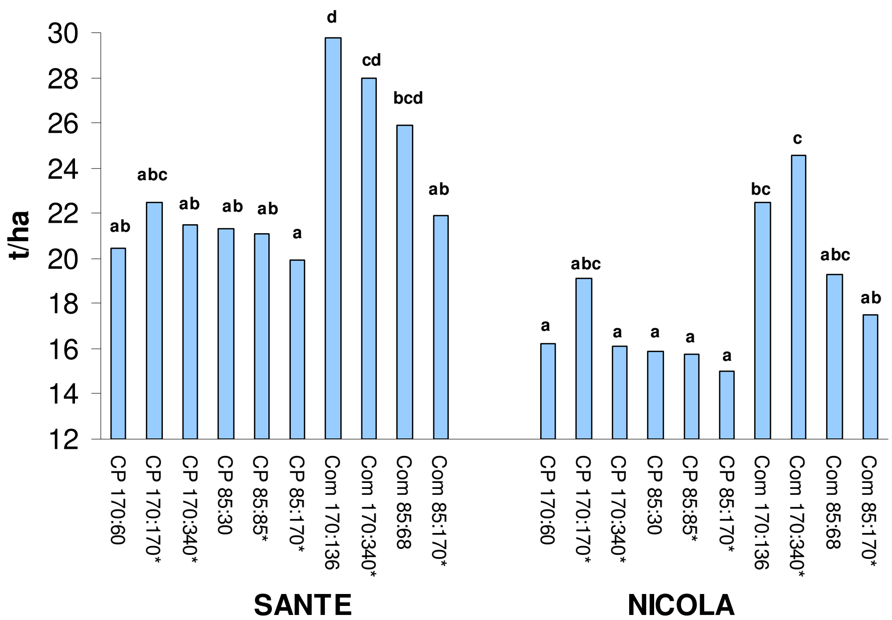
As expected, Sante showed significantly higher resistance against late blight than Nicola (Fig. 5.6). There was no significant difference in late blight development between fertility input treatments. However, there were significant differences in yield between fertility input treatments with the higher level of cattle-manure-compost treatments (170 Kg N) resulting in 40% higher yields than all other chicken-manure pellet based treatments (Fig. 5.7). Differences in nutrient release characteristics between cattle-manure-based compost and chicken-manure pellets are thought to be the main reason for the differences in yield between the two different fertility input sources applied at similar N and K input levels. When a similar range of treatments was tested in pot-based sand-cultures, chicken-manure pellets gave significantly higher yields than cattle-manure-based compost. This is thought to be due to the lack of microbial activity driven mineralization of organic fertilisers in sand compared to organic field soils.

Fig. 5.6 Late blight development in two varieties (Sante and Nicola) at different fertility inputs.



NICOLA **SANTE**

Fig. 5.7 Yield of two potato varieties (Sante and Nicola) at different fertility input levels



* ANOVA showed significant differences between varieties ($p<0.001$), fertility input types ($p<0.001$) and levels ($p<0.001$) but not N:K ratios. There were no significant interactions between variety and nutrient treatments or between nutrient input level and N:K ratio. Means with the same letter are not significantly different according to Tukey's Honest Significant Difference test.

2002

The effects of type and level of fertility input and N:K ratios on the development of foliar and tuber blight and tuber yield

Materials and Methods

The experiment was carried out at Nafferton Farm, Stocksfield, Northumberland in 2002. Plots of 6m x 5m were fertilised with cattle-manure-based compost at 85 Kg N per ha and at various N:K ratios by adding potassium sulphate in addition to cattle-manure based compost. Some of the potassium was applied to the foliage (in the form of an aqueous solution of potassium sulphate) in addition to the soil (Table 5.3). Potato variety Sante was planted with 6 replicates per treatment. Foliar blight incidence was recorded at regular intervals after the first symptoms were detected (James, 1971). Potato haulms were destroyed when 95% of the foliage was destroyed by foliar blight. Crops were harvested in early September and assessed for yield, tuber size distribution and tuber blight incidence.

Table 5.3 Fertility treatments and N:K ratios

Treatments	Application	kg N/ha	kg K/ha	N:K ratio
1) Compost*	soil	85	68	1 : 1.25
2) Compost*	soil	85	170	1 : 2
3) Compost*	soil	85	465	1 : 5.5
4) Compost*	soil+foliar	85	68	1 : 1.25
5) Compost*	soil+foliar	85	170	1 : 2
6) Compost*	soil+foliar	85	465	1 : 5.5

Results

The level of potassium nutrition and method of application (soil + or foliar) had no significant effect on the progress of foliar or tuber blight infection (Fig. 5.8). Also there were no significant differences in tuber yields between different K-level and application methods (Fig. 5.9).

There was no evidence in either 2001 or 2002 that the level of potassium applied to the soil or to the soil + foliage or the N:K ratio had any effect on blight infection and hence yield when nitrogen input was kept constant. However, there had been strong indications in 2001 that the form in which fertility inputs are supplied (i.e. chicken-manure pellets or cattle-manure-based compost) may have a significant effect on tuber yield, even if there are no apparent effects on blight infection. This provides a strategy through fertility management to optimise tuber yield, which has potential to offset the effects of defoliation due to blight and experiments in 2003 were designed to test this and also another hypothesis i.e. that the level inherent biological activity in the soil to which the organic manure inputs are applied influences the magnitude of the yield response to these fertility inputs.

Fig. 5.8 Foliar blight development in variety Sante with different potassium levels and application methods.

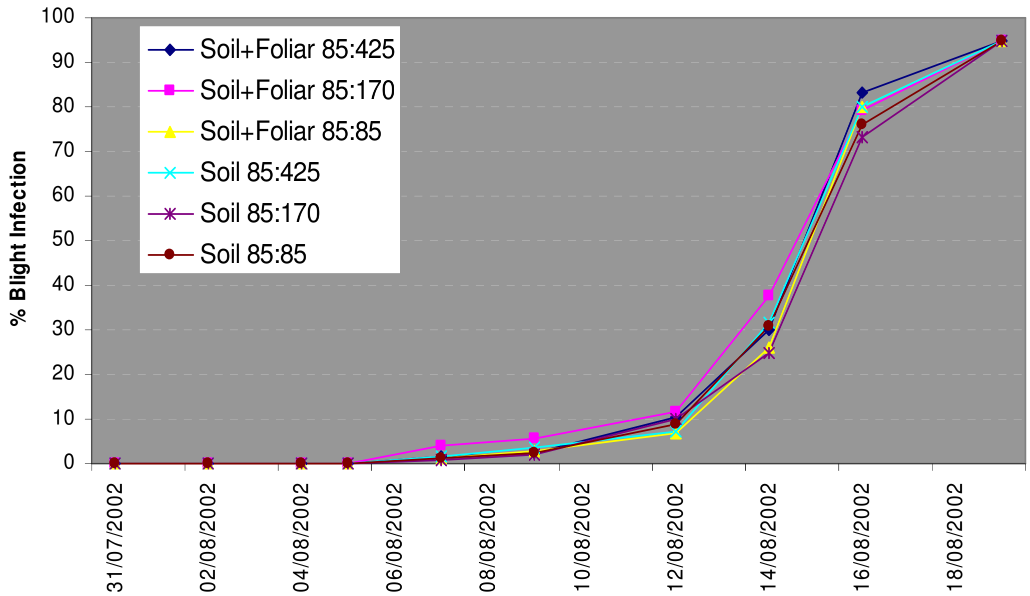
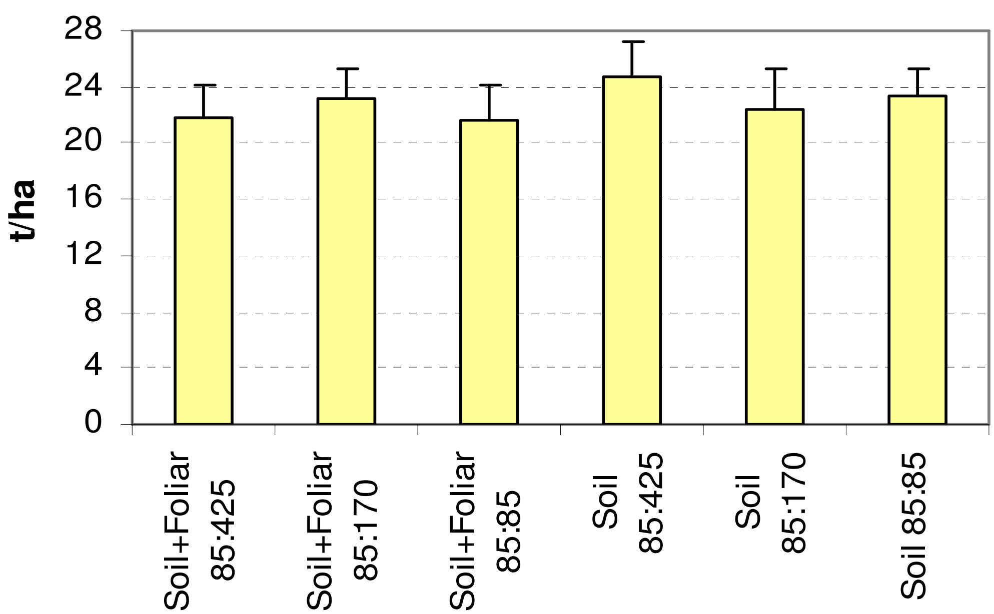


Fig. 5.9 Potato yield with compost and different potassium applications (soil and soil+foliar).



2003

The effects of type and level of fertility input and N:K ratios on the development of foliar and tuber blight and tuber yield

Materials and Methods

The experiments were carried out at Nafferton Farm, Stocksfield, Northumberland and Stockbridge Technology Centre (STC) , North Yorkshire in 2003. At both sites, plots of 3m x 10m were fertilised prior to planting with either cattle-manure-based compost, or uncomposted dairy-cattle-manure from an organic source, or proprietary chicken- manure pellets for organic crops (Greenvale). These fertility inputs were applied at rates to achieve inputs of 85 kg/ha N, 170 kg/ha N and 250 kg/ha N, based on nutrient analysis of the samples (Table 5.4). Potato variety Sante was planted with 6 replicates per treatment. Plots were inoculated with a standard suspension of *Phytophthora infestans* spores on 21 July. Foliar blight incidence was recorded at regular intervals after the first symptoms were detected (James, 1971). The aim had been to destroy potato haulms when 95% of the foliage was destroyed by foliar blight. However, extremely hot and dry conditions in August 2003 led to modest levels of blight and premature senescence of the canopy. Tops were removed irrespective of the level of blight infection about two weeks prior to harvest in mid-September. At harvest, yield and tuber size grading were assessed. Tuber blight incidence was recorded at harvest and in early January, after about 3 month's storage. Measurements of respiration rates of soil samples from the two sites indicated that the level of microbial activity was higher at Nafferton than at STC. Previous crops were a 2 year grass/clover ley and soybeans respectively

Table 5.4 Fertility treatments

Treatments	kg N/ha
1) Compost (Comp)	85
2) Compost (Comp)	170
3) Compost (Comp)	250
4) Dairy cattle manure (FYM)	85
5) Dairy cattle manure (FYM)	170
6) Dairy cattle manure (FYM)	250
7) Chicken manure pellets (CP)	85
8) Chicken manure pellets (CP)	170
9) Chicken manure pellets (CP)	250

Results

In the UK and in many parts of Europe weather conditions were extremely hot and dry in August 2003. During a record breaking heat wave in the second week, temperatures ranged from 30 -35^{o}C. Consequently, blight development which began in the crops during relatively wet and humid conditions in late July at both Nafferton and STC was arrested as lesions dried up. Levels of foliage blight were much lower than in 2001 and 2002 when 95% foliar infection was recorded. The maximum level recorded at Nafferton was about 30% by the time premature senescence began. At STC, blight infection was negligible although irrigation was used to encourage infection with blight. Because of these exceptional conditions responses to the applied fertility treatments either in terms of level of blight infection or in terms of tuber yield were limited. Nevertheless, tuber yields were relatively high because of adequate water supplies earlier in the season and the absence of blight. With very low levels of foliar blight and dry and warm conditions that persisted until harvest, levels of infection with tuber blight were negligible at harvest or after 3 months storage.

At Nafferton, there were no significant differences between types and levels of fertility inputs on foliar and tuber blight or on total or graded yields (Figures 5.10, 5.11, 5.12).

Figure 5.10. The effects of fertility input type (Cattle-manure-based compost – Comp; Chicken-manure pellets – CP; Uncomposted diary-cattle-manure – FYM) and level (85, 170 or 250 kg/ha N) on the change with time in foliar blight infection at Nafferton 2003.

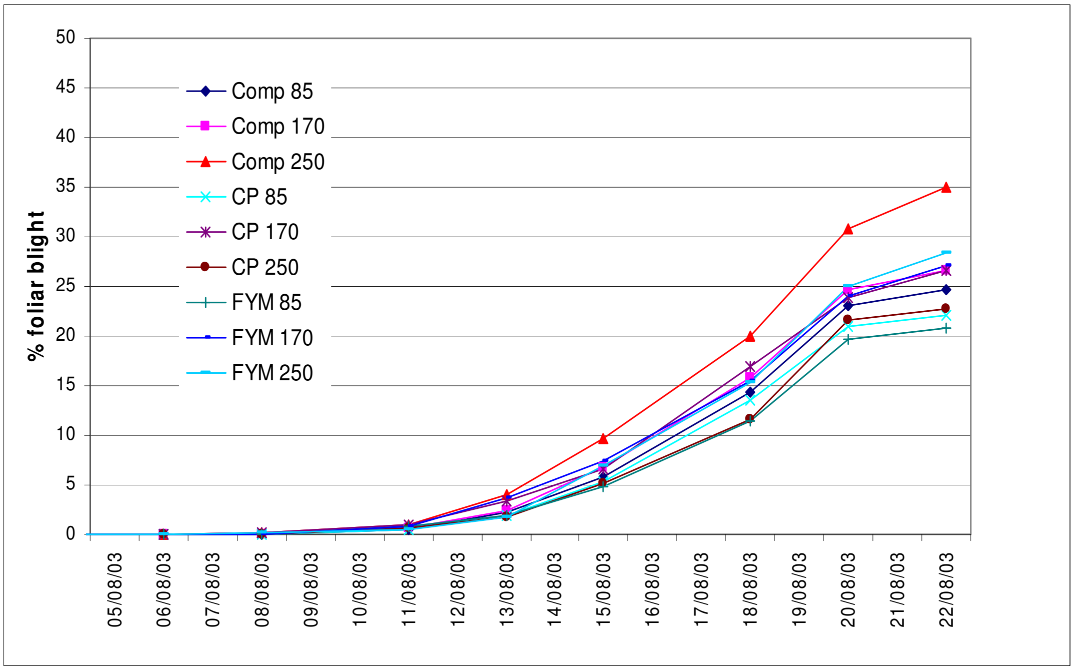


Figure 5.11 The effects of fertility input type (Cattle-manure-based compost – Comp; Chicken-manure pellets – CP; Uncomposted diary-cattle-manure – FYM) and level (85, 170 or 250 kg/ha N) on total tuber yields (t/ha) at Nafferton 2003.

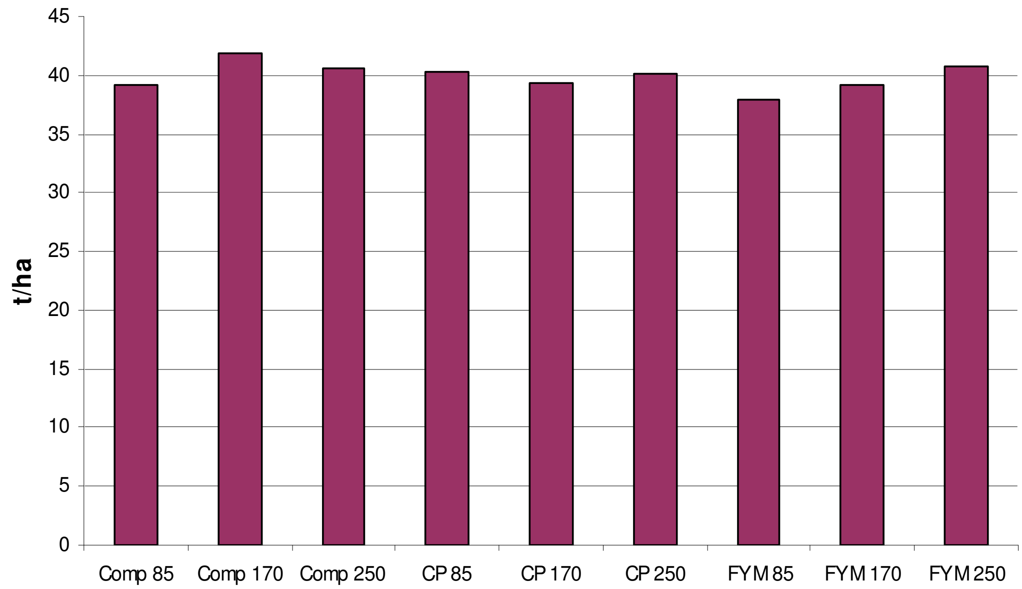
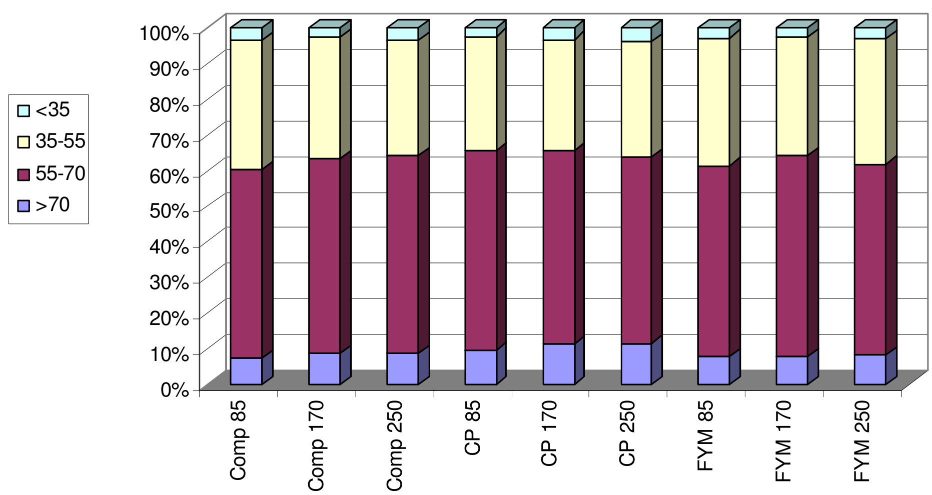


Figure 5.12 The effects of fertility input type (Cattle-manure-based compost – Comp; Chicken-manure pellets – CP; Uncomposted diary-cattle-manure – FYM) and level (85, 170 or 250 kg/ha N) on tuber size grading at Nafferton 2003. (<35mm, 35-55mm,55-70mm,>70mm).



At STC, there were no significant differences between treatments on either foliar or tuber blight and levels were negligible despite inoculation of the foliage and subsequent irrigation because of the over-riding effects of the high temperatures and dry weather in August. However, there were significant differences between treatments on total and graded tuber yields and numbers of tubers (Table 5.5). Effects of fertility input type and level were significant ($p<0.001$), but there was no significant interaction between type and level. Chicken-manure pellets gave the highest yields of tubers which were approximately 20%

higher than where cattle-manure-based compost or uncomposted dairy-cattle manure was used. Application of fertility inputs at 170 and 250kg/ha N significantly outyielded the 85 kg/ha N level. The lowest yield was produced by cattle-manure-based compost and uncomposted dairy-cattle manure at 85 kg/ha N and the highest by 250 kg/ha N supplied as chicken-manure pellets. The number of tubers and yields of larger tubers responded to fertility input type and level in a similar way to total tuber yield: they were highest following application of chicken-manure pellets at 250 kg/ka N. Tuber blight was negligible in all treatments and only one or two blighted tubers were found.

Table 5.5 The effects of fertility input type and level on total tuber yield (t/ha).

	Chicken manure pellets (CP)	Compost (Comp)	Dairy cattle manure (FYM)	Mean
85 kg/ha	36.9ab	29.6b	28.7b	**31.7a**
170 kg/ha	40.7ab	33.2ab	33.1ab	**35.7ab**
250 kg/ha	43.0a	38.6ab	33.6ab	**38.4b**
Mean	**40.2a**	**33.8b**	**31.8b**	

The responsiveness of the potato crop at STC to the fertility input as chicken manure pellets was probably due to:

- the lower initial fertility of the site following a disappointing crop of soybeans (the crop followed a two year grass/clover ley at Nafferton)
- the higher proportion of N in the readily available soluble form in chicken-manure pellets compared with cattle-manure-based compost and uncomposted dairy-cattle manure
- the use of irrigation at STC during the dry, hot conditions in August (which was applied primarily to encourage infection of the foliage with late-blight)
- the relatively short growing season caused by the August drought that limited the opportunity for the crop to respond to nutrients released by the cattle-manure-based compost and uncomposted dairy-cattle manure compost later in the season

Conclusions

Over three contrasting seasons, there was no evidence that different types and levels of fertility inputs affected infection of either the potato foliage or the tubers with late blight. However, tuber yield, number of tubers and tuber size grading were affected.

In general, in 2001, at a site that had been in a long-term organic system for about 15 years, cattle-manure-based compost was more effective than chicken-manure pellets. This suggested that the inherent fertility of the site and soil microbiological activity may influence the efficacy of applied fertility inputs, with compost at an advantage where these are high. However, further studies are required to identify the interaction between soil biological activity/N mineralisation potential and fertility input types and levels.

In 2002, at a site that had only recently been converted to organic production, there was no difference between fertility input types or levels. In 2003, where conditions were extremely hot and dry, there was no difference at Nafferton, where potatoes followed a 2 year grass/clover ley, irrigation was not available and the crop senesced early. However, at the STC site (which was only very recently converted to an organic cropping system and has very light, sandy soils), where initial levels of fertility were lower than at Nafferton and irrigation was applied in August to encourage late blight and delay crop senescence, the crop was more responsive to chicken-manure pellets that contained a higher level of N in the soluble form than either cattle-manure-based compost or uncomposted dairy-cattle manure. There was no evidence in either 2001 or 2002 that the level of applied potassium, whether applied to the soil and/or foliage or the N:K ratio affected infection with late blight. Evidence suggested that the type and level of fertility input influences yield directly because of effects on crop and tuber growth and effects may be substantial. On the other hand, effects of fertility management on the onset and severity of infection with late blight appear to be relatively small or even absent. Therefore, decisions regarding fertility management of potato crops in organic cropping systems should be made primarily with regard to its direct effects on crop growth and yield, rather than on possible effects on infection with late blight.

b) POT EXPERIMENTS

Summary

A series of pot experiments was made in parallel with the field experiments in the United Kingdom over the period 2001 to 2005 to investigate the effects of animal manures (and some other organically-based fertility inputs e.g. plant and seaweed extracts) and N:K ratios**.** Pot experiments allow a greater opportunity to control inputs and environment and to make more detailed assessments.

The types of basal fertiliser (compost or chicken manure pellets) affected both foliar blight (significant differences were recorded in only in one of the 3 pot trials) development and tuber yields (in all trials). Foliar blight development in plants receiving cattle manure based compost was lower than in those receiving chicken manure pellets. This may have been due to lower physiological susceptibility in compost fertilised plants or to the fact that their canopies were much smaller. Canopy size is known to affect the micro climate and smaller canopies were described to reduce the chance of spore infection.

Nitrogen in nitrate form is more favourable to development of blight than in the ammonium form according to previous reports. In this experiment, the nitrate levels in the chicken manure pellets were approximately 10 times higher than from cattle manure based compost, which would have been expected to release mainly NH_4 via mineralization. This may have been an additional reason for the observation that foliar blight severity of the plants treated with chicken manure pellets was higher than in those treated with compost based manure.

The level of N applied to crops also had an important impact on foliar blight and tuber yield in most varieties. Disease severity was higher in plants that received 680 kg N/ha than 170 kg N/ha. However, it was not possible to identify the exact mechanisms (physiological versus microclimate of canopy structure related mechanisms) responsible for the reduced susceptibility in the crops fertilised with compost.

When applied at similar total N-input levels chicken manure pellets (which have a high content of water soluble N) always gave significantly higher yields than manure based compost (which contains very low levels of water soluble N). These results conflict with the results from field trials carried out in soils which had been under organic farming management for > 5 years In field trials, manure based composts always gave higher yields than chicken manure pellets. This may have been due to the higher biological activity (and associated N-mineralization rates) in organically managed soils compare to sand (which is known to have very low biological activity).

In the pot experiment carried out in 2002 the 50:50 mixture of compost and chicken pellets gave the highest yield when compared to both compost and chicken pellets at the same N-input level of 680 kg N. This indicates that the addition of organic matter based N-inputs has a beneficial effect on plant growth, even in a low biological activity substrate, provided that additional N-is applied in water soluble form but the exact reasons for the high yields associated with the mixed compost/chicken pellet treatment was not clear.

In 2001, a range of liquid fertility inputs including pine extract, seaweed extracts and fish emulsion had no effects on late blight infection of leaves or tubers but seaweed extract

increased tuber yield by approximately 20% in the most resistant varieties which may have been due to a growth promoting effect or micronutrient supplementation (which could have been an effect as plants were grown in sand culture).
There were no effects of N:K ratios on late blight infection but increasing both K input to very high levels as N levels increased, reduced yields. Tuber blight infection was not affected by fertility input treatment or by the depth of planting of the mother tuber.

In 2005, in the absence of late blight infection, highest yields were obtained from plants that were free from water stress and supplied with 170kg/ha N in the form of chicken manure pellets. Yields from this treatment were almost double those from plants that were water-stressed and received no farm-yard-manure-based compost or chicken manure pellets. Where water was in short supply, application of organic manure in either form and at either 85 or 170 kg/ha N, yields were similar to those of plants that received no supplementary fertility inputs. At the same level of nitrogen input, chicken manure pellets gave higher yields than farm-yard-manure based compost averaging 12%. Yields of all treatments were higher where water was in adequate supply. On the whole, the effects of soil microbial activity or 'inherent fertility', organic manure type, level of nitrogen input and irrigation were additive. There was one interaction between the type and level of fertility input. At the higher level of nitrogen input (170kg/ha), yields were greater when chicken-manure pellets were used rather than farm-yard-based manure compost probably associated with the higher content of water soluble nitrogen. The lack of any other treatment interactions indicated that the responsiveness of the potato plant to different types and levels of nitrogen input under conditions prevailing in this experiment was not affected by water supply or the microbiological activity or 'inherent fertility' of the soil.
Clearly, the results from field and pot experiments did not unequivocally support the hypothesis that the best type and level of organic manure to apply depends upon the water supply and microbiological activity or 'inherent fertility' of the soil. However, all demonstrated that fertility management is a key determinant of potato crop performance in an organic system which was also obvious from the experiments described in Section 2 of this Chapter – Position in the rotation re:fertility building grass/clover crops. The strategy should aim to use the organic manures of different types that are available to achieve a favourable yield response. Evidence does not suggest that the risk of, or severity of infection with late blight will be increased as fertility input increases (as might be expected). Therefore the message is clear: growers should focus on fertilising for yield not for managing late blight.

2001 a

The effects of type and level of fertility input and N:K ratios on the development of foliar and tuber blight and tuber yield

Material and Methods

Individual plants were grown in the open in 40-litre pots filled with nutrient–free coarse sand amended with different fertility inputs. In addition to the cattle-manure-based compost and chicken-manure pellets (Greenvale Ltd.), mineral NPK fertiliser was used as the third fertility input type. A wide range of levels of both N and K were applied and a range of N:K ratios was achieved (Table 5.6). Foliar blight incidence was recorded at regular intervals after the first symptoms were detected. Potato haulms were destroyed when 95% of the foliage was destroyed by foliar blight. Crops were harvested at the end of October and assessed for yield, tuber size distribution and tuber blight incidence.

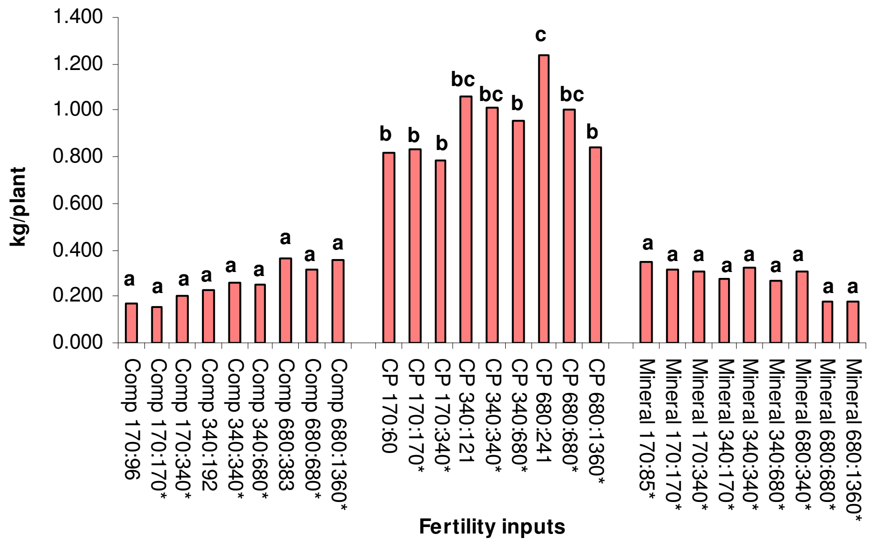
Table 5.6 Fertility inputs and N:K ratios

Fertility input	**Nitrogen Levels kg/ha**	**Potassium Levels Kg/ha**	**N:K ratios**
Cattle-manure-based compost (Comp)	170 340 680	96;170;340 192;340;680 383;680;1360	1.8:1;1:1;1:2 1.8:1;1:1;1:2 1.8:1;1:1;1:2
Chicken-manure pellets (CP)	170 340 680	60;170;340 121;340;680 241;680;1360	2.8:1;1:1;1:2 2.8:1;1:1;1:2 2.8:1;1:1;1:2
Mineral fertiliser (Mineral)	170 340 680	85;170;340 170;340;680 340;680;1360	2.0:1;1:1;1:2 2.0:1;1:1;1:2 2.0:1;1:1;1:2

Results

In common with the 2001 field experiment described above, although the levels of applied treatments were different, there was no significant difference in blight development between the different treatments in the pot experiment. However, there were treatment differences in tuber yields. ANOVA showed significant differences between input types (cattle-manure-based compost, mineral fertiliser, chicken-manure pellets; $p<0.001$), N-input levels ($p<0.001$) and N:K ratio ($p=0.012$). There were also significant interactions between input type & N-input level ($p<0.001$), N-input level & N:K ratio ($p=0.031$) and input type & N:K ratio ($p=0.033$). Tukey's Honestly significant difference test showed that there was no significant difference between all combinations of N-input levels and N:K ratios when mineral fertiliser and cattle-manure-based compost fertility input was used. However, with chicken-manure pellets, the highest nitrogen input level (680 kg/ha) gave significantly higher yields than the two lower input levels 170 and 340 kg/ha), but only when the highest N:K ratio (2.8:1) was used. At a chicken-manure pellet based N input level of 680 kg/ha, the yield significantly decreased when the N:K ratio was decreased from 2.8:1 to 1:2 (Fig. 5.13). Therefore, it was not possible to reduce blight incidence by decreasing the N:K ratio. Since increasing the potassium supply to the soil at the highest nitrogen input level reduced yield, this experiment indicates that potassium soil applications are an unsuitable method to reduce yield losses due to potato blight.

Fig. 5.13 Potato yield (variety Nicola), at different fertility input levels, types and N:K ratios



2001 b

The effects of variety choice, fertility input type and planting depth on tuber blight infection

Materials and Methods

In the experiment in 2001 a completely randomised block factorial design with six replications was used. Six varieties of potato: Cara, Sante, King Edward, Kestrel, Eve Balfour and 874120 (Sarpo Mira) were studied. Cattle manure based compost or chicken manure pellets (Greenvale Ltd.) were applied at a rate equal to 340 kg N per ha. Individual plants were grown in 40-litre pots filled with nutrient-free coarse sand. In order to examine the effects of planting depths on tuber blight development, un-chitted tubers were planted at a depth of 10 and 25cm. Crop growth, development and yield and the progress of infection with both foliage and tuber blight were assessed according to the previously described methods. Foliar blight assessments were carried out between the 24 August and 2 October.

Results

Foliar blight development in term of AUDPC in susceptible varieties was higher than in the resistant ones. Also, AUDPC was higher (for 5 of the 6 varieties) when chicken manure pellets were the basal fertiliser than where cattle manure based compost was used (Figure 5.14). Tuber yields were higher when chicken manure pellets were used as the basal fertiliser as and approximately 5 times higher than those that received cattle manure based compost (Figure 5.15). Although the main purpose of this experiment was to investigate the relationship between planting depths and tuber blight infection, the levels of tuber blight were so low, that the effects of planting depths could not be determined (Table 5.7). There was also no significant effect of planting depth on tuber yield (results not shown).

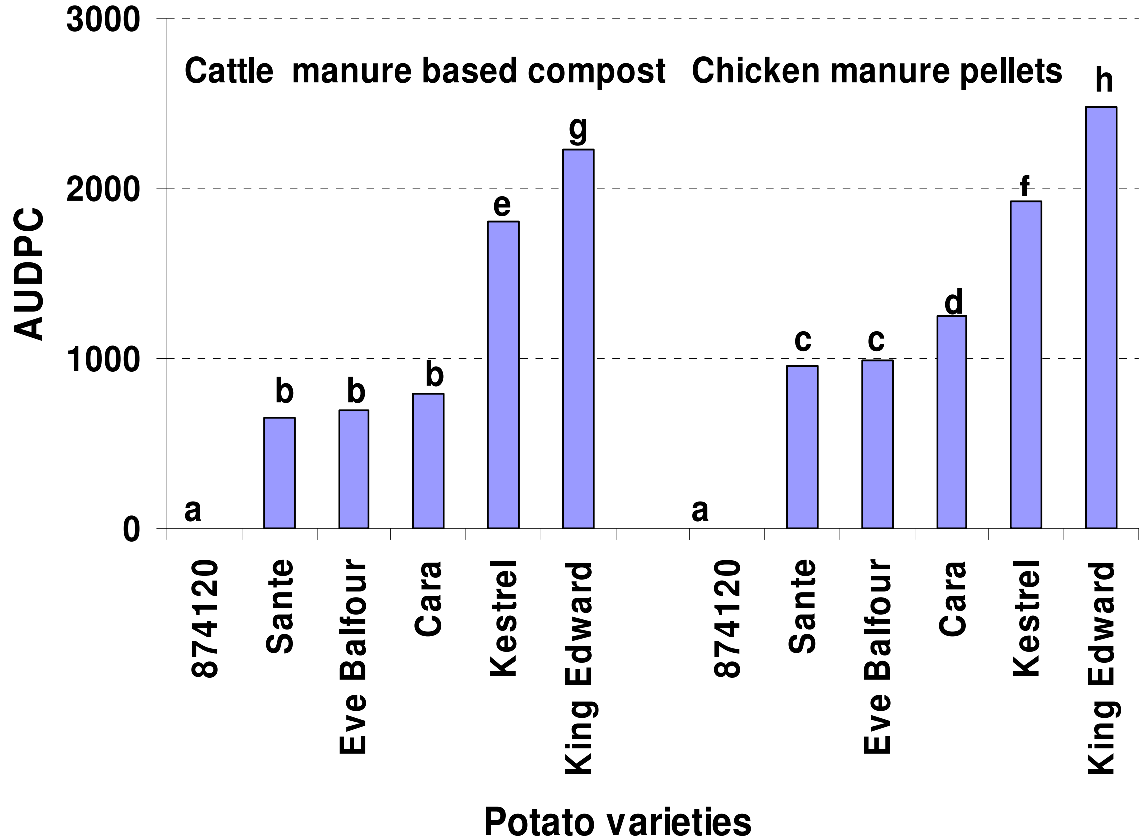


Figure 5.14 AUDPC of different varieties of potato grown with different types of basal fertilizers; cattle manure based compost and chicken manure pellets. Different letters indicate highly significant differences (P<0.01) according to Tukey's Honestly Significant Difference (HSD) test.

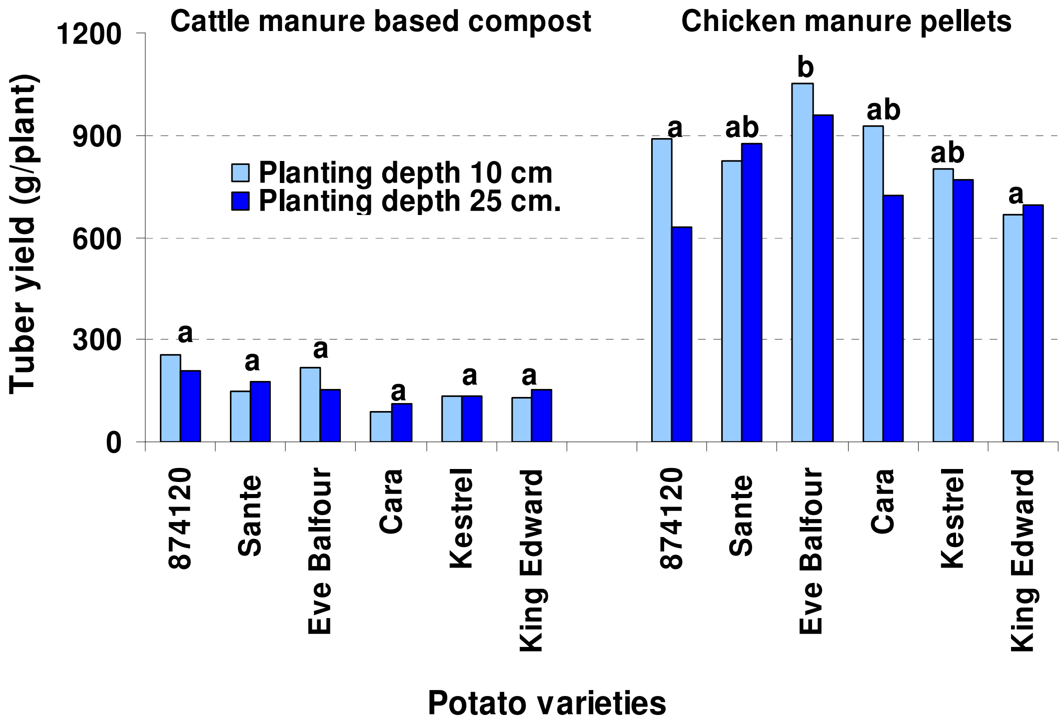


Figure 5.15 Tuber yields of potatoes amended with different basal fertiliser inputs (cattle manure based compost or chicken manure pellets) and different planting depths (10 and 25 cm.). Different letters indicate highly significant differences apply to all these 2 columns ($P<0.01$) according to Tukey's Honestly Significant Difference (HSD) test.

Table 5.7 Tuber blight infection (% by number of tubers affected) and weight (g/plant) of different varieties of potato grown with different types of basal fertilizers; cattle manure based compost and chicken manure pellets and planted at different depths; 10 cm. and 25 cm. at harvest (17/11/01) and after storage (17/2/02) in 2001. After storage data are shown in brackets.

Potato varieties	Planting depths							
	10 cm.				25 cm.			
	Cattle manure based compost		Chicken manure pellets		Cattle manure based compost		Chicken manure pellets	
	Infected tuber							
	% by number	g/plant	% by number	g/plant	% by number	g/plant	% by number	g/plant
874120	0 (0)	0 (0)	1.7 (2)	25 (60)	1.7 (0)	30 (0)	0 (2)	0 (81)
Sante	0 (0)	0 (0)	3.3 (4)	130 (72)	0 (2)	0 (40)	1.7 (0)	85 (0)
Eve Balfour	3.3 (4)	120 (110)	1.7 (2)	30 (20)	0 (0)	0 (0)	3.3 (4)	150 (90)
Cara	0 (0)	0 (0)	1.7 (2)	40 (46)	1 (1.9)	25 (54)	3.3 (5)	83 (115)
Kestrel	0 (0)	0 (0)	0 (0)	0 (0)	0 (4)	0 (60)	3.3 (0)	40 (0)
King Edward	4 (4)	60 (94)	5 (6)	72 (119)	0 (0)	0 (0)	0 (0)	0 (0)

2001 c

The effects of seaweed extracts on foliar and tuber blight development and crop yield

Introduction

Seaweed extracts preparations have been reported to induce/activate the natural resistance of plants against oomycete fungi (e.g. Gebrüder Schaette KG, product information). Furthermore, seaweed and other extracts (e.g. from compost and plant e.g. Brassica extracts and a range of other products e.g. chitin), permitted under organic farming standards were also reported to exhibit antifungal or resistance inducing activities. Several modes of action were suggested for this effect including direct antimicrobial activity and induced resistance already mentioned, but also stimulation of crop growth by plant growth regulators present in extracts and/or supply of micronutrients required for optimum growth and/or activity of plant resistance mechanisms. However, very limited information is available about the efficacy of seaweed extracts against late blight under UK conditions.

The work commenced with tests for direct antimicrobial activity of four seaweed extracts in excised leaf bio-assays, following the same procedures for the evaluation of compost extracts as described in Chapter 6: Alternative Treatments, Section 1: Compost extracts leaf bioassay. None of the four seaweed preparations tested resulted in a significant reduction in foliar lesion expansion in the excised leaf bio-assay. Sea weed extracts therefore did appear to have any direct antifungal activity against *Phytophthora infestans*. However, other modes of action may exist that cannot be detected in excised leaf assays. For example, if seaweed extracts were elicitors for resistance mechanisms in plants, this may not be detected in excised leaves due to senescence and inefficient expression of resistance mechanisms in excised leaves. Therefore, a further pot trial was established with four potato varieties and three foliar applied liquid treatments which were claimed by the manufacturers to control diseases by a mechanism of induced resistance, although stimulation of growth may be an effect. In addition to the seaweed extract treatment, pine extract and a fish emulsion were also tested as it was suggested that these may have similar effects.

The potential for achieving yield increases through foliar application of mineral micronutrients (especially Zinc, Copper, Molybdenum and Manganese) contained in such products is well described in the literature and micro-nutrient applications (other than Copper) were also linked to reduced levels of foliar blight in conventional farming focused research programmes. However, late blight disease severity was also suggested to be influenced by soil applications of N, P, and K fertilization. For example, in previous studies high rates of nitrogen (greater than 200 kg/ha) applied as mineral fertiliser to soil, increased late blight severity, but in contrast increased rates of P and K application decreased lesion size.

The main objectives of the pot trials described here was therefore:

(i) to study the effect and interaction between (a) pre-planting soil fertility inputs of organic-matter-based macronutrient fertilisers (cattle-manure-based compost and chicken-manure pellets) and (b) post-emergence applications of treatments which may act as micro-nutrient fertility inputs, growth promoters and/or elicitors of resistance (seaweed extracts, pine waste extracts and anaerobically digested fish waste).

(ii) To compare the effect of different fertility input treatments in varieties with different levels of genetic resistance to late blight

Material and Methods

The experiment was carried out in 2001 using a completely randomised, split plot design with 6 replications. Four varieties of potato were compared: 874120, Eve Balfour, King Edward and Kestrel. Individual plants were grown from un-chitted tubers planted at a depth of 25cm below the surface in 40-litre pots filled with nutrient-free coarse sand amended with either cattle manure based compost (supplied by Tio Ltd., Dalcross, Inverness) or chicken manure pellets (supplied by Greenvale Ltd., Hull) at a rate equal to 170 kg N per ha, which is the maximum rate allowed in organic production systems. (Cattle-manure-based compost and chicken-manure pellets represented organic fertility input types with different levels of water soluble, readily plant available N (one with a high and one with a low content of NH_4/NO_3)). Pots either received no additional foliar fertiliser application (water was added to control pots at a rate equivalent to the solutions of liquid fertility inputs) or received weekly liquid fertiliser inputs (for 9 consecutive weeks between 5 June and 7 September). Liquid fertility inputs used were either: (a) a seaweed extract (1.15 % w/w N), (b) an anaerobic fish digest (3.52 % w/w N), or (c) a pine extract preparation (0.15 % w/w N), at concentrations recommended by the manufacturers (9, 54 and 50ml per pot respectively). According to the suppliers, these preparations have the following characteristics:

(i) Pine extract is a plant growth stimulant made from natural conifer foliage. It is said to stimulate soil microbial activity and to create a "healthy" environment for the plants. It was previously shown to directly stimulate the growth of buds, flower, and roots, to enhance general plant health and to increase the yield and quality of most crops.

(ii) Seaweed extracts are known to supply a range of micronutrients and to have growth promoting effects, but have a relatively low content of N. They were described by the suppliers to act as a supplementary micronutrient fertiliser, which may increase potato tuber yield and decrease loss from blight infection.

(iii) Fish emulsion has a high content of N and K and was therefore thought to act mainly as a macronutrient source.

Crop growth, development and yield and the progress of infection with both foliage and tuber blight were assessed as described previously. The foliar blight assessments were carried out between 24 August and 2 October.

Results and Discussion

The pre-planting soil fertility input type significantly affected both the level of infection with foliar blight and tuber yields. Effects on foliar blight in terms of Area Under the Disease Progress Curve (AUDPC) varied considerably among the four varieties and type of base fertiliser. The AUDPC was greater for susceptible varieties (Fig. 5.16). For varieties Eve Balfour and Kestrel the AUDPC was higher when chicken manure pellets were used as the base fertiliser, than where cattle manure-based compost was used (Fig. 5.16). There was no significant difference in blight development between plants receiving different liquid fertiliser inputs.

Tuber yield was affected by the type of basal fertiliser (cattle-manure-based compost or chicken-manure pellets), liquid fertiliser inputs and potato varieties. Tuber yields of plants fertilised with chicken manure pellets were approximately 3 times higher than those that had received cattle manure based compost (Figs. 5.17 and 5.18). Seaweed extract was the only liquid fertiliser that significantly increased tuber yield, but this effect was more pronounced when chicken-manure pellets were used as the main basal fertiliser (Figure 5.17 and 5.18). Tuber yield increased by approximately 20% when seaweed extract was used (Figure 5.19).

The effects of fertility inputs on tuber blight infection (expressed as a % of total tubers infected) were very small and it was not possible to analyse the results statistically due to the large number of treatments in which no tuber blight was observed. Only King Edward showed some symptoms of tuber blight (data not shown).
Since (a) application of seaweed extract resulted in higher yields only with the two more resistant varieties and (b) the fact that one of the resistant varieties (874120 Sarpo Mira) showed no blight symptoms until the end of the trial, but a significant increase in yield after seaweed extract application, it is unlikely that induced resistance was the mode of action for the observed yield increase. Also "additional nitrogen supply" is unlikely to have been the mode of action because the 2 other foliar applied treatments used resulted in similar or higher additional nitrogen input than the seaweed extract (seaweed extract 0.1 g N per application; pine extract 0.08 g N per application and fish emulsion 1.9 g N per application): fish emulsion, which provided almost 20 times the amount of N compared with seaweed extract and would have been expected to result in higher yield if the nitrogen supply would have been a limiting factor.

Additional experiments are, however, required to pin-point the exact mode of action(s) and focus on determining the extent to which (a) growth promoting effects (e.g. of plant growth regulators present in the seaweed extract) and/or (b) improved micronutrient supply have contributed to the observed increase in yield in resistant varieties. If the results of pot trials were confirmed in the field (see Section 7: Foliar sprays and microbial soil inocula in this Chapter) recommendations for the use of sea weed extracts may be most appropriate for use with resistant varieties only, since the more susceptible varieties seem unlikely to produce the additional yield required to make the application of seaweed extracts cost effective.

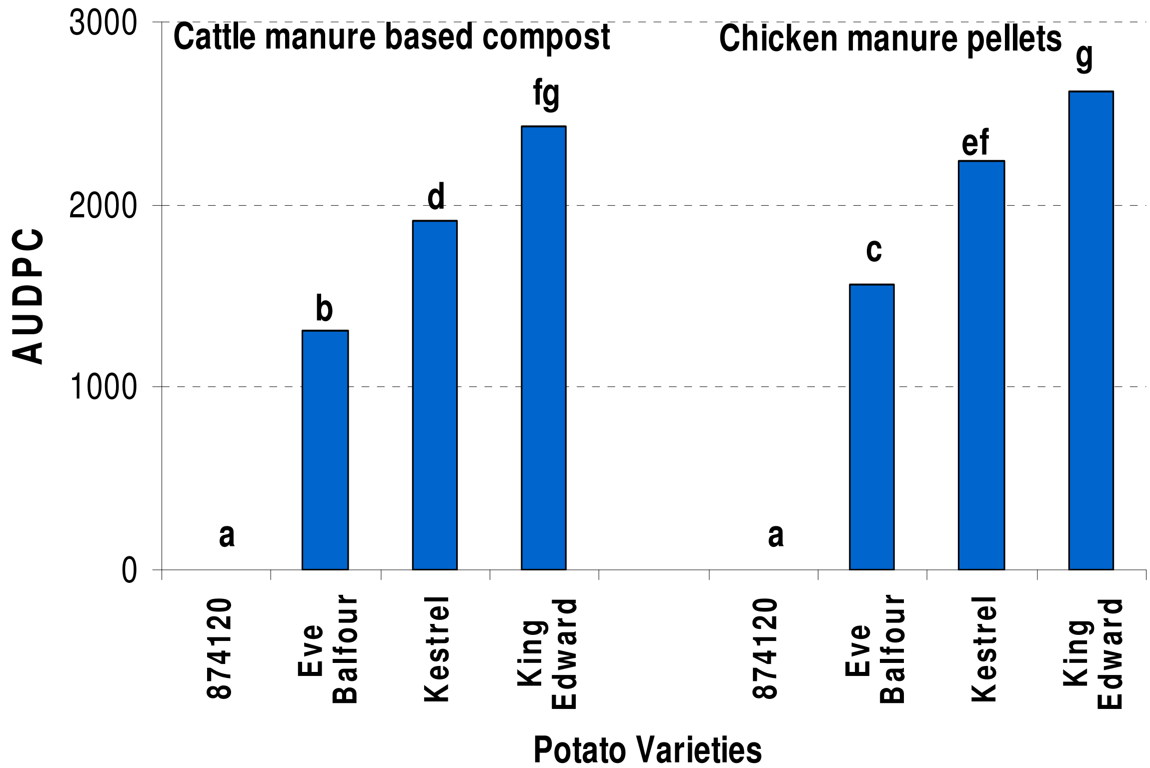


Figure 5.16 AUDPC of different varieties of potato grown with different types of basal fertilizers; cattle manure based compost and chicken manure pellets (both applied at a rate equal to 170 kg N per ha). Different letters indicate highly significant differences ($P<0.01$) according to Tukey's Honestly Significant Difference (HSD) test.

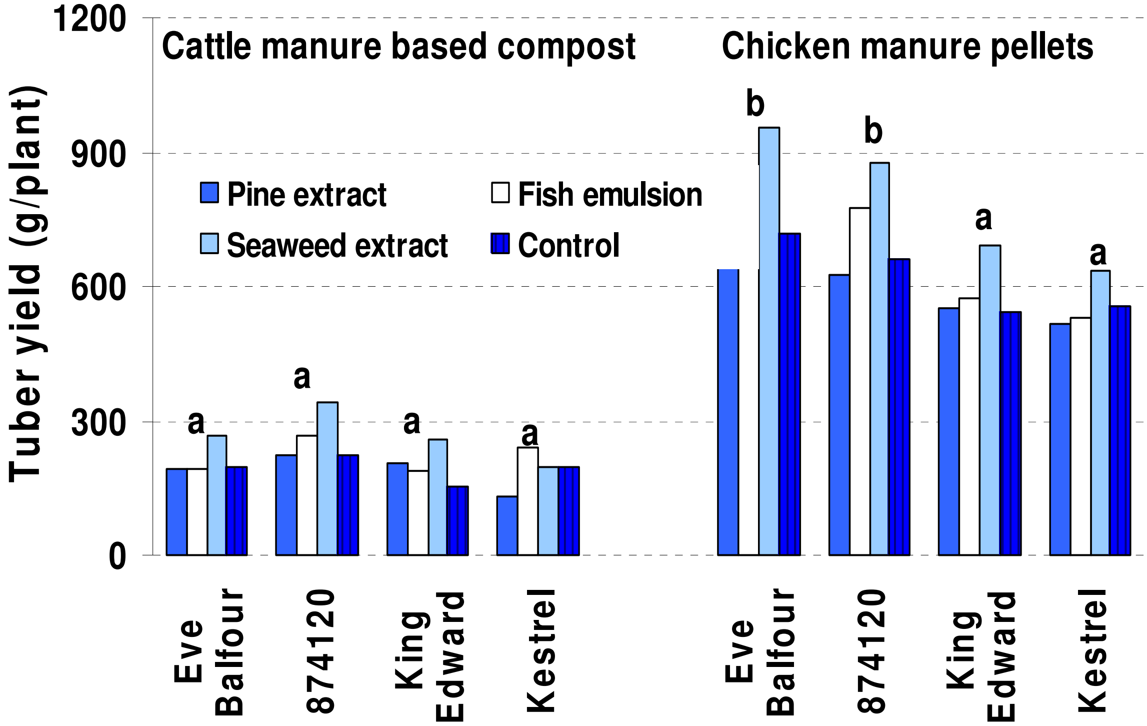


Figure 5.17 Tuber yield of different varieties of potato grown with different types of basal fertilizers; cattle manure based compost and chicken manure pellets and liquid fertiliser inputs (both applied at a rate equal to 170 kg N per ha). Different letters indicate highly significant differences ($P<0.01$) apply to all these four columns according to Tukey's Honestly Significant Difference (HSD) test.

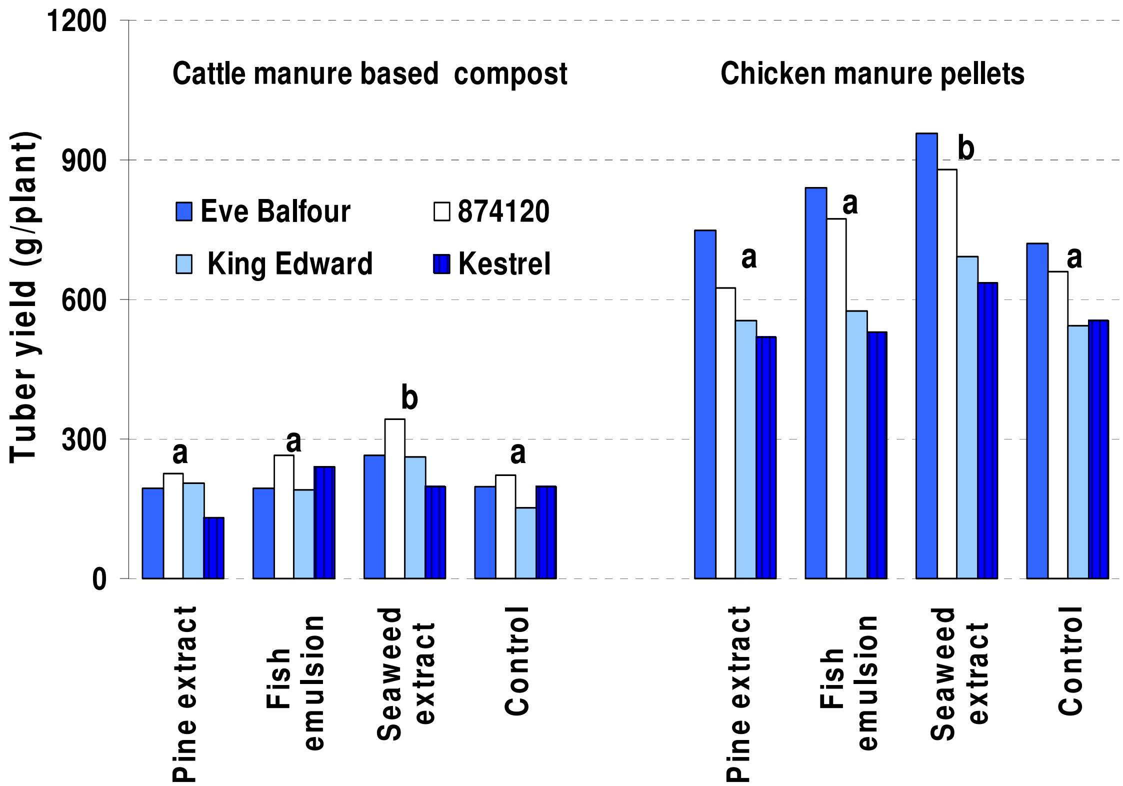


Figure 5.18 Tuber yield of different varieties of potato receiving different liquid fertilisers input types; pine extract, fish emulsion and seaweed extract. The base fertiliser (chicken pellets or manure) were applied at a rate of 170 kg N per ha. Different letters indicate highly significant differences apply to all these four columns (P<0.01) according to Tukey's Honestly Significant Difference (HSD) test.

2002

The effects of nitrogen input type and level and variety on infection with blight and tuber yield

Methods and Materials

The 2002 pot experiment was a completely randomised design with 6 replicates. The aim was to study the effects of sources and rates of N on blight development and tuber yield. Four varieties of potato were used: 874120, Eve Balfour, Cara and Sante. Different types of basal manure and different rates of Nitrogen were applied as (a) cattle manure based compost, (b) chicken manure pellets (Greenvale Ltd.) or (c) as a combination of compost and chicken manure (Table 5.8) were applied to individual plants grown in 40-litre pots containing nutrient-free coarse sand

Un-chitted tubers were planted at a depth of 25cm. Although, the N rate in some treatments in this experiment and in experiment 2001a described above was 680 kg/ha (4 times the permissible level) the aim was to (i) compensate for the lack of N supplied from soil organic matter and mineral pools via mineralisation (sand is completely void of organic matter based nitrogen pools), (ii) mimic the high N-input levels from grass/clover swards that are often used as preceding crops for organic potato crops and (iii) mimic the much higher levels of organic matter inputs (250 kg N per ha may be applied on an annual basis) often used for potato (even when these are planted after grass clover leys). However, more intermediate levels of nitrogen inputs using the same input types were also studied in this and other experiments described in the report.

Table 5.18 Fertility input treatments used in the pot experiment 2002.

Treatment number	Nitrogen from Cattle manure based compost (N kg/ha)	Nitrogen from Chicken manure pellets (N kg/ha)	Total Nitrogen added (N kg/ha)
1	170	-	170
2	-	170	170
3	85	85	170
4	680	-	680
5	-	680	680
6	340	340	680

Results

Blight development and tuber yield differed significantly between varieties ($p<0.001$) and rate and source of N. The most resistant variety (874120) showed the lowest AUDPC compared with Eve Balfour, Cara and Sante which are moderately resistant varieties (Figure 5.19). There were significant differences in foliar blight development between rates and sources of N. Plants receiving 170 kg/ha N from either cattle manure based compost or chicken manure pellets showed the lowest AUDPC. Plants that received 170 kg N/ha from a mixture of 85 kg N/ha chicken manure pellets and 85 kg N/ha cattle manure based compost showed the highest levels of blight. When fertility inputs were applied at rate of 680 kg/ha N similar levels of blight were observed with all fertility input types (Figure 5.20). Potatoes fertilised with cattle manure based compost at the rate of 170 kg N/ha gave the lowest yield, whilst those receiving N from chicken manure pellets gave higher yields (Figure 5.21). The mixture of cattle manure based compost and chicken manure pellets at the rate 680 kg N/ha gave the highest yield as all treatments (Figure 5.21). As in the pot experiments in 2001 level of tuber blight was very low, and the effects of N input level and variety on tuber blight infection could not be examined (Table 5.4.1.4).

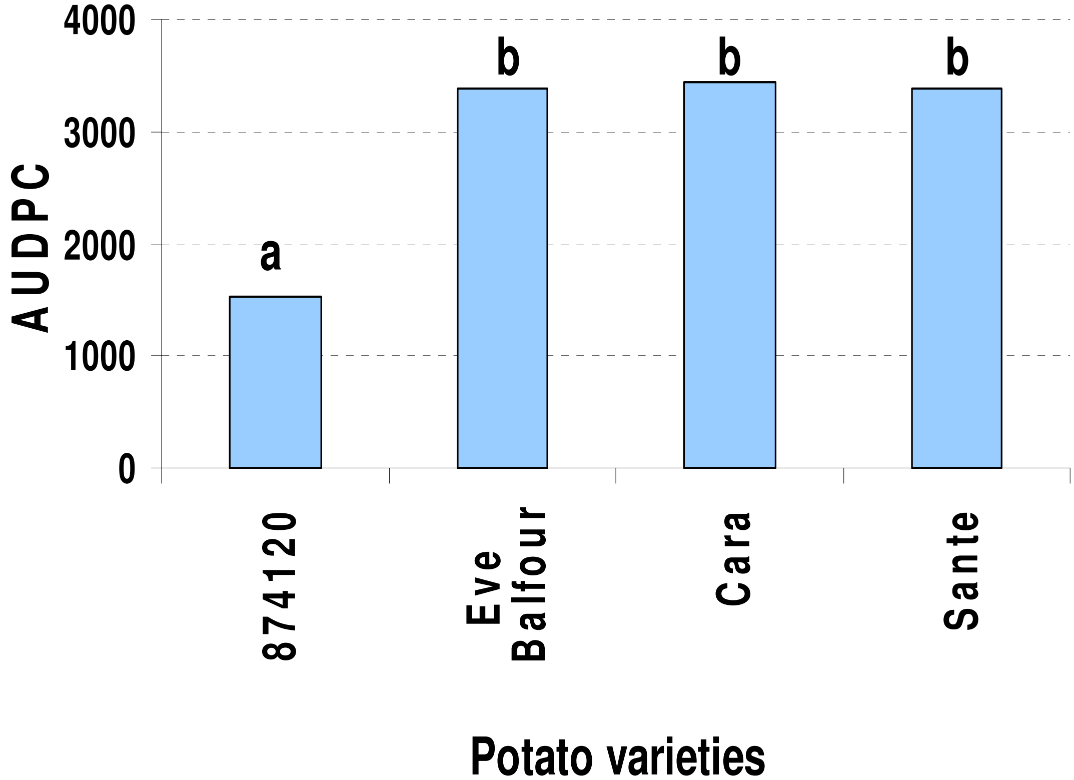


Figure 5.19 AUDPC of different varieties of potato. Different letters indicate highly significant differences (P<0.01) according to Tukey's Honestly Significant Difference (HSD) test.

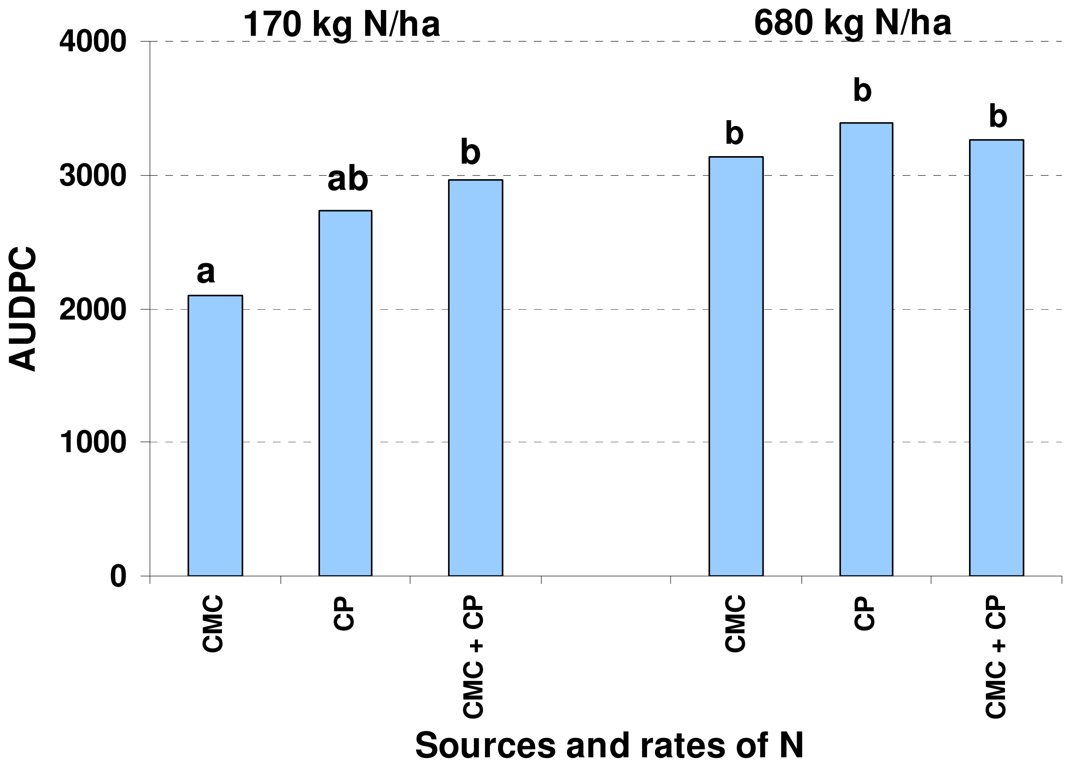


Figure 5.20 AUDPC of potatoes grown with different rates and sources of N. Different letters indicate highly significant differences ($P<0.01$) according to Tukey's Honestly Significant Difference (HSD) test.

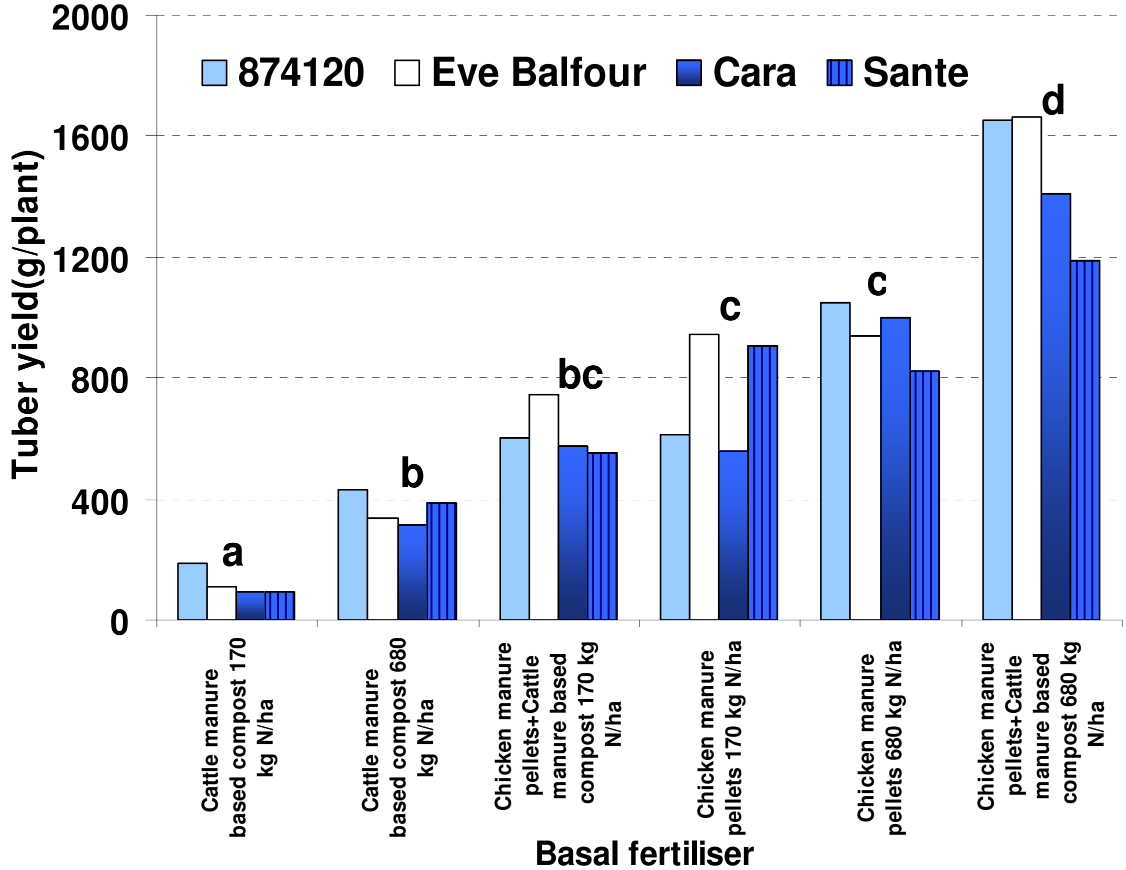


Figure 5.21 Tuber yield of potatoes grown with different rates and sources of N. Different letters indicate highly significant differences apply to all these 4 columns (P<0.01) according to Tukey's Honestly Significant Difference (HSD) test.

Table 5.19 Tuber blight infection (% by number of tubers affected) and weight (g/plant) of different varieties of potato grown with different rates and sources of N in 2002 at harvest (14/10/02) and after storage (13/1/03).

Potato varieties	Sources and rates of N	% Infected tuber at harvest		% Infected tuber after storage	
		Infected tubers			
		% by number	g/plant	% by number	g/plant
874120	Cattle manure based compost 170 kg N/ha	0	0	0.60	59.00
	Chicken manure pellets 170 kg N/ha	0	0	0	0
	Cattle manure based compost + Chicken manure pellets 170 kg N/ha	0	0	0	0
	Cattle manure based compost 680 kg N/ha	0	0	0.98	33.70
	Chicken manure pellets 680 kg N/ha	0	0	7.84	110.60
	Cattle manure based compost + Chicken manure pellets 680 kg N/ha	0.44	29.80	1.39	47.95
Eve Balfour	Cattle manure based compost 170 kg N/ha	0	0	2.08	44.90
	Chicken manure pellets 170 kg N/ha	0	0	0.93	28.90
	Cattle manure based compost + Chicken manure pellets 170 kg N/ha	0	0	0	0
	Cattle manure based compost 680 kg N/ha	0	0	5.63	62.60
	Chicken manure pellets 680 kg N/ha	2.96	126.70	6.41	98.20
	Cattle manure based compost + Chicken manure pellets 680 kg N/ha	0	0	1.63	92.10

Table 5.19 (continued) Tuber blight infection (% by number of tubers affected) and weight (g/plant) of different varieties of potato grown with different rates and sources of N in 2002 at harvest (14/10/02) and after storage (13/1/03).

Potato varieties	Sources and rates of N	% Infected tuber at harvest		% Infected tuber after storage	
		Infected tubers			
		% by number	g/plant	% by number	g/plant
Cara	Cattle manure based compost 170 kg N/ha	1.67	25.00	2.68	110.60
	Chicken manure pellets 170 kg N/ha	0	0	1.85	47.90
	Cattle manure based compost + Chicken manure pellets 170 kg N/ha	4.17	32.60	4.46	7.40
	Cattle manure based compost 680 kg N/ha	2.76	62.15	6.67	182.50
	Chicken manure pellets 680 kg N/ha	0	0	0	0
	Cattle manure based compost + Chicken manure pellets 680 kg N/ha	0	0	1.11	49.90
Sante	Cattle manure based compost 170 kg N/ha	0	0	0	0
	Chicken manure pellets 170 kg N/ha	0	0	12.74	59.70
	Cattle manure based compost + Chicken manure pellets 170 kg N/ha	0	0	3.33	33.40
	Cattle manure based compost 680 kg N/ha	0.57	28.90	2.19	65.30
	Chicken manure pellets 680 kg N/ha	3.27	50.85	3.61	174.90
	Cattle manure based compost + Chicken manure pellets 680 kg N/ha	1.85	52.70	4.55	122.20

Discussion

Potato varieties and fertility inputs used in this study differed considerably in terms of their effects on foliar blight infection and tuber yields. However, the 3 pot experiments resulted in very low levels of tuber blight and as a result the effects of fertility treatments and planting depths on tuber blight infection could not be determined for different varieties. Possibly, this was, because all varieties used had relatively high levels of tuber blight resistance or because the sample units (one potato plant per pot) gave a very small sample sizes compared with field plots.

The more foliar blight resistant varieties had less foliar blight infection and this is likely to be the main reason for the higher yields. These observations are similar to those of the field experiments that are described elsewhere. Generally, late cultivars are known to be more tolerant which is likely to be due to their more vigorous foliage growth, and this was observed in all experiments.

The types of basal fertiliser (compost or chicken manure pellets) affected both foliar blight (significant differences were recorded in only in one of the 3 pot trials) development and tuber yields (in all trials). Foliar blight development in plants receiving cattle manure based compost was lower than in those receiving chicken manure pellets. This may have been due to lower physiological susceptibility in compost fertilised plants or to the fact that their canopies were much smaller. Canopy size is known to affect the micro climate and smaller canopies were described to reduce the chance of spore infection.

However, it is not only the amount of N, but also the form of N that was shown to affect blight susceptibility of the canopy. It has been previously reported that nitrogen in the nitrate form is more favourable to development of blight than in the ammonium form. In this experiment, the nitrate levels in the chicken manure pellets were approximately 10 times higher than from cattle manure based compost, which would have been expected to release mainly NH_4 via mineralization. This may have been an additional reason for the observation that foliar blight severity of the plants treated with chicken manure pellets was higher than in those treated with compost based manure.

The level of N applied to crops also had an important impact on foliar blight and tuber yield in most varieties. Disease severity was higher in plants that received 680 kg N/ha than 170 kg N/ha and they may have been due to direct and indirect effects.

Direct effects would be changes in susceptibility at the plant tissue level affecting the ability of plants to defend themselves against pathogen attack. N abundance results in the production of young, succulent growth, a prolonged vegetative period, and delayed maturity of the plant. This is thought to make the plant more susceptible to pathogens that normally attack such tissue, and result in longer periods in which the foliage remains susceptible.

Indirect effects of increased fertilisation on late blight would be caused by changes in canopy size. Changes in canopy size may affect the micro climate and thereby the infection process. The infection process by *P. infestans* sporangia is known to be affected by temperature and humidity, since its spores require water, an appropriate temperature range to germinate and especially a high humidity. Over-fertilisation with nitrogen causes dense plant and foliage growth. The canopy dries out slowly because of restricted and air movement maintaining >90% relative humidity for extended periods, giving a high risk of infection.

There can also be a plant size effect: the smaller the plants, the higher the fraction of spores that is likely to fall on the ground rather than on potato leaves, potentially slowing the epidemic infection as previously suggested.

Based on the assessments carried out in the experiments it was not possible to identify the exact mechanisms (physiological versus microclimate of canopy structure related mechanisms) responsible for the reduced susceptibility in the crops fertilised with compost. Future studies could focus on the expression of pathogenicity-related genes and proteins and/or microscopy based examination of leaf structure and morphology to identify differential expression of physiological resistance mechanism.

When applied at similar total N-input levels chicken manure pellets (which have a high content of water soluble N) always gave significantly higher yields than manure based compost (which contains very low levels of water soluble N).
The results from the pot experiments conflict with the results from field trials carried out in soils which had been under organic farming management for > 5 years. In field trials, manure based composts always gave higher yields than chicken manure pellets. This may have been due to the higher biological activity (and associated N-mineralization rates) in organically managed soils compare to sand (which is known to have very low biological activity).

In the pot experiment carried out in 2002 the 50:50 mixture of compost and chicken pellets gave the highest yield when compared to both compost and chicken pellets at the same N-input level of 680 kg N. This indicates that the addition of organic matter based N-inputs has a beneficial effect on plant growth, even in a low biological activity substrate, provided that additional N-is applied in water soluble form.
These results may, however, also have been due to a reduction in salt stress/toxicity caused by the extremely high levels of chicken pellets.

2005

The effects of soil microbiological activity and water supply on the response of potato yield and quality to different types and levels of fertility inputs

Introduction

Previous field and pot experiments from 2001 to 2004 demonstrated that:

- Level and type of fertility input had no significant effect on the level of late blight infection, either in the foliage or in the tubers
- Yield and tuber size grading were affected by fertility management

However, it was clear that responses to different types and levels of fertility inputs were most probably dependent on two key factors

- Microbiological activity of the soil (influenced by the duration of organic management and use of fertility building crops and use of organic manures)
- Soil water supply as influenced by rainfall and/or irrigation (which affects the availability and uptake of nutrients by the crop)

The implications are that the most efficient fertility management programme in organic cropping systems to optimize utilization of applied nutrients and the performance of the potato crop is site specific. It may depend upon the inherent fertility and microbiological activity of the site as affected by previous management (methods and duration) and water supply, as affected by local meteorological conditions and availability of water and equipment for irrigation.

Field experiments comparing different 'soils' with controlled water inputs are extremely challenging because there are many confounding factors and it is difficult to control water inputs from rainfall.. Therefore, to achieve the required degree of environmental control, especially over water supply a pot experiment was carried out in 2005.

Methods and Materials

The 2005 experiment was a completely randomised design with 8 replicates. The aim was to study the effects of soil microbiological activity and water supply on the response of potato tuber yield and size distribution (Variety Sante) on different types and levels of fertility inputs in the absence of late blight infection. These were similar to those investigated in previous experiments. There were 20 treatments: Different types of basal manure and different rates of Nitrogen were applied as (a) cattle manure based compost, (b) chicken manure pellets (Greenvale Ltd.) and there was a control treatment that received no supplementary fertility input. Two soils with different levels of inherent soil microbiological activity, but of the same type (sandy-loam) were used. and collected from adjacent fields at Nafferton Farm. The soil of 'low' microbiological activity was collected from a field under conventional management that had been sown with oilseed-rape, treated with 'Temik' (aldicarb) for the control of soil pests and synthetic fertilizers over a long period with relatively little input of farm-yard-manure. The soil of 'high' microbiological activity was collected from a field under organic management that had been cropped with a grass/red clover ley for five years and received applications of farm-yard-manure and compost. Individual plants were grown in a glass-house and planted in 40-litre pots containing the different soils on 28 April. There were two levels of water input over the growing season – frequent or 'optimum' irrigation and restricted input. Plants were observed daily throughout the whole period of growth, and water was applied at the rate of 2 litres of water per application to individual pots for the optimum treatment whenever plants began to show the first signs of stress/wilting. For the 'restricted' treatment, only 1 litre of water was applied per pot and observations confirmed that these plants were more severely stressed than those receiving the optimum application by the time that water was applied. A summary of treatments is given in Table 5.20.

Table 5.20 Details of treatments used in the pot experiment 2005.

	'Optimum' water supply	**'Restricted' water supply**
High soil microbiological Activity		
Compost	85 kg/ha	85 kg/ha
	170 kg/ha	170 kg/ha
Chicken-manure pellets	85 kg/ha	85 kg/ha
	170 kg/ha	170 kg/ha
No additional manure	0 kg/ha	0 kg/ha
Low soil microbiological Activity		
Compost	85 kg/ha	85 kg/ha
	170 kg/ha	170 kg/ha
Chicken-manure pellets	85 kg/ha	85 kg/ha
	170 kg/ha	170 kg/ha
No additional manure	0 kg/ha	0 kg/ha

Measurements were made of the chlorophyll content of leaves with a 'Spadmeter' on 24 June and 3 August. At the end of the season, potatoes were harvested at the end of October and tuber yield was assessed and tubers size grading in the bands <45mm, 45-65 mm and 65-85mm. Tuber dry-matter content was determined on a composite, fresh sub-sample sample of tubers of about 150g, taken from the different size grades

An analysis of the farm-yard based manure compost and chicken manure pellets is shown in Table 5.21 and the quantities of nutrients applied with each fertility treatment in Table 5.22.

Table 5.21. Analysis of farm-yard-manure-based compost and chicken manure pellets.

	Compost	**Chicken manure pellets**
Moisture content %	43.5	10.0
Total solids %	56.5	90.0
g/kg (dry matter basis)		
Carbon	229	429
NH4-N	0.24	11.6
Nitrate N	0.35	0.2
Organic N	20.3	37.1
Total N	20.9	48.9
P	6.7	14.0
K	19.6	28.0
P_2O_5	15.4	33.0
K_20	23.5	33.0
C:N ratio	11:1	9:1

Table 5.22. Inputs of major nutrients applied (kg/ha) with compost and chicken manure pellets at nitrogen levels of 85 and 170 kg/ha

	Compost		**Chicken manure pellets**	
	85kg/ha N	170kg/ha N	85kg/ha N	170kg/ha N
kg/ha				
Carbon	931	1863	744	1488
NH4-N	1.0	2.0	20.2	40.4
Nitrate N	1.4	2.8	0.4	0.8
Organic N	82.6	165.2	64.5	129.0
Total N	85	170	85	170
P	27.2	54.4	24.3	48.6
K	79.7	159.4	138.5	277.0
P_2O_5	62.6	125.2	57.4	114.8
K_20	95.6	191.2	57.4	114.8

Measurements were made of the chlorophyll content of leaves with a 'Spadmeter' on 24 June and 3 August. Potatoes were harvested at the end of October and tuber yield was assessed in the size bands <45mm, 45-65 mm and 65-85mm. Tuber dry-matter content was determined on a composite, fresh sub-sample sample of tubers of about 150g, taken from the different size grades

Results and Discussion

Chlorophyll contents of leaves measured on two occasions indicated the nutrient status of the leaves. They decreased between the first and second assessment as the plants matured. Irrigation and fertility input type (P<0.001) and nitrogen input level (P<0.05) significantly increased it at both sampling times, indicating better nutrient status of the leaf tissue with increasing levels of applied nutrients. However, soil type (level of soil microbiological activity) had no effect.

Effects of treatments on total tuber number and tuber yield are shown in Figures 5.22 and 5.23. Yields ranged from a minimum of 457g/plant (restricted water, no supplementary fertility input in soil of 'high' microbial activity) to a maximum of 895g/plant (optimum irrigation, chicken manure pellets at 170kg/ha N in soil of low microbiological activity) representing almost a doubling of yield (an increase of 96%).

Figure 5.22. Effects of soil type, water input, fertility input type and level of nitrogen on total tuber number

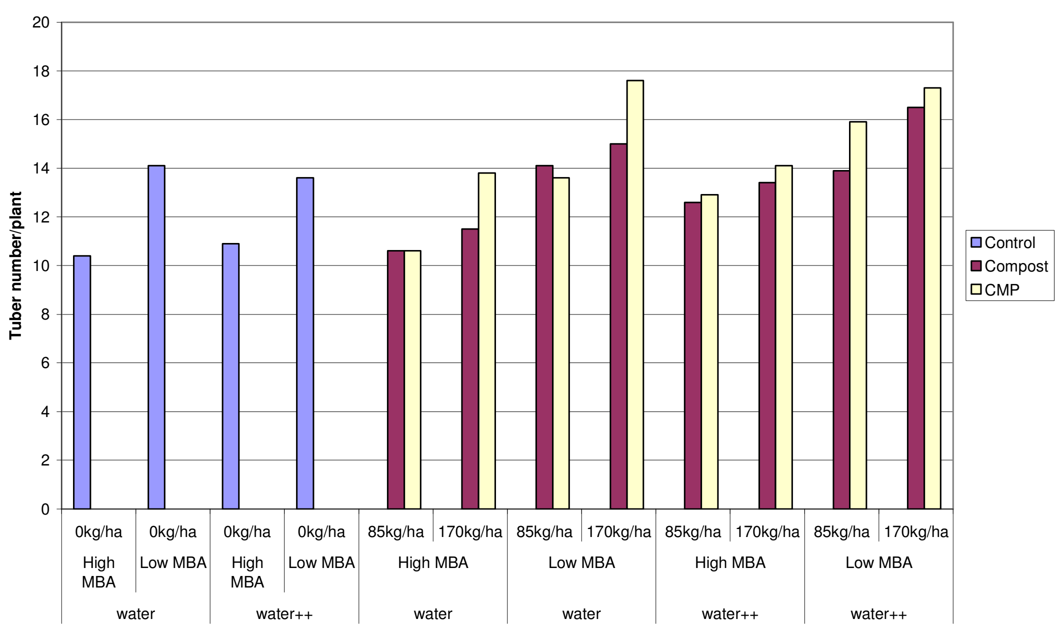
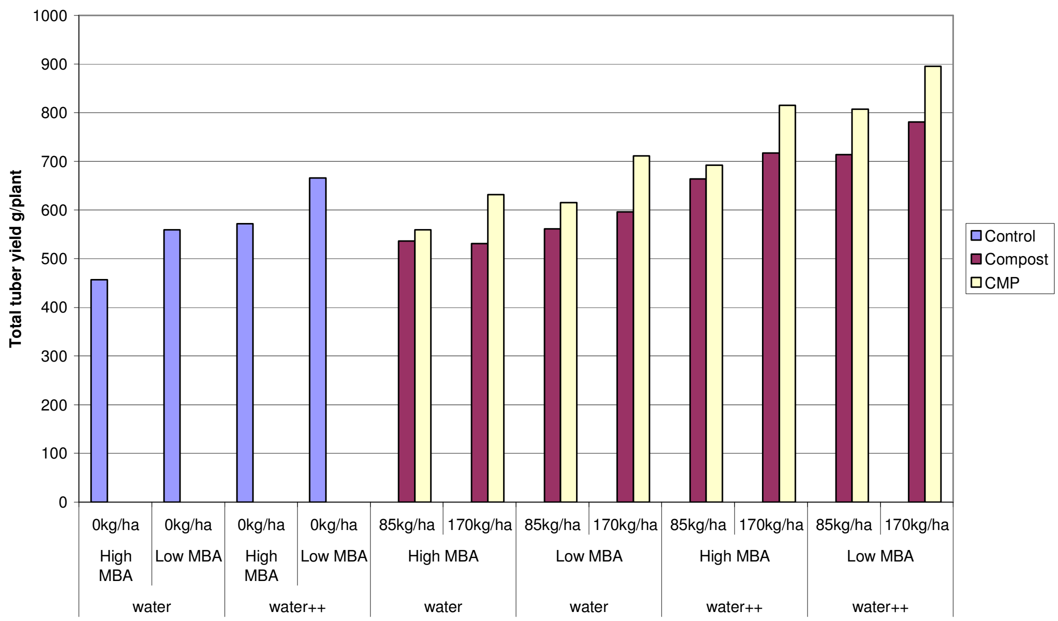


Figure 5.23. Effects of soil type, water input, fertility input type and level of nitrogen on total tuber yield

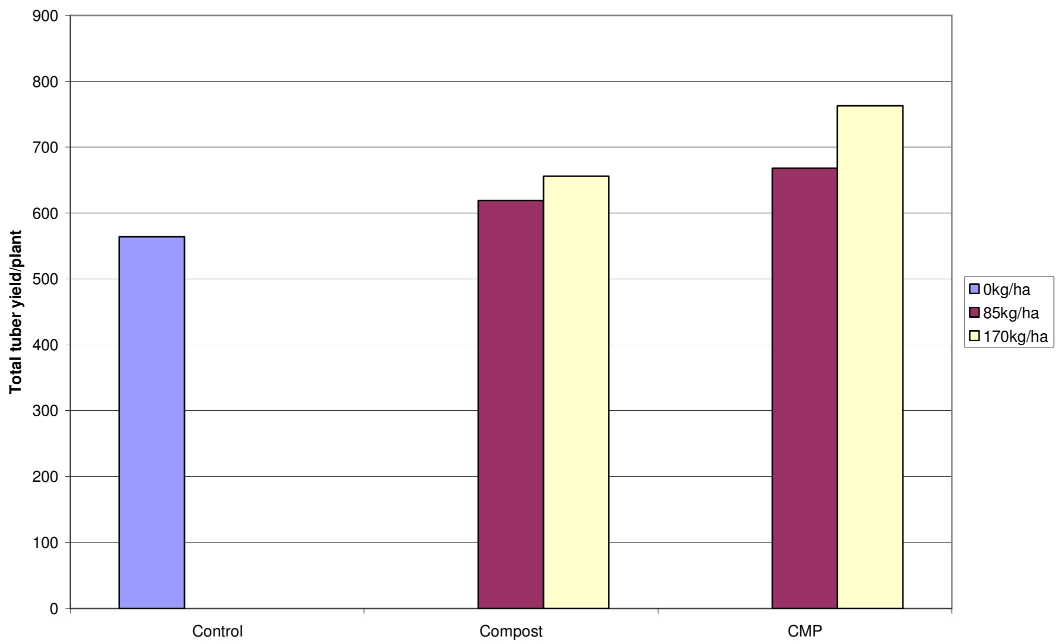


As expected, restricting the supply of water resulted in lower yields. Averaged over all treatments, sub-optimal water supply resulted in a loss of yield of just over 20%. However, the total number of tubers was not affected and lower yields were because tubers were smaller and fewer tubers achieved the 45-65mm and 65-85mm size grades. The level of soil microbial activity had a highly significant effect on total tuber yield and tuber number. Unexpectedly however, the most productive soil in terms of both tuber yield and tuber number was the one that had been designated 'low microbial activity' on the basis of its previous history i.e. conventional cropping with limited inputs of organic manure and several years since the field was last in a grass ley. At the time that the soil was collected in spring 2005, the field was in oil-seed rape and had been treated with a pesticide (aldicarb). Both these treatments would be expected to have decreased soil microbiologically activity. Exudates from brassica tissues (e.g. glucosinolates and iso-thiocyanates) have been shown to have suppressive effect against certain micro-organisms in soil. Indeed, incorporation of brassica tissues into greenhouse soils have been shown to be effective against corky root rot in tomatoes as an alternative to fumigation with methyl bromide or steam sterilisation (H. Giotis, 2006, personal communication). The loss of soil microbial activity would, on the basis of our initial hypothesis, decrease the mineralization capacity of the soil and therefore limit the response of the crop to applied compost, but this was not apparent. This observation was not only unexpected but also very difficult to explain. A possibility is that pathogenic microbiological population including fungi, bacteria and nematodes, was decreased by the combination of aldicarb and brassica exudates and this had a positive effect e.g. improved root growth, improved tuber set. It seems unlikely that difference in soil fertility was responsible, because the fertility would be greater following the 5-year grass/clover ley than after rape in a conventional rotation. Assessments of the two soils proteomics profiles at the beginning and end of the growing season may clarify the picture. (These assessments are currently in progress).

As expected, any additional fertility input irrespective of type or level increased yield total yield. Application of either farm-yard manure based compost or chicken manure pellets significantly increased both total tuber yield, yield of large tubers (65-85mm) and total tuber number (all $P<0.001$) and 65-85mm tubers ($P<0.05$) compared with the control which had no supplementary fertility input. Compost and chicken manure pellets increased total tuber yield by about 13 and 27% respectively and total tuber number by about 10 and 17% respectively. The greater effect of chicken manure pellets compared with farm-yard-manure-based compost for the same input of nitrogen (both 85 and 170kg/ha) was probably because of the higher content of more readily available nitrogen i.e. NH_4-N and nitrate N (Tables 5.21 and 5.22). Chicken manure pellets contained approximately 24% of total nitrogen in the mobile or water soluble form compared with less than 5% for farm-yard-manure-based compost. However, both fertility input types contained similar amounts of P and K so that the differences in their effects were assumed to be due mainly to differences in readily available nitrogen. There were no significant effects of fertility input type on tuber dry matter percentage.

The level of N input (and consequently the input of P and K that was linked to N) had significant effects on total tuber yield and yields of large tubers 65-85 mm ($P<0.001$), total number of tubers ($P<0.01$) but no effects on graded yields or number of tubers or dry matter percentage. 85kg/ha and 170kg/ha nitrogen increased yield by 14 and 26% respectively compared with the control (which had no supplementary fertility input). Doubling the input of nitrogen from 85 to 170kg/ha had a modest effect on tuber yield and on average increased it by 12%. However, there was a fertility input type x nitrogen level interaction for total tuber yield (and this was the only interaction observed). At the 85kg/ha N level, yields were similar for both farm-yard-manure-based compost and chicken manure pellets (Figure 5.24) despite more of the nitrogen being in the readily available form in the chicken manure pellets. Doubling the application of manure-based compost to provide 170kg/ha N gave no significant yield increase compared with the 85 kg/ha N level applied either as compost or as chicken pellets. However, the 170kg/ha N level applied as chicken manure pellets gave a significantly higher yield than all of the other treatments i.e. the chicken manure pellets were more effective at the higher input level. This may have been because potato plants' demands for N could be met by readily available, water soluble N, but at lower levels of input, or with manure-based composts at either level of N input, uptake was more dependent on current mineralisation of N from organic matter by soil microbial activity.

Figure 5.24. Effect of fertility input type and level of nitrogen on total tuber yield



The absence of interactions between treatments (with the one exception mentioned previously) did not support the hypothesis that effectiveness of fertility inputs depends on the soil microbiological activity and/or water supply. Therefore the results do not support the view that different fertility practices in terms of the best type of organic manure and level should be used for different situations e.g. irrigation regime or soil microbiological activity. However, a number of important principles are reinforced. Results confirm the importance of water supply for total and graded yield and the need to avoid water stress. They also support the observations from many irrigation experiments with conventional crops that there is no interaction between irrigation and the level fertiliser application i.e. the optimum nitrogen input for maximum yield is the same for both irrigated and non-irrigated crops. Where inputs were limited to 85 kg/ha N, farm-yard-manure based compost was as effective as chicken manure pellets and would be much cheaper option in practice. Whilst doubling the input of farm-yard-manure-based compost and hence nitrogen from 85 to 170kg/ha N gave no increase in yield of potato in the current season,, in a commercial cropping situation, further benefits would be realised later in the rotation. Where the objective is to maximise total and graded yields then irrigation to demand and the use of fertility inputs based on poultry manure at the maximum level permitted under organic standards (170kg/ha/year N as organic manure average over the whole of the cropped area) is the best combination, but the value of the extra yield may not cover the additional cost unless a cheap supply of poultry manure of known analysis is available.

2005

The effects of soil microbiological activity, water supply and different types and levels of fertility inputs on potato tuber proteomics

Summary

Potatoes were grown in a glasshouse in the UK in 2005 to study the effects of soil microbiological activity, water supply and different types and levels of fertility inputs on potato tuber yield and quality. In a complementary study, to determine the extent of agronomic treatment effects at a more fundamental level, proteomes of samples of tubers from different treatments were analysed. Two dimensional gel electrophoresis (2-DE) analysis revealed qualitative difference between the proteomes investigated: proteomes of potatoes grown with the addition of chicken-manure pellets supplying 170 kg/ha N, were more variable than those grown with organic, cattle-manure based compost at the same level of N supply, or with no supplementary fertility input (0 kg/ha N). There was little variation between the proteomes of potatoes grown with cattle-manure-based compost or with no supplementary fertility input. Differences between proteomes of tubers grown with different types and levels of fertility inputs are indicative of a direct interaction between the growing tuber and the resources available to the mother plant. Differential expression of genes may help to identify targets for crop improvement strategies and variety production to optimise yields over a range of different growing environments and minimise effects of deficiencies of resources or stress conditions

Introduction

An understanding of the responses within a biological system to external stimuli is key to matching agriculturally important crop species and individual varieties to specific environmental growing conditions such as soil type and fertility input. Broad range scale-profiling or "omic" studies increase the identification of differential gene expression between biological samples over targeted comparative assessment. Specifically, proteomics is the study of the proteins expressed by the genome and has only recently been applied to the analysis of crops grown in the field.

In this study the proteome of potato tubers (*Solanum tuberosum*) was assessed with respect to growth under different fertility inputs commonly used in organic cropping systems. Two dimensional gel electrophoresis (2-DE) analyses were used to show qualitative differences between the proteomes. The long term aim of such studies and the technology is to 'design' crop production systems that match specific genotypes to particular environments or sets of inputs and *vice versa*.

Materials and Methods

A full account of the treatments applied was reported in the previous section. In this report, results of proteome analysis are presented for tubers sampled from the following treatments:

Soil: High Biological Activity
Fertility inputs: No supplementary fertility input; chicken-manure pellets 170 kg/ha N; cattle-based manure compost 170 kg/ha N

(Proteome analyses of tuber samples from the other treatments are currently being analysed).

Sample preparation

In 2005, tubers were planted in the greenhouse in pots with different soils and types and levels of fertility inputs. Following harvest in autumn, an average-size tuber was taken from each of the three fertility treatments for proteomic analysis: four replicate samples were taken from each treatment. Each selected tuber was washed, sliced, freeze-dried and then milled to a free flowing powder.

Total protein extraction

Protein was extracted with phenol (Hurkman and Tanaka) from approximately 100mg freeze dried material (typically equivalent to 0.9-1.0g fresh tissue). Total protein content was measured using the 2D-Quant method (Amersham) and 60µg of each sample was precipitated from the phenol extraction buffer using the 2D-Clean Up method (Amersham). The protein pellet was re-suspended in 87.5µl De-Streak buffer with 0.5% pH4-7 IPG buffer added. Protein extracts from each sample within each treatment were pooled to give a total protein load of 240µg per 2-DE gel and each gel was run in triplicate.

2-DE

The first-dimension isoelectric focusing was performed using 18-cm immobilized pH gradient (IPG) strips (Amersham Biosciences, Uppsala) with a linear pH range of 4 to 7 in an Ettan IPGPhor isoelectric focusing system. The IPG strips were rehydrated overnight with total protein diluted in 8 M urea, 2% (w/v) CHAPS, 0.5% (v/v) IPG buffer 4 to 7, 0.28% (w/v) DTT, bromophenol blue up to a volume of 350 µL. After rehydration, the focusing was run using the following conditions: from 0 to 500V in 1 hour, from 500 to 1,000V in 1 hour, from 1,000V to 8,000V in 3 hours, finally 8,000V until 36,000 Vh. After focusing, the strips were stored at –70°C and equilibrated at room temperature in 6 M urea, 50mM Tris-HCl, pH8.8, 30% (v/v) glycerol, 2% (w/v) SDS, 1% (w/v) DTT for 10 min, and another 10 min in the same buffer but with 2.5% (w/v) iodoacetamide replacing DTT. The second dimension was run in the Ettan DALTsix system (Amersham Biosciences) in 19 x 23 cm homogeneous 12% SDS-PAGE gels, according to the manufacturer's instructions. The gels were run with constant 25- to 30-mA current overnight. The gels were stained with SYPRO Ruby fluorescent stain (Invitrogen), according to the manufacturer's instructions, except that 250 ml of the stain solution were used for each gel. Gel images were acquired with the Fluor-S fluorescent image analyzer (Bio-Rad) using an excitation wavelength filter of 470 nm and an emission wavelength filter of 580 nm.

Image and Data Analysis

Gel image analysis was performed with Progenesis (NLD). Protein spot intensities were normalized to the total intensity of valid spots to minimize possible errors due to differences in the amount of protein and staining intensity. Spots with a normalized volume of less that 0.016 were removed as they typically were identified as false positives. After another round of background removal and normalizing, spot intensities were exported and plotted in SPSS or Excel.

Results

2-DE

The 2-DE gels for the potato tuber gave between 700 and 1400 identifiable spots, depending on treatment, with some variation in the number of spots between individual samples (fig 5.25). Gel matching identified those proteins that were present in the proteomes of different treatments compared on a pair-wise basis, thus showing the degree of commonality between the two proteomes. This degree of commonality varied between the pairings of the treatments investigated. Gel matching identified; 49 proteins present in all three treatments, 91 proteins uniquely present in the no input and cattle-manure-based compost treatments (and therefore absent from the chicken-manure pellet treatment) ; 32 present only in no input and chicken-manure pellets experiments (and therefore absent from the cattle-manure-based compost treatment), and only 4 unique proteins shared between cattle-manure-based compost and chicken-manure pellets treatments (which were absent from the no fertility input treatment). Plotting normalised intensities of matched spots for each treatment in a pair-wise matrix (fig 5.26) shows trends indicating the spread of proteins within the different proteomes. Whilst the charts show there is a core set of proteins whose expression appears to be unaffected by the fertility treatments, there are several outlying proteins that show differential expression with respect to the different fertility treatments.

However, with the conditions required for image analysis of the gels based on the generation of an average gel to match spots between different treatments and the small number of replicates for gels (n=3), it is not possible to say that these differences are highly significant, but nevertheless, they are extremely interesting.

Discussion

The aim of this work was to gain an insight into the modulation of the potato proteome in response to different fertility treatments at field applied rates, typical of an organic cropping system. The data indicate that the different treatments did cause a qualitative difference to the proteome of the potatoes grown under the different conditions and that the underlying differential gene expression is that of a direct interaction between the developing tuber and the resources available to the plant.

Those differentially expressed proteins may provide targets for crop improvement strategies to allow the modification of potato varieties to give improved yields under several agricultural environments.

Proteomic profiling by 2-DE is a promising tool for screening biological responses and has only recently been utilised in the field of crops analysis. Although the number of proteins that can be analysed by 2-DE is limited with respect to the predicted numbers of proteins present in the entire proteome of the plants, it remains the most widely used tool for high-resolution protein separation and quantification. The use of proteomics, and other profiling tools, will not only contribute to our knowledge and understanding of perturbations to biological systems but they will also identify those genes necessary to overcome suboptimal growing environments.

The work reported here represents the analyses that have been completed so far. Further proteomic analyses are being undertaken to allow comparisons across the complete set of soil microbiological activity, water supply and type and level of fertility inputs.

In addition, analyses will be made of the microbial communities of the different soils/treatments to investigate any shifts in the bacterial and fungal populations from the beginning to the end of the experiment. In particular, changes that may have beneficial effects in terms of nutrient recycling from ‘organic’ manures or suppression of plant pathogens leading to improvements in crop performance and sustainability of cropping systems are of particular interest.

As soon as the analyses have been completed, the results will be published in peer-reviewed scientific publications.

Figure 5.25. 2-DE gel image from potatoes grown with no additional fertility treatments. 240µgtotal protein sample resolved in the first dimension on 18cm pH4-7 IPG stips, protein separated in the second dimension by electrophoresis through 12% homogeneous PAGE. Gel image used as reference gel for gel matching using Progenesis (Non Linear Dynamics).

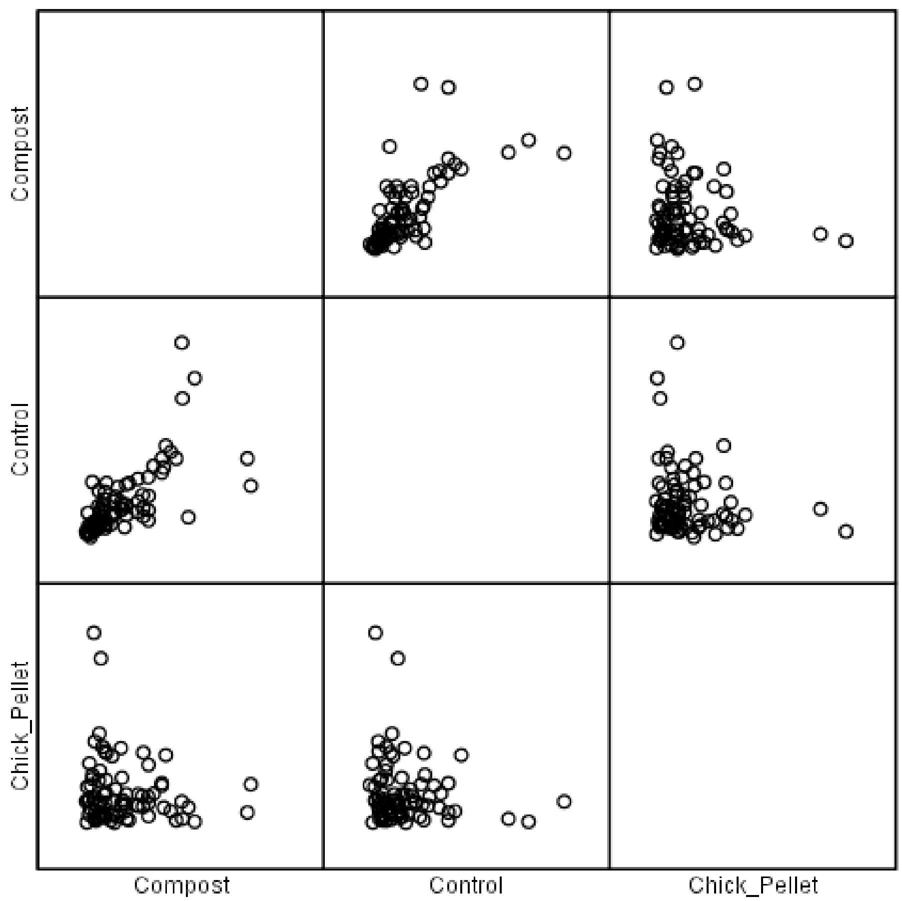


Figure 5.26. Matrix scatter plots for each fertility treatment. Scatter plots show normalised spot intensities for matched spots for each treatment. Compost: Organic compost added at 170KgN/ha equivalent, Chick_Pellet: Chicken pellets added at 170KgN/ha equivalent, Control: No fertility input added to organically managed soil.

Section 4: Planting date and seed tuber chitting

Summary

Experiments in the UK and the Netherlands tested pre-sprouting (chitting) and early planting of seed tubers, which should encourage early bulking and evasion of late blight. Observations of the effects of planting date and chitting on infection with late blight and potato growth and yield showed that responses will depend 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 both varieties that differed in resistance to late blight. However, differences between planting dates depended on when planting began and the interval between planting dates which affected the length of the growing season. When planting was late and the difference between the dates small, as in 2001 in the UK (planting in began early May with 2 weeks between planting dates), yield effects were small. On the other hand, when the season was longer because the weather was unfavourable for blight, as in the Netherlands in 2003, there were no differences either, because late planted crops had time to catch up with the early planted ones which senesced sooner. Sequential harvests in this last experiment clearly demonstrated that tuber bulking in the early planting both started and finished before the late planting which continued to grow and accumulate yield.

Effects of chitting on yield were similar to the effects of early planting. Fully chitted seed almost invariably gave higher yields in 2002 in the Netherlands and in late planted Valor in the UK presumably because of more advanced tuber bulking. The advantage of chitting seemed to be less when the growing period was longer, either because weather conditions were unfavourable for late blight as in the Netherlands in 2003, or because of a higher resistance level of the variety as in Lady Balfour in the UK in 2002.
Results of the experiments show that the 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 and crops are allowed to grow on, later planted or non-chitted seed may out yield early planted or chitted seed because of a larger and more persistent leaf canopy and increased solar radiation interception leading up to harvest (Allen and Scott, 2001). On the other hand, if blight infection is early, the more advanced treatments will show to advantage. Since it is impossible to accurately predict when blight will arrive at any location before the crop is planted, early planting and pre-sprouting are useful insurance treatments in organic production systems that should minimise the consequences of blight infection.
Planting date and chitting treatment influence the physiological age of the crop and the number of leaves per stem when blight first appears which may affect susceptibility to blight. 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, probably reflecting the complex control of inherent resistance of potato plants to blight.

Effects of planting date and pre-sprouting seed tubers on the development of late blight (*Phytophthora infestans*) infection, crop yield and quality of contrasting varieties of potatoes grown in organic systems.

Introduction

In most seasons in Europe, potato crops grown according to organic standards become infected with late blight (*Phytophthora infestans)*. The sooner that infection occurs and the foliage is destroyed, the shorter the period of tuber bulking and the lower the yield will be. Therefore an important strategy to adopt to minimise the effects of late blight is to establish crops as early as possible, so that acceptable yields are achieved before the disease intervenes. Components of such a strategy to promote earliness include the use of early maturing varieties, large seed tubers, pre-sprouted (chitted) or physiologically old seed and planting as early as conditions allow.
Early maturing varieties outyield late ones early in the season, but they are generally more susceptible to late blight. More resistant late varieties should produce higher yields eventually, but they should also be established as early as possible. For all varieties, pre-sprouted (chitted) seed usually emerge, initiate tubers and begin bulking sooner than unsprouted and reach acceptable levels of marketable yield earlier in the season. However, recent experiments have shown that, in certain cases, crops grown from chitted tubers may suffer greater infection with blight because they are physiologically older and more susceptible at the time of disease attack than those grown from non-chitted tubers (Karalus and Rauber, 1996; Karalus and Rauber, 1997).With early planting, yields will usually be higher than in later planted crops by the time blight infection occurs, but the potential advantage of chitted seed will only occur if disease susceptibility is not increased. There is also a risk that early planting of well-chitted seed into cold soils may cause a 'shock' that leads to premature tuber initiation and limited plant growth including disorders such as 'coiled-sprout' and 'little-potato'. Therefore, potential yield benefits of early planting and chitting will be limited if there are adverse interactions with blight inoculum density that increase disease susceptibility because of physiological or environmental effects.

Recent evidence suggests that early crop establishment could enhance blight resistance irrespective of variety or growing conditions which is an additional advantage. Visker *et al*, (2003), showed that within plants, later-formed leaves towards the apex of the stem are progressively more resistant to blight than older, basal leaves Therefore, the more leaves there are on the plant stems, the more resistant it should be overall. Plants that are established early will have a greater proportion of apical leaves in the canopy than in late established ones by the time late blight appears and should be more resistant.

The agronomic practices mentioned previously are widely used to minimise adverse effects of late blight on yield. However, an integrated strategy has not been optimised for varieties with different degrees of blight susceptibility, or in regions with different blight pressure or in production systems that do not use copper fungicides. The experiments reported here investigated effects of planting date and pre-sprouting or chitting seed tubers of potato varieties with different levels of blight susceptibility on blight infection, crop yield and quality of crops grown in organic systems without the use of copper fungicides in the United Kingdom and the Netherlands.

UNITED KINGDOM (UK)

Materials and Methods

Experiments were made in the United Kingdom, in 2001 and in 2002 on a biodynamic farm in the north-east of Scotland near Aberdeen. All experiments included two varieties with different levels of blight susceptibility grown in organic production systems, three pre-sprouting or chitting treatments and two planting dates. Chitting treatments were: unchitted (kept at <6^{o}C until planting); fully-chitted in a glass-house for approximately six weeks before planting to achieve approximately 300 Day Degrees above 4^{o}C; partially-chitted (kept at <6^{o}C until approximately two weeks before the target planting date).
In the UK, treatments were replicated six times in a completely randomised block design. Plots were 15m long by 3m (4 rows) wide and 6m of the two central rows were harvested for yield assessments. Early and late planting dates were approximately two weeks apart in the UK in both 2001 and three weeks in 2002. In 2001 however, conditions were too wet to start planting until early May. Details of the treatments are summarised in Table 1.

Foliar blight incidence was recorded at least once a week until the first symptoms were detected, and twice a week thereafter, according to the methodology of James (1971). Cumulative disease severity was calculated as the Area under disease progress curve (AUDPC) using the following equation:

$$\text{AUDPC} = \sum_{i=1}^{n-1}\left(\frac{x_{i+1}+x_i}{2}\right)\left(t_{i+1}-t_i\right)$$

where $\mathbf{x_i}$ = % infested foliage at assessment i
$\mathbf{t_i}$ = time (days) of assessment i
n = Number of assessments

Potato haulms were destroyed when at least 50% of the foliage was infected. Crops were harvested by hand two to three weeks later. Tubers were separated into different sizes using square-mesh riddles of 35, 55 and 70mm and the weights recorded. A sample of about 25kg of tubers from each plot consisting of apparently healthy tubers of different sizes was stored for 6 - 8 weeks at ambient temperatures and then assessed for blight infection.

Results

In 2001, foliage of the susceptible variety Nicola was significantly more infected with late blight than Santé: AUDPC (% days) were approximately 300 and 90 respectively. There was a significant interaction between planting date and variety for the severity of infection. Early and late planted Nicola was affected to a similar extent, but in Santé, the disease was more severe in the later planting although disease levels were low in this variety (Table 2). Chitting treatments did not significantly affect when blight was first seen in the foliage, nor the rate of infection. Despite the threefold difference in AUDPC between the two varieties, both gave a total yield of about 20t/ha. However, a greater proportion of the yield of Nicola was in smaller size grades than in Sante. To some extent this reflected differences in tuber shape - Nicola's tubers are longer and thinner than Sante's. There were no significant effects of planting date or chitting treatment on yield of either variety in 2001(Table 4). Levels of tuber blight infection were relatively low in 2001 (about 4% by number on average or 1 to 2% by weight) and unaffected by treatment.
In 2002, Valor was more severely infected with foliage blight and reached 50% infection 10-14 days sooner than Lady Balfour, in mid- rather than late-August (Table 3). In Valor, the

rate of infection was unaffected by either planting date or chitting treatment. In contrast, it was significantly slower in late-planted Lady Balfour than in the early planting which accounted for the significant effect of planting date on AUDPC (Table 3). Lady Balfour gave more than twice the yield of Valor (~34t/ha on average compared with ~16 t/ha). Delayed planting significantly decreased tuber yields in both varieties, by almost 8t/ha in Lady Balfour and 4t/ha in Valor. Lady Balfour was unaffected by chitting treatment, but full chitting significantly increased yield of Valor when planted late (Table 5). Early planting increased the yield of large tubers above 55mm but there were no clear effects of chitting on tuber size grading Once again, there were no effects of treatments on tuber blight incidence which reached a maximum of about 2% by number. Very dry and hot conditions in autumn 2002 at the time of harvest suppressed its development.

Table 1. Details of the experiments

	United Kingdom	
	2001	2002
Varieties*	Nicola – second early (2/3) Sante – maincrop (7/6)	Valor – maincrop (5/7) Lady Balfour – maincrop (8/7)
Planting dates Early Late	3 May 17 May	10 April 1 May
Chitting Treatments	Unchitted Partially chitted Fully chitted	
Defoliation	At 50% foliar blight infection	
Harvest date	22-24 September	24 September

* Figures in brackets denote levels of resistance to foliage blight and tuber blight respectively (NIAB, 2004).

Table 2. The effects of planting date and chitting treatment on AUDPC of Nicola and Sante in the UK in 2001.

	Nicola		Sante		
	Early Planted	Late Planted	Early Planted	Late Planted	Chitting treatment Means (N.S.)
Unchitted	295a	282a	82ab	123a	196
Partially chitted	264a	361a	70ab	78ab	193
Fully chitted	308a	303a	51b	114a	194
Mean (p<0.001)	289	315	68	105	
Variety means (p<0.001)	Nicola 302		Sante 87		
Planting date means (p<0.01)	Early 179		Late 210		

Within a variety, treatments followed by different letters are significantly different from each other at the 5% probability level according to Tukey's Honestly Significant Difference (HSD) Test.

Table 3. The effects of planting date and chitting treatment on AUDPC of Lady Balfour and Valor in the UK in 2002.

	Lady Balfour		Valor		
	Early Planted	Late Planted	Early Planted	Late Planted	Chitting treatment Means (N.S.)
Unchitted	625a	293c	863a	777a	640
Partially chitted	625a	264c	883a	813a	646
Fully chitted	723a	340c	879a	792a	684
Mean (p<0.001)	658	299	875	794	
Variety means (p<0.001)	Lady Balfour 479		Valor 835		
Planting date means (p<0.001)	Early 767		Late 547		

Within a variety, treatments followed by different letters are significantly different from each other at the 5% probability level according to Tukey's Honestly Significant Difference (HSD) Test.

Table 4. The effects of planting date and chitting treatment on total tuber yields (t/ha) of Nicola and Sante in 2001 in the UK.

	Nicola		Sante		
	Early Planted	Late Planted	Early Planted	Late Planted	Chitting treatment Means (N.S.)
Unchitted	22.4a	21.3a	23.1a	20.1a	21.7
Partially chitted	20.6a	20.0a	22.9a	21.9a	21.4
Fully chitted	19.9a	21.0a	20.6a	24.8a	21.6
Mean (N.S.)	21.0	20.8	22.2	22.3	
Variety means (p<0.05)	Nicola 20.9		Sante 22.2		
Planting date means (N.S.)	Early 21.6		Late 21.5		

Within a variety, treatments followed by different letters are significantly different from each other at the 5% probability level according to Tukey's Honestly Significant Difference (HSD) Test.

Table 5. The effects of planting date and chitting treatment on total tuber yields (t/ha) of Lady Balfour and Valor in the UK in 2002.

	Lady Balfour		Valor		
	Early Planted	Late Planted	Early Planted	Late Planted	Chitting treatment Means (N.S.)
Unchitted	37.4a	30.4b	17.5a	10.3b	23.9
Partially chitted	37.8a	31.1b	20.4a	15.5a	26.2
Fully chitted	40.7a	30.8b	18.1a	18.7a	27.1
Mean (p<0.001)	38.6	30.8	18.6	14.8	
Variety means (p<0.001)	Lady Balfour 34.7		Valor 16.8		
Planting date means (p<0.001)	Early 28.4		Late 22.8		

Within a variety, treatments followed by different letters are significantly different from each other at the 5% probability level according to Tukey's Honestly Significant Difference (HSD) Test.

NETHERLANDS (NL)

Materials and Methods

In 2002 and 2003 two experiments were performed to optimise this strategy for two varieties (Santé and Appell). Early planting and late planting were compared for non-chitted, shortly chitted and fully chitted seed.

The experiments were set up as a split-plot-design, with planting dates in the whole plots, and varieties and chitting treatments fully randomised. There were four replications.
The ‘early’ planting date was the first period after the winter the soil was suitable for planting (28 March 2002 and 1 April 2003). The 'late' planting date was 7 weeks later (8 May, both in 2002 and 2003).
There were three chitting treatments:

- *No chitting*. Seed was stored at 6 °C until planting.
- *Shortly chitting*. Seed was for the last 2 weeks before planting stored at outside temperatures. At the moment of planting it was at the stage of eye emergence.
- *Fully chitting*. Seed was chitted in a light environment for 6 weeks before planting.

Weekly assessments included the number of stems per hectare, growth stages, percentage soil coverage, crop height, disease severity of late blight, yield (gross, net, size grades), underwaterweight and tuber infection by late blight. Foliar late blight was expressed as the percentage leaf area infected, using the scale of James (1970).
Data were analysed using the statistical program Genstat.

Results
In 2002 there were no differences in blight infection that could be related to planting date or chitting. Appell was far more resistant to foliar late blight than Santé.
Early planting as well as the use of chitted seed gave higher yields compared to late planting or the use of non-chitted seed (see Table 6). The effects of chitting decreased when the potatoes grew older. As a result, yield differences related to chitting were more pronounced for the late planted potatoes (which have a shorter growing period). Treatments also influenced the maturity of yields: Tubers harvested from early-planted plots had higher dry-matter-contents than those from late-planted plots. The same was true for chitted plots compared to non-chitted plots.

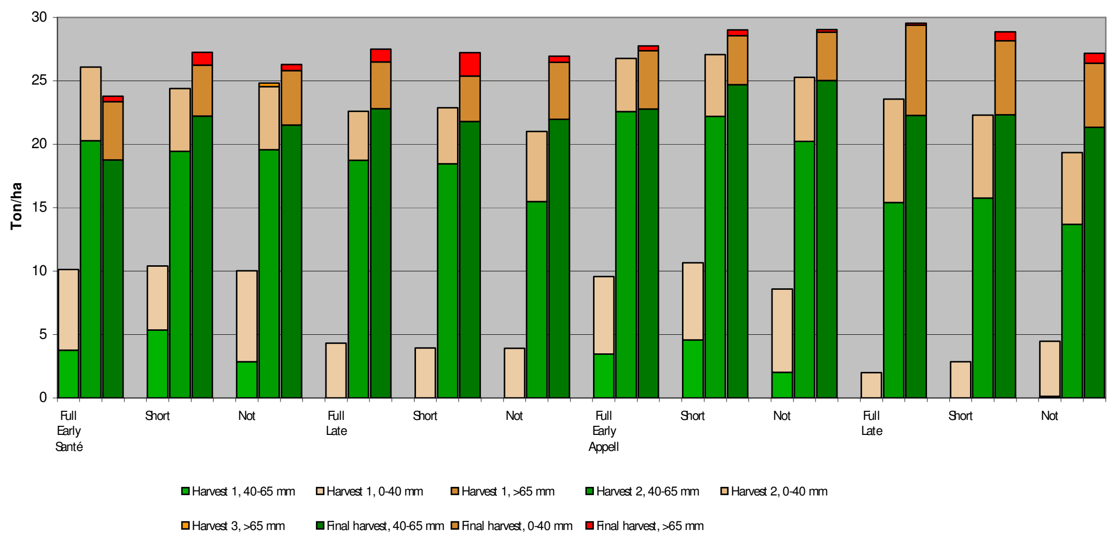
Table 6. Yields in 2002

	Planting date	Early			Late		
	Chitting	Full	Short	Not	Full	Short	Not
Appell	Net yield (tonnes/ha)	43.77 ^{c}	40.23 ^{c}	40.04 ^{c}	33.84 ^{b}	28.72 ^{a}	25.65 ^{a}
	Yield 40-65 mm (tonnes/ha)	38.95 ^{d}	36.17 ^{d}	36.47 ^{d}	25.06 ^{b}	20.21 ^{a}	16.86 ^{a}
	Percentage 0-40 mm	10.71 ^{a}	8.84 ^{a}	8.42 ^{a}	25.84 ^{b}	29.60 ^{b}	34.56 ^{c}
	Percentage 40-65 mm	89.21 ^{c}	90.15 ^{c}	91.43 ^{c}	74.16 ^{b}	70.40 ^{b}	65.44 ^{a}
Santé	Net yield (tonnes/ha)	28.26 ^{d}	21.87 ^{c}	23.19 ^{c}	8.07 ^{b}	5.14 ^{a}	3.29 ^{a}
	Yield 40-65 mm (tonnes/ha)	23.08 ^{e}	12.69 ^{c}	15.51 ^{d}	3.52 ^{b}	0.82 ^{a}	0.15 ^{a}
	Percentage 0-40 mm	14.5 ^{a}	41.9 ^{b}	32.6 ^{b}	62.1 ^{c}	85.3 ^{d}	96.8 ^{d}

For all parameters differences between fully chitting and shortly chitting were larger than differences between shortly chitting and not chitting at all.

2003, however, was a completely different year. Weather circumstances were dry and hot, the first blight infection appeared late (11 July, instead of 18 June in 2002) and developed slowly. In the first half of the season differences in plant growth between the two planting dates and the three chitting treatments were clear, comparable to the differences in 2002. However yield differences did not show up: final yields were the same for early and late planted potatoes, although earlier on yields for the early planting dates were higher (see figure 1).

Figure 1. Yields in 2003



Discussion

Observations of the effects of planting date and chitting on infection with late blight and potato growth and yield showed that responses will depend to a large extent on local conditions, over which the grower has limited control.
Early planting extends the potential growing period and usually leads to a higher yield by the time that defoliation is necessary. This was the case in 2002 in both the UK and the Netherlands when early planting gave significantly higher yields than late planting for both varieties that differed in resistance to late blight. However, differences between planting dates will depend on when planting begins and the interval between planting dates which affects the length of the growing season. When planting is generally later and the difference between the dates is relatively small, as in 2001 in the UK (planting in began early May with 2 weeks between planting dates), yield effects are likely to be relatively small or even absent. On the other hand, when the season is long because the weather is unfavourable for blight, as in the Netherlands in 2003, there may be no differences either, because late planted crops have time to catch up with the early planted ones which senesce sooner. Sequential harvests in this last experiment clearly demonstrated that tuber bulking in the early planting both started and finished before the late planting which continued to grow and accumulate yield.

Effects of chitting on yield were similar to the effects of early planting. Fully chitted seed almost invariably gave higher yields in 2002 in the Netherlands and in late planted Valor in the UK presumably because of more advanced tuber bulking. The advantage of chitting was also smaller when the growing period was extended, either because weather conditions were unfavourable for late blight as in the Netherlands in 2003, or because of a higher resistance level of the variety as in Lady Balfour in the UK in 2002.

Planting as soon as soil and weather conditions permit maximises the potential length of the growing season and hence yield, before blight infects the crop. Pre-sprouting tubers has a similar effect. However, if the crop is planted early or with chitted seed when temperatures are low or soil conditions are sub-optimal, the crop canopy may be smaller and less persistent. This effect is more pronounced with determinate varieties that produce a limited number of leaves during the growing period (Allen and Scott, 2001). In such cases, the consequences of blight infection would be more severe than in later planted crops. Early planting and chitting seed also gives scope for earlier harvesting before soil and weather conditions deteriorate reducing tuber damage and disease. Most growers will aim to plant as early as possible because of the benefits.. However, in Northwest Europe, deliberately planting crops late e.g. in July, is a specialist approach practiced on a limited scale for production of 'new' potatoes for harvesting in autumn, but the risk of infection with blight from early-planted maincrops is well known.

For any planting date, some of the effects of pre-sprouting seed tubers may be similar to those of early planting and the practice may even compensate for delayed planting (Hulscher at al, 2003). However, if the sprouts on chitted tubers are damaged or removed during planting the potential benefits will be lost. Furthermore, effects of chitting and possible sprout damage on the numbers of stems and tubers and hence graded, marketable yields need to be considered.

Results of the experiments show that the 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 and crops are allowed to grow on, later planted or non-chitted seed may out yield early planted or chitted seed because of a larger and more persistent leaf canopy and increased solar radiation interception leading up to harvest (Allen and Scott, 2001). On the other hand, if blight infection is early, the more advanced treatments will show to advantage. Since it is impossible to accurately predict when blight will arrive at any location before the crop is planted, early planting and pre-sprouting are useful insurance treatments in organic production systems that should minimise the consequences of blight infection.

Planting date and chitting treatment influence the physiological age of the crop and the number of leaves per stem when blight first appears which may affect susceptibility to blight. 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, probably reflecting the complex control of inherent resistance of potato plants to blight.

It is generally observed is that susceptibility of potato plants to late blight changes as they age: they are most susceptible when very young, most resistant when of intermediate age and become more susceptible again as they reach the end of the season. (Mooi, 1965; Stewart, 1990). However, Carnegie and Colhoun (1982) observed that changes in susceptibility with plant age may also depend on genotype. It appeared that susceptible varieties became more susceptible as they aged whereas resistant varieties became even more resistant. Plants may also be more susceptible if they are under stress. Irrespective of these effects however, the composition of the canopy will have an effect. Visker et al ((2003) showed that within a plant, younger, apical leaves are more resistant than basal leaves suggesting that the production of as many leaves as possible before the disease strikes will be a beneficial strategy. This could be achieved by breeding new cultivars but agronomic management may also have an effect. Both early planted and chitted crops will be older than late planted or crops grown from unchitted seed throughout the season and more susceptible to stress at any time. The number of leaves and their position in the canopy will also be affected. As the change in blight susceptibility during plant growth and the effect of variety is clearly complex it is difficult to determine or predict the likely effects of planting date and chitting. However, their effects on stem numbers and canopy architecture may also affect the microclimate within the crop e.g.

humidity and the duration of leaf wetness and development of the disease. However, in other experiments within the Blight-MOP programme which studied effects of plant configuration and spacing there was no difference in the level of blight infection between populations of about 150000 and 350000 stems per hectare. Since stem populations produced by the different sprouting treatments were well within this range, the potential effect of this mechanism seems to be trivial so far as chitting is concerned and unlikely to counteract the potentially beneficial effects on yield before blight intervenes.

References

Allen E.J. and Scott, R.K. (2001). BPC Research Review – Potato Agronomy. British Crop Protection Council.

Carnegie, S.F. and Colhoun, J. (1982). Susceptibility of potato leaves to *Phytophthora infestans* on potato plants in relation to plant age and leaf position. Phytopathology. Z.104, 157-167.

James, C. (1971). A manual of assessment keys for plant disease. Canada Department of Agriculture.

Karalus, W. & Rauber, R. (1996). Einfluss des Vorkeimens auf den Krankheitsbefall bei Kartoffeln im ökologischen Landbau. (Effects of pre-sprouting on potato diseases in organic farming). Zeitschrift f. Pflanzenkrankheiten und Pflanzenschutz (Journal of Plant Diseases and Protection) ,103 (4), 420 – 431.

Karalus, W. & Rauber, R. (1997). Effect of pre-sprouting on yield of maincrop potatoes (*Solanum tuberosum* L.) in Organic Farming. Journal of Agronomy and Crop Science, 179, 421 – 429.

NIAB, (2004) Pocket guide to varieties of potatoes.2003. National Institute of Agricultural Botany, Cambridge.

NIVAP, (2003) Dutch Potato Variety List.
Mooi, J.C. (1965). Experiments on testing field resistance to *Phytophthora infestans* by inoculating cut leaves of potato varieties. European Potato Journal, 8, 182-183.

Stewart, H. E. (1990). Effect of plant age and inoculum concentration on expression of major gene resistance to *Phytophthora infestans* in detached potato leaflets. Mycological Research, 94, 823-826.

Visker, M. H. P. W., Keizer, L. C. P., Budding, D. J., Van Loon, L. C., Colon, L. T. and Struik, P. C. (2003). Leaf position prevails over plant age and leaf age in reflecting resistance to late blight in potato. Phytopathology, 93 (6), 666 – 674..

Section 5: Plant configuration & spacing

Summary

In 2001and 2002, experiments were made to test the effects of plant population and configuration on late blight infection on varieties Nicola (susceptible) and Sante (resistant). Populations tested in the UK were 33000, 44000 and 89000 plants/ha in two or three row beds. These populations represent the commercial range for the production of large, baking potatoes at the lower population and small salad potatoes at the highest population. In NL, populations ranged from 38000 to 75000/ha grown in ridges either 75cm or 90cm apart. In both years and in both countries UK and NL, the results were consistent in both varieties. There were no effects of plant population or configuration (bed arrangement or distance between rows) on the timing of the initial infection of foliage with blight, or on the rate at which the epidemic developed. There were no treatment effects on tuber blight infection in any experiment, but the incidence of tuber blight was very low.

To some extent, the magnitude of effects of plant population and spacing on late blight may be influenced by disease pressure. In the UK in 2001, disease pressure was amongst the most severe experienced during the past 15 years and no method of blight management could be expected to have much of a beneficial effect. On the other hand, the differences in canopy cover and structure caused by different plant populations may not have persisted long enough to have any effect, i.e. if the canopies closed before infection became established irrespective of population and configuration. It seems unlikely that manipulating density and configuration is a promising method of decreasing late blight damage in practice in organic or conventional crops. The main determinant will be the need to maximise yield in particular size fractions to meet the demands of the target market outlet.

Indeed, there were substantial effects of plant population and spacing on yields within particular size grades. With the exception of Sante in UK in 2001 which did not show the expected effect, yields of undersized tubers <35mm (UK) or <40mm (NL) increased markedly as populations increased from 33000 to 89000/ha and 38000 to 89000/ha in UK and NL respectively. This would be beneficial where small tubers are required for the market but not for large tubers and *vice versa.*

In the 2002 experiment in the Netherlands, increasing the level of K fertiliser application above that required for yield had no effect on foliage or tuber blight. This observation is in agreement with a number of other experiments testing effects of K level and N: K ratio on late blight infection in organic potato crops grown in the UK that is reported elsewhere.

Effects of planting configuration and spacing on the development of late blight, crop yield and quality of potatoes grown in organic systems.

Introduction

Late blight (*Phytophthora infestans*) (Mont.) de Bary, is one of the most serious fungal disease affecting potatoes throughout the world (Oerke *et al*., 1994). Infection leads to destruction of the foliage and potential infection of tubers. Losses of marketable yield may be considerable, depending on the timing and severity of infection. Both conventional and organic crops are affected, but the scope to use fungicides to control the disease in crops grown to organic standards is limited (*Tamm et al*., 2004). Consequently, integrated control strategies based on complementary agronomic and other treatments are the foundation for control. One of several agronomic treatments that needs to be considered as part of such an integrated approach is plant population and spatial distribution.

P. infestans infection and spread in the foliage of potato crops is facilitated by periods of high humidity and prolonged leaf wetness. Planting different populations in different configurations by changing between-row and/or within-row spacing affects the crop's microclimate because of changes in canopy structure and time of closure and consequently the duration of periods of high humidity and leaf wetness. Lower plant populations and wider spacings with a more open, well-aerated canopy should be less susceptible to blight infection than denser crops. However, effects of on yield and tuber size-grading must also be considered. If blight infects the crop early, lower plant densities and wider spacings may be beneficial because a greater proportion of tubers will have reached marketable size by the time the foliage is destroyed. On the other hand, if infection is delayed the yield of larger tubers will increase. In this case, defoliation may be necessary to limit production of oversized tubers. These may be difficult to market and be affected by hollow heart and also be more susceptible to harvest and handling damage and storage rots than smaller tubers.
The main objective of this study was to quantify the interactions between varieties with different late blight resistance levels and plant configuration and spacing with respect to blight development and severity in Western Europe.

UNITED KINGDOM (UK)

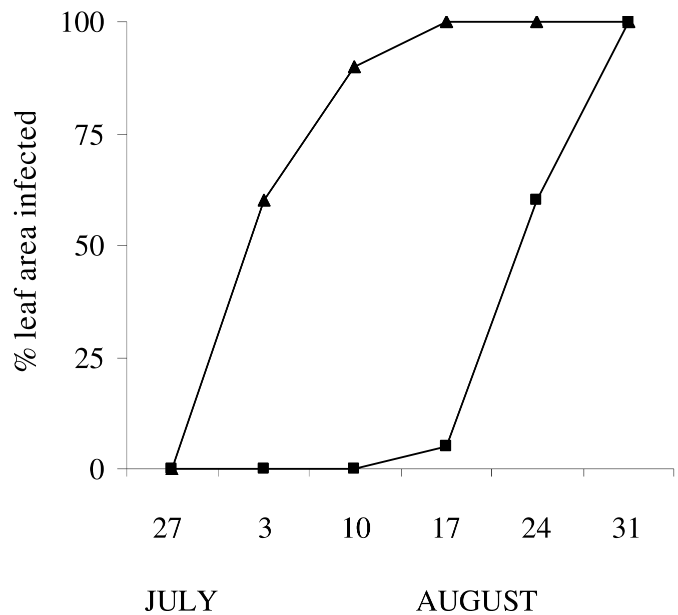
Materials and Methods

There was one experiment in the United Kingdom in 2001 at Brocklewood, SAC, Auchincruive Estate, South Ayrshire, Scotland on a sandy loam soil and grown to organic standards. Varieties, Nicola (blight susceptible) and Sante (blight tolerant), were grown in beds with either two or three rows per bed, at three in-row spacings (13, 26 and 35cm for two-row beds and 20, 38 and 51cm for three-row beds). Densities were 33000, 44000 and 89000 plants /ha for the 2-row beds and 34000, 46000 and 87000 for 3-row beds. The experiment was a split-plot design with varieties on main plots and bed configuration and spacing combinations fully randomised on sub-plots. Treatments were replicated four times. Plots were three beds, 5.19m wide and 10m long and planted with a fully automatic planter on 15 May (Nicola) and 18 May (Sante). Planting was delayed by exceptionally high rainfall in the spring and early summer. Infector blocks of potatoes (cv. King Edward) were planted at both ends of the plots and inoculated with two phenylamide sensitive and two phenylamide resistant isolates of *P. infestans* on 29 June. Foliar blight infection was assessed at regular intervals throughout the season. Defoliation was achieved naturally, by allowing the disease to completely destroy the tops. The number of stems and the height of the canopy were recorded on 5 July. At final harvest on 16-19 November, total yield and yield of tubers <30mm, 30-35mm, 35-45mm, 45-55mm, 55-70mm and >70mm were recorded. Tuber blight infection was assessed on 50 tubers per plot at the end of November, prior to storage. Diseased tubers were discarded from this sample and the remaining healthy tubers were stored for approximately two months until the end of January 2002 and then reassessed for tuber blight infection. Infection of foliage with late blight was assessed according to the method and scale of James (1970).

Results

In 2001, weather conditions at the UK site were very favourable for foliar blight infection with frequent periods of high risk. It was one of the worst seasons of blight pressure in the past 15 years. However, blight development was slight in spite of several Smith periods until the end of July and then it developed rapidly in the susceptible variety Nicola, but not until about 3 weeks later in the more resistant variety Sante. Nicola was completely destroyed by mid-August and Sante about three weeks later in early September (Figure 1).

Figure 1. The change with time in % foliage infected with late blight in cvs. Nicola (▲) and Sante (■) in the United Kingdom, 2001.



There were no significant effects of planting density or configuration on infection of the foliage, possibly because blight pressure was so severe and there were no interactions with variety. However, the treatments gave the expected effects on canopy structure with very highly significant ($P<0.001$) effects of variety and plant spacing on plant height and stem number per hectare (Table 1). Nicola was about 20cm taller than Sante and in both varieties plants at close spacing were about 10cm taller than at medium or wide spacing. Close spacing doubled the number of stems compared with the medium and wide spacings from about 200000 to 400000 stems/ha in Nicola and 150000 to 300000 stems/ha in Sante.

On average, total yield of Nicola (18.9t/ha) was about half that of Sante (37.7t/ha). Yield of Nicola in the 0 – 35mm size grade ranged from 10% by weight at the widest to 36.9% at the closest spacing. In contrast, Sante produced only 1 to 2.4% of total yield in the 0 – 35mm size grade over the whole range of spacings.. (Table 2a). The varietal differences in yield and size grading reflected the differences in susceptibility to late blight; Nicola was completely defoliated by the disease about three weeks before Sante. There were no significant main or interaction effects of configuration and spacing on total yield, but the number and yield of tubers was affected by spacing in both varieties. Closer spacing increased the number and yield of tubers in the smaller size grades but configuration had no significant effects (Table 2a).

The incidence of tuber blight was very low at harvest (<1% by weight and number of tubers) and no blighted tubers were detected after about two months storage. This probably reflected the very rapid development of the foliar blight epidemic and the warm air temperatures when there was a potential risk of tuber infection later in the season. The tops of Nicola were completely dead by the middle of August and Sante by the end of August.

Table 1. The effects of plant population and configuration on the number of total above ground stems (000/ha) and average plant height (cm) in a) United Kingdom 2001 and on the number of total above ground stems (000/ha)

a) United Kingdom 2001		Plant population (000/ha)					
		33	44	89	34	46	87
		Bed configuration					
Variety		2-row			3-row		
Nicola	Stems (000/ha)	168	232	404	188	233	423
Santé	Stems (000/ha)	144	151	325	127	182	343
Nicola	Plant height (cm)	53b	58ab	71a	52b	58ab	72a
Santé	Plant height (cm)	39b	44ab	58a	40b	45ab	49ab

Within a variety, treatments followed by different letters are significantly different from each other at the 5% probability level according to Tukey's Honestly Significant Difference (HSD) test.

Table 2. The effects of planting configuration and spacing on total tuber yield (t/ha), yield in the marketable size range (t/ha) and % total yield less than 35mm in
a) United Kingdom 2001 and on the number of total above ground stems (000/ha)

a) United Kingdom 2001		Plant population (000/ha)					
		33	44	89	34	46	87
		Bed configuration					
Variety		2-row			3-row		
Nicola	Total yield (t/ha)	20.1ab	17.7c	17.1c	19.4ab	20.5a	18.7bc
	Yield 35-70mm (t/ha)	18.1	15.3	11.9	16.9	16.7	11.8
	% 0-35mm	10.0	13.6	30.4	12.4	18.5	36.9
Santé	Total yield (t/ha)	38.7a	38.2ab	37.9ab	38.9a	36.8bc	35.9c
	Yield 35-70mm (t/ha)	34.1	34.8	36.3	35.3	34.8	33.9
	% 0-35mm	1.0	1.0	2.4	1.8	1.6	1.9

Within a variety, treatments followed by different letters are significantly different from each other at the 5% probability level according to Tukey's Honestly Significant Difference (HSD) test.

NETHERLANDS (NL)

Materials and methods

In 2001 two ridge distances (75 and 90 cm) and three plant densities (38000, 50000 and 75000 pl/ha) were compared. In 2002 two plant densities (38000 and 75000 pl/ha) were compared on 90 cm ridges. After ridge formation an additional K-fertilisation in three levels (0, 280 and 560 kg K/ha) was given with N-poor Vinasse (Vinasse is a by-product of the sugar refining industry that is rich in K). In both experiments Santé and Nicola were tested, as representatives of a relatively resistant and a relatively susceptible variety, respectively.
The 2001-experiment was a split-plot design with ridge distance in the main plots and the other treatments fully randomised. The 2002-experiment was a fully randomised block design. In both years there were 4 replications.
Weekly assessments included the number of stems per hectare, growth stages, percentage soil coverage, crop height, disease severity of late blight, yield (gross, net, size grades), underwaterweight and tuber infection by late blight. Foliar late blight was expressed as the percentage leaf area infected, using the scale of James (1970). Data were analysed with the statistical program Genstat (analysis of variance).

Results

In both years plant growth was similar for all treatments. There were no effects of ridge distance, plant density or K-fertilisation on late blight infection. Yield effects, however, did occur. On the 90-cm-ridges marketable yields were higher when compared to the 75-cm-ridges, and the size fraction distribution was better (less undersized tubers) (see Table 3). In both years Santé gave higher yields than Nicola (Table 1).

Underwaterweights were between 350 and 410 and were not influenced by any treatment.

Table 3 Yields

Brut yields include small tubers, but exclude tubers with soft rot at harvest.
Per row numbers with different letters behind them are significantly different from each other (5% level). Numbers with the same letter are not significantly different.

2001		38000 plants/ha		50000 plants/ha		75000 plants/ha	
	Ridges	75	90	75	90	75	90
Nicola	Brut yield (tonnes/ha)	25.65 ^{a}	26.55 a ^{a}	25.72 ^{a}	28.57 ^{ab}	29.05 ^{b}	29.51 ^{b}
	% 0-40 mm	28.9 ^{bc}	11.0 a ^{a}	30.3 ^{bc}	20.9 ^{abc}	34.0 ^{c}	16.7 ^{ab}
	Yield 40 - 65 mm (tonnes/ha)	18.26 ^{ab}	23.09 ^{bc}	17.84 ^{a}	22.44 ^{abc}	18.96 ^{ab}	24.47 ^{c}
Santé	Brut yield (tonnes/ha)	28.76 ^{a}	32.95 ^{a}	32.33 ^{a}	32.75 ^{a}	33.89 ^{a}	34.21 ^{a}
	% 0-40 mm	9.26 ^{a}	6.56 ^{a}	9.56 ^{a}	8.63 ^{a}	16.87 ^{b}	10.03 ^{a}
	Yield 40 - 65 mm (tonnes/ha)	24.71 ^{a}	29.80 ^{a}	28.32 ^{a}	29.01 ^{a}	27.72 ^{a}	30.13 ^{a}

2002		38000 plants/ha			75000 plants/ha		
	Extra K	0K	280K	560K	0K	280K	560K
Nicola	Brut yield (tonnes/ha)	18.42 ^{a}	19.68 ^{a}	20.72 ^{a}	23.10 ^{a}	19.38 ^{a}	21.93 ^{a}
	% 0-40 mm	29.7 ^{a}	27.8 ^{a}	28.6 ^{a}	42.4 ^{ab}	45.4 ^{b}	41.3 ^{ab}
	Yield 40 - 65 mm (tonnes/ha)	11.27 ^{a}	12.16 ^{a}	12.57 ^{a}	11.43 ^{a}	9.33 ^{a}	11.12 ^{a}
Santé	Brut yield (tonnes/ha)	29.37 ^{a}	27.70 ^{a}	31.41 ^{a}	30.37 ^{a}	30.93 ^{a}	32.84 ^{a}
	% 0-40 mm	14.6 ^{ab}	16.8 ^{ab}	8.9 ^{a}	24.1 ^{b}	21.2 ^{b}	18.3 ^{ab}
	Yield 40 - 65 mm (tonnes/ha)	20.60 ^{ab}	18.67 ^{a}	23.27 ^{b}	19.43 ^{ab}	20.49 ^{ab}	22.49 ^{ab}

Discussion and Conclusions

Both in the 2001 and in the 2002 experiment there were no effects found of plant density or ridge distance on the initial infection of a potato crop by late blight, nor on the development of the epidemic or on tuber infection. In earlier experiments a delay of the infection was reported (Smid & Meijer, Hulscher et al.) but plant densities were so low that yields were influenced in a negative way. In addition, the effect on Phytophthora was not very strong. This makes it unlikely that manipulating the crop structure by reducing plant density and/or enlarging the distance between ridges is a reliable instrument to prevent damage by *Phytophthora infestans*. The same can be concluded for extra K-fertilisation as an instrument for enhancing late-blight-resistance of a potato crop. Plant density and ridge distance, however, do have effects on yield and size grade distribution. Although these measures do not influence late blight resistance directly, they can play a role in durable management systems of organic potato growing. After all, in the context of a yearly threat of a severe late blight infection, everything that has a positive influence on potato yields, both quantitative and qualitative, will be helpful.

General Discussion

In both years and in both countries, the results were consistent in both varieties. There were no effects of plant population or configuration (bed arrangement or distance between rows) on the timing of the initial infection of foliage with blight, or on the rate at which the epidemic developed. There were no treatment effects on tuber blight infection in any experiment, but the incidence of tuber blight was very low.

The range of plant densities and configurations tested may not have been wide enough to affect late blight infection. However, the range tested did cover that used commercially to produce small tubers for sale as pre-packaged salad tubers at close spacing to large tubers for baking at wide spacing. Consequently, it seems unlikely that manipulating density and configuration is a promising method of decreasing blight damage in practice in organic or conventional crops. In other work in the Netherlands, where an effect was recorded, it was at densities below the commercial limit (Smid & Meijer, 1999; Tiemens-Hulscher et al, 2003). Furthermore, the reductions in blight infection were very small and far outweighed by the reduction in marketable yield caused by the low population (Tiemens-Hulscher et al, 2003). Thus it seems unlikely that growers will plant at populations lower than those currently used - however they are configured – with the specific objective of managing late blight. Their decisions on plant spacing will be determined primarily on yield and tuber size grading requirements and other blight control methods will be more important. Again, in the Netherlands, previous experiments comparing the same population grown on 75 and 90cm rows showed no effects on blight infection, but 90cm rows produced a higher yield and fewer undersize tubers (<40mm), especially in the variety Ditta (Vergroesen, 1999). However, differences in yield and size grade distribution between different row widths are most likely to occur when the blight-epidemic starts early. Yields will then be lower and consist of smaller tubers, so that differences in size grade distribution become more obvious. Effects will also be larger in varieties that form smaller tubers (as Nicola does when compared with Santé).

To some extent, the magnitude of effects of plant population and spacing on late blight may be influenced by disease pressure. In the UK in 2001, disease pressure was amongst the most severe experienced during the past 15 years, which provided an extreme test for the treatments. Furthermore, Sante which was the more resistant variety at this site may have been challenged by the high levels of disease in Nicola which began to develop about three weeks earlier. This may explain why Sante appeared to be much less resistant to foliage blight than had been anticipated on the basis of previous field observations and published information. The situation was different in the Netherlands however where the crops were deliberately defoliated at 10% foliar infection (to comply with National regulations) and there were no differences between the timing and rate of infection in the two varieties. Effects might be different for varieties which are more resistant to blight and are isolated from susceptible ones.

In 2001, the relative difference in the foliar resistance of Nicola and Sante to late blight, in the two countries was marked. There appeared to be little difference in the Netherlands: both cultivars reached approximately 10% foliage infection at the same time. In the UK however, the epidemic started about three weeks later in Sante than in Nicola. It seems unlikely that differences in the pathogen populations in the two countries could account for these observations and differences in growing conditions are most likely to be responsible (W. Flier, personal communication).

There was no evidence in these experiments that manipulating plant configuration and spacing had an effect on late blight infection. This suggests that it has little to offer as a sole late blight management technique in either conventional or organic crops. However, it may be effective in combination with other blight management methods that limit blight pressure as part of an overall, integrated control strategy. Other components of the control strategy may have to be adapted. For example, results showed clearly that where crops are grown at high populations to produce small tubers for the market, the numbers and lengths of stems and the density of the canopy will be increased. The dense foliage may provide a more favourable micro-climate for blight infection than in crops grown at lower densities. This will be difficult to penetrate and cover completely with fungicides leading to a greater risk of the disease. Thus where foliar-applied blight control agents are to be used in dense crops, directed spraying to ensure that leaves at the base as well as at the top of the stem are covered may be more effective than overhead spraying.

In the 2002 experiment in the Netherlands, increasing the level of K fertiliser application above that required for yield had no effect on foliage or tuber blight. This observation is in agreement with a number of other experiments testing effects of K level and N: K ratio on late blight infection in organic potato crops grown in the UK that is reported elsewhere.

References

Hulscher, M. et al. (2001, not published). Voortgangsbericht nr. 2 van het project "Naar een oplossing van het Phytophthora-probleem in de biologische teelt van aardappelen". Louis Bolk Institute and Plant Research International, Driebergen / Wageningen

Hulscher, M. et al. (2003). "Naar beheersingsstrategieën voor Phytophthora infestans in de biologische aardappelteelt". Louis Bolk Instituut and Plant Research International, Driebergen / Wageningen

James, C. (1971) A manual of assessment keys for plant disease. Canada department of Agriculture.

Oerke, E., Dehne, H., Schonbeck, F. & Weber, A. (1994). Crop production and crop protection, Elsevier, Amsterdam.

NIAB, (2003) Pocket guide to varieties of potatoes.2002. NIAB Cambridge.

NIVAP, (2003)

Smid, H.G. and W.J.M. Meijer (1999). Gewasdichtheid en de infectiekansen van Phytophthora bij aardappelen. Nota 162, AB-DLO, Wageningen.

Tamm et al. (2004). Assessment of the socio-economic impact of late blight and state-of-the art management in Europaen Organic Potato Production Systems. Research Institute of Organic Agriculture, FiBL, Frick, Switzerland (http://www.orgprints.org/2936).

Tiemens-Hulscher, M. et al. (2003). Naar beheersingsstrategieën voor *Phytophthora infestans* in de biologische aardappelteelt. Louis Bolk Instituut en Plant Research International, Driebergen / Wageningen

Vergroesen, J. (1999, not published). Kort verslag van de 90-cm-proef 1998 en 1999. Agrico / Bioselect, Emmeloord

Section 6: Irrigation regimes

Summary

The effects of three irrigation regimes were tested for two varieties (a late blight susceptible Charlotte and more resistant variety, either Sante or Eden) which are frequently grown in organic potato cropping systems.
No supplementary irrigation was compared with the 'usual' or standard irrigation practice of application two or three times per week up to a total of about 170-180mm water over the season and optimized irrigation (made with reference to soil moisture meters) with about 70-90mm water i.e. about half the amount used in the usual practice.

In 2002, significant late blight infection was absent despite artificial inoculation, so that no conclusions could be drawn about the effects of irrigation regime on the onset, rate and severity of infection of different varieties of potatoes. However, yield was improved by about 50% in both Charlotte (significantly) and Sante (not significantly) by irrigation compared with natural rainfall. Tuber size grading was also improved in both varieties. Most noticeably, decreasing the amount of water applied during irrigation from 174 to 93mm did not significantly reduce the yield or size grading benefits. In 2003, late blight infection did occur and reached up to 80% of leaf area infected in the susceptible variety Charlotte. However, irrigation did not increase infection compared with the unirrigated controls. Once again, irrigation improved both total and marketable yields and the effects of the optimised treatment were not significantly different from the usual treatment. Irrespective of the potential effects of water supply on blight infection (which did not appear to be problematic in these experiments), it is clear that irrigation is essential to achieve high marketable yields in this area of France: these experiments show that the benefits can be achieved by reducing the quantities of water normally applied, by reference to an objective scheduling mechanism. This is also likely to be true for other areas and countries. Optimising water use has become more demanding as restrictions on the use of water in Agriculture are becoming ever more severe.

Introduction

The potato crop is very sensitive to water supply because it is relatively shallow rooting and roots are less effective at taking up water than in other arable crop species. Where natural rainfall is low and water stress develops, yields will be depressed because leaf growth is limited and the efficiency of conversion of intercepted solar radiation declines. Tuber size grading will also be affected with a greater proportion of small tubers and secondary growth causing deformation of tuber shape may be a problem. Specific gravity may also be affected, and water shortage in the early stages of tuber growth may result in tuber infection with common scab caused by *Streptomyces scabies.* Supplementing natural rainfall with irrigation however can overcome these detrimental yield and quality effects caused by water shortage. Because of the risks associated with drought, many farmers irrigate their potato crops and these are given priority within the cropping system because of the potential gains in output and this is particularly the case for large-scale conventional growers. However, both rainfall and overhead irrigation present a risk in relation to late blight infection. Wetting the leaves, stems and soil, causes ideal conditions within the crop for infection. Splash from falling water droplets (i.e. 'rainsplash') also helps to spread the disease. Movement of irrigation equipment may also transmit the disease and causes unavoidable damage to the tops, exposing stems to infection and the soil ridges which may encourage tuber blight infection. Clearly, irrigation management must balance these risks in both conventional and organic cropping systems. The amount and frequency of irrigation is very much dependent on the local climatic conditions and availability of water and within Europe. According to the survey presented in

Chapter 1, only 33% of growers irrigated their crop in 2000. The remainder did not do so because the crop was not water stressed or no water or irrigation equipment was available. Only 6 of the 118 growers interviewed chose not to irrigate because of fears that it would cause late blight to spread and all of these were in the Netherlands.
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.
Experiments were carried out in France in 2002 and 2003 in an area where weather conditions mean that irrigation of potatoes is a very high priority. An irrigation regime based on 'optimised' water input was compared with 'normal' practice based on experience and no irrigation. As interactions between varieties with different resistance levels and irrigation regimes with respect to blight development and severity may be important, treatments were applied to a susceptible and more resistant variety. There could be less need to restrict water applications in more resistant potato varieties in which the pathogen often requires longer periods of leaf wetness for infection to take place.

Material and Methods

The same experimental protocol was used in both years in France. Treatments included: two varieties: Charlotte (susceptible) in both 2002 and 2003 and Santé in 2002 and Eden (moderately resistant) in 2003 and three irrigation treatments : i) no irrigation ii) standard practice irrigation with two or three applications per week iii) optimised irrigation applied with reference to a soil humidity sensor. The experiments were arranged in randomised blocks with four replicates. Plots were 6 m (eight rows) x15m long with 75 cm between the rows and 30cm between tubers in the row resulting in a planting density of about 45000 tubers/ha with a gap of about 1m between plots. No pesticide treatments were applied.

The level of late blight infection on each plot was recorded weekly on 13 m of the two central rows and the plants' phenological stage at the same time. Both the incidence of late blight i.e. the number of plants infected with late blight on the central two rows and the severity i.e. percentage of foliar surface diseased by late blight on twenty plants on the two central rows were recorded.

Ten metres of the central two rows of each plot were harvested for yield estimation and the proportion of tubers within usable size classes and diseased tubers were determined on a sub-sample of 30-50kg.

Results and Discussion

2002

As no naturally occurring late blight appeared during the first weeks of the experiment, artificial inoculation was made on the rows of Bintje (10 inoculation points per plot) on 26 June. Although some symptoms appeared 5 days later, these first lesions dried up despite irrigation, because of the windy and sunny weather. Consequently, no conclusions concerning effect of the irrigation regime on the onset and development of late blight could be drawn.

The total irrigation applied was 174mm for the standard practice and 93mm for the optimised irrigation. Irrigation clearly affected total yield. Increasing the amount and frequency of irrigation increased total yield significantly in Charlotte but not in Sante. Without irrigation, yields were 20t/ha for Charlotte and 13t/ha for Santé but with irrigation exceeded 30t/ha for Charlotte and 20t/ha for Santé (Figure 1).

Irrigation regime significantly affected tuber size grading in Charlotte but not Santé. For Charlotte, without irrigation, tubers bigger than 50 mm accounted for only 15% of yield but 50% following standard irrigation practice. The difference between the unirrigated treatment and the two irrigated treatments was significant, but there was no difference between irrigated treatments. The trend was similar for Santé but differences between all three irrigation regimes were smaller and not statistically significant.

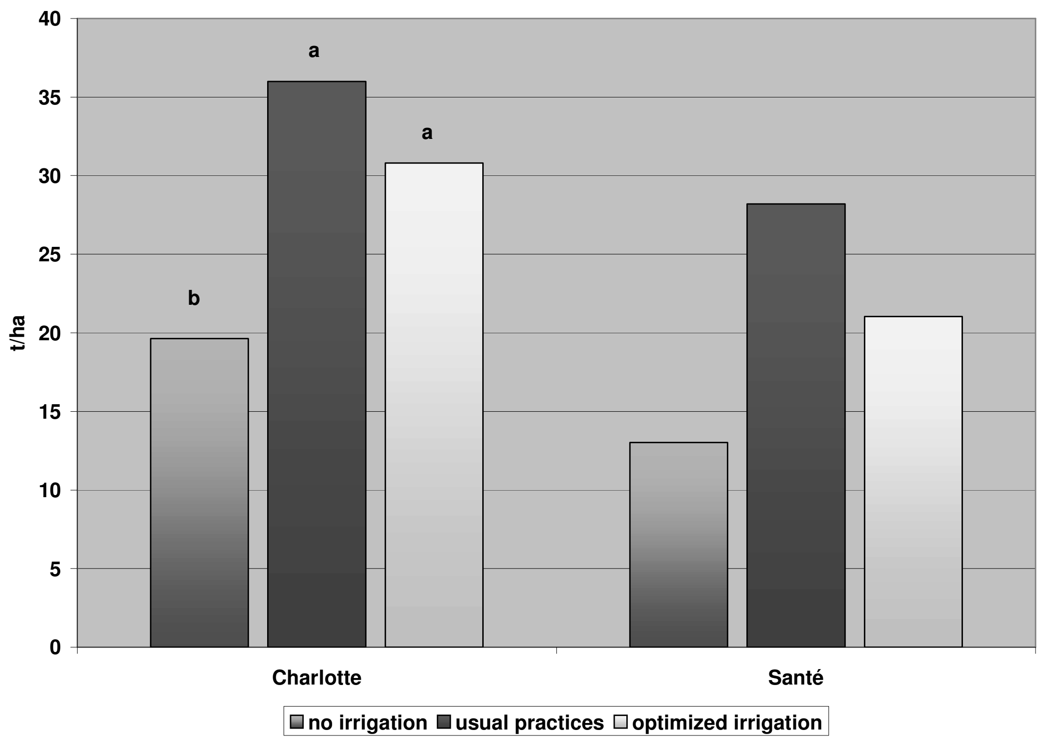


Figure 1. The effect of irrigation regime on total yield of Charlotte and Sante in 2002.

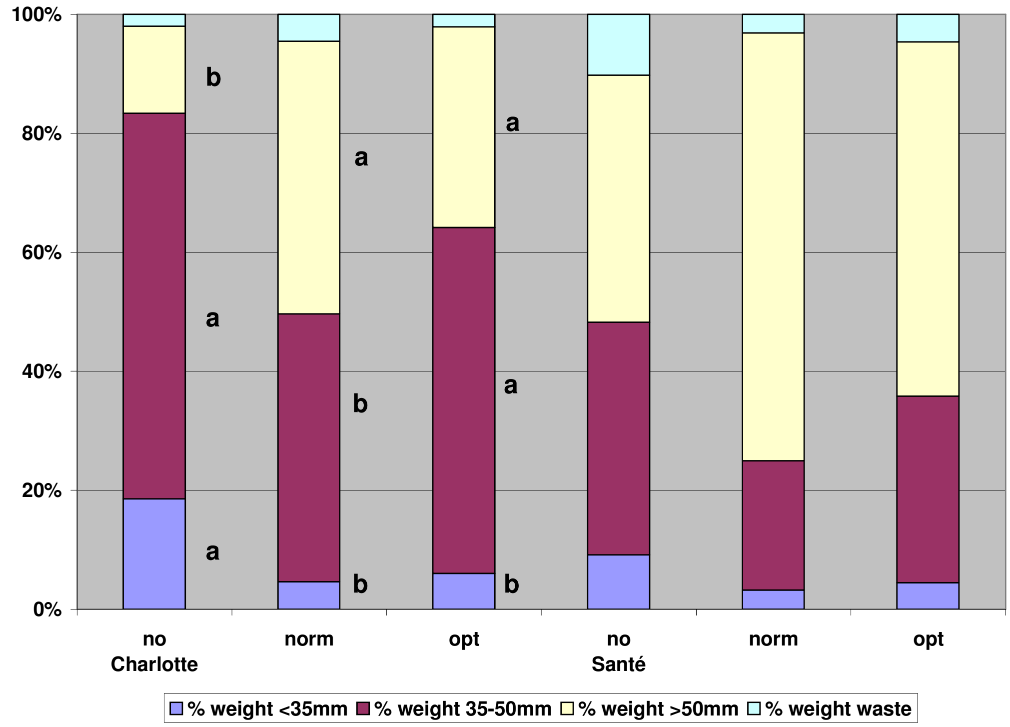


Figure 2. The effect of irrigation regime on graded yields in Charlotte and Sante 2002.

Conclusions

In the conditions prevailing in 2002, reducing applied irrigation by a half (from 174 to 93 mm) did not significantly decrease yield or the proportion of yield in the larger size grades. Without irrigation however, yields were severely depressed and tubers were smaller on average indicating the importance of water supply for potato production in Mediterranean conditions. Both Charlotte and Santé responded similarly to irrigation, but differences were only significant for Charlotte.
In 2003, the irrigation experiment was situated in another region of France, where irrigation is commonly used, and late blight occurs frequently.

2003

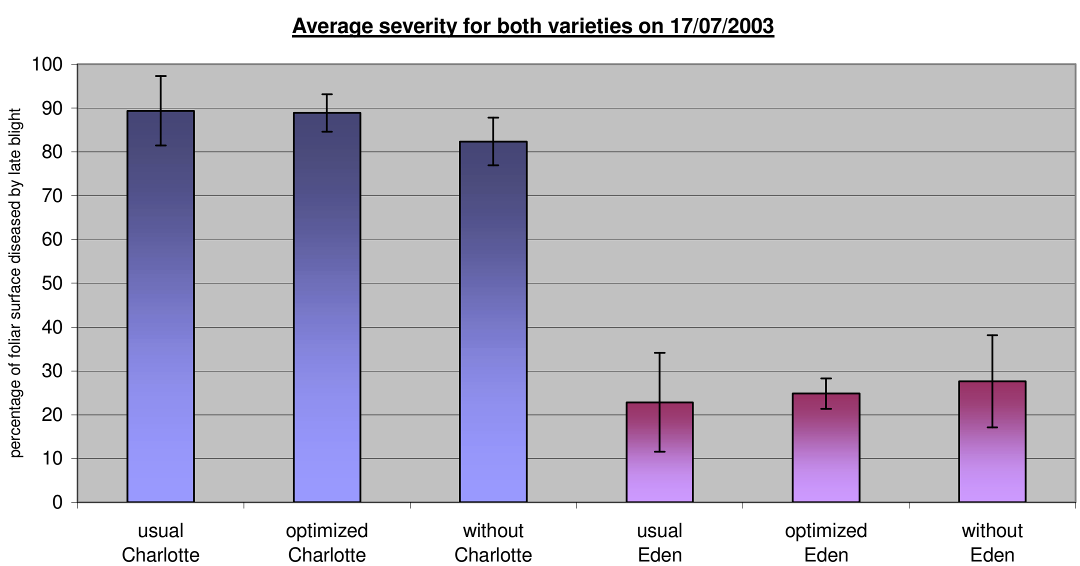
In 2003 the total amount of irrigation applied was 167 mm for the usual or standard practice and 67 mm for the optimized irrigation. Late blight infection was more severe than in 2002 when minimal infection occurred. Details of infection with late blight in terms of the percentage of plants showing signs of infection and percentage of foliage infected are shown in Table 1 and 2 respectively.

Table 1: Average incidence (percentage of plants diseased by late blight)

		date			
variety	**irrigation**	**17/06/03**	**23/06/03**	**01/07/03**	**17/07/03**
Charlotte	**without**	32.50	87.50	98.75	100.00
	optimized	50.00	97.50	100.00	100.00
	usual practices	40.00	96.25	98.75	100.00
Eden	**without**	26.25	90.00	87.50	100.00
	optimized	11.25	57.50	80.00	100.00
	usual practices	18.75	78.75	81.25	100.00

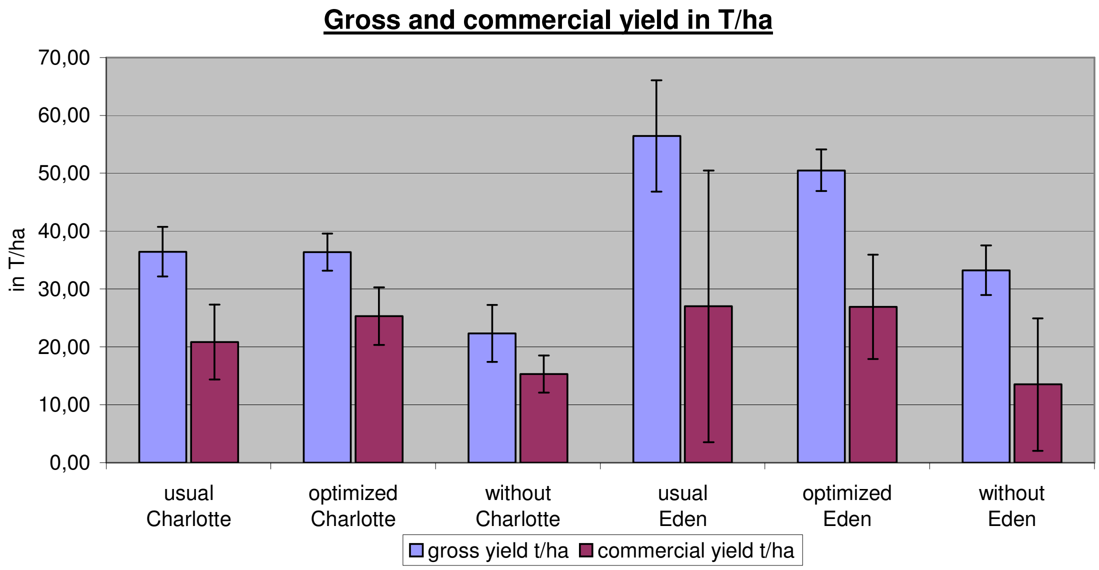
Table 2: Average severity (percentage of the foliar surface diseased by late blight)

		date			
variety	**irrigation**	**17/06/03**	**23/06/03**	**01/07/03**	**17/07/03**
Charlotte	**without**	0.28	0.56	1.13	82.38
	optimized	0.44	0.70	1.59	88.88
	usual practices	0.28	0.81	1.54	89.38
Eden	**without**	0.20	0.66	0.62	27.63
	optimized	0.06	0.36	0.59	24.81
	usual practices	0.10	0.52	0.58	22.81



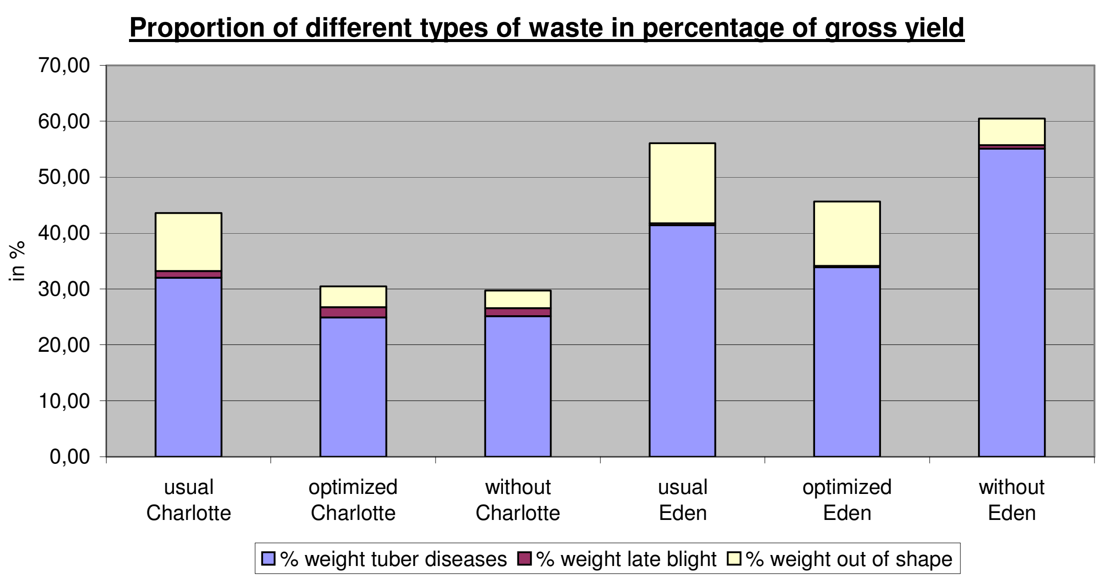
On 17 July, between 80% and 90% of the foliage of the variety Charlotte was infected late blight and there was no significant difference (Newman-Keuls 5%) between the 3 irrigation regimes. For variety Eden, which was more resistant, the percentage of foliar surface diseased by late blight was lower, between 20% and 30%, but there were no significant differences (Newman-Keuls 5%) between the 3 irrigation regimes. Consequently, irrigation regime did not seem to have an effect on foliar blight in 2003.

Yield



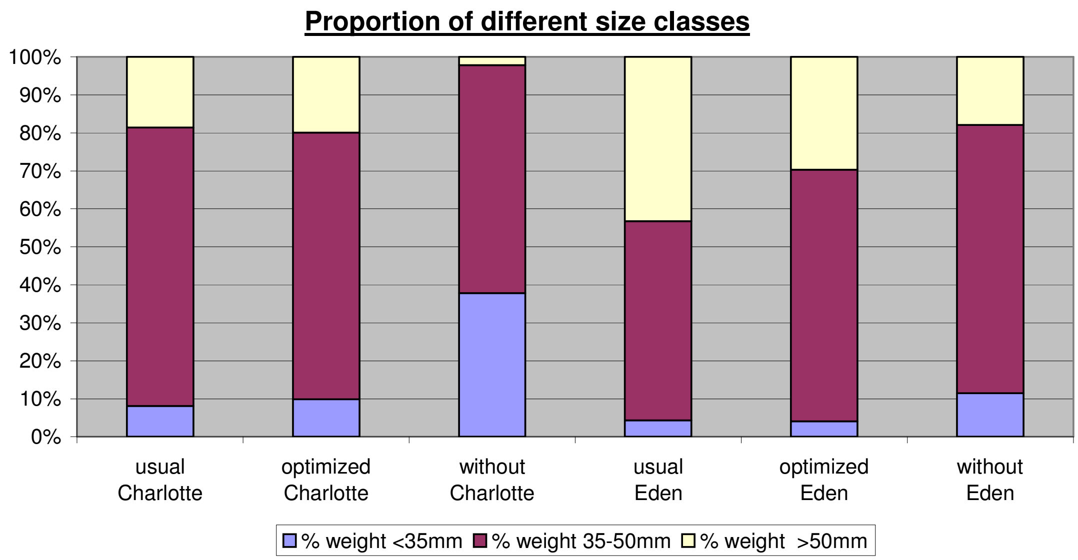
Total yields were quite high for both varieties exceeding 35 t/ha for Charlotte and 50 t/ha for Eden when irrigation was applied.

Irrigation increased total yield significantly for both Charlotte and for Eden: yields without irrigation were 22t/ha for Charlotte and 33t/ha for Eden compared with more than 35t/ha for Charlotte and more than 50t/ha for Eden. Eden appeared to be more sensitive to restricted (optimised) irrigation than Charlotte producing about 56t/ha with the usual irrigation regime and about 51t/ha for optimized irrigation. There was no significant difference between irrigation regimes in terms of marketable or commercial yields although they were lower where irrigation was absent.



The proportion of outgrades was high and about 30% for Charlotte and about 50% for Eden. Black scurf and silver scurf infection was widespread in 2003 and these fungi were responsible for the majority of the waste. Only a few tubers were attacked by late blight and confined to Charlotte but there was no significant difference between irrigation regimes.

Size classes



Eden produced larger tubers than Charlotte. With usual practices, 45% of Eden's tubers exceeded 50 mm but only 20% of Charlotte's tubers. Eden, which is resistant to late blight, maintained green foliage longer and matured later than Charlotte and so that tubers bulked for longer than Charlotte which died off earlier. Effects of irrigation on tuber size grading were similar to those observed in 2002: irrigation produced larger tubers. The effect was significant for tubers <35mm because yields of tubers for both varieties in this size grade were smaller without irrigation. However, there was no difference between the two irrigated treatments. For tubers >50 mm, the trend was the same but there were no statistical differences. For Charlotte, without irrigation only 2% of tubers were >50mm but this increased to 20% when optimized irrigation was applied.

Whilst reducing the amount of irrigation water by more than a half did not affect size grading in Charlotte, it did in Eden. 30% of Eden's yield was in tubers >50mm for optimized irrigation compared with 45% for usual irrigation.

Conclusions

In the conditions prevailing in 2003, it appeared that irrigation had only small effects on the onset and rate of infection of both varieties with late blight in the foliage. Reducing irrigation water applied by more than half did not reduce disease severity. There were no significant differences between treatments for tuber late blight infection. Limiting irrigation slightly reduced total yield and resulted in more yield in the smaller size grades but the differences between treatments were not statistically significant.
Clearly irrigation in this region of France remains indispensable because without irrigation, total yield was significantly decreased and the tubers were smaller. The effects were similar for both varieties, although Eden appeared to be more susceptible than Charlotte to restricted irrigation, in terms of total yield and tuber size grading.

Section 7: Foliar sprays and microbial soil inocula

Summary

Various alternative treatments have been developed for the control of fungal pathogens including plant extracts, compost extracts and microbial preparations (Biological Control Agents or BCAs) applied to either the foliage and/or soil. Some of these have been proposed as potential treatments for the control of late blight in potatoes. However, there is little data about their efficacy.

In Denmark in 2001, three different compost extracts (from horse manure, straw and cattle slurry and cattle deep litter) were investigated in leaf bioassay experiments in growth chambers. Based on these experiments, raw compost and autoclaved compost of cattle deep litter was selected for further test under field conditions in 2002 and 2003. The compost extract was compared to a standard copper fungicide. Contrary to the leaf bioassay, no effect of the compost extracts alone was registered under field conditions in 2002 or 2003. In the trials 2003, a soap (potassium oleate) was included. The potassium oleate alone delayed the late blight epidemic approximately one week. A synergistic effect between the autoclaved compost extract and the potassium oleate was observed which resulted in a few days further delay in late blight epidemic compared to potassium oleate alone.

In the UK in 2002 and 2003, eight different foliar sprays, including plant and compost extracts, chitin and silica were applied to potatoes in the field in each year at regular intervals and compared with copper oxychloride. (Microbial preparations were evaluated in another experiment, which is described in Chapter 7 Section 1: Sprayer systems for copper-based fungicide and novel products). Copper oxychloride effectively controlled foliage blight in 2002 and resulted in an increase of about 25% yield of tubers compared with the untreated control. The 'non-copper' sprays were no different from the untreated control in terms of foliage blight or yield in 2002. In 2003, potential responses to spray treatments were considered to be extremely limited by very hot, dry weather. These conditions suppressed late blight infection (although foliar infection did reach about 20 – 30% by the end of the season) and may have deactivated or denatured some of the 'non-copper' sprays. Copper oxychloride kept infection below 5% throughout the season and gave the highest yields of tubers. Other treatments were no better than the untreated control in terms of either late blight infection or tuber yield. This was also the case in 2002 when weather conditions were more normal. In two contrasting years, none of the 'non-copper' spray treatments gave effects that were different than the untreated control. Copper oxychloride consistently gave the best control of foliage blight and highest yield. Effective alternatives that are acceptable in organic production systems were not identified in experiments done in either Denmark or the UK. Other alternatives were tested in other experiments and are reported in Chapters 6: Alternative treatments and Chapter 7: Application & formulation technology.

Introduction

The objective of these experiments and others in the Blight-MOP programme was to identify the potential effects of a range of plant and compost extracts, microbial products and other materials applied as foliar sprays on late blight development and crop yield. If these materials are shown to suppress late blight, they could be very valuable as components in an integrated blight control strategy in the absence of copper fungicides. These materials may have antagonistic properties, or induce resistance to late blight and hence decrease infection with the disease.

DENMARK (DK)

Material and methods

The field experiment was carried out at DIAS Flakkebjerg (East Denmark) in 2002 and 2003 with two varieties (the susceptible variety Bintje and the moderately resistant variety Sava) in a completely randomised design with four blocks. The plot size was 4.5 x 9.5 m. The experiment was carried out in a conventional field but with organic management including 120 kg N (organic manure) in early April. Based on leaf bioassay experiments in 2001, compost extract from cattle deep litter which showed good effect against potato late blight was selected for evaluation in the field (See Chapter 6 Section 1). The compost extract was used either as raw extract or as an autoclaved, sterilized extract to exclude any biological activity. A copper fungicide (Fitoran grün, 40 % copper oxychloride, standard dose 2-3 kg/ha with 8-10 days interval) was chosen as the reference product. In 2003, an additive (Potassium oleate, a potassium salt of fatty acid and vegetable oil, commercial product "Duxon insect Soap BD 40")) was included to enhance the efficacy of the compost extract.

Table 1. Different compost extracts tested against potato late blight in field trials 2002 and 2003.

Products	Dose/ ha	Intervals
Untreated	-	-
Fitoran grün (Cu- product)	1.0 kg*)	3 days
Cattle deep litter extract (no 6)	400 l	3 days
Cattle deep litter (no 6), autoclaved (only 2002)	400 l	3 days
Cattle deep litter extract (no 6) + Potassium oleate (only2003)	400 l+ 10 l	3 days
Cattle deep litter, autoclaved + Potassium oleate (only 2003)	400 l+ 10 l	3 days
Potassium oleate (only 2003)	10 l	3 days

*) 1/3 of standard (label) dose.

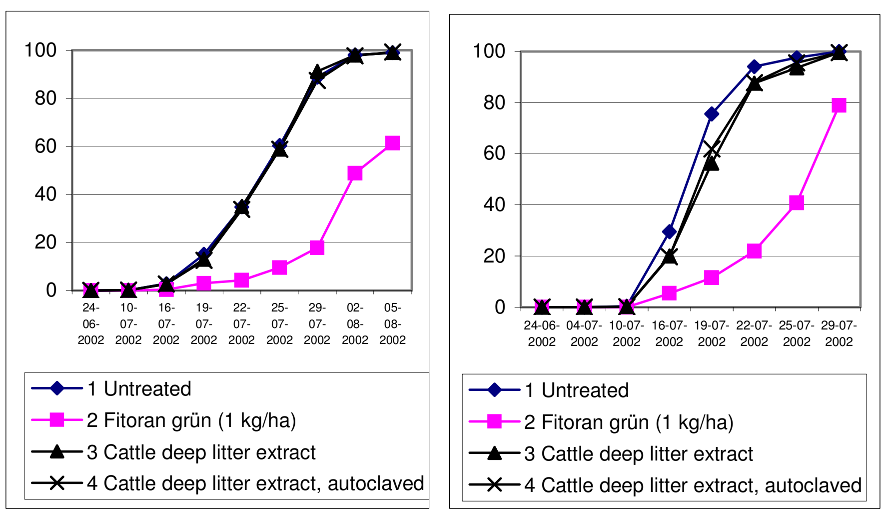
The cattle deep litter compost extract was made at DIAS Foulum and sent to Flakkebjerg at weekly intervals. Composts were started at regularly intervals in Foulum, so that the age of the compost at the day of treatment was approximately 50 days after initiation of the composting process. The compost extract was just filtered before use. The first spraying was done early at row closure. Compost extract, copper fungicide or potassium oleate were sprayed at 3-4 days intervals with a conventional spray technique using Hardi flat nozzles (ISO) 03, pressure: 3.75 bar and 4 km/h in 400 l water. The dose for the copper fungicide (Fitoran grün) was 1 kg/ha, which was one third of the standard (label) dose to avoid any possible phytotoxic effects because of the frequent spray. Spraying was done late afternoon to avoid to quick drying in the sun. Artificial inoculation was done with late blight sporangia suspension in two spreader rows between two replicate blocks early July (1000 sporangia/ml). Assessment of late blight and possible phytotoxic effects (yellow leaves) was done weekly throughout the season. Soil samples: 1) Before planting, Nmin, P and K was sampled (0-30 cm) in each variety and field replicate (8 samples of 16 subsamples from each replicate. 2) One week after desiccation, Nmin, P and K was sampled in each plot (48 samples of 16 subsamples from each plot; 6 x 2 x 4). Soil samples were frozen until chemical analyses were made. Foliage samples from all plots were analysed for N, P and K when the first attacks of late blight were seen in the field. The last fully expanded leaves (without attacks) from different 20 plants were taken from each plot and frozen to await further analyses (48 samples of 20 leaves). At harvest, tuber yields of various tuber size categories and dry matter concentrations were determined for each plot and tuber blight were assessed on 100 tubers per plot.

Results and discussion

No significant effect of the compost extract without additive on late blight infection was detected in 2002 and 2003 (fig. 1-3). However, in 2003 the additive (potassium oleate) appeared to have a synergistic with the autoclaved compost extract (figs 2 and 3) and improved control. The effect was most pronounced in Bintje (fig 3). When the additive was applied alone, the late blight epidemic was delayed by approximately one week.

In 2002, there were no significant differences in tuber yield between untreated plots and plots sprayed with compost extracts. However, spraying with copper-based fungicide increased the yield by19 % in Bintje and 39 % in Sava. (data not shown).

In 2003, there were no significant increases in yield of the two varieties after spraying with compost extracts alone compared to untreated plots (fig 4). Combining compost extracts and soap gave, however, a slight improvement of yield.



a) Sava **b) Bintje**

Figure 1. Results 2002: Development of potato late blight (*Phytophthora infestans*) in the variety a) Sava and b)Bintje treated with either raw or autoclaved extracts of composted cattle deep litter or a copper fungicide (Fitoran grün).

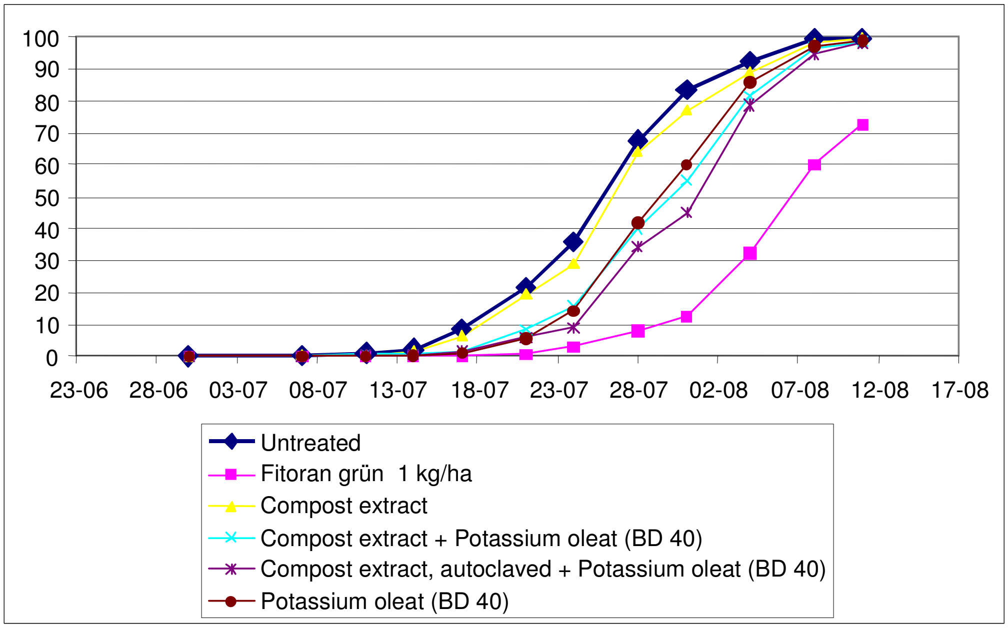


Figure 2. Results 2003: Development of potato late blight (*Phytophthora infestans*) in the variety **Sava** treated with raw or autoclaved extracts of composted cattle deep litter in combination with Potassium oleate (Potassium salt of fatty acid). Copper fungicide (Fitoran grün) is included for comparison.

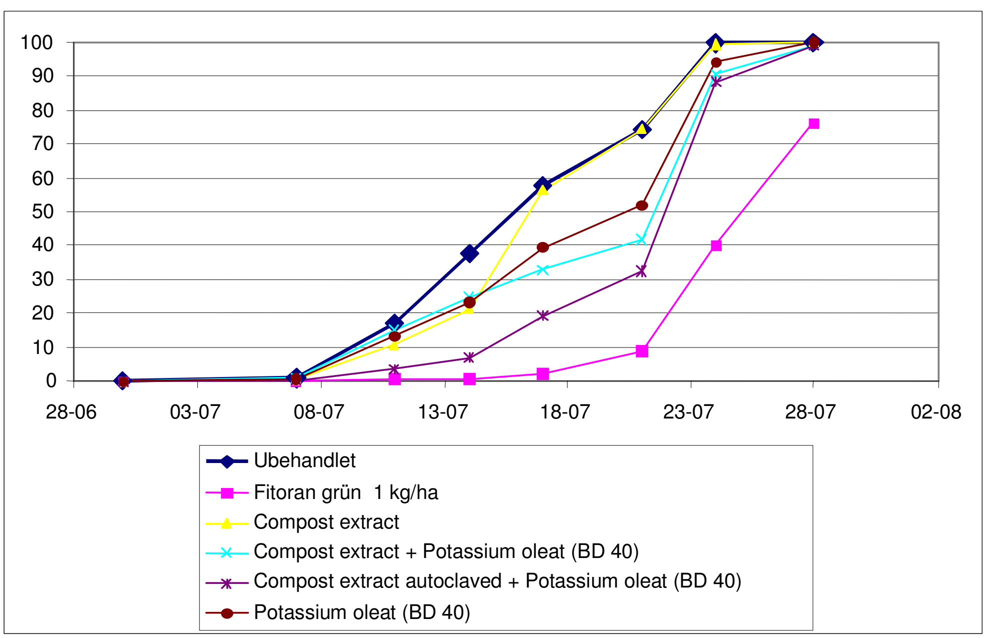
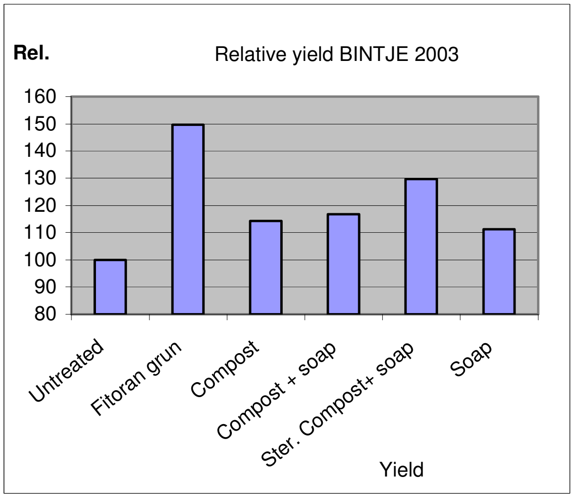


Figure 3. Results 2003: Development of potato late blight (*Phytophthora infestans*) in the variety **Bintje** treated with raw or autoclaved extracts of composted cattle deep litter in combination with Potassium oleate (Potassium salt of fatty acid). Copper fungicide (Fitoran grün) is included for comparison.



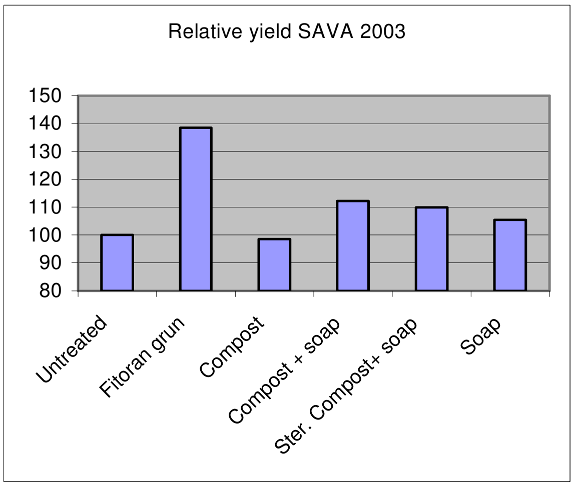


Figure 4. Relative tuber yields of varieties Bintje and Sava 2003. Ster. Compost = Autoclaved compost extract.

Conclusion

Raw compost and autoclaved compost of cattle deep litter was selected for test under field conditions and compared with a standard copper fungicide. Contrary to the leaf bioassay, no effect of the compost extracts alone was observed under field conditions. In 2003, a soap (potassium oleate) was included in the trials in order to test if the efficacy against late blight could be improved by combining the compost extract with additives. The potassium oleate alone delayed the late blight epidemic approximately one week and there was a synergistic effect between the autoclaved compost extract and the potassium oleate which resulted in a few days further delay in late blight epidemic compared to potassium oleate alone.

UNITED KINGDOM (UK)

Materials and Methods

In both 2002 and 2003, an experiment was carried out at the University of Newcastle's Nafferton farm in a high fertility situation following a grass/clover second-year ley. In 2002, Nicola, an early variety very susceptible to both foliage and tuber blight was planted on 24 April. Plots were 6m (8 rows) x 5 m long and treatments were replicated four times in a randomised block design. In 2003, variety Sante, was planted on 25 April 2003. Plots were 3m (4 rows) x 10 m long and treatments were replicated four times in a randomised block design. In both years, 8 foliar sprays were applied on seven occasions, at approximately weekly intervals from mid-June (before crops met across the rows) until early-August. The foliar applied spray treatments are shown in Table 2.

Table 2 Foliar applied treatments

Treatment	2002	2003
1. Untreated control	+	+
2. Copper oxychloride	+	+
3. Fresh Compost extract - (FYM based)	+	+
4. Mature compost extract- (FYM based)	+	-
5. Greenwaste compost extract	+	+
6. Seaweed extract	+	
7. Brassica extract (from oil-seed rape)	+	+
8. Silica (Silioplant)	+	+
9. Chitin (Chitosan)	+	+
10. Comcat (plant extract/strengthener)	-	+
11. Croplife (plant extract/strengthener)	-	+

The treatments were prepared and applied according to previously developed methods and protocols and commercial recommendations where appropriate. All types of compost extract and the brassica extract from oil seed rape plants were made with a commercial compost 'tea' maker (See Chapter 6 and 7 for further details of methodology).
Sprays were applied on seven occasions beginning at 8 weeks after planting before potato plants met across the rows (i.e. from late June to early August). However, according to recommendations, Comcat was applied only twice in 2003; firstly at the 2-3 leaf stage shortly after crop emergence and secondly just prior to flowering. The first Croplife spray was applied at the 2-3 leaf stage.
Plots were inoculated with a standard suspension of *Phytophthora infestans* spores in the third week in July. Foliar blight incidence was recorded at regular intervals after the first symptoms were detected (James, 1971). The aim had been to destroy potato haulms when 95% of the foliage was destroyed by foliar blight. This was done in 2002 and crops were harvested about 2 weeks later during September. However, extremely hot and dry conditions in August 2003 led to modest levels of blight and premature senescence of the canopy. Tops were removed irrespective of the level of blight infection about two weeks prior to harvest in mid-September 2003. At harvest, yield and tuber size grading (<35mm, 35-55mm, 55-70mm and >70mm) were assessed. Tuber blight incidence was recorded at harvest and in early January, after about 3 month's storage.

Results and Discussion

In 2002, none of the 'non-copper' sprays had any effects on development of foliar blight and were no better than the untreated control (Fig 5 and Table 3). Copper oxychloride delayed infection by about 10 days and this resulted in an increase in yield of approximately 6-7 t/ha or 25% compared with the other treatments (Fig. 6).

The results in the field experiment were similar to those observed in the laboratory leaf-bioassay assessments reported in Chapter 6 (Alternative treatments Section 1: Compost extracts: leaf bioassay). As far as compost extracts were concerned – the effects were either absent, small or inconsistent. In addition, the same compost extracts were applied in the experiments reported in Chapter 7 (Application and formulation technology Section 1: Sprayer systems for copper-based fungicides and novel treatments) in a different geographical location, to a different variety (Sante) and with an overhead or double-headed vertical lance sprayer. Again there were no detectable effects. However, there is a possibility that the ineffectiveness of these 'non-copper' sprays may be due to rapid breakdown on potato foliage in the field or a lack of persistence or rain-fastness or the spray interval may need to be shortened. The addition of adjuvants to compost extract sprays was tested in Denmark.

Fig. 5 Effect of foliar treatments on foliar late blight development in potato variety Nicola

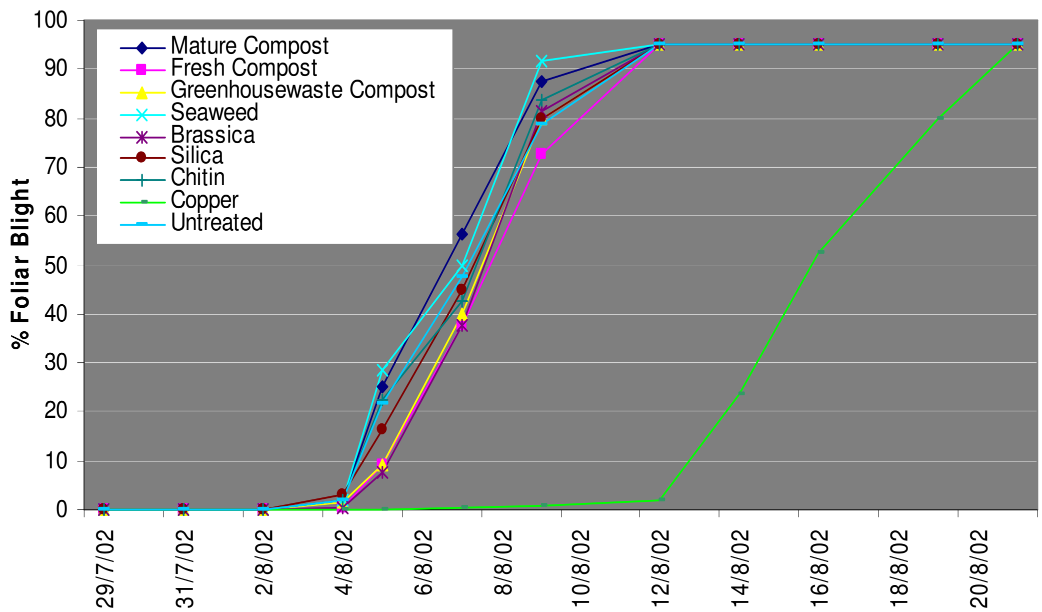
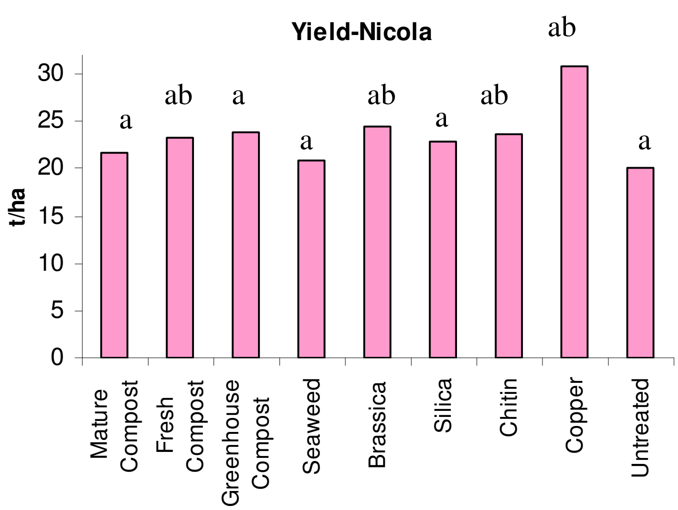


Table 3 Effect of foliar treatments on area under the disease progress curve (AUDPC)

Treatments	AUDPC (means)
Mature Compost	1411.5 a
Fresh Compost	1279.5 a
Greenwaste Compost	1300.9 a
Seaweed	1486.8 a
Brassica Extract	1295.0 a
Silica	1324.2 a
Chitin	1334.5 a
Copper	486.1 b
Untreated	1333.5 a

Treatments showing the same letter are not significantly different according to Tukey's honestly significant difference test

Fig. 6 Effect of foliar treatments on tuber yield in potato variety Nicola



Treatments showing the same letter are not significantly different according to Turkey's Honestly significant difference test

In 2003, in the UK and in many parts of Europe, weather conditions were extremely hot and dry in August. During a record breaking heat wave in the second week, temperatures ranged from 30 -35°C. Consequently, blight development which began in the crops during relatively wet and humid conditions in late July at Nafferton was arrested as lesions dried up. Levels of foliage blight were much lower than in 2002 when 95% foliar infection was recorded. The maximum level recorded at Nafferton was about 30% by the time premature senescence began in August.

The effects of treatments on foliar blight are shown in Figure 7. In the 'non-copper' spray treatments and the untreated control, foliar blight infection reached 20-30% by the time that crops were defoliated. However, copper oxychloride effectively controlled late blight and

maintained the level of infection below 5%. Under the prevailing weather conditions in 2003, the distribution of blight infection was very variable across the experimental site, particularly from North to South. This complicated the picture and it was necessary to transform Area Under The Disease Progress Curve (AUDPC) data to square root values. Analysis showed that there were no differences in AUDPC between the untreated control and the 'non-copper' sprays (Table 4). However, there were some treatments that were shown to be not significantly different from copper oxychloride, although they had substantially greater levels of late blight in the foliage during late August.
Despite the dry and hot conditions throughout August, total tuber yields were relatively high ranging from about 43 to 53 t/ha (Table 5). Crops treated with copper oxychloride gave highest yields corresponding to the most effective level of blight control. The 'non-copper' treatments produced yields that were not significantly different from the untreated control. However, because the yield of several of the treatments, including the untreated control, were also not different from the copper oxychloride treatment, it is difficult to explain effects on the basis of differential effects on the level of foliage blight. A possible explanation is that some of the treatments had an adverse effect on crop growth, independent of their effects on late blight because the crop was under stress. However, the situation was almost certainly complicated and obscured by the very unusual and extreme weather conditions in August 2003.There were no significant effects of treatments on tuber size grading (Figure 8) or on tuber blight incidence which was very low (0.05% of tubers infected.)
In 2003, Comcat, Croplife and copper oxychloride were also applied to variety Sante at Stockbridge Technology Centre (STC) in North Yorkshire in the field experiment described in Chapter 7 (Application and formulation technology Section 1: Sprayer systems for copper-based fungicides and novel treatments). However, blight was virtually absent at this site and there were no detectable effects of any spray treatment on foliar infection or on yield. Leaves taken from treated plants immediately after spray application were infected with a standard suspension of *Phytophthora infestans* blight spores in a standardised leaf biossay in the laboratory. These tests showed the effectiveness of copper oxychloride but there was no conclusive evidence that any of the other non-copper sprays were effective.

Figure 7 The effects of a range of foliar sprays on the progress of infection with foliage blight in 2003.

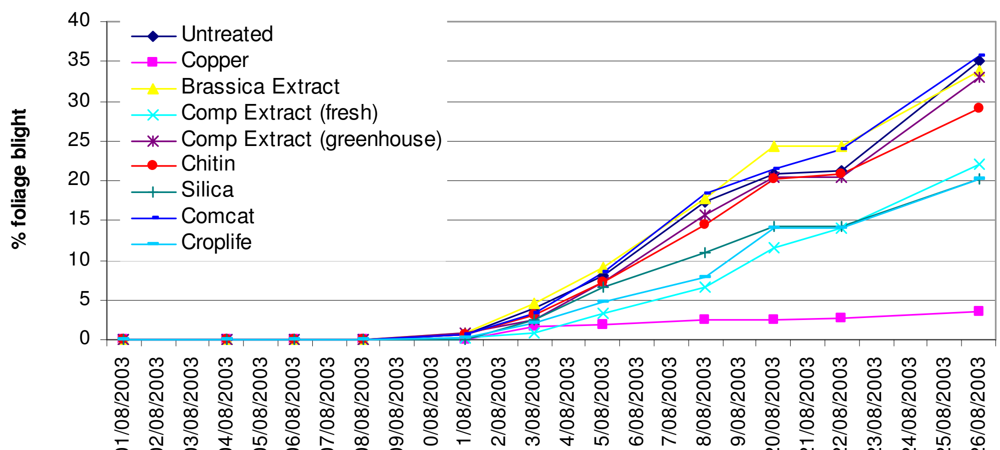


Table 4 The effects of foliar sprays on AUDPC (square root transformation) in 2003.

	Sqrt AUDPC
Untreated	14.29 b
Copper	5.66 a
Brassica extract	13.19 ab
Compost extract (fresh)	12.54 ab
Compost extract (greenwaste)	13.80 b
Chitin	13.47 b
Silica	11.46 ab
Comcat	14.91 b
Croplife	11.44 ab

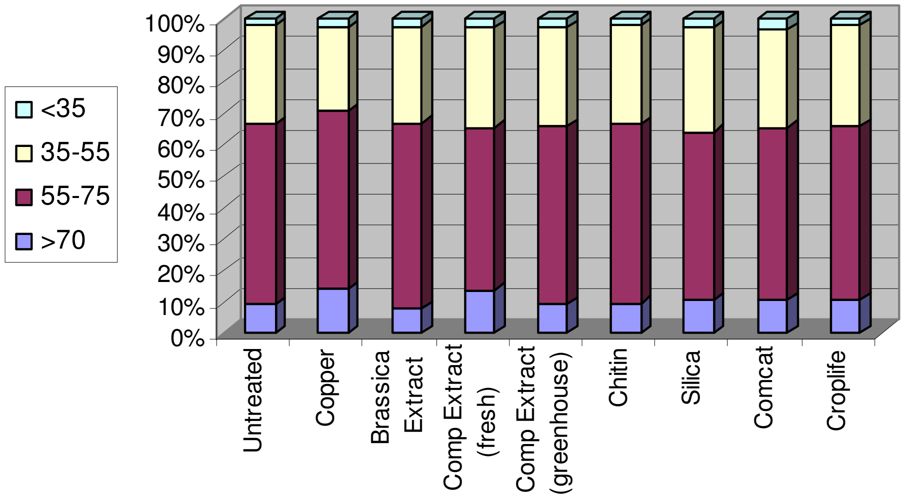
Values followed by the same letter are not significantly different at the 0.05% level of probability according to Tukey's Honestly Significant Difference Test.

Table 5 The effects of foliar sprays on total tuber yield 2003

	Total yield (t/ha)
Untreated	47.1 ab
Copper	52.4 b
Brassica extract	45.1 ab
Compost extract (fresh)	43.4 a
Compost extract (greenwaste)	46.6 ab
Chitin	42.7 a
Silica	48.0 ab
Comcat	47.3 ab
Croplife	43.4 a

Values followed by the same letter are not significantly different at the 0.05% level of probability according to Tukey's Honestly Significant Difference Test.

Figure 8 The effects of foliar sprays on tuber size grading (<35mm, 35-55mm, 55-75mm, >70mm) in 2003.



Section 8: Defoliation strategy and timing

Summary

In 2001and 2002, experiments were made in the United Kingdom (UK) to test the effects of time and method of crop defoliation on subsequent infection of tubers with late blight. The methods of defoliation tested included the three that are allowed in organic production: burning with a propane gas-burner, mechanically defoliating the tops with a fail and a combination of burning and flailing. These were applied to varieties with different levels of resistance to late blight in the tubers and at different severities of foliar blight infection. Yields and tuber size grading were largely unaffected by time or method of defoliation although yields, as expected, were higher where defoliation was delayed and from the undefoliated control treatment because of a longer growing period. If tuber blight had been prevalent, lower levels following burning or mechanical defoliation would have been expected to compensate for lower total yields by giving a higher marketable yield because of less outgrades. However, only moderate levels of tuber blight developed in both 2001 and 2002 irrespective of the resistance of the variety, so that it was not possible to draw firm conclusions about the efficacy of the different treatments for reducing the risk of infection with tuber blight and improving marketable yields. However, in 2001, all defoliation methods reduced sporulation potential of the stems compared to the undefoliated control, but to a similar degree. Moreover, there was no evidence to suggest that 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 to decline before lifting the tubers) differed between treatments. Thus, it seemed that the simplest and cheapest method of defoliation i.e. by flailing may suffice but this needs to be tested further where conditions are more conducive to the development of tuber blight. However, if done too early, flailing may be followed by regrowth of foliage which further could extend the risk of infection compared with treatments involving burning with a propane-gae burner.

Introduction

Defoliation (destruction of the foliage by physical, chemical and thermal methods) is used to reduce the risk of the transfer of the late blight pathogen spores from infected potato foliage to tubers, either while they are still in the ground or while they are being lifted during harvest. Infected tubers are unmarketable and if put into store with healthy tubers may cause severe deterioration as secondary rots caused by bacteria may develop. Infected tubers that survive over winter are also the major source of inoculum that causes infection in newly emerging crops in the following year. The success of defoliation is considered to depend on timing, method and prevailing environmental conditions (e.g. defoliation during periods of precipitation is thought to increase tuber infections). The objective of the two experiments made in the 2001 & 2002 seasons which are reported here was to study the effect of defoliation strategy and timing on crop yield and quality and the development of tuber blight in different potato varieties.

Material and methods

In 2001 the experiment was made in the UK in the West of Scotland**,** the three principal defoliation methods permitted under current organic standards - heating, flailing and combinations of both methods - and three different defoliation times at different levels of foliar blight were tested on varieties Sante and Midas (Midas is more blight resistant than Sante). Twelve metre sections of beds were defoliated when 25-50% of leaf area became infected and assessments made of sporulation potential of the haulm post-defoliation, degree of tuber skin-set, the 'safe' interval between defoliation and harvest, and yield and tuber size grading and tuber blight infection. The potential for sporulation of the haulm was assessed by incubation of residual foliage samples from the variety Midas at 6, 12 and 18 days after defoliation under suitable, high humidity conditions for 24 to 48h. In both varieties, samples of tubers (30 tubers per plot) were harvested at intervals of approximately 1, 2, 3 and 4 weeks after defoliation and stored under conditions to encourage the development of tuber blight to test if the 'safe' interval between defoliation and harvest could be shortened where flailing or burning had been used.
The same three defoliation methods were also used in 2002 in the UK in N. Yorkshire, England (STC) and compared with untreated controls in which plants' foliage was left to die off in the field. Two potato varieties (Cara and Valor) with different foliar growth habits were included in trials. The plots were inoculated twice with *P. infestans* to ensure that the disease became established and its progress was then monitored at frequent intervals. Defoliation was carried out at 2 stages of foliar disease development (when 5-15% and 25-45% of leaf area was infected with *P. infestans*). For plots defoliated when between 25 and 45% of the leaf area was infected, plots were either irrigated or not irrigated after defoliation to determine the effect of precipitation on the development of tuber blight: rainfall washes zoospores from the treated haulm into the soil. At harvest, the tubers from each plot were size graded and the number and weight in each category recorded. Three sub-samples were taken from each plot; one was assessed immediately for presence of tuber blight and the other two were stored at 4-8°C and assessed after 6 and 14 weeks.

Results

2001

In 2001, **t**he three defoliation methods reduced the potential for production of sporangia (Fig 1). Flailing, heat treatment and combination of flailing and heat treatment significantly decreased number of sporangia per plant, with the latter being most effective. Flailing was probably effective because it transferred most of the diseased foliage to the furrow bottom and away from the tubers in the ridge. Heating/burning alone of a dense canopy left more foliage above the ridge and protected the stem bases resulting in high number of sporangia being produced on haulms after defoliation. There was no effect of defoliation treatment on the rate of tuber skin set and there was no evidence in either variety that the 'safe' interval between defoliation and harvesting differed between treatments i.e. the harvest interval could not be reduced where heat or flailing had been used in the defoliation process (Figs. 2 and 3).

Defoliation treatments had little effect on yield or tuber size grading or level of infection with tuber blight in either variety and in any treatment (Data not shown)

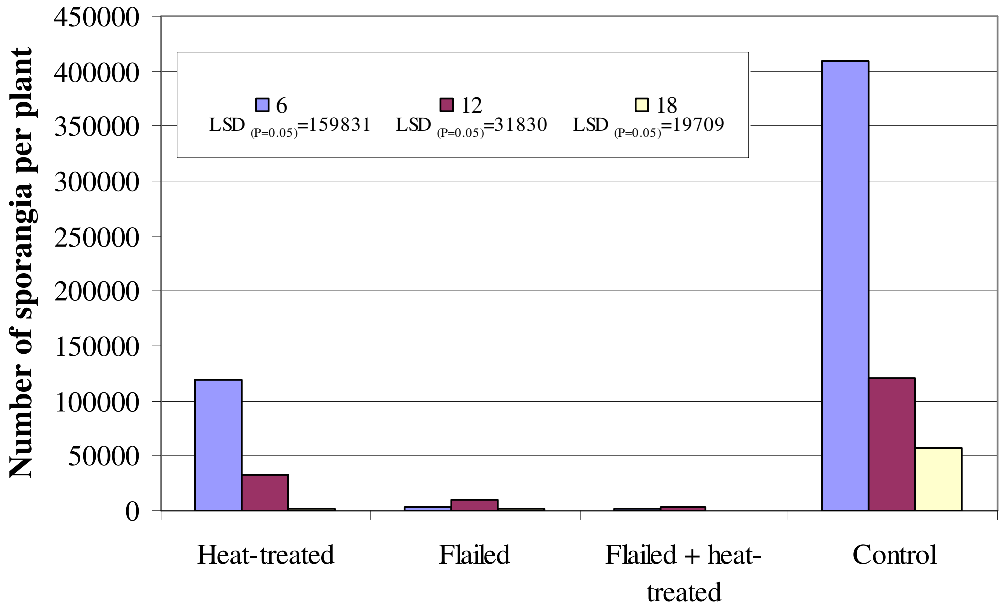


Fig. 1 Number of sporangia produced per plant after incubation of treated haulm under high humidity for 24-48 hours (6, 12 and 18 days after defoliation treatment applied on 23 August) in the variety Midas.

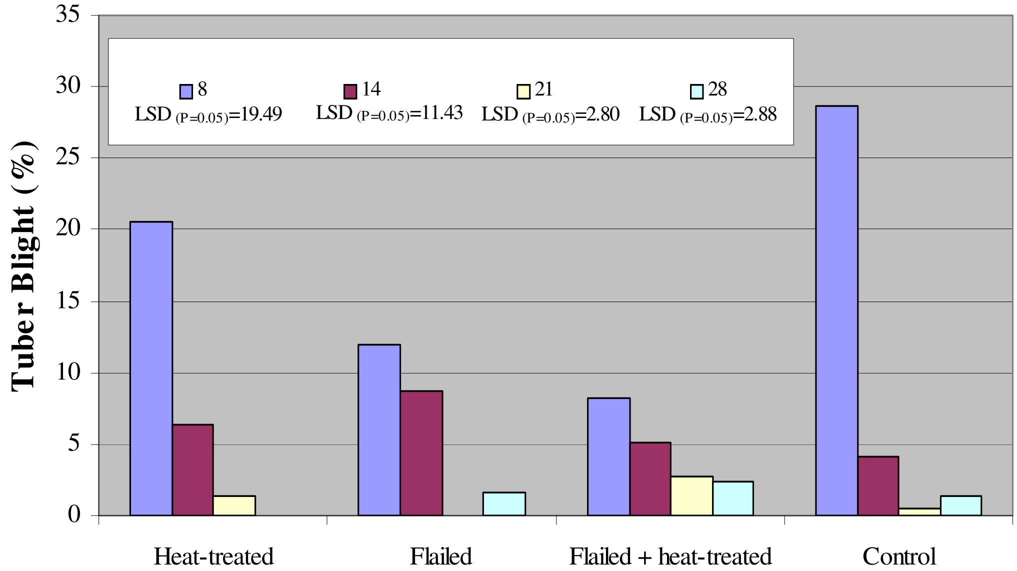


Fig. 2 Tuber blight (% by weight) in tuber samples harvested 11, 18, 25 and 32 days after defoliation treatment (non-irrigated plots) variety Midas

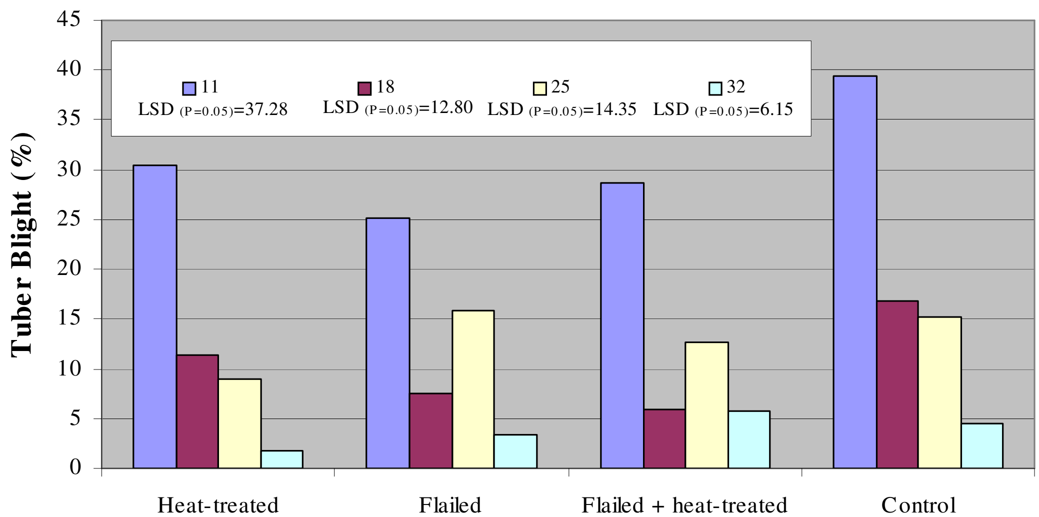


Fig. 3 Tuber blight (% by weight) when tubers harvested 8, 14, 21 and 28 days after defoliation treatment (non-irrigated plots) variety Sante.

2002

Foliar blight developed late, but increased rapidly after 8 August during a period of wet weather. The first set of plots was defoliated at approximately 7% leaf area infected. The second set of plots was defoliated on the 19 August, when approximately 30% of the leaf area was infected. Half of the plots defoliated on the 19 August were irrigated for approximately two hours within 24 hours of the second defoliation treatments. The disease continued to develop in the non-defoliated control plots, and approximately 90% of the foliage was infected in control plots on 2 September (Figs. 4 and 5) and all plots were harvested on 7 October. Yields were relatively high and there were few significant differences in the number or weight of tubers in the various size categories between treatments (Figs 6 to 7). Defoliation at 5-15% foliar blight gave significantly lower yields than defoliation at 25-45% and yields were highest from the undefoliated plots. However there was no significant yield difference between late defoliation and the non-defoliated control treatment. There was no significant difference in tuber size distribution between treatments, but as expected, the tuber size distribution was significantly ($p<0.05$) different between varieties.

Levels of tuber blight were extremely low at the first and second assessment dates and there were no treatment effects (Data not shown). These results were broadly consistent with the results from the experiment in the previous year.

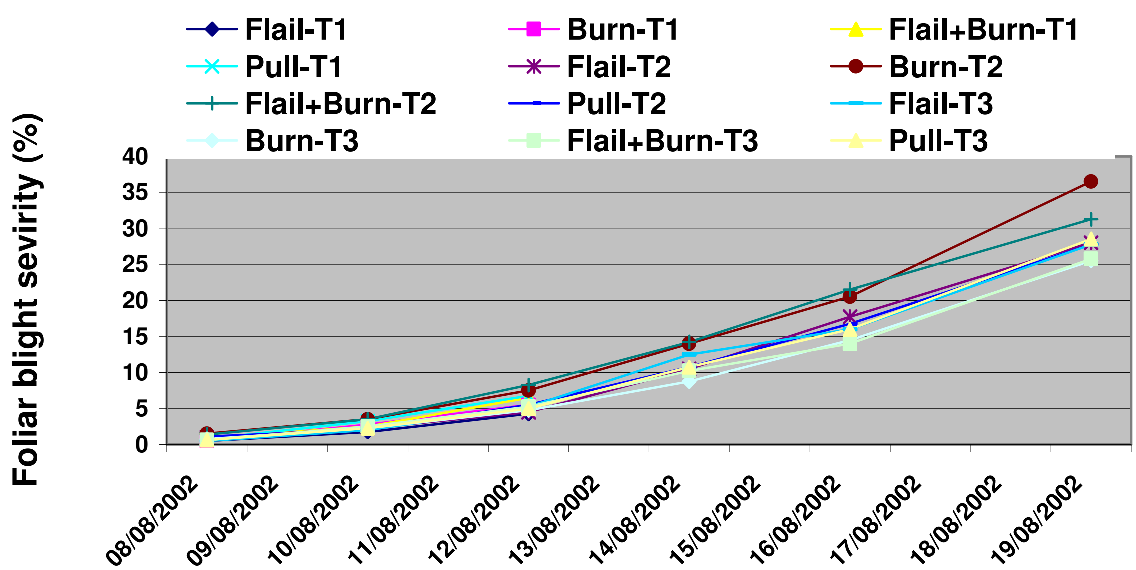


Fig. 4 Foliar blight development in Valor (T1= defoliated at 5-15% blight; 2= defoliated at 25-45% blight; and T3= defoliated at 25-45% blight and irrigation).

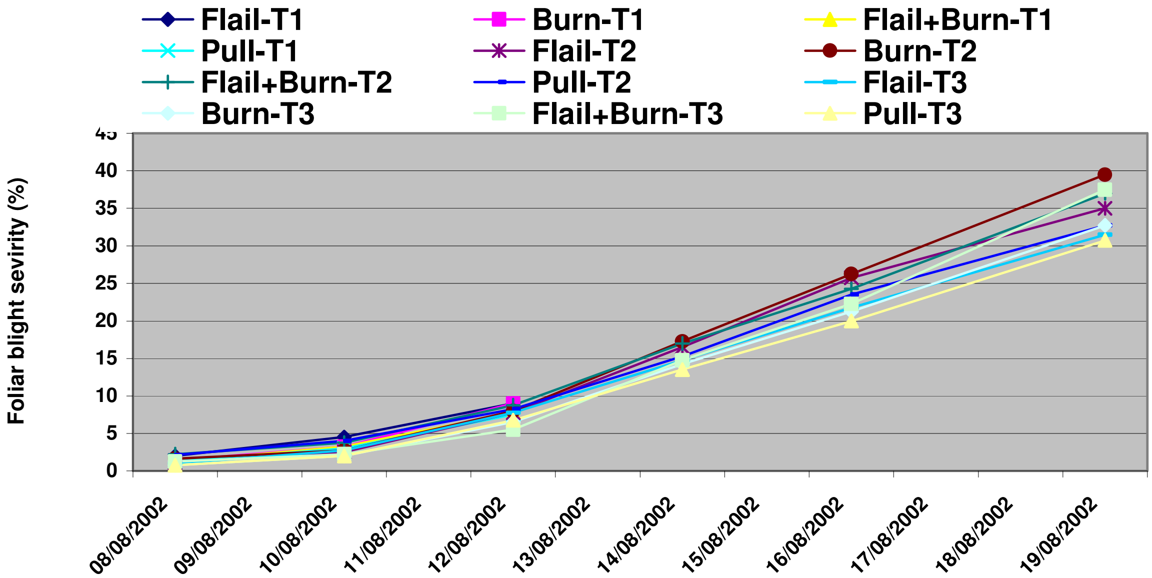


Fig. 5 Foliar blight development in Cara (T1= defoliated at 5-15% blight; 2= defoliated at 25-45% blight; and T3= defoliated at 25-45% blight and irrigation)

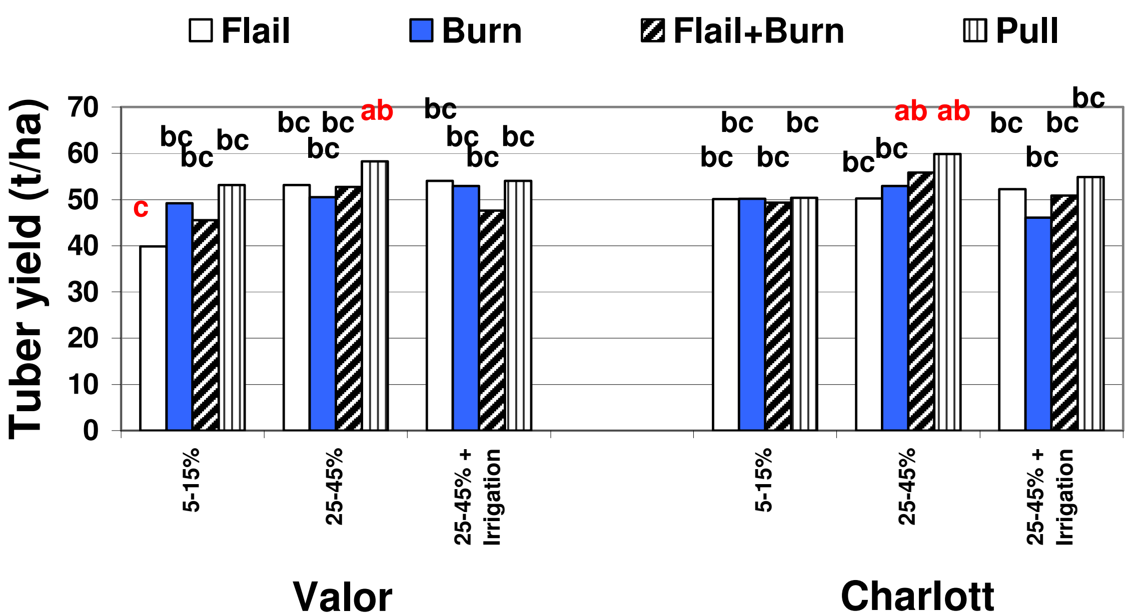
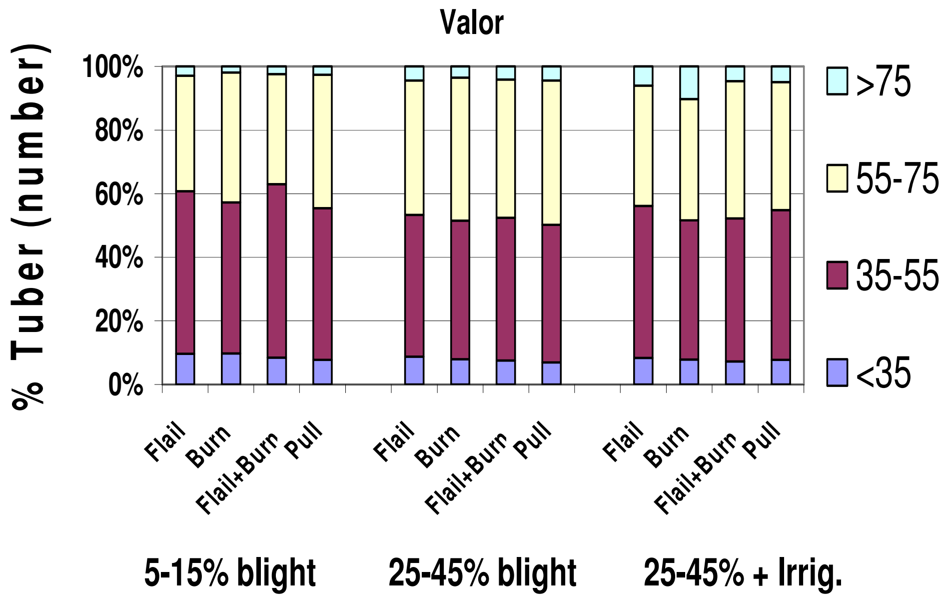


Fig. 6 Effect of defoliation time and method on tuber yield in different potato varieties. Different letters indicate significant differences (P<0.05) according to Tukey's Honestly Significant Difference (HSD) test (n=4).



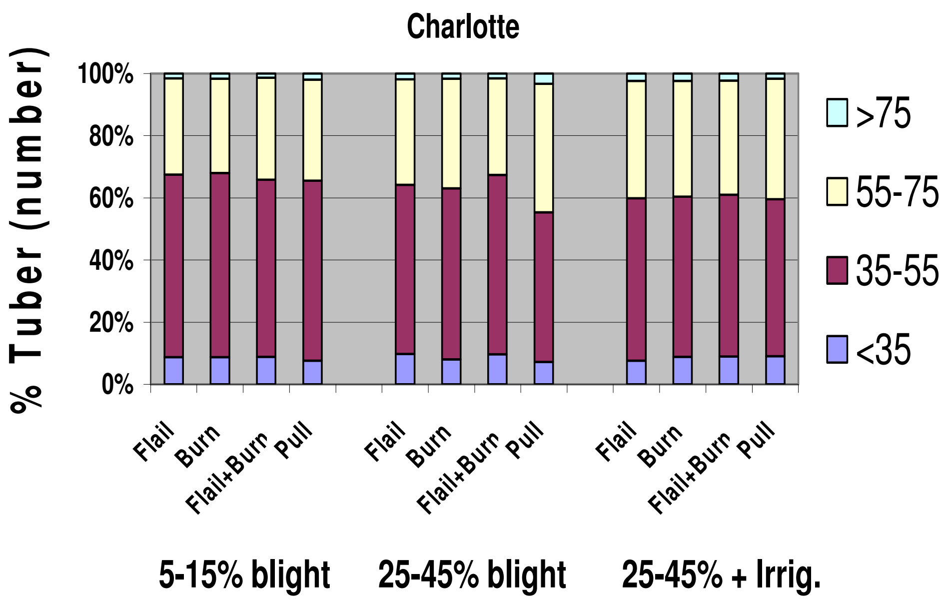


Fig. 7 Effect of defoliation time and method on tuber size (% weight) in 2 different potato varieties (Valour and Charlotte)

Discussion and Conclusions

Because there was only moderate tuber blight development in both field trials seasons (2001 and 2002), it is not possible to draw firm conclusions on the efficacy of the different defoliation methods studied here for the reduction of risk of tuber blight infection. However, results from the study into sporulation levels on stems indicated that there was no significant difference between the different defoliation methods which suggests that the most expensive treatment i.e. combined flailing and burning may not be necessary, but the treatments should be tested under conditions favourable for tuber blight infection. However, effective haulm removal may still be required to facilitate harvesting and control tuber size grading.

Furthermore, slightly later defoliation at a higher level of foliage blight infection did not increase tuber blight incidence (under the moderate tuber blight pressure conditions in the 2 trials), but provided significantly higher yields. Therefore, it may be possible to delay defoliation of potato crops in organic systems compared to conventional crops to achieve higher yields without increasing infection with tuber blight. However, this needs to be confirmed in future trials before such recommendations can be made.

Section 9: Consolidated Report on Agronomic Strategies

Introduction

In addition to the use of resistant/tolerant varieties, agronomic practices may delay or reduce the incidence of, and/or the severity of late blight by affecting characteristics such as the physiological age or size of the canopy, the proximity between adjacent plants, the micro-climate within the crop and the susceptibility of the plant tissues to the pathogen. Alternatively, they may help to avoid or at least, decrease its effects. By advancing the onset or increasing the rate of tuber bulking certain practices may reduce the potential impact by building reasonable yields before blight infection with blight necessitates defoliation that terminates tuber bulking. The Blight-MOP project examined a number of agronomic strategies in order to optimise:

(i) volunteer potato removal methods (volunteers are a primary inoculum source for *P. infestans*),

(ii) nutritional regimes (to avoid susceptibility or increase resistance to late blight or to enhance crop growth) including position in the rotation relative to fertility building crops, animal manures and N:K ratios

(iii) seed tuber pre-sprouting treatments, crop planting dates, plant configuration and spacing, foliar sprays and microbial soil inocula and irrigation schedules (to avoid periods of high blight pressure in the growing season)

(iv) methods and timing of defoliation (to maximise yield while avoiding tuber infection)

and hence develop integrated "locally adapted" agronomic management systems for late blight in EU-organic potato production.

Volunteer removal strategies:
Potato volunteers are an important source of inoculum for late blight that may be more prevalent following organic crops because subsequent mechanical and hand-weeding to control the problem may be inadequate. Putting pigs onto land after potato crops to excavate and eat volunteer tubers may be a useful alternative or additional control strategy. The additional fertility inputs from the pigs may be beneficial but soil disturbance may be a problem. In experiments in 2001 and 2003 in the Netherlands sows (2001) and finishing pigs (2003) removed volunteer potatoes very quickly and effectively following harvest. However, there were some undesirable effects. In 2001, many of the pregnant sows aborted following feeding on the potato volunteers but there was no conclusive proof that consumption of the potatoes was responsible. In 2003, the meat quality of the finishing pigs was lower than that from others that had not participated in the experiment, costing about €60 per pig. In both years, the pigs created compaction in the top 6-18cm soil layer and establishment problems in the succeeding cereal crop. Therefore, whilst this method is extremely effective for volunteer

control, risks to sow health, carcass quality and soil structure (which will depend on soil type and moisture status as well as the density of the pigs and their duration on the field) mean that it cannot be recommended unconditionally on the basis these results from the Blight-MOP project.

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

Crop rotation is a crucial element of soil fertility management strategy. The position of potatoes in the rotation is almost invariably pre-determined to benefit from fertility built up during the production of the preceding crops (although there are also crop protection benefits). In organic rotations, potatoes usually follow grass/clover or a cereal crop that is grown immediately after grass/clover. Indeed, in the survey, 40% of growers followed grass/clover with potatoes and another 40% followed cereals with potatoes: the remainder followed other crops such as vegetables/roots with an interval of 4 to 7 years between most potato crops. Resistance to late blight may be influenced by nutrient demand and status at different growth stages as well as soil fertility status. Immediately after a grass/clover ley, there will be a higher level of available soil nitrogen than after a cereal. This could lead to higher yields, but may also render crops more susceptible to blight. However, many of the growers surveyed remarked that potato crops lacking vigour because of nutrient deficiency were more susceptible to late blight infection than those with an adequate supply. Resistance expression by potatoes may also depend on crop nutrient demand at different growth stages as well as soil fertility status. Since stages of maximum nutrient demand differ between early, mid, and late bulking potato varieties, this is likely to result in temporal differences between varieties with respect to blight resistance. Field trials were set up 2002 and 2003 in Germany and the Netherlands to assess the effect of the position within the rotation of potato-varieties with different bulking times on the late blight attack. Potatoes were grown in two rotations i.e. directly after a fertility building crop of grass/clover or Lucerne, or after wheat or barley following a grass/clover pre-crop. The aim was to assess the effect of different nutrition levels on late blight infection, yield and quality of potatoes in organic production in view of increasing restrictions on the use of copper-fungicides.

In Germany, experiments confirmed that the fertility of a site has a major effect on crop performance and that adequate nitrogen supply is the most important aspect of potato growing if varieties are to achieve their full yield potential under organic conditions. In this respect, a pre-crop of grass/clover (rather than a cereal) was considered to be an appropriate way of building up the nitrogen supply and therefore the potential for a high yield. The requirement to achieve levels of fertility sufficient to meet the demand for unhindered growth was given higher priority than the risk of increased infection with late blight. Whilst there was no significant effect of the pre-crop species on the severity of infection, there was a clear trend: disease severity was increased in the potatoes after grass/clover which was attributed to more conducive micro-climatic conditions in the foliage rather than the nutritional status of the crop *per se*. Variety had the strongest influence on late blight incidence and severity: 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 (i.e. there was a significant interaction between variety and copper).
In practice, so far as variety choice is concerned, there are two main options for the grower: either to grow an early bulking variety such as Nicola, which although may be more susceptible to late blight, produces an acceptable yield before infection stops bulking, or to grow a late bulking, but more resistant variety such as Simone. Where there is a challenge from the disease and copper fungicides are used, varietal susceptibility is offset and varieties such as Nicola or preferably Rosella can be grown successfully. The denser foliage of Rosella set a high yield potential and yield was satisfactory even without copper fungicide treatment although the late blight epidemic was relatively mild in both years. On the other hand, the more resistant, but later bulking variety Simone built up a good yield even without copper

fungicide spraying and thus represents the type of variety that is suitable in situations where the use of copper fungicides is not permitted. 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 that the roots are able to take up.
For the most part, experiments in the Netherlands gave similar results 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 the regulatory requirement to defoliate the crops at a low level of disease, there were no effects on the duration of crop growth, although Lucerne gave a slight but insignificant yield increase. There were large effects of variety on blight infection dependent upon the level of resistance (Appell was the most resistant and Santé the most susceptible). There were also significant differences in yield between the varieties due to the combined effects of differences in maturity (i.e. the onset and duration of tuber bulking) and susceptibility to late blight. 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:
Little is known about effects of different organic-matter-based fertility inputs applied pre- or post planting on potato crop growth, yield and blight susceptibility in organic systems. However, balanced fertility management is thought to increase resistance of potatoes to fungal diseases and high levels of available K are thought to increase blight resistance. With N however, a common view seems to be that high inputs decrease blight resistance and give a dense canopy with a micro-climate that favours the development of the disease. The message from growers in the survey contradicted this view, as they believed that nutrient-deficient plants under stress may be more susceptible to infection despite their small tops. Notwithstanding fertility management effects on late blight infection however, nutrient supply is an important determinant of potential yield. It affects leaf canopy size and longevity and hence rate and duration of tuber bulking before the crop is defoliated, either by the disease or by deliberate flailing and/or burning. The grower survey confirmed that many potato crops in organic systems receive relatively limited inputs of nutrients and some are deficient (occasionally for N and often for K) because of the limited availability of organic manures available to meet the requirements of all crops in the rotation. Consequently in many cases, yield may be more restricted by effects of a lack of nutrients on crop and tuber growth than on late blight infection. Optimising fertility management and utilisation of applied nutrients is therefore a major agronomic objective in potato production and balancing losses due to increased blight infection with gains from improved growth is critical.

All of the field trials were carried out in the United Kingdom from 2001 to 2003, to quantify effects of different 'organic' fertilisation regimes and interactions between N and K supply on foliar and tuber blight resistance, disease development and tuber yields in (a) sites/soils which had been under organic soil management for different lengths of time and (b) different seasons. A series of complementary pot trials ran in parallel with the field trials from 2001 to 2005 and had similar objectives. In addition however, effects of tuber planting depth on infection of the progeny tubers with late blight and effects of levels of soil microbiological activity and water supply on the crop's responsiveness to different fertility management regimes were also investigated. Such an approach is important in determining the most appropriate soil fertility management programme to adopt for the potato crop in organic cropping systems in different situations.

In the field in 2001, fertility treatments had no effect on the course of blight infection development in either Sante (resistant) or Nicola (susceptible) but affected yield. Crops treated with cattle-manure-based compost significantly outyielded those treated with chicken-manure pellets by the order of 40% at a site that had been in organic production for many years. The reverse was true in sand culture in the pot experiments. Inherent differences in the contents of water-soluble nitrogen compounds and microbial activity between the field soil and sand were thought to be responsible for these results.
Suggestions in the literature that the level of K applied to potato crops in the soil and to the foliage affects blight infection were not supported by our results in either 2001 or 2002 and N:K ratio had no effects either. 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. In 2001, at 85 or 170 kg/ha N, cattle-manure-based compost increased yield significantly compared with a chicken manure fertiliser pellets in a well-established, long-term organic site as mentioned above. This may have been a result of the soil having a high, inherent biological activity leading to efficient mineralisation of nutrients from cattle-manure-based compost. Data was not available to test this, but this hypothesis was to be tested in 2003. However, August 2003 was very dry which suppressed late blight infection and there were no treatment effects on foliage blight at either site. At Nafferton, total tuber yield was unaffected by type and level of fertility input but at STC, yields were higher with chicken manure pellets than with cattle-manure-based compost or uncomposted dairy cattle manure (FYM) at all levels of applied N (85, 170 and 250 kg/ha N) and highest at 170 and 250 kg/ha N. Presumably, this reflected a less fertile site at STC where potatoes followed a poor crop of soybeans with a lower level of microbiological activity, than at Nafferton (potatoes followed a 2 year grass/clover ley). Irrigation at STC in August may have also improved availability of the higher levels of soluble mineral N in the chicken manure pellets than in compost or dairy cattle manure. Clearly, although fertility type and level did not affect blight in any experiment, it seemed that the magnitude of effects on tuber yield was dependent upon soil fertility (and probably the level of soil microbial activity) and soil moisture availability. However, further studies are required to identify the interaction between soil biological activity/N mineralisation potential and fertility input types and levels.

Evidence suggested that the type and level of fertility input may directly affect yield to a considerable extent by influencing crop and tuber growth whilst effects on the onset and severity of late blight infection seem to be relatively small or possibly absent. Therefore, decisions regarding fertility management of potato crops in organic cropping systems should be made primarily with regard to direct effects on crop growth and yield, rather than on possible effects on late blight infection.

In the pot experiments basal fertiliser type (cattle-manure-based compost or chicken-manure pellets) affected both foliar blight (although significant differences were recorded in only in one of the 3 pot trials) and tuber yields (in all trials). Foliar blight was lower in cattle manure based compost treatments than where chicken manure pellets were used. This might have been because compost fertilised plants were less susceptible (possibly associated with lower levels of available nitrate than with chicken manure pellets) and/or because they had much smaller tops which would reduce the chance of spore infection. When applied at similar total N-input levels chicken manure pellets (which have a high content of water soluble N) always gave significantly higher yields than manure based compost (which contains very low levels of water soluble N). These results conflict with the results from field trials carried out in soils which had been under organic farming management for > 5 years In field trials, manure based composts always gave higher yields than chicken manure pellets. This may have been due to the higher biological activity (and associated N-mineralization rates) in organically managed soils compared to sand (which is known to have very low biological activity).

Disease severity was higher in plants that received an excessive amount of 680 kg N/ha compared with a limit of 170 kg N/ha which may have been due to either physiological or morphological effects. At the same N-input level of 680 kg N in the 2002 pot experiment, the 50:50 mixture of compost and chicken manure pellets gave higher yields when compared with either 100% from compost or from chicken manure pellets. This indicates that in a substrate of low biological activity (sand), a combination of organic-matter-based and water soluble N-inputs is more favourable for yield but the reasons are unknown.

Liquid fertility inputs of pine extract, seaweed extract and fish emulsion had no effects on late blight infection of leaves or tubers. However, tuber yield was increased by approximately 20% in the most resistant varieties treated with seaweed extract. This may have been due to a growth promoting effect or the benefits of micronutrient supplementation in the very low fertility sand substrate culture medium.

As in the field, there were no effects of N:K ratios on late blight infection but increasing K input to very high levels as N levels increased, reduced yields. Tuber blight infection was not affected by fertility input treatment or by the depth of planting of the mother tuber.

In 2005, in the absence of late blight infection, highest yields were obtained from plants that were free from water stress and supplied with 170kg/ha N in the form of chicken manure pellets. Yields from this treatment were almost double those from plants that were water-stressed and received no farm-yard-manure-based compost or chicken manure pellets. Where water was in short supply, application of organic manure in either form and at either 85 or 170 kg/ha N, yields were similar to those of plants that received no supplementary fertility inputs. At the same level of nitrogen input, chicken manure pellets gave higher yields than farm-yard-manure based compost averaging 12%. Yields of all treatments were higher where water was in adequate supply. On the whole, the effects of soil microbial activity or ‘inherent fertility’, organic manure type, level of nitrogen input and irrigation were additive. There was one interaction between the type and level of fertility input. At the higher level of nitrogen input (170kg/ha), yields were greater when chicken-manure pellets were used rather than farm-yard-based manure compost probably associated with the higher content of water soluble nitrogen. The lack of any other treatment interactions indicated that the responsiveness of the potato plant to different types and levels of nitrogen input under conditions prevailing in this experiment was not affected by water supply or the microbiological activity or ‘inherent fertility’ of the soil.

Clearly, the results from field and pot experiments did not unequivocally support the hypothesis that the best type and level of organic manure to apply depends upon the water supply and microbiological activity or ‘inherent fertility’ of the soil. However, all demonstrated that fertility management is a key determinant of potato crop performance in an organic system which was also obvious from the experiments described in Section 2 of this Chapter – Position in the rotation re:fertility building grass/clover crops. The strategy should aim to use the organic manures of different types that are available to achieve a favourable yield response. Evidence does not suggest that the risk of, or severity of infection with late blight will be increased as fertility input increases (as might be expected). Therefore the message is clear: growers should focus on fertilising for yield not for managing late blight.

Planting date and seed tuber chitting:

Early planting and/or chitting (pre-sprouting) of seed tubers advances tuber bulking compared with late planting and/or the use of unchitted seed tubers. Thus, when late blight infects the foliage, early-planted crops grown from chitted seed should have achieved a higher yield than late-planted crops grown from unchitted seed by the time that infection leads to destruction of the canopy. In the main, these principles have been established for conventionally grown crops that have been protected from blight by fungicides. The objective of this experiment was to evaluate this strategy in organic production systems for varieties with different blight susceptibility ratings, in different regions of the EU with different blight pressure, and in the absence of copper fungicides. It was also important to test whether crops grown from chitted seed (or planted early) are more susceptible than those grown from unchitted seed either for physiological reasons (i.e. by affecting physiological age of the canopy) or by increasing the size of the canopy and affecting the microclimate. If so, the potentially beneficial effects of chitting (or early planting) may not be realised.

Experiments in the UK and the Netherlands from 2001 to 2003 tested pre-sprouting (chitting) and early planting of seed tubers. Observations showed that crop responses to these treatments will depend 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 both varieties that differed in resistance to late blight e.g. Nicola (susceptible) and Sante (resistant) Valor (moderately resistant) and Lady Balfour (highly resistant). However, 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 reached the threshold for crop defoliation, because 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 (planting in began early May with 2 weeks between planting dates), yield effects were small. On the other hand, when the season was longer because the weather was unfavourable for blight, as in the Netherlands in 2003, there were no differences either, because late planted crops had time to catch up with the early planted ones which senesced sooner. Sequential harvests in this last experiment clearly demonstrated that tuber bulking in the early planting both started and finished before the late planting which continued to grow and accumulate yield.

Effects of chitting on yield were similar to effects of early planting. Fully chitted seed almost invariably gave higher yields in 2002 in the Netherlands and in late planted Valor in the UK presumably because of more advanced tuber bulking. The advantage of chitting seemed to be less when the growing period was longer and was also smaller when the growing period was extended, either because weather conditions were unfavourable for late blight as in the Netherlands in 2003, or because of a higher resistance level of the variety as in Lady Balfour in the UK in 2002.

Results of the experiments show that the 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 and crops are allowed to grow on, later planted or non-chitted seed may out yield early planted or chitted seed because of a larger and more persistent leaf canopy and increased solar radiation interception leading up to harvest. If blight infection is early, the more advanced treatments will show to advantage. Since it is impossible to accurately predict when blight will arrive at any location before the crop is planted, early planting and pre-sprouting are useful insurance treatments in organic production systems that should minimise the consequences of blight infection.

Planting date and chitting treatment influence the physiological age of the crop and the number of leaves per stem when blight first appears which may affect susceptibility to blight. 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, probably reflecting the complex control of inherent resistance of potato plants to blight which changes throughout the growth of the crop and is influenced by the age distribution of leaves within the canopy.

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 even though the effect is indirect. The response to planting date and pre-chitting in situations where infection with blight occurs will depend on the time at which the disease enters the crop and the level of infection at which the crop must be destroyed. If it is early, early planting and fully-chitted seed can be expected to show to advantage. With later infection/defoliation, the initial advantage of early planting and fully-chitted seed can be lost. Tuber bulking in later planted unchitted seed will usually begin later as the crop is physiologically young. However, it may continue for longer provided the growing season is long enough and reach yields that equal or exceed those of crops from early planted/and or chitted seed that are physiologically older and senesce sooner.

Plant configuration and spacing:

P. infestans infection and spread in potato foliage is facilitated by periods of high humidity and prolonged leaf wetness. Planting different populations in different configurations by changing between-row and/or within-row spacing affects the crop's microclimate because of changes in canopy structure and time of closure and consequently the duration of periods of high humidity and leaf wetness. Lower plant populations and wider spacings with a more open, well-aerated canopy should be less susceptible to blight infection than denser crops. However, effects on yield and tuber size-grading must also be considered. If blight infects the crop early, lower plant densities and wider spacings may be beneficial because a greater proportion of tubers will have reached marketable size by the time the foliage is destroyed. If infection is delayed the yield of larger tubers will increase. In this case, defoliation may be necessary to limit production of oversized tubers. These may be difficult to market and be affected by hollow heart and also be more susceptible to harvest and handling damage and storage rots than smaller tubers.

The main objective of this study was to quantify the interactions between varieties with different late blight resistance levels and plant configuration and spacing with respect to blight development and severity in Western Europe. In 2001and 2002, experiments were made to test the effects of plant population and configuration on late blight infection on varieties Nicola (susceptible) and Sante (resistant). Populations tested in the UK were 33000, 44000 and 89000 plants/ha in two or three row beds. These populations represent the commercial range for the production of large, baking potatoes at the lower population and small salad potatoes at the highest population. In NL, populations ranged from 38000 to 75000/ha grown in ridges either 75cm or 90cm apart. In both years and in both countries UK and NL, the results were consistent in both varieties. There were no effects of plant population or configuration (bed arrangement or distance between rows) on the timing of the initial infection of foliage with blight, or on the rate at which the epidemic developed. There were no treatment effects on tuber blight infection in any experiment, but the incidence of tuber blight was very low. To some extent, the magnitude of effects of plant population and spacing on late blight may be influenced by disease pressure. In the UK in 2001, disease pressure was amongst the most severe experienced during the past 15 years and no method of blight management could be expected to have much of a beneficial effect. Alternatively, the differences in canopy cover and structure caused by different plant populations may not have persisted long enough to have any effect .i.e. if the canopies closed before infection became established irrespective of population and configuration.

In other experiments reported in the literature where plant population and spacing have decreased severity of blight infection, populations have been lower than would be used commercially. Detrimental effects on yield and tuber size grading would far outweigh any beneficial effects on blight. It seems unlikely therefore that manipulating density and configuration is a promising method of decreasing late blight damage in practice in organic or conventional crops. The main determinant will be the need to maximise yield in particular size fractions to meet the demands of the target market outlet. Indeed, there were substantial effects of plant population and spacing on yields within particular size grades. With the exception of Sante in UK in 2001 which did not show the expected effect, yields of undersized tubers <35mm (UK) or <40mm (NL) increased markedly as populations increased from 33000 to 89000/ha and 38000 to 89000/ha in UK and NL respectively. This would be beneficial where small tubers are required for the market but not for large tubers and *vice versa.*

The evidence is clear that manipulating plant configuration and spacing has little to offer as a sole late blight management technique in either conventional or organic crops. However, it may be effective in combination with other blight management methods that limit blight pressure, as a component of an integrated control strategy. In this case, certain crop management practices may have to be adapted. For example, where crops are grown at high populations to produce small tubers for the market, the numbers and lengths of stems and the density of the canopy will be increased. This will be difficult to penetrate and cover completely with fungicides leading to a greater risk of the disease. Thus where foliar-applied blight control agents are to be used in dense crops, directed spraying to ensure that leaves at the base as well as at the top of the stem are covered may be more effective than overhead spraying. Defoliation of such canopies prior to harvest, may also require additional passes with a flail or a burner to be successful.

Irrigation regimes:

The potato crop is very sensitive to water supply because it is relatively shallow rooting and roots are less effective at taking up water than in other arable crop species. Where natural rainfall is low and water stress develops, yields will be depressed because leaf growth is limited and the efficiency of conversion of intercepted solar radiation declines. Tuber size grading will also be affected with a greater proportion of small tubers and secondary growth causing deformation of tuber shape may be a problem. Specific gravity may also be affected, and water shortage in the early stages of tuber growth may result in tuber infection with common scab caused by *Streptomyces scabies.* Supplementing natural rainfall with irrigation however can overcome these detrimental yield and quality effects caused by water shortage. Because of the risks associated with drought, many farmers irrigate their potato crops and these are given priority within the cropping system because of the potential gains in output and this is particularly the case for large-scale conventional growers. However, both rainfall and overhead irrigation present a risk in relation to late blight infection. Wetting the leaves, stems and soil, causes ideal conditions within the crop for infection. Splash from falling water droplets (i.e. 'rain splash') also helps to spread the disease. Movement of irrigation equipment may also transmit the disease and causes unavoidable damage to the tops, exposing stems to infection and the soil ridges which may encourage tuber blight infection. Clearly, irrigation management must take these risks into account and 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).

The amount and frequency of irrigation is very much dependent on the local climatic conditions and availability of water. Overhead spray irrigation is used increasingly in organic potato crops to enhance yield. According to the survey presented in Chapter 1 only 33% of organic growers irrigated their crops in 2000, but the remainder did not do so because the crop was not water stressed or no water or irrigation equipment was available. Only 6 of the 118 growers interviewed chose not to irrigate because of fears that it would cause late blight to spread and all of these were in the Netherlands. 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.

Experiments were carried out in France in 2002 and 2003 in an area where weather conditions mean that irrigation of potatoes is a very high priority. An irrigation regime based on 'optimised, water input was compared with 'normal' practice based largely on previous experience and an unirrigated or 'rainfed' control. As interactions between varieties with different resistance levels and irrigation regimes with respect to blight development and severity may be important, treatments were applied to a susceptible and more resistant variety. There could be less need to restrict water applications in more resistant potato varieties in which the pathogen often requires longer periods of leaf wetness for infection to take place. In 2002, significant late blight infection was absent despite artificial inoculation, so that no conclusions could be drawn about the effects of irrigation regime on the onset, rate and severity of infection of different varieties of potatoes. However, yield was improved by about 50% in both Charlotte (significantly) and Sante (not significantly) by irrigation compare with natural rainfall. Tuber size grading was also improved in both varieties. Most noticeably, decreasing the amount of water applied during irrigation from 174 to 93mm did not significantly reduce the yield or size grading benefits. In 2003, late blight infection did occur and reached up to 80% of leaf area infected in the susceptible variety Charlotte. However, irrigation did not increase infection compared with the unirrigated controls. Once again, irrigation improved both total and marketable yields and the effects of the optimised treatment were not significantly different from the usual treatment. Irrespective of the potential effects of water supply on blight infection (which did not appear to be problematic in these experiments), it is clear that irrigation is essential to achieve high marketable yields in this area of France: these experiments show that the benefits can be achieved by reducing the quantities of water normally applied, by reference to an objective scheduling method. This is also likely to be true for other areas and countries. Optimising water use has become more demanding as restrictions on the use of water in Agriculture are becoming ever more severe.

Foliar sprays and microbial soil inocula:

Various alternative treatments have been developed for the control of fungal pathogens including plant extracts, compost extracts and microbial preparations (Biological Control Agents or BCAs) applied to either the foliage and/or soil. Some of these have been proposed as potential treatments for the control of late blight in potatoes. However, there is little data about their efficacy. The objective of these experiments and others in the Blight-MOP programme was to identify the potential effects of a range of plant and compost extracts, microbial products and other materials applied as foliar sprays on late blight development and crop yield. If these materials are shown to suppress late blight, they could be very valuable as a component in an overall blight control strategy in the absence of copper fungicides. These materials may have antagonistic properties, or induce resistance to late blight and hence decrease infection with the disease.

In Denmark in 2001, three different compost extracts (horse manure, straw and cattle slurry and cattle deep litter) were investigated in leaf bioassay experiments in growth chambers. Based on these experiments, raw compost and autoclaved compost of cattle deep litter was selected for further test under field conditions in 2002 and 2003. The compost extract was compared to a standard copper fungicide. Contrary to the leaf bioassay, no effect of the compost extracts alone was registered under field conditions in 2002 or 2003. In the trials

2003, a soap (potassium oleate) was included. The potassium oleate alone delayed the late blight epidemic approximately one week. A synergistic effect between the autoclaved compost extract and the potassium oleate was observed which resulted in a few days further delay in late blight epidemic compared to potassium oleate alone.

In the UK in 2002 and 2003, eight different foliar sprays, including plant and compost extracts, chitin and silica were applied to potatoes in the field in each year at regular intervals and compared with copper oxychloride. (Microbial preparations were evaluated in another experiment, which is described in Chapter 7 Section 1: Sprayer systems for copper-based fungicide and novel products). Copper oxychloride effectively controlled foliage blight in 2002 and resulted in an increase of about 25% yield of tubers compared with the untreated control. The 'non-copper' sprays were no different from the untreated control in terms of foliage blight control or yield in 2002. In 2003, potential responses to spray treatments were considered to be extremely limited by very hot, dry weather. These conditions suppressed late blight infection (although foliar infection did reach about 20 – 30% by the end of the season) and may have deactivated or denatured some of the 'non-copper' sprays. Copper oxychloride kept infection below 5% throughout the season and gave the highest yields of tubers. Other treatments were no better than the untreated control in terms of either late blight control or tuber yield. This was also the case in 2002 when weather conditions were more normal. In two contrasting years, none of the 'non-copper' spray treatments gave effects that were different than the untreated control. Copper oxychloride consistently gave the best control of foliage blight and highest yield. Effective alternatives that are acceptable in organic production systems were not identified in experiments done in either Denmark or the UK. Other alternatives were tested in other experiments and are reported in Chapters 6: Alternative treatments and Chapter 7: Application & formulation technology.

Defoliation strategies:

A major reason for defoliation (destruction of the foliage by physical, chemical and thermal methods) is to reduce the risk of the transfer of the late blight pathogen spores from infected potato foliage to tubers, either while they are still in the ground or while they are being lifted during harvest. Infected tubers are unmarketable and if put into store with healthy tubers may cause severe deterioration if secondary rots caused by bacteria develop. Infected tubers that survive over winter are also the major source of inoculum that causes infection in newly emerging crops in the following year. The success of defoliation is considered to depend on timing, method and prevailing environmental conditions (e.g. defoliation during periods of precipitation is thought to increase tuber infections). The objective of the two experiments made in the United Kingdom in 2001 & 2002 was to test the effects of time and method of crop defoliation on subsequent infection of tubers with late blight. The methods of defoliation tested included the three that are allowed in organic production: burning with a propane gas-burner, mechanically defoliating the tops with a fail and a combination of burning and flailing, compared with an untreated control. These were applied to varieties with different levels of resistance to late blight in the tubers and at different severities of foliar blight infection. Defoliation was done on two occasions at low and moderate and levels of infection, which was about one week apart. In additional treatments, irrigation was applied immediately after defoliation in order 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 although yields, as expected, were higher where defoliation was delayed and from the undefoliated control treatment because of a longer growing period. In practice, where tuber blight is prevalent, lower levels of infection following burning or mechanical defoliation would probably compensate for lower total yields by giving a higher marketable yield because of fewer outgrades. In contrast however, when conditions are conducive for the development of tuber blight, whilst early defoliation may reduce total yield, marketable yield may be improved because fewer tubers have to be graded out because of infection with blight.

However, only moderate levels of tuber blight developed in both 2001 and 2002 irrespective of the resistance of the variety, so that it was not possible to draw firm conclusions about the efficacy of the different treatments for reducing the risk of infection with tuber blight and improving marketable yields. However, in 2001, all defoliation methods reduced sporulation potential of the stems compared to the undefoliated control, but to a similar degree. Moreover, there was no evidence to suggest that 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) differed between treatments. Thus, it seemed that the simplest and cheapest method of defoliation i.e. by flailing may suffice but this needs to be tested further where conditions are more conducive to the development of tuber blight. However, if done too early, flailing may be followed by regrowth of foliage which further could extend the risk of infection compared with treatments involving burning with a propane-gas burner.