Effects of windrowing, irrigation and defoliation of potatoes on silver scurf (*Helminthosporium solani*) disease

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SUMMARY

Field experiments with the potato variety Désirée at Cambridge, UK, in 1988–90 examined the effects of windrowing on the development of blemishing diseases during storage on tubers from crops grown with differing irrigation regimes and dates of defoliation and harvest. Irrigation reduced levels of silver scurf (*Helminthosporium solani*) at harvest in all three years and increased black dot (*Colletotrichum coccodes*) in one year. Early crop defoliation slightly increased silver scurf at harvest in one year only. Silver scurf developed less during storage at 3 °C than at 7 °C and disease levels on tubers after storage were related to levels present at harvest. The effects of leaving tubers for up to 6 h in a windrow at harvest on silver scurf after storage were small and inconsistent between years despite similar drying conditions. The results suggest that windrowing may be of little practical use in controlling silver scurf during storage.

INTRODUCTION

The economic importance of blemishing diseases of potato has increased considerably as unblemished tubers command an increasing premium. Silver scurf is a particular problem as this disease can increase considerably during storage. Irrigation has been found to reduce silver scurf on tubers at harvest (Adams *et al.* 1987; Hide 1987) although effects after storage are unclear. Black dot is, however, increased by irrigation (Adams *et al.* 1987; Read & Hide 1988). As with many other diseases, both silver scurf and black dot increase when harvesting is delayed but early harvesting can result in damage to unset potato skins. Defoliation prior to harvest is widely practised (Potato Marketing Board 1979) and may improve skin set as well as facilitating harvesting. Wilcockson *et al.* (1985) found that delay in harvest date after defoliation increased silver scurf after storage and their data show an apparent decrease in silver scurf with defoliated crops compared with control crops harvested without prior defoliation.

Two-stage harvesting, where two or more rows are dug and left in a windrow before being loaded, is widely practised in the USA mainly to allow increased work rates, but windrowing also allows tubers to dry. Dry-curing potatoes at a humidity of 80% or less before storage instead of the usual 95% has sometimes been found to reduce levels of blemishing diseases (Potato Marketing Board 1987; Hide & Boorer 1991) and similar effects might be expected from the rapid drying of tubers in a windrow at harvest.

These experiments examined the effects of windrowing and different irrigation regimes on blemishing diseases to determine the possible benefits of windrowing in practice. Defoliation of crops prior to harvest was compared with defoliation at harvest to establish effects on skin set, disease and weight loss during storage.

MATERIALS AND METHODS

Experiments were carried out in the field at Cambridge University Farm in 1988–90 with the potato variety Désirée. Scottish seed graded 25–35 mm was used. The experimental area was planted on the dates given in Table 1 with a tractor-drawn 'cup-planter' in rows 71 cm apart at a spacing of 25 cm along the row. Application of fertilizer was done by machine before planting at the following rates (kg/ha): 136 N, 60 P, 170 K and 36 Mg in 1988 and 1990 and 126 N, 55 P, 158 K and 34 Mg in 1989. The herbicide Opogard (terbutryn and terbuthylazine) was applied before emergence.

Plots were marked out after planting and the treatments indicated in Table 1 were imposed as appropriate. In all years, there were four completely replicated blocks and irrigation and harvest date

Table 1. *Details of the field experiments investigating silver scurf infection on potatoes at Cambridge, UK*

Year	Irrigation treatment	Defoliation (weeks before harvest)	Windrowing (h)	Planting date	Harvest date(s)
1988	Throughout or none after 4 Aug	0 or 2	0, 2, 4 or 6	26 Apr	24 Aug or 28 Sep
1989	Throughout or none after 24 Jul	0 or 2	0, 2, 4 or 6	10 May	12 Sep or 10 Oct
1990	Throughout or none; Wet or dry at harvest	0, 2, 4 or 6	0 or 6	23 Mar	11 Sep

Table 2. *Details of rainfall and irrigation (mm) for the field experiments on potatoes at Cambridge, UK*

	1988			1989			1990		
		Irrigation			Irrigation			Irrigation	
	Rain	All plots	Treatments only	Rain	All plots	Treatments only	Rain	All plots	Treatments only
May	41	0	0	7	0	0	8	0	20
Jun	39	15	0	41	30	0	26	0	12
Jul	99	0	0	39	20	25	26	0	90
Aug	44	0	40	27	7	95	23	0	25
Sep	45	0	35	13	0	50	41	0	30*

* Applied prior to harvest as additional treatment.

combinations formed main plots. In 1988 and 1989 windrowing and defoliation subplots were randomized within main plots but in 1990 windrowing treatments comprised sub-subplots randomized within defoliation treatments. Subplots comprised three (1989 and 1990) or four rows (1988) with only the guarded centre row(s) harvested. At least one additional guard row separated irrigation treatments. The harvest area of each subplot was 4·27, 3·20 and 5·69 m² in 1988, 1989 and 1990 respectively.

Irrigation was applied by overhead sprinkler to main plots as indicated in Table 2. In 1990, a wet harvest treatment was imposed by application of 30 mm of irrigation *c.* 60 h before harvest. Fully irrigated treatments were free from water stress throughout growth whereas the dry treatments had insufficient water in all years. Water stress was slight in August and September 1988, greater in 1989 and severe throughout growth in 1990 due to differences in rainfall between years and the early application of treatments in 1990 (Table 2).

Defoliation was done with a mechanical, tractor-powered cutter. Plots were harvested with a single-row elevator-digger after discard plants at the ends of the plots had been dug with a hand fork. Tubers were either placed immediately into paper potato sacks or left on the soil surface to windrow according to treatments. In all years, conditions during windrowing caused rapid drying of tubers with relative humidity in the range 40–60%.

Tubers were graded over a 40 mm riddle and a sample of at least 25 tubers > 40 mm was put into net bags and entered storage at 7 °C and 95% relative humidity *c.* 1 week after harvest. Sprout growth was controlled by application of Chlorpropham (CIPC) sprout inhibitor as required. In 1988, a duplicate sample was placed in a commercial store where temperatures were reduced during September and October to a holding temperature of 3 °C thereafter. Tubers were stored until mid-May the following year so that the storage period ranged from 30 to 38 weeks depending on harvest date.

Assessment of disease levels was made by inspection of 50 seed tubers at planting and *c.* 25 ware tubers per subplot at harvest and after storage (only 2 tubers per plot at harvest in 1988). Tubers for assessment were washed and the percentage of surface covered by silver scurf and black dot recorded. For seed tubers, five plugs were cut from the surface of each tuber at random and incubated for 10 days at 20 °C before microscopic examination. The seed in 1988–90 had 10·3, 10·6 and 10·2% surface area infected with silver scurf and sporulation of *Helminthosporium* was noted on 61, 72 and 27% of plugs respectively. Levels of

Table 3. *The effects of irrigation (dry or fully irrigated), defoliation treatments (D1, defoliated at harvest; D2, D3 and D4, defoliated 2, 4 & 6 weeks before harvest) and harvest date (H1, early harvest; H2, late harvest) on total tuber yields (t/ha fresh weight) in Désirée at Cambridge, UK*

	Dry				Fully irrigated				S.E.*	
Year	H1D2	H1D1	H2D2	H2D1	H1D2	H1D1	H2D2	H2D1	(*a*)	(*b*)
1988	35·4	41·7	59·4	62·7	37·3	44·1	62·3	66·2	1·22	1·50
1989	33·4	36·7	41·2	42·1	50·4	59·2	62·3	64·3	1·29	1·80
	D4	D3	D2	D1	D4	D3	D2	D1	—	—
1990	25·4	26·8	27·9	27·0	46·8	44·8	49·6	50·1	1·10	1·24

* S.E. (*a*) for comparing different levels of defoliation at the same level of irrigation and harvest date; (*b*) for comparing different levels of irrigation and harvest date at the same or different levels of defoliation.
D.F. error: mainplots, 9; subplots, 87 (1988 and 1989) or 36 (1990).

Table 4. *The effects of irrigation (dry or fully irrigated), defoliation treatments (D1, defoliated at harvest; D2 defoliated 2 weeks before harvest) and harvest date (H1, early harvest; H2, late harvest) on skinning of tubers (% tuber surface) in Désirée in 1988 and 1989* at Cambridge, UK*

	Dry				Fully irrigated				S.E.†	
Year	H1D2	H1D1	H2D2	H2D1	H1D2	H1D1	H2D2	H2D1	(*a*)	(*b*)
1988	9·8	30·3	5·5	3·7	12·7	30·9	6·8	10·9	2·01	1·90
1989	2·9	8·1	1·1	1·4	4·2	12·2	1·7	1·8	0·30	0·46

* No significant skinning for any treatment in 1990.
† S.E. (*a*) for comparing different levels of defoliation at the same level of irrigation and harvest date; (*b*) for comparing different levels of irrigation and harvest date at the same or different levels of defoliation.
D.F. error: mainplots, 9; subplots, 87.

disease on ware tubers were compared by calculation of the mean surface area infected and by a disease code whereby scores of 0, 1, 2 or 3 were given to tubers with 0, 0–5, 5–25 and > 25% surface cover respectively. Analysis of disease levels using codes and mean percentage surface cover gave similar results and the simpler measure of percentage surface cover was therefore presented. At harvest, the percentage of skin surface removed by grading and washing was also recorded. In 1988, the thickness of the tuber periderm at harvest was measured on two plugs of tuber tissue per plot. Plugs of tissue were excised using a borer, fixed in formyl acetic acid, embedded in paraffin wax and sectioned for microscopic examination.

RESULTS

The dates of 50% plant emergence in 1988–90 were 28 May, 5 June and 5 May respectively. In 1988, near complete foliar ground cover was maintained from early July until final harvest in September for both irrigation regimes whereas, in 1989, fully irrigated plots had full ground cover at the early harvest and *c.* 50% cover by the late harvest compared to *c.* 50% cover at the early harvest and almost complete senescence at the late harvest in the dry plots. In 1990, only irrigated plots achieved full ground cover and by the first defoliation date (30 July; 6 weeks before harvest) ground cover was declining rapidly so that, by harvest, no leaf cover remained even with irrigation.

In all years, total tuber yield was decreased in the unirrigated plots particularly in the dry seasons of 1989 and 1990 ($P < 0.01$; Table 3). Yield was higher with delay in defoliation and harvest ($P < 0.01$; Table 3). Skinning decreased with delay in harvest in 1988 and 1989 (Table 4) but in 1990 there was negligible skinning for any treatment at harvest. Early defoliation resulted in substantially less skinning from early harvests in 1988 and 1989 but at the later harvests there was negligible effect of time of defoliation. Periderm thickness of tubers at harvest in 1988 was greater with early defoliation (154 ± 2·6 μm) than with defoliation at harvest (145 μm) but was not affected by harvest date or irrigation.

The level of silver scurf infection at harvest was reduced by irrigation in all years (Table 5). Silver

Table 5. *The effect of irrigation (dry or fully irrigated) on silver scurf infection at harvest (% tuber surface) in Désirée at Cambridge, UK*

Year	Dry	Fully irrigated	S.E. (9 D.F.)
1988*	2·0	0·7	0·23
1989	3·3	0·9	0·28
1990	13·6	8·7	0·74

* Late harvest only (none detected at early harvest).

Table 6. *The effect of irrigation (dry or fully irrigated) on black dot infection (% tuber surface) in Désirée in 1990**

	Dry	Fully irrigated	S.E. (9 D.F.)
At harvest	0·8	7·9	0·57
After storage	0·9	8·5	0·27

* Negligible levels of black dot in 1988 and 1989.

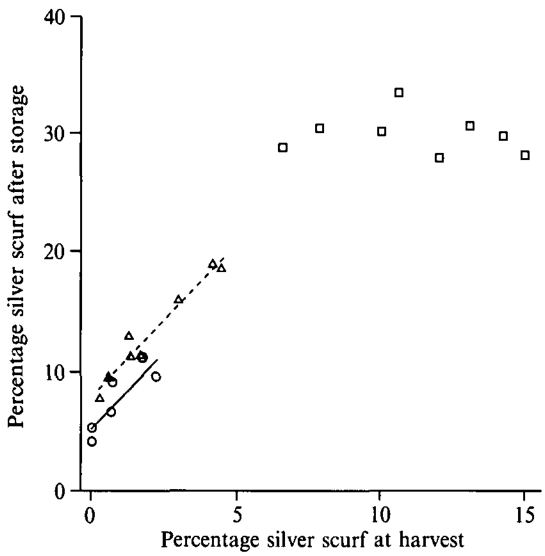

Fig. 1. The relationship between silver scurf infection (% surface area of tuber affected) at harvest and after storage at 7 °C for 30–38 weeks. 1988/89, ○ and solid line ($y = 5·21 + 2·60x$); 1989/90, △ and broken line ($y = 7·92 + 2·60x$); 1990/91, □. (Percentage variance accounted for by regression (1988/89 and 1989/90 combined) = 94·2 %.)

scurf at harvest was slightly greater after defoliation 2 weeks before harvest (2·3 ± 0·17 % surface affected) than when defoliated at harvest (1·8 %) in 1989 but

Table 7. *The effect of irrigation (dry or fully irrigated) on silver scurf infection after storage (% tuber surface) in Désirée*

Year	Dry	Fully irrigated	S.E. (9 D.F.)
1988(1)	4·2	2·5	0·35
1988(2)	7·6	6·3	0·45
1989(2)	16·2	10·4	1·38
1990(2)	28·9	30·5	0·90

(1) Stored at 3 °C; (2) stored at 7 °C.

Table 8. *The effect of date of harvest on silver scurf infection after storage (% tuber surface) in Désirée*

Year	Early harvest	Late harvest	S.E. (9 D.F.)
1988(1)	2·1	4·6	0·35
1988(2)	4·7	9·1	0·45
1989(2)	11·2	15·4	1·38

(1) Stored at 3 °C; (2) stored at 7 °C.

there was no significant difference in other years. Silver scurf at harvest was lower at the early dates of harvest in 1988 and 1989 (1988 nil; 1989 1·4 ± 0·28 %) than the later harvest (1988 1·3 %; 1989 2·8 %).

Levels of black dot at harvest were negligible in 1988 and 1989 but in 1990 black dot was increased by irrigation (Table 6). Black dot after storage was negligible in 1988/89 and 1989/90 and increased only slightly during storage in 1990/91 with differences between irrigation treatments maintained (Table 6).

Silver scurf increased during storage and the levels of silver scurf after storage at 7 °C until May could be linearly related to levels at harvest for 1988/89 and 1989/90 (Fig. 1). The combined data for 1988/89 and 1989/90 were better represented by two parallel lines than a single relationship or lines of different slopes. The data from 1990/91 alone showed no relationship between levels at harvest and after storage, although the higher levels at harvest in 1990 compared with 1988 and 1989 resulted in higher levels after storage (Fig. 1). The increase in silver scurf in 1988/89 was lower at 3 °C than at 7 °C but differences between treatments were consistent between stores. Differences in silver scurf between irrigation treatments were maintained after storage in 1988/89 and 1989/90 but not in 1990/91 (Table 7). Irrigation just prior to harvest in 1990 to give wet harvesting conditions had no effect on silver scurf or other diseases after storage. Early defoliation increased silver scurf after storage at both harvests in 1988 by *c.* 1 % of tuber

Table 9. *The effect of windrowing on silver scurf infection after storage (% tuber surface) in Désirée (mean of irrigation and defoliation treatments)*

Time in windrow (h)... Year	Early harvest 0	2	4	6	Late harvest 0	2	4	6	S.E.* (*a*)	(*b*)
1988[1]	2·3	2·0	2·5	1·8	3·0	4·8	5·3	5·2	0·43	0·51
1988[2]	5·0	4·6	4·6	4·7	8·1	9·4	8·4	10·6	0·73	0·78
1989[2]	13·6	11·3	9·9	9·7	17·9	15·8	14·5	13·6	1·52	1·90
1990[2]	30·5	—	—	29·0	—	—	—	—	0·77	—

[1] Stored at 3 °C; [2] stored at 7 °C.
* S.E. (*a*) for comparing different levels of windrowing at the same harvest date; (*b*) for comparing different harvest dates at the same or different levels of windrowing.
D.F. error: mainplots, 9; subplots, 87 (1988 and 1989) or 51 (1990).

Table 10. *The effect of irrigation (dry or fully irrigated), defoliation treatment (D1, defoliated at harvest; D2, D3 and D4, defoliated 2, 4 or 6 weeks before harvest) and harvest date (H1, early harvest; H2, late harvest) on weight loss (% of fresh weight) during storage in Désirée*

Year	Dry H1D2	H1D1	H2D2	H2D1	Fully irrigated H1D2	H1D1	H2D2	H2D1	S.E.* (*a*)	(*b*)
1988[1]	8·6	7·2	6·6	8·2	10·0	8·8	8·7	9·2	0·60	0·67
1988[2]	14·1	13·7	11·2	12·3	17·5	15·1	16·0	16·5	0·67	0·98
1989[2]	5·8	5·6	5·1	5·0	6·6	8·9	6·4	7·2	0·24	0·29
	D4	D3	D2	D1	D4	D3	D2	D1	—	—
1990[2]	6·1	5·9	6·2	5·9	7·2	6·1	6·3	6·1	0·23	0·25

[1] Stored at 3 °C; [2] stored at 7 °C.
* S.E. (*a*) for comparing different levels of defoliation at the same level of irrigation and harvest date; (*b*) for comparing different levels of irrigation and harvest date at the same or different levels of defoliation.
D.F. error: mainplots, 9; subplots, 87 (1988 and 1989) or 36 (1990).

surface area but defoliation had no effect in 1989 or 1990. Silver scurf after storage was lower from the early harvest date in 1988 and 1989 than from the later harvest (Table 8).

Windrowing had no effect on silver scurf at the early harvest in 1988 but, at the later harvest, silver scurf was lower without windrowing than from any of the windrowing treatments (Table 9). In 1989, silver scurf decreased with increasing duration of windrowing at both harvests with *c.* 4% reduction in silver scurf cover from 6 h windrowing compared with direct harvesting (Table 9). There was no effect of windrowing in 1990.

Weight loss was higher in 1988 at 7 °C than at 3 °C but treatment differences were similar in both stores. Weight loss was increased by irrigation in 1988 and 1989 but not in 1990 (Table 10). Early defoliation increased weight loss at the early but not the late harvest in 1988 (Table 10). The increased weight loss following early defoliation occurred despite an increase in periderm thickness and decreased susceptibility to skinning. The initial weight loss in 1988 (up to 7 December) was not affected by defoliation (and periderm thickness) but greater weight loss by the end of storage following early defoliation was associated with the higher levels of silver scurf which developed during storage. In 1989, early defoliation decreased weight loss in irrigated plots but not in dry plots (Table 10) and was associated with increased resistance to skinning but no difference in silver scurf. There was an increase in weight loss of *c.* 1% from defoliation 6 weeks before harvest in fully irrigated plots in 1990 compared with later defoliation (Table 10). In 1989, windrowing reduced weight loss by up to 1·8% for the late harvest but by < 1% for the early harvest (Table 11) but there was no significant effect of windrowing on weight loss in 1988 or 1990. High weight loss in 1988/89 compared with 1989/90 and 1990/91 was associated with rotting of *c.* 1% of tubers in both the 3 °C and 7 °C stores.

Table 11. *The effect of windrowing on weight loss (% of fresh weight) during storage in Désirée*

Time in windrow (h)... Year	Early harvest 0	2	4	6	Late harvest 0	2	4	6	S.E.* (a)	(b)
1988(1)	9·8	10·0	7·0	7·8	8·4	7·9	8·2	8·1	0·60	0·64
1988(2)	14·9	17·2	14·5	13·8	15·2	15·6	14·2	13·8	0·67	0·84
1989(2)	7·0	6·8	6·9	6·0	7·0	6·1	5·2	5·5	0·24	0·27
1990(2)	6·7	—	—	5·8	—	—	—	—	0·32	—

(1) Stored at 3 °C; (2) stored at 7 °C.
* S.E. (*a*) for comparing different levels of windrowing at the same harvest date; (*b*) for comparing different harvest dates at the same or different levels of windrowing.
D.F. error: mainplots, 9; subplots, 87 (1988 and 1989) or 51 (1990).

DISCUSSION

Results from these experiments confirm the findings of other authors (Adams *et al.* 1987; Read & Hide 1988) that irrigation decreases levels of silver scurf at harvest but can increase black dot (one year in three). After-storage assessment showed that effects of irrigation were maintained during storage except when levels at harvest were high in 1990. Irrigation may reduce silver scurf infection by washing conidia of *Helminthosporium solani* produced on the surface of the seed tuber below the soil surrounding the progeny tubers, thus reducing the incidence of silver scurf on the progeny at harvest and the development of silver scurf during storage. Irrigation might also reduce silver scurf at harvest by delaying the senescence of the crop if development of silver scurf occurs more rapidly at senescence. Early defoliation in 1988 resulted in only a small increase in silver scurf at harvest and after storage but there was no effect in the other two years. Development of silver scurf may, therefore, be encouraged by artificially hastening senescence although the effects appear to be small.

Windrowing resulted in small and inconsistent effects on silver scurf in different years although in all years conditions during windrowing allowed the rapid drying of tubers. The increase in silver scurf from windrowing in 1988 may have resulted from increased soil contact. The reduction in 1989 was greater with increase in duration of windrowing up to 6 h, which suggests that longer exposure of tubers resulted in progressively greater killing of infections. Low levels of silver scurf at harvest in 1988 may have precluded killing of infections by windrowing to control silver scurf but in 1990, where infection at harvest was high, effects might have been expected and were not found. The unpublished data of E. J. Allen and of J. M. Colenso from eight experiments at Cambridge University Farm in 1985–88 with the varieties Record and Pentland Dell showed a small reduction in silver scurf after storage with windrowing in only one experiment (Record in 1987) and an increase in one experiment (Record in 1985). It appears that whilst small benefits in control of silver scurf might be achieved in some years, effects are unlikely to be large because the period of drying is relatively short, latent infections may be unaffected by drying and increased exposure to soil containing conidia in the windrow may result in new infections. Even with the longer periods of drying (2 weeks) used for dry curing, significant control of silver scurf is not always found (Potato Marketing Board 1988, 1991; Hide & Boorer 1991) and storing without prior curing can be as effective as dry curing (Potato Marketing Board 1990) for silver scurf may be increased by normal curing at high temperature and humidity rather than killed by dry conditions.

Although seed had similar areas of silver scurf infections in all years, levels on progeny tubers differed between years even for well-irrigated treatments. In 1990, levels of silver scurf after harvest in mid-September were higher than from comparable harvest dates in 1988 and 1989, but the crop emerged on 5 May (nearly 1 month earlier than in 1988) so that the time from tuber initiation to harvest was longer, allowing greater infection by silver scurf. The interval from tuber initiation to harvest appears to be a major factor in determining levels of silver scurf and further work to investigate the transmission of silver scurf from seed to progeny tubers is being undertaken. Reducing the transfer of disease from seed to progeny and the use of irrigation and early harvesting combined with storage at low temperatures can ensure low levels of silver scurf infection after storage.

Differences in weight loss between irrigation and defoliation treatments were related to differences in skinning at harvest so that greater skinning from irrigated plots and late defoliation treatments, particulary at early harvests, increased weight loss significantly. The high weight loss in 1988/89 compared to that in 1989/90 and 1990/91 was partly due to poor skin set. Reduction in weight loss from late defoliation at early harvest in 1988 and windrowing in 1989 were related to the reduction in silver scurf indicating that even small differences in silver scurf may result in significant effects on weight loss. Nevertheless the relatively small and inconsistent effects of windrowing appear not to merit the use of this technique for the control of silver scurf alone, although it may be justified by other considerations such as increased work rates.

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