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Challenges to Organic Potato Farming: Disease and Nutrient Management

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Abstract For organic potato producers the two main challenges are disease and nutrient management. Both factors are limited by regulations that on the one hand prohibit the use of chemical fertilisers, especially nitrogen and, on the other hand, most synthetic pesticides. Late blight, caused by *Phytophthora infestans* is commonly thought to be the factor most limiting yield. However, because there is no really effective fungicide available to control late blight, there are virtually no yield loss data available for organic farming conditions. In this paper the state of the art of organic potato management with respect to disease and nutrient management is summarised. In a second part, the interactive effects of N-availability in the soil, climatic conditions and late blight were studied in the presence and absence of copper fungicides from 2002–2004 for the mid-early main-crop cv. Nicola. From the experimental work it became clear that copper fungicides in most cases do slow down epidemics adding an average of 3 days to the growth duration. However, only 30% of the variation in yield could be attributed to disease reduction. A model including disease reduction, growth duration and temperature sum from planting until 60% disease severity was reached, and soil mineral N contents at 10 days after emergence could explain 75% of the observed variation in yield. However, the model failed when N-supply was extremely high. The implications of the results on the management of organic potatoes with respect to cultivar choice, nutrient and disease management are discussed. In conclusion, several points emerge from the results: In organic farming, yields are foremost limited by nutrient availability in spring and early summer. The effects of late blight on yields may often be overestimated and cannot be deducted from results in conventional farming because of the strong interaction with nutrient status. Resistance clearly remains the most important strategy against late blight in organic potato production. However, as important or even more important than resistance is the early development and bulking behaviour and the ability of a cultivar to make use of organic nutrients

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efficiently. In the absence of efficient organic pesticides it is possible to reduce blight pressure to a certain extent by arranging the crop in small narrow fields perpendicular to the main wind direction neighboured either by non-hosts or completely resistant potatoes.

Keywords Organic farming · plant nutrition · *Phytophthora infestans* · yield loss · copper fungicides

Abbreviations

AUDC	area under the disease progress curve
Days	growth duration (days) from planting until 60% diseased leaf area
N10	N-min at day 10 after emergence
N21	N-min at day 21 after emergence
Ttot	temperature sum: sum of daily mean temperatures from planting until 60% diseased leaf area
Disred	disease reduction: AUDC with copper application divided by AUDC without copper application

Introduction

For organic potato producers the two main challenges are disease and nutrient management. Both factors are limited by regulations that on the one hand prohibit the use of chemical fertilisers, especially nitrogen and, on the other hand, synthetic pesticides (EU-regulation 2092/91).

Plant nutrition in organic farming therefore relies on carefully designed rotations including ideally 25% or more legumes in the rotation and the addition of organic fertilisers such as solid and liquid animal manures, green manures and composts. With the exception of liquid manure these fertilisers are usually slow release and highly dependent on the soil moisture and temperature for mineralisation processes that make the nutrients available to the plants (Van Delden, 2001; Gruber et al., 2003; Haase et al., 2005). In high-value vegetable crops, more expensive fertilisers that supply nutrients more rapidly such as hair meal pellets, molasses, horn and legume meals etc., are also used (Müller and von Fragstein und Niemsdorff 2005; Raupp, 2005).

In potato production, rotations, cover and green manure crops and animal manure are typically used to manage nutrients. Unfortunately, there are strong interactions between the type and timing of nutrient application and several pests and diseases, especially wire worms and black scurf (caused by *Rhizoctonia solani*). While wire worms (*Agriotes* spec. among others) are often a problem if the potatoes follow in the rotation after several years of pasture or grass-clover (Paffrath, 2002; Schepl and Paffrath, 2003) *R. solani* is favoured by high amounts of raw organic materials from manure or possibly also grass-clover pre-crops under suboptimal climatic conditions (Karalus, 2000; Radtke et al., 2000). Besides such negative effects remarkably positive effects of the use of straw mulch were found. On the one hand, straw mulch applications reduced potato virus Y infestation (Saucke and Döring, 2004) while at the end of the potato season the straw reduced nitrogen leaching (Döring et al., 2005).

After emergence of the potato the haulm and roots develop simultaneously. Haulm development is strongly affected by the nitrogen supply/availability in the first weeks after emergence (Harris, 1992; Van der Zaag, 1992; Marschner, 1995; Vos, 1995; Neuhoff, 2000) and by the time of flowering (roughly 6 weeks after emergence) when the main bulking period starts a leaf area index (LAI) of 2.5–3 is needed to allow for optimal bulking (Marschner, 1995; Van Delden, 2001). We have found that for a potential yield of 35 t ha^{-1} the crop needs to take up 110–130 kg N ha^{-1} during main foliage growth until start of tuber bulking (Schulte Geldermann et al., own unpublished data) and an N need between 27 and 35 kg per 10 t of yield has been reported in organic systems (Möller, 2000). However, in high nitrogen-input conventional systems uptakes of 40–50 kg N per 10 t of yield have been reported (Harris, 1992; Van der Zaag, 1992; Marschner, 1995). It appears that N-use efficiency might be higher in low-input systems.

A too abundant haulm growth (high nitrogen supply) delays tuber initiation and crop maturation (Millard and MacKerron, 1986; Harris, 1992; Marschner, 1995). Excessive haulm growth may also prolong the duration of leaf wetness favouring the formation of spores, spore germination and infection by the early and late blight pathogens (Stevenson, 1993; Radtke et al., 2000; Wright, 2002).

For plant protection in organic potato production, only a few effective pesticides are available. The most important insect pest, the Colorado potato beetle (*Leptinotarsa decemlineata*) has to be managed preventively by reducing initial populations in the field through crop rotations and a minimum distance between fields in successive years of ideally about 100 m. Remaining populations can be controlled in organic potato production with commercially available products based on *Bacillus thuringiensis var. tenebrionis* (Bt) or extracts of the Neem tree (see, e.g., http://www.bba.de/oekoland/index.htm). For fungal or bacterial diseases, on the other hand, there is currently no treatment available that reliably reduces diseases with the exception of copper-based fungicides. While copper fungicides reliably work as contact fungicides if applied prophylactically, their environmental side effects during production (mining) of copper and also in the soil and especially towards aquatic environments are unacceptable (Alloway, 1995) in general and especially when considering organic principles. Therefore, these fungicides are already prohibited in several European countries (Scandinavia and the Netherlands) and severely limited under German and Swiss organic regulations (a maximum of 3 and 4 kg Cu ha^{-1} and year are allowed, respectively; Tamm et al., 2004). Under EU organic regulation 2092/92 (amended with prescription Nr. 473/2002 from March 15th 2002) until 2005 up to 8 kg ha^{-1} year^{-1} elemental copper are allowed and from 2006 to 2008 up to 6 kg ha^{-1} year^{-1} with the final aim of prohibition. In parallel, the Swiss forecasting system that had been designed for the application of systemic fungicides has by now been expanded to allow for the optimisation of copper-based contact fungicides in organic farming (Musa-Steenblock and Forrer, 2005).

In organic potato production the growing period is often limited due to early death of the haulm caused by disease and pest attack, especially by late blight. To extend the post-emergence growth period in organic potato production, it is important to plant physiologically old (chitted) seed tubers and to plant as early as weather and soil conditions allow (Karalus and Rauber, 1997). As a consequence, soil temperatures during early potato development are often not very high and thus impede mineralisation of nutrients from the organic residues in the soil during the critical period after crop emergence.

There is virtually no firm data available on the effects of *P. infestans* on yields in organic potato production (Tamm et al., 2004). This is because of the fact that no effective organic pesticides are available to achieve a healthy control in yield loss studies. More typically, comparisons are made between an untreated control and potatoes treated with substances allowed in organic farming. Depending on site, year and time and type of application up to 25% yield increases have been achieved with copper fungicides or various plant strengtheners (Kainz and Möller, 2003; Möller and Meinck, 2003). Yield increases in comparison to an untreated control cannot be used for yield loss analysis. On the one hand the efficacy of the treatments depends on disease pressure, and, on the other, the yield potential at the site is not known.

An alternative approach to yield loss analysis in the absence of a healthy control was taken by Bouws-Beuermann (2005) by making use of the typical natural spatial variation in late blight severity across a field. They divided their experimental plots into multiple row sections of 3 to 6 m length that were all assessed separately for disease severity over time and also harvested separately. This approach resulted in subplots differing up to three-fold in area under the disease progress curve (AUDC). Depending on cultivar and year, between 0 and 24% of the variation in yield could be explained by area under the curve, indicating that factors other than disease play a dominant role in determining yields.

To assess the socio-economic impacts of late blight in organic production and the possible impacts of a copper ban, within the EU Blight-MOP Project (**B**light **M**anagement in **O**rganic **P**otato Production, see http://www.ncl.ac.uk/tcoa/producers/research/blightmop/) a survey on organic potato growing was conducted in seven European countries involving 115 farms (Tamm et al., 2004). It became evident that yields are severely limited in organic farming and a majority of farmers claimed that they suffered yield losses due to late blight. Where it is legally allowed, farmers do therefore use copper fungicides. Late blight and black scurf are currently the most important diseases in organic farming. In addition, common scab (caused by *Streptomyces scabies*), silver scurf (*Helminthosporium solani*) and sometimes soft rot (caused by *Erwinia carotovora var. atroseptica*) may cause serious problems.

While diseases appeared to be an important limitation on organic potato production, the data from the survey indicate that plant nutrition is at least as important. For example, on the farms surveyed organic manure inputs ranged from 0–350 kg N ha^{-1} (with a few extremely high values above 400 kg) with the majority applying between 100 and 200 kg ha^{-1}. Relating the inputs to the available N in the surveyed fields revealed that the amount of available N was below 100 kg ha^{-1} in all countries except France and the results clearly suggest that yields in organic farming are in large part limited by nutrient supply. A similar picture emerged for K-inputs which also tend to be below the recommended rates (Tamm et al., 2004).

The purpose of this paper is to present some data on the interactive effects of climatic conditions, nutrient supply and disease on yield of cv. Nicola (a mid-early main-crop potato). The data are drawn out of a total of five experiments conducted from 2002–2004 under various experimental conditions with and without application of copper fungicides.

Materials and Methods

In all experiments described, cv. Nicola (breeder Saatzucht Soltau/Bergen, Germany) was used. From 2002 to 2004 Nicola was grown at the experimental farm Hebenshausen (Heb) of the University of Kassel (annual mean temperature 7.9 °C, precipitation 619 mm). Pre-crops were either grass-clover (GC) or winter wheat (WW) and in addition, in 2004, spring oats. No additional fertilisers were used. In all 3 years, there were four replications for all treatments planted. However, because of inclement weather interrupting planting operations in 2002, planting dates varied by 3 weeks among replications (Table 1). Plot sizes varied from 6 × 10 m to 18 × 15 m.

In addition to the site in Hebenshausen, in 2004, cv. Nicola was grown in two sections of a nearby field (Eich, same climatic conditions) and in two sections of a farmers field (Etze, mean temperature 8.7 °C, ppt 645 mm) in unreplicated plots of 15 × 30 m. In Eich, in one section of the field the pre-crop was cabbage that had been harvested while in a second section of the field the cabbage had not been harvested due to marketing problems (Cab2). In Etze, the pre-crop was winter wheat.

At all sites, copper hydroxide (Cuprozin) was applied between 4 and 5 times per season at a rate of 500 g copper and 400 l ha^{-1} per application. Application dates were based on an internet-based late blight warning system as soon as the first blight lesions were observed in the area immediately surrounding the experiments. However, in 2002 and 2004, inclement weather conditions often prevented optimal timing of the applications.

Soils were analysed prior to planting in late March/early April and between 4 and 6 times during the growing season at each site concentrating on the time of maximum growth of the crop in May–July. Nitrate-N was determined in 0–60 cm depth according to a standard assessment method (Schinner et al., 1996).

Plots were checked regularly until the beginning of the late blight epidemic. After this, disease was assessed twice weekly on five plants per plot (2002 and 2003) and in 8 to 16 plot sections covering 7.5 m length of a row in 2004. Percent diseased leaf area was estimated following the key of James (1971).

The area under the disease progress curve was calculated per plot in 2002 and 2003 and per assessment site in 2004 based on the equation given by Kranz (1996).

At Heb and Eich daily mean temperatures and precipitation were measured with a local weather station while for Etze data from the German Weather service were obtained.

Whereas the data from Eich and Etze were based on unreplicated plots, for Heb replication means were used for the years 2003 and 2004. For Heb 2002, this was not possible, however, because of the different planting dates and extremely different epidemic conditions among replications. Therefore, plots were used separately in the regression analysis.

The following parameters were derived for a multiple regression analysis:

- Growth duration from planting until disease severity of 60% diseased leaf area (determined visually from the disease progress curves) was reached (**Days**)
- Temperature sum (sum of daily mean temperatures) from planting until 60% disease severity (**Ttot**)

Table 1 Variation in growing conditions for cv. Nicola in three sites in different years and after various pre-crops: earliest and latest date at which 60% diseased leaf area (60% DLA) was reached, ranges for growth duration (Days), temperature sums (Ttot), soil N-min contents up to 60 cm depth (kg/ha) at day 10 (N10) and day 21 (N21) after emergence and disease reduction (Disred) observed. The lowest (Min) and highest (Max) observed value at a given site is shown for each parameter.

Site, year	Planting date	Pre-crops[a]	60% DLA[b]		Days		Ttot[c]		N10		N21		Disred[d]	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Heb02	23.4/15.5	GC, WW	30.7	19.8	80	109	1465	1858	75	125	67	100	−0.06	0.48
Heb03	15.4	GC, WW	12.8	12.8	119	119	2000	2000	85	105	65	70	0.64	0.89
Heb04	16.4	GC, WW, Oat	25.7	31.7	100	106	1371	1451	60	110	60	110	0.10	0.40
Eich04	3.4	Cab1, Cab2	21.7	27.7	109	115	1375	1474	100	190	250	250	0.21	0.32
Etze04	19.4	WW	28.7	4.8	100	107	1372	1503	85	85	100	100	0.40	0.44

[a] Pre-crops were: GC = grass-clover, WW = winter wheat, Cab1 = cabbage, Cab2 = cabbage that was not harvested.

[b] In 2003 the crop was defoliated as late blight reached only 35%.

[c] Sum of daily mean temperature from planting to 60% disease severity. In 2003, until defoliation.

[d] Disease reduction is the AUDC with copper application divided by AUDC without copper application.

- N-min at day 10 after emergence (**N10**)
- N-min at day 21 after emergence (**N21**)
- Disease in copper treated plots compared to non-treated plots within site (**Disred**)

It is considered that until 60% diseased leaf area, there will be no substantial yield loss (Möller, 2000). Also, data from sequential harvests of cv. Nicola in Heb04 showed that there was no more yield increase after disease severity of about 60% had been reached (C. Bruns et al., own unpublished data). Therefore, 60% was used as the cut-off point to determine the growth duration of the crop. In 2003, almost no late blight occurred and the crop was defoliated on August 12th. Therefore, the growth duration until defoliation is taken instead.

Relative disease was calculated as the proportion of AUDC in copper-treated plots compared to untreated plots.

Data were analysed with Statistical Analysis Systems (SAS, 1988) using stepwise forward multiple regression maximising R^2 (MAXR option). The procedure first selects the best regression based on a single parameter, then based on two factors and so on until no further improvement in R^2 can be achieved by adding a factor. For final model selection, the residual plots together with the tolerance values of the colinearity analysis were also considered.

Results

The climatic and growing conditions varied considerably among sites and years resulting in a wide database with respect to growth duration as influenced by *P. infestans* epidemics (Table 1). The maximum temperature sum from planting to 60% disease severity was 1858 during 108 days in 2002. In contrast, 2004 was much cooler, with a maximum of 1503 in 107 days in Etze and only 1474 in 115 days in Eich, respectively (Table 1). Generally, very dry and hot conditions during June and July 2003 resulted in very slow disease development up to a maximum of 35% when the crop was defoliated. Therefore, in 2003, the temperature sum was calculated up to defoliation, which was 2000 during 119 days and there was no variation in growth duration and temperature sums among treatments in that year.

Late blight was first observed on July 8 in 2002 and on July 16 and 14 in 2003 and 2004, respectively. In 2002, conditions for the disease were very favourable in July and epidemics in some plots progressed extremely rapidly. Depending on planting time, copper application and epidemic situation, the growth durations and temperature sums varied from 81–108 days among the different plots. In contrast, the variation was much smaller among sites and pre-crops in 2004 (Table 1).

The nitrate-N dynamics also varied greatly among years, sites and pre-crops with the extremely high values of 250 kg N-min ha^{-1} 21 days after emergence (N21) after pre-crop cabbage in Eich04 reaching levels that are more common to conventional agricultural conditions (Table 1).

Copper sprays did not always result in disease reductions and in one case in 2002 there was even a slight increase (Table 1). However, overall the growth duration of sprayed plots was increased between 0–11 days in comparison to unsprayed plots and there was a highly significant correlation ($R^2 = 0.66$) between disease reduction and additional growing days (Fig. 1).

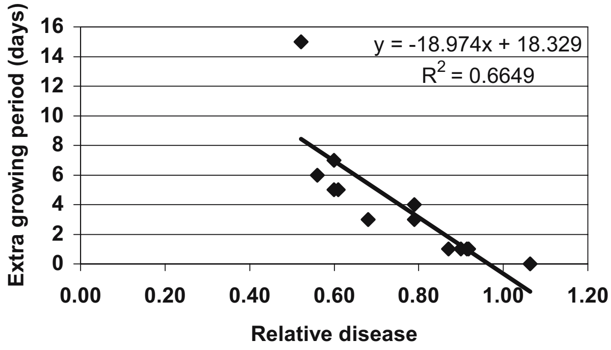

Figure 1 Effects of disease reductions due to copper applications on the growing period of cv. Nicola in different sites and years. Data from 2003 are omitted as the crop was defoliated.

Total yields varied between 11.7 t ha^{-1} in Heb02 in a plot planted late after pre-crop winter wheat and hit early by late blight and not protected by copper sprays and 41.0 t ha^{-1} after grass clover in Heb03 (Fig. 3). There appeared to be no yield benefit due to the extraordinarily high N contents in Eich04 (see Table 1) where total yields ranged between 29.4 and 40.5 t ha^{-1}(Fig. 3).

The multiple regression procedure yielded different results depending on the inclusion or exclusion of the extreme N-values of Eich in 2004. When omitting these data points a clear picture emerged (Table 2). In the single parameter model, disease reduction correlated best with total yield. However, only 26% of the variation in yield was explained by the model (R^2 = 0.26, Table 2). Also, plotting disease reduction versus yield (Fig. 2) shows that in the case of no disease reduction yields varied from the lowest observed yields to almost the highest. In the best two-parameter model, growth duration (Days) together with the soil mineral N content at 21 days after emergence (N21) could explain 42% of the variation in yield. The correlation could be slightly improved by adding the temperature sum (Ttot) and replacing N21 with N10 (R^2 = 0.57). While adding disease reduction (Disred) did not improve the correlation substantially (R^2 = 0.61) (Table 2) the residual plot of the four-parameter model revealed a much better and less biased fit than the three-parameter model. On the other hand, the correlations between the parameters used were not excessively high (tolerance values between 0.49 and 0.88) while in the five-

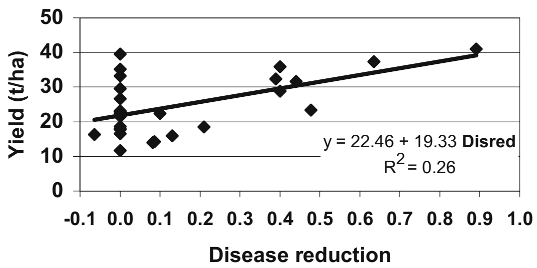

Figure 2 Effects of disease reduction (Disred) on total tuber yield of cv. Nicola after various pre-crops excluding the data from Eich04.

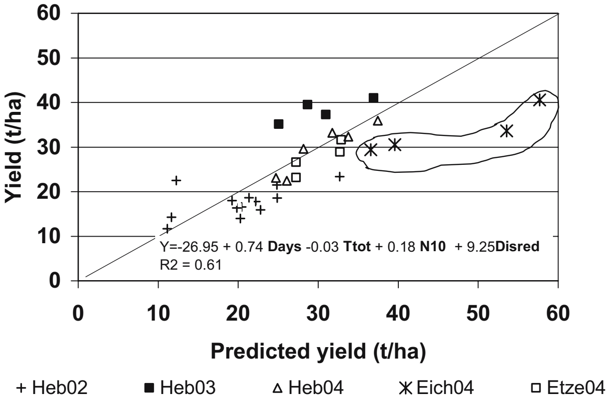

Figure 3 Results of the multiple regression of total tuber yield per ha on growth duration (Days), temperature sum (Ttot), soil N-min content at day 10 after emergence (N10), and disease reduction due to copper application (Disred). The regression is based on the values excluding the data from Eich04. On the basis of the model, predicted values for Eich04 are overestimated (circled data points) due to the extreme N-levels at that site (see Table 1). The 45° line represents the expected values.

Table 2 Results of multiple regression of total yield optimising for R^2 with one to five variables excluding the data from Eich04. Variables are growth duration (Days), temperature sum (Ttot), N-min measurements at day 10 (N10) and 21 (N21) after crop emergence and disease reduction (Disred). Colinearity analysis for Model 4. See Materials and methods for details.

Model	Parameter	Estimate	Error	SS	F-value	P-value	R^2	Tolerance[a]
1	Intercept	22.46	1.27	19,135	310.56	<0.0001	0.26	
	Disred	19.33	4.48	1148	18.63	<0.0001		
2	Intercept	−60.43	14.40	866	17.61	0.0001	0.42	
	Days	0.59	0.11	1311	26.64	<0.0001		0.89
	N21	0.30	0.06	1083	22.02	<0.0001		0.89
3	Intercept	−40.92	11.27	498	13.17	0.0007	0.57	
	Days	0.88	0.12	1949	51.57	<0.0001		0.62
	Ttot	−0.03	0.00	1238	32.76	<0.0001		0.62
	N10	0.22	0.05	647	17.11	0.0001		0.97
4	Intercept	−26.95	12.35	165	4.76	0.0339	0.61	
	Days	0.74	0.13	1127	32.48	<0.0001		0.49
	Ttot	−0.03	0.00	1084	31.23	<0.0001		0.59
	N10	0.18	0.05	377	10.85	0.0018		0.88
	Disred	9.25	3.96	189	5.44	0.0238		0.72
5	Intercept	−17.67	15.06	48	1.38	0.2467	0.62	
	Days	0.79	0.14	1151	33.28	<0.0001		0.44
	Ttot	−0.03	0.01	611	17.67	0.0001		0.21
	N10	0.26	0.09	270	7.80	0.0075		0.30
	N21	−0.12	0.12	40	1.15	0.2885		0.19
	Disred	9.40	3.96	195	5.63	0.0217		0.72

[a] The tolerance values of the colinearity analysis are given for the models with more than one parameter. The maximum value of 1 indicates no colinearity among parameters.

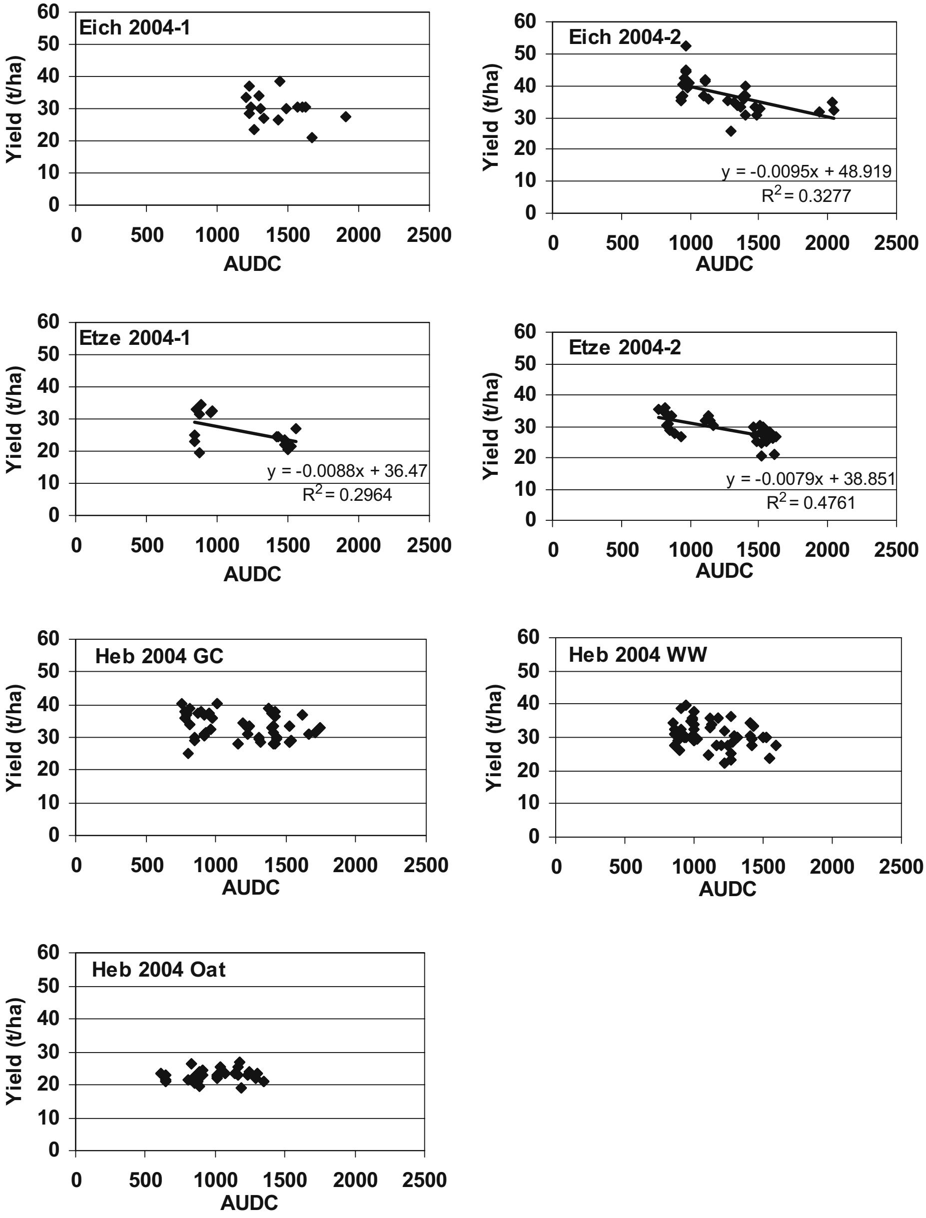

Figure 4 Effects of area under the disease progress curve (AUDC) on total tuber yield of cv. Nicola in three different sites with different pre-crops in 2004. The sites are listed in Table 1 where Eich1 has cabbage as pre-crop and Eich2 unharvested cabbage. Both Etze 1 and Etze 2 had winter wheat as pre-crop, but the experiment was conducted in two different fields.

parameter model the tolerance values for Ttot, N10 and N21 became unacceptably low (Table 2). The predicted yields based on the four-parameter model are plotted against the observed values in Fig. 3. From the figure it can be seen that the yields in 2002 were much lower than in 2003 and 2004. On the basis of the model prediction (Table 2), the predicted yields for Eich04 were between 36 and 57 t ha^{-1} (Fig. 3, circled data points), i.e., between 7 and 20 t higher than realised.

When the data from Eich04 were included, the stepwise inclusion of parameters into the model started with growth duration followed by the temperature sum and disease reduction. Only in the model with four or five parameters the N-values became relevant and overall their importance was much reduced.

In 2004, detailed disease assessments were available for 8 or 16 assessment sections per plot with and without copper treatment that were subsequently harvested separately. Thus, it was possible to assess yield loss relationships by site (Fig. 4). While in three cases, two in Etze and one in Eich between 29 and 47% of the variation in yield could be explained with AUDC, in the other four cases there was no correlation between disease and yield.

Discussion

From the experimental work it became clear that while the use of copper fungicides in most cases did slow down epidemics, the gains in growth duration were very low. Results on the yield benefits due to spraying were ambiguous. Only the inclusion of other environmental factors over time made it possible to interpret the data. Overall, yields of cv. Nicola could be predicted reasonably well when including information on growth duration and the temperature sum from planting until 60% disease severity was reached, soil mineral N contents at 10 days after emergence and disease reduction due to copper application. An exception was the site Eich04 where the N levels in the soil had been unusually high and for which the model was not adequate.

Yields in Eich04 were surprisingly low in comparison to the other sites with 29–40 t ha^{-1} despite the extremely high N-values (up to 280 kg ha^{-1} on June 3) and the long growth duration. However, relative to the other sites crop death was early. The crop had been planted on April 3 2004, 13 to 16 days earlier than in Heb04 or Etze04 (Table 1) and it also emerged earlier.

It is likely, that several factors interacted to limit the yields in Eich04. First, because of the high N-levels an unusually high leaf mass was built up early on. While this is decisive for the potential yield, likely tuber initiation was delayed as has been described above (Millard and MacKerron, 1986; Harris, 1992; Marschner, 1995; Vos, 1995). Late blight infections were stronger and epidemic progress faster in Eich04 than in the other sites in 2004 or in 2002 (60% severity reached within 7 to 13 days in Eich04, 9 to 19 days in Heb and Etze04, up to 35 days in Heb02, data not shown). This could in part have been due to the very dense crop growth which probably led to a more favourable microclimate for late blight development. Thus, it is likely that the crop died before the potential yield was reached. With N-levels rising well above 200 kg ha^{-1} in Eich04, it is likely, that the crop would have behaved like a conventional crop and it would have continued to increase its tuber mass until mid-August in the absence of late blight. Möller (2002) reported that depending on available N tubers stop growing between mid July (70–90 kg N-uptake), end July (110–140 kg N-uptake) and mid-August (140–180 kg N-uptake). The significant effect of AUDC on yield in Eich04 site 2 (Fig. 4) is in line with this prediction. At that site, copper had reduced AUDC by 32%. The lack of a significant effect of AUDC on yield in site 1 in Eich04 can be explained by the fact that disease pressure was overall higher there due to an early disease focus and copper being less effective (reduction of 21%).

The lack of significant correlations between AUDC and yield in Heb04 (Fig. 4), where N-levels were much lower than in Eich04 probably indicates that at the levels of N supplied tuber growth had already largely ceased by the time late blight became limiting and the measured yield differences are almost entirely due to differences in N. On June 3, 16 days after emergence, nutrient peaks of 70, 110 and 140 kg N ha^{-1} were measured after pre-crop oats, winter wheat and grass clover, respectively with levels dropping to about 20 kg ha^{-1} by July 15 after all pre-crops. This indicates that probably between 40 and 70 more kg N ha^{-1} were taken up by the crop after winter wheat and grass-clover providing for more than 10 t extra yield potential based on the results by Möller (2000) who reported that between 27 and 35 kg N uptake are needed per 10 t of yield. Total yields after pre-crop oats were between 22 and 23 t ha^{-1} while after winter wheat and grass-clover they reached 29–32 t ha^{-1} and 33–36 t ha^{-1}, in the absence and presence of copper, respectively, corresponding well with that prediction. Although leaf area was not measured in the field, there were clearly visible differences among the different pre-crops. For example, canopy closure was never reached after pre-crop oats but was achieved after winter wheat and grass-clover. Also, after oats the crop flowered almost 2 weeks earlier than after the other pre-crops.

While the N-levels in Etze04 were similar to those in Heb04 after winter wheat, in Etze disease did affect yields significantly. While N-levels were comparable (Table 1), the soils at Etze were considerably poorer in general quality than in Heb (52 versus 76 Soil Points, respectively on a scale with a maximum of 100, based on the official soil map data available to the farmers). This could have led to differences in N-uptake dynamics by the crop and to differences in tuber growth dynamics. If tuber formation was delayed in Etze in comparison to Heb then effects of disease should have been greater. Without exact measurements on crop N uptake and sequential yields, it will not be possible to determine the reasons for the different behaviour.

However, data on N-uptake by the crop are needed for a more exact prediction of yield potential and analysis of yield losses.

Because of the interactions with N-supply it is not surprising that the yield-loss relationships measured were either non-existing or weak (Fig. 4), which is in line with previous observations by Bouws-Beuermann (2005). The slopes of the significant regressions were very similar and the intercepts varied according to the N-supply of the sites. However, predicting yield potential from the regressions would be an over-interpretation. When analysing different varieties with this method, slopes varied indicating more or less severe effects of late blight on yield (Bouws-Beuermann, 2005). Interestingly, in this study, the slope was three times steeper in a more resistant (AUDC = 1050) but later bulking cultivar than in a susceptible (AUDC = 2500) early bulking cultivar indicating a strong cultivar interaction. Obviously, the effects of disease were stronger on the later bulking cultivar.

Currently, there are only a few means available to organic farmers to reduce late blight or yield losses in the absence of copper. The most efficient is the use of resistant varieties. Field hygiene, pre-sprouting and early planting reduce the risk of yield losses due to late blight. Depending on soil conditions (moisture and temperature) early planting may lead to increased problems with black scurf. Overall, only resistance and possibly hygiene can reduce disease progress or initial infection while pre-sprouting only is a measure to reduce yield losses through a partial escape because bulking of the potatoes starts earlier before onset of late blight epidemics (Karalus and Rauber, 1997). None of the alternative formulations based on products allowed in organic farming (plant extracts, microbial products, clay or other minerals etc.) and tested within the EU Blight MOP project has so far led to consistent reductions in disease severity (Stefan et al., 2003; Blight MOP annual report 2005, unpublished). However, several studies indicate that there is a tendency that effects are more likely to occur when disease pressure is moderate (Schliephake et al., 2001; Neuhoff et al., 2003). Thus, clearly, any cultural method that reduces disease pressure will improve the likelihood for an alternative spray to be of benefit.

One way to reduce disease pressure is by reducing the overall amount of susceptible host tissue, i.e., potato density, in an area. Increases in planting distance within the limits of practical relevance have failed to contribute to disease control. Alternatively, various diversification strategies can be used to reduce the density of susceptible plants. These strategies are based on different cropping patterns such as cultivar mixtures, alternating rows or strips of different cultivars and strip intercropping of potatoes with other non-host crops.

Cultivar mixtures had moderate effects reducing focal and general epidemics under low inoculum pressure (Garrett and Mundt, 2000; Finckh et al., 2003). Similarly, when planting different potato varieties in alternating rows, the best results were obtained for the slowest epidemics (Andrivon et al., 2003). When intercropping potatoes with other crops, the microclimatic conditions within the crop will be affected by the type of intercrop and the width of the potato beds, which may also affect late blight severity and its spread. Consistent disease reductions were obtained when potatoes were strip intercropped with grass-clover or, to a lesser degree with spring wheat especially when the strips were arranged perpendicular to the prevailing wind direction (Finckh et al., 2004). In this case, several mechanisms worked synergistically within the system. First, inoculum was carried out of narrow strips and lost from the potatoes to the non-hosts. Second, probably, the neighbour crop acted as a filter to incoming inoculum reducing disease spread from strip to strip. Depending on the neighbouring crop, the microclimate within the strips was altered resulting in changes in disease severity and in patterns of disease spread (Bouws-Beuermann, 2005).

One of the benefits a farmer has by not growing all his or her potatoes in one large field but rather in several separated fields is that usually initial disease is not uniformly distributed and the more the potato crop is subdivided the more disease spread between fields is reduced and single fields have an increased chance of escaping early infections. The chances of being infected by incoming inoculum or of harbouring an infected seed tuber are naturally reduced in small isolated fields in comparison to large fields.

Conclusions

In conclusion, several points emerge from the literature and the results. In organic farming, yields are foremost limited by nutrient availability in spring and early summer. This has been shown in several experiments at the University of Kassel (Bruns et al., 2003; Schulte-Geldermann et al., own unpublished data) and it was indirectly concluded from on-farm observations by Möller (2000). In general, late blight reductions through copper-based sprays are limited and increase with reduced disease pressure. Thus, copper fungicides will only lead to yield increases when early bulking highly nutrient efficient potato varieties are used in a cropping system that minimises disease pressure to start with and the soils in spring and early summer are provided with sufficient warmth and water to allow for timely mineralisation. To complete the forecasting tool optimising copper fungicide application in organic farming (Musa-Steenblock and Forrer, 2005) it will be necessary to add and evaluate data on crop nutrient status, developmental stage and soil fertility to determine if the application of copper will be beneficial in a given situation.

Our data help explain why yield loss relationships cannot be transferred from conventional systems to organic systems and also indicate that often the effects of late blight on yield in organic farming are overestimated.

Resistance clearly remains the most important strategy against late blight in organic potato production. However, maybe even more important than resistance is the early development and bulking behaviour and the ability of a cultivar to make use of organic nutrients efficiently. In the absence of efficient organic pesticides it is possible to reduce blight pressure to a certain extent by arranging the crop in small narrow fields perpendicular to the main wind direction neighboured either by non-hosts or completely resistant potatoes.

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