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Yield losses caused by late blight (*Phytophthora infestans* (Mont.) de Bary) in potato crops in Ireland

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Field experiments, using foliage blight susceptible cultivars, were conducted at Oak Park, Carlow from 1983 to 2007 to determine the loss in potato production caused by crop infection with *Phytophthora infestans*. In each of the 25 years an untreated control was compared with protectant and with systemic fungicide programmes to determine the effect of late blight on the defoliation percentage at the end of the season, the area under the disease progress curve, marketable tuber yield, total tuber yield and yield of blighted tubers. The earliest date of first recorded late blight was 22 June and the latest was 15 September, but in 15 of the 25 years, blight was first recorded between 17 July and 13 August. Disease reached epidemic proportions in all but 4 of the years. Yields varied considerably among years. The mean loss in total yield from not using a fungicide was 10.1 t/ha. Differences in yield were significant across the 25 seasons. No overall increase in aggressiveness of the pathogen could be detected over the 25-year period.

Keywords: late blight; losses; *Phytophthora infestans*; yield

Introduction

Late blight, caused by *Phytophthora infestans* (Mont.) de Bary, has been endemic in Ireland since 1845. Despite the long history of losses from potato late blight, little definitive information exists on the effect of the disease on the rate of defoliation or tuber production between years. Following disease outbreak, the rate of development of the epidemic is weather dependent and it has been suggested that in Ireland the disease reaches epidemic proportions in 7 out of 10 years (Cox and Large, 1960). These authors described an epidemic year

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as one where the level of defoliation or percentage of foliage blight in the unsprayed controls reached 75% or more before the end of the season. They also suggested that in the worst years, unsprayed crops would be totally defoliated by mid-August, with a loss of half the crop yield. Murphy and McKay (1933) carried out trials with the cultivar Up-to-Date over a 6-year period and concluded that the average benefit from three applications of burgundy mixture was a yield increase of 2.5 t/ha (24%). More recently, the annual loss from the disease has been estimated at 8% (Copeland, Dowley and Moore, 1993). There have been no recent reports on long term studies on the benefits of late blight control in potatoes. During the last 30 years we have seen the introduction of many new fungicides, the development of metalaxyl resistance in *P. infestans* (Dowley and O'Sullivan, 1981) and the discovery of the A_2 mating type of the pathogen in Ireland (O'Sullivan and Dowley, 1991). It has also been shown that in the same period, the previously existing population of *P. infestans* has been replaced by a new population (Tooley *et al*., 1993) and that the population has become more diverse (Griffin *et al*., 2002). Against this background of continuous change, we have examined the loss from late blight in the absence of fungicide treatment in Ireland from 1983 to 2007.

Materials and Methods

The foliage susceptible cultivars Kerr's Pink and Rooster were used in trials conducted at Oak Park Research Centre, Carlow from 1983 to 1995 and from 1996 to 2007, respectively. Both varieties are susceptible, having foliage blight resistance scores of 4 and 5, respectively, on a 1 to 9 scale (Dowley, Griffin and Hennessy, 2008). In each year the preceding crop was a cereal and the soils were free draining medium loams with low clay and organic matter contents. The pH varied from 6.4 to 6.8. The trial sites were ploughed to a depth of 25 cm during the winter and were tilled prior to planting. The compound fertiliser 10N:10P:20K was broadcast at the rate of 1.76 t/ha and the sites were then rotovated in preparation for planting. Certified seed (Elite, Class E) was planted into preformed drills using an automatic planter. The design for each trial was a randomised complete block with 3 treatments and 4 replications per treatment. The three treatments were an unsprayed control, a protectant fungicide programme and a systemic fungicide programme. Each replicate consisted of 6 drills, 8.2 m long. The drill width was 0.76 m and the distance between tuber centres was 0.33 m. The total replicate size was 37.5 m^2 from which a 25 m^2 plot was harvested across the centre 4 drills. An unplanted divider strip (3 m) was left between replicate treatments to facilitate mechanical harvesting. Weed control consisted of paraquat (600 g active ingredient (a.i.)/ha) and simazine (600 g a.i./ha) applied pre-emergence. In each of the years, foliage infection was by natural air-borne inoculum, no artificial inoculum was used.

Fungicide treatments

The protectant programme consisted of mancozeb (80% a.i.) at 2.25 kg/ha all season. The systemic programme consisted of three sprays of Ridomil MZ 72 (8% a.i. metalaxyl + 64% a.i. mancozeb) at 2.50 kg/ha followed by mancozeb (2.25 kg/ha) until the end of the season. The date of desiccation varied from the middle to the end of September. For the fungicide-treated plots, spraying commenced in mid-June when the plants were beginning to meet along the drill and continued at 10-day intervals throughout the season using a Hardi sprayer with flat spray nozzle number 370694/4110-20. The spray volume was equivalent to 250 l/ha and the spray pressure was 300 kPa. Machinery access was by means of rotovated spray paths to prevent crop damage.

Disease assessment

During each growing season, disease levels were assessed at weekly intervals up to desiccation using the British Mycological Society foliage blight assessment key (Cox and Large, 1960). These data were used to calculate the area under the disease progress curve (AUDPC) for each treatment in each year (Fry, 1978) and also, to allow comparisons among years, the relative area under the disease progress curve (RAUDPC) was calculated as described by Shtienberg *et al*. (1990). Disease outbreak was recorded as the date when the first blight lesions were observed in the centre 4 drills of each replicate. The crop was desiccated with diquat at the end of September and harvested in October/November using a two-row elevator digger. The produce was stored at a temperature of over 10 °C for at least 2 weeks to allow tuber blight to develop. The produce was then graded into the following sizes: <45 mm, 45 to 65 mm, 65 to 85 mm, >85 mm, blighted and other diseases. After grading the produce was weighed and the yield (t/ha) was calculated. Marketable yield is defined as the healthy yield between 45 and 85 mm in size.

Data analysis

The statistical analysis involved combining the information over years. As the effect of weather on cropping follows no general pattern from year to year, a mixed-model approach was used in which year was taken as a random effect. Blocks were also treated as a random effect nested within year. Interaction between year and treatment was also included as a random term. It was expected that there would be little difference between the cultivars Kerr's Pink and Rooster in their susceptibility to foliage blight but, in order to avoid making this assumption, the analysis was conducted as a hierarchical structure with cultivar as a factor and then years 1983 to 1995 nested within Kerr's Pink and years 1996 to 2007 nested within Rooster. Analysis of the combined years was conducted using Proc MIXED (SAS, 2004) for all responses except foliage blight. Proc GLIMMIX was used to fit a generalised linear model with random effects to the percentage data for foliar blight at the end of the season.

The complete set of yearly data was used in the analysis of total and marketable yield but the blighted yield was problematic because the large number of zero values prevented making the assumption of normal errors. The zero values were regarded as truncated data because some years could be viewed as having effectively a negative disease pressure (e.g. 1995). In order to simplify the approach for this minor component of the investigation, the analysis was carried out conditional on there being blighted yield in the control treatment. The analysis for blighted yield applies only to years with blighted yield in more than two of the control blocks.

For all trials conducted with the variety Rooster additional meteorological data were also available from the NegFry decision support system. The accumulated risk value (ARV) is the number of blight units recorded by the NegFry decision support system over the period 1 June to 30 September each year and is a measure of blight infection pressure (Hansen, Andersson and Hermansen, 1995). ARV were added as a covariate to the model for Rooster only and the full data set was also examined for trends over time.

Results

Disease was confirmed in 24 of the 25 years of the experiment, with no disease recorded in the very dry, warm year of 1995. Over these years, the date of the first record of late blight in the experimental area, varied between 22 June and 15 September. This date was dependent on the preceding weather conditions. For most years the disease was first recorded in the second half of July or the first half of August (Figure 1).

Level of foliage blight

The disease reached epidemic proportions in all but 4 of the 25 years (1984, 1992, 1995 and 1998). In all years (except 1995 when there was no disease), the application of a fungicide significantly reduced the percentage of foliage blight at the end of the season (Figure 2). The mean effects of the treatments are shown in Table 1. There was a highly significant difference between both Protectant and Systemic treatments and the Control ($P < 0.001$). There was also a significant difference between the means for the Protectant and the Systemic with the Systemic treatment having a significant advantage ($P = 0.012$), although not large in practical terms. Tests showed that no difference could be inferred between the cultivars with respect to the effects of the treatments.

The application of a fungicide significantly ($P < 0.001$) reduced the RAUDPC (Figure 3 and Table 2). The systemic programme had significantly lower RAUDPCs compared with the protectant programme ($P = 0.005$). There was no evidence for a significant difference between cultivars.

Marketable and total yield

Marketable yield varied considerably between years with the lowest marketable yield (8.57 t/ha) obtained for the untreated control in 1985 which was the most severe blight year with an RAUDPC value (log scale) of 0.752 for the untreated control. The highest marketable yield (71.2 t/ha) was obtained for the systemic programme in 1989 which coincided with one of the lowest RAUDPC values. Overall, there was a significant negative correlation between marketable yield and RAUDPC. In all 24 years where late blight was present, the use of a fungicide resulted in higher

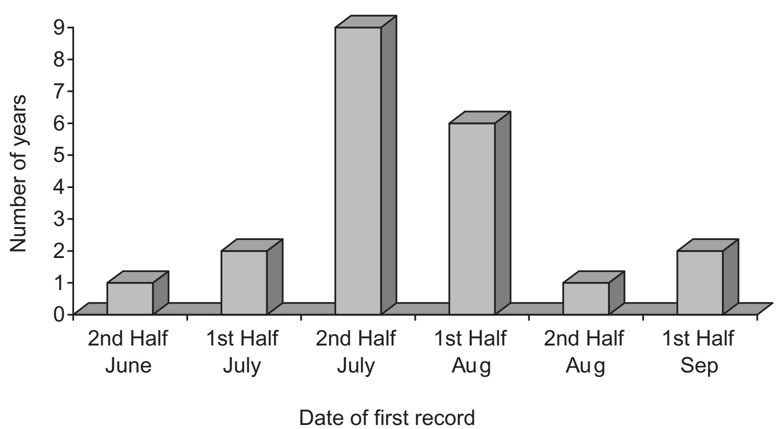

Figure 1. The frequency of the date of the first record of late blight over a 25-year period (1983 to 2007).

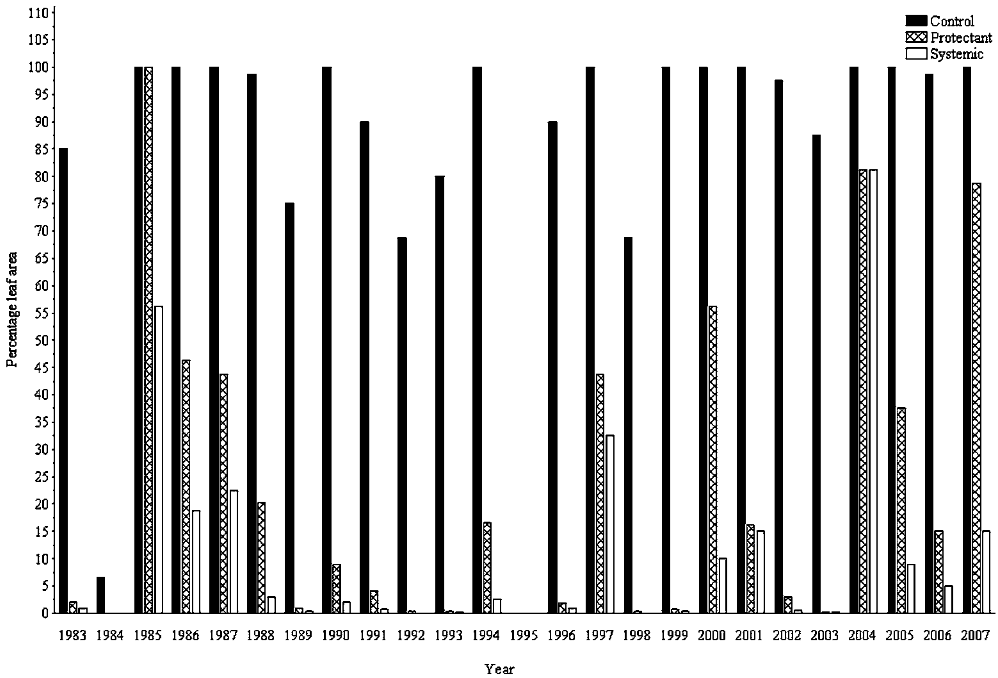

Figure 2. Annual means for the level of foliage blight at the end of the season for fungicide treatments (protectant and systemic programmes) and untreated control.

Table 1. Mean effect of fungicide treatment on foliage blight percentage at the end of the season over the years 1983 to 2007

Treatment	Foliage blight (%)	s.e.
Untreated	93.3	3.41
Protectant	14.7	6.19
Systemic	4.9	2.64

marketable yield (Table 3 and Figure 4). The mean increase in marketable yield following the use of a fungicide over the 25 years was 10.1 t/ha ($P < 0.001$). In general the systemic programmes tended to have higher marketable yields than the protectant programmes, but the effect was not significant overall ($P = 0.69$). There was no significant difference between the cultivars.

Total yield also varied considerably over the period of the experiment with the lowest total yield (8.9 t/ha) recorded for the untreated control in 1985. The highest total yield (75.9 t/ha) was obtained for the systemic programme in 1989 (Figure 5). In all 24 years where late blight was present, the use of a fungicide resulted in higher total yields (Table 3). The mean increase in total yield following the use of a fungicide over the 25 years was 10.1 t/ha ($P < 0.001$). In general the systemic programmes resulted in higher total yield than the protectant programmes but this effect was not significant. There was no significant difference between cultivars.

Tuber blight

Yields of blighted tubers after storage and grading are given in Figure 6. Being

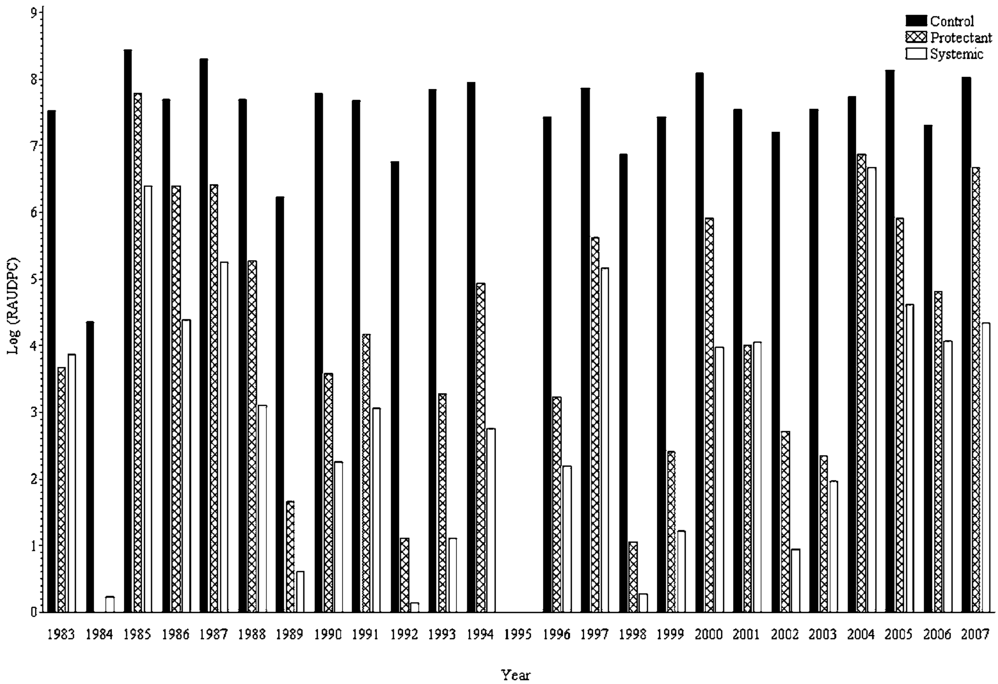

Figure 3. Annual means for the relative area under the disease progress curve (RAUDPC) for fungicide treatments (protectant and systemic programmes) and untreated control.

Table 2. Mean effect of fungicide treatment on the relative area under the disease progress curve (RAUDPC) over the years 1983 to 2007

Treatment	RAUDPC	RAUDPC (log scale)
Control	0.298	5.65 ± 0.314[1]
Protectant	0.0142	2.67 ± 0.314
Systemic	0.00535	1.8 ± 0.314

[1] s.e.

Table 3. Mean effect of fungicide treatment on marketable yield and total yield over the years 1983 to 2007

Treatment	Marketable yield (t/ha)	Total yield (t/ha)
Control	33.0	39.1
Protectant	42.6	48.7
Systemic	43.6	49.7
s.e.	2.53	2.56

weather dependent, the level of tuber blight varied considerably over the years. No tuber blight was recorded in 1985, 1995, 2003 or 2004. In the remaining 19 years where tuber blight was confirmed, the results were variable. In 8 of the years, tuber blight infection was higher following the fungicide treatments than in the untreated control but the difference was never significant. In 11 of the years, the untreated control had the highest level of tuber blight. Results for the analysis conditional on the presence of blighted yield in the controls are given in Table 4. Both the protectant and the systemic treatments were significantly better overall than the control ($P = 0.044$ and $P = 0.001$, respectively). The systemic programme tended to have a lower level of tuber blight than the protectant programme, but this difference was not significant. The difference between the protectant and control was

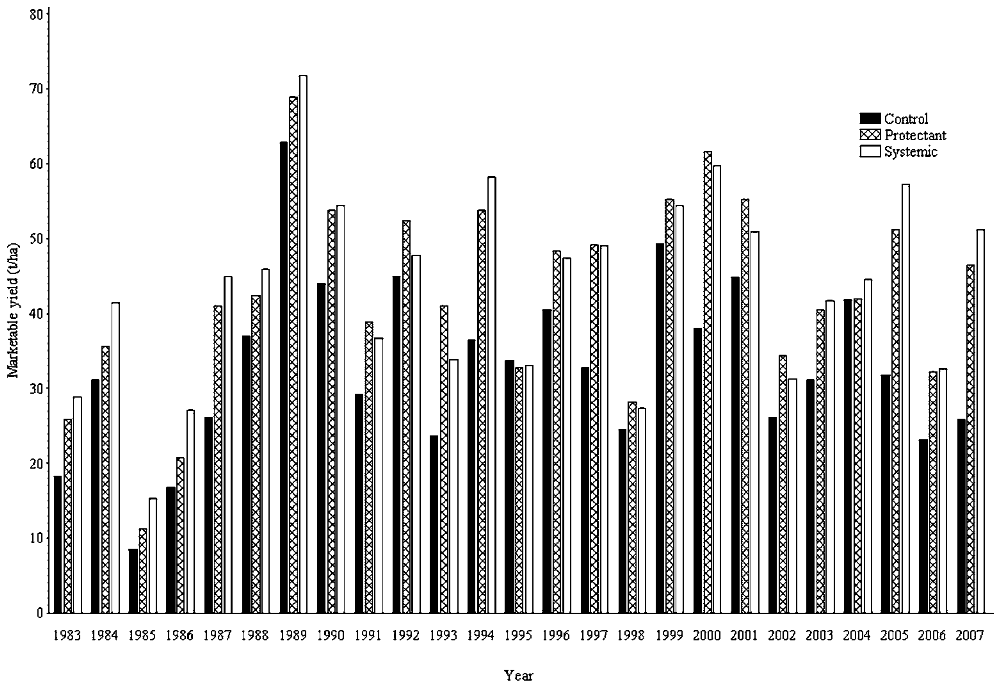

Figure 4. Annual means for yield of marketable tubers for fungicide treatments (protectant and systemic programmes) and untreated control.

not significant if the early years of high blighted yield were excluded from the analysis. There was no significant difference between cultivars.

Trends over time were examined using the full data set and for the two cultivars separately. No statistically significant relationship was found between RAUDPC and time. No significant relationship was found between RAUDPC and weather information as summarised by ARV.

Discussion

Despite the general belief among potato producers in Ireland that the date of disease outbreak is occurring earlier each year, the current results confirm that the date of disease outbreak in the Carlow area is no earlier than it was in the third quarter of the last century (Frost, 1974). This shows that, at least for the Carlow area, there has been no major change in the date of disease outbreak over time.

The relative area under the disease progress curve is a measure of disease development over the whole course of the epidemic. Both the level of defoliation at the end of the season and the RAUDPC values indicated large variation in disease severity between years which could be related to the date of disease outbreak and the subsequent weather conditions (Figures 2 and 3). It has been confirmed that certain strains of *P. infestans* from Northern Ireland are more aggressive towards the foliage than other strains (Carlisle *et al*., 2002). If these aggressive isolates became predominant in the population, it would be expected that the disease would progress more rapidly through the crop over time. However, the

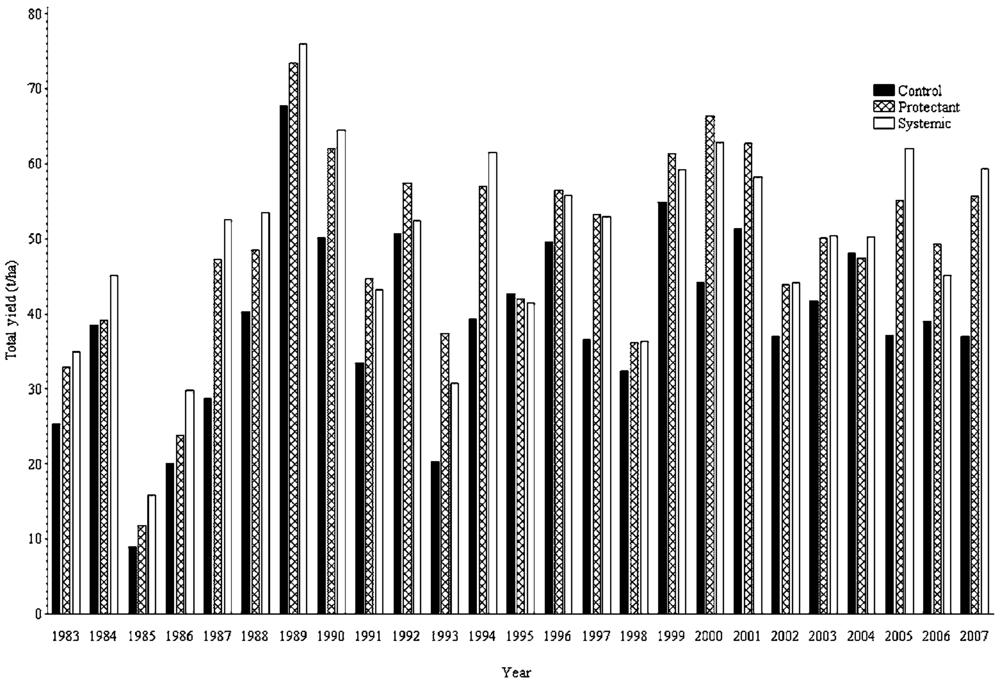

Figure 5. Annual means for total yield of tubers for fungicide treatments (protectant and systemic programmes) and untreated control.

current results indicate that there has been no discernible change in disease severity over the years other than that which could be accounted for by differences in weather patterns. In all years when blight was present, fungicide application significantly reduced disease incidence irrespective of the method of measurement used. Even greater reduction in losses could be expected if the spray interval was reduced from 10 days to 7 days as became the accepted practice towards the end of the experimental period. In general, the systemic programme resulted in lower disease levels than the protectant programme but a separate analysis by year showed that this difference was only significant in a minority of years. This is in general agreement with the results of earlier experiments (Dowley, 1994).

Losses from late blight can be quantified by examining the differences in yield between fungicide treated and untreated plots. Over the 25 years of the study there was an average increase of 10.1 t/ha in both marketable and total yield from the use of a fungicide programme. The years where differences were small were those when disease pressure, as measured by the RAUDPC, was low. Since the early work on the benefit of fungicide use (Murphy and McKay, 1933), the marketable yield has increased by over 30 t/ha, better fungicides are available and are applied more frequently, fertilizer applications have increased and crop agronomy together with the genetic potential of varieties have improved. This leads to better leaf canopy and a longer growing season which should make the micro-climate more favourable

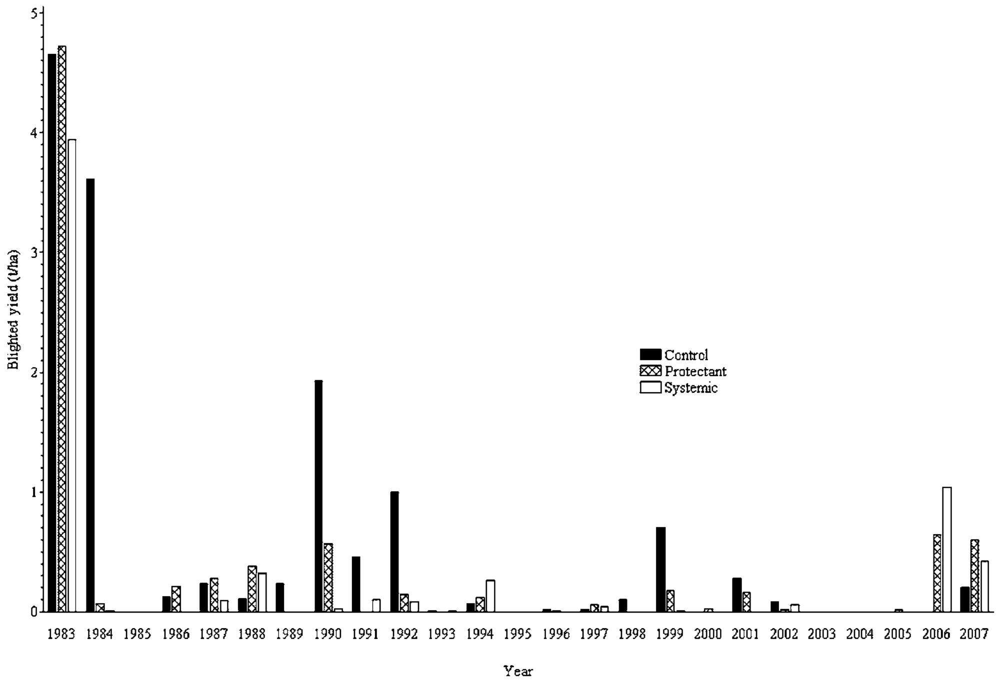

Figure 6. Annual means for yield of blighted tubers for fungicide treatments (protectant and systemic programmes) and untreated control.

Table 4. Treatment means for the effect of fungicide treatment on the yield of blighted tubers on both the original and a log scale[1]

Treatment	Blighted yield (t/ha)	Blighted yield on log scale
Control	0.46	–0.63 ± 0.316
Protectant	0.20	–1.24 ± 0.316
Systemic	0.12	–1.58 ± 0.316

[1] Over the period 1983 to 2007 but excluding years (1985, 1995, 2003, 2004) when no tuber blight was detected.

for disease development with resultant greater losses. When these factors are taken into account the increase in yield from fungicide application of 24% reported by Murphy and McKay (1933) is similar to the current 25 year average increase of 26% in total yield.

Differences in the level of tuber blight over the years were large. This could be attributed to differences in date of disease outbreak, variation in foliage blight level throughout the seasons and variation in rainfall and soil moisture content following tuberisation. Despite the lack of significance in many of the years, the levels of tuber blight in the untreated control were so high that difficulties would be encountered during storage, grading and marketing of the produce.

The effect of late blight recorded here was a loss of 23% in marketable yield. When the figure of 8% loss from blight infection in sprayed crops, estimated by Copeland *et al.* (1993), is taken into account then the potential average annual loss in marketable yield from not applying a fungicide would be about 31%.

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