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Effects of seed size, planting density and planting pattern on the severity of silver scurf (*Helminthosporium solani*) and black scurf (*Rhizoctonia solani*) diseases of potatoes

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Summary

The effects of different seed sizes, planting densities and planting patterns on the transmission of silver scurf (*Helminthosporium solani*) and black scurf (*Rhizoctonia solani*) diseases of potatoes were examined in five field experiments with cv. Estima in 1991–93.

In all experiments, silver scurf was more severe with increase in seed size and planting density. At high planting density, silver scurf was less severe from a square planting pattern than from planting in wide rows. The incidence of black scurf also tended to increase with increase in seed size and was increased markedly by high planting density.

Key words: Silver scurf, black scurf, potato, seed size, planting density, planting pattern

Introduction

The surface of the potato tuber is a carrier of many diseases, including the blemishing diseases silver scurf (*Helminthosporium solani* Dur. & Mont.) and black scurf (*Rhizoctonia solani* Kühn) which reduce the value of washed and pre-packed potatoes. Many seed stocks in the UK are so contaminated, particularly with *H. solani* (Carnegie, 1992), and methods to reduce the severity of diseases which develop on ware tubers as a result of seed tuber-borne inoculum are sought.

The spread of *H. solani* from seed tubers results from the production of copious conidia on their surface (Jellis & Taylor, 1977). Firman & Allen (1995) found that more conidia were produced by large than small seed tubers and suggested that the number of conidia was related to the severity of disease on daughter tubers.

A range of seed tuber sizes and planting densities can be used for potato production (Allen & Wurr, 1992), resulting in differences in the surface area of seed planted and in plant spacing, both of which may influence the spread of blemishing diseases. Potatoes are usually grown in rows with seed tubers spaced closer within a row than between rows but reducing row width may also influence disease spread. Experiments reported in this paper investigated the effects of seed tuber size, planting density and planting pattern on the development of silver scurf and black scurf in ware potatoes.

Materials and Methods

Five field experiments with cv. Estima were grown on a sandy clay loam at Cambridge University Farm in 1991–93. Fertiliser was applied at the rate (kg ha^{-1}) 170 N, 52 P, 150 K, 33 Mg in 1991, at 120 N, 52 P, 150 K, 33 Mg in 1992 and at 180 N, 79 P, 224 K, 49 Mg in 1993. Seed was planted by hand using a dibber either into ridges 71 cm apart (Expts 1 & 2) or into a flat seed-bed (Expts 3–5). Seed tubers were planted at the same depth (*c.* 12 cm) irrespective of their size. The herbicides terbutryne and terbuthylazine (Opogard, Ciba-Geigy) were applied before emergence, and paraquat was also applied if necessary to control weeds which had already germinated. Irrigation was applied by overhead sprinkler in all experiments.

The experiments consisted of three complete replicates of all combinations of seed size and planting density (Expts 1 & 2) or seed size, planting density and pattern (Expts 3–5) (Table 1). The plots were arranged in three blocks. Plots for Expts 1 & 2 were four rows wide. Plots for Expts 3–5 had four rows for the 90 cm row width, five rows for the 71 cm row width and six or 12 rows for the square pattern at low and high planting density respectively. The outer rows were guard rows in all plots, but in the square pattern at the high planting density, two rows on either side of the plot were guard rows.

In 1991 Scottish Elite class 25–35 mm seed was the sole seed stock used for both experiments and was hand weighed to obtain the sizes used (Table 1). In 1992 and 1993 two seed stocks, Scottish Elite class 25–35 mm and a stock of once-grown seed were compared. The Scottish seed was split-graded and 30–35 mm seed was used. The once-grown seed in 1992 and 1993 was the produce of Scottish Elite class 25–35 mm seed planted at Cambridge University Farm in July 1991 and July 1992 respectively, and was graded and hand weighed to obtain the sizes used. In 1992 all seed was held at 2°C after grading and was unsprouted at planting. In 1991 and 1993 seed was allowed to sprout in wooden trays in an illuminated frost-free chitting store. In 1991 all seed tubers were well sprouted at

Table 1. *Details of field experiments with the potato variety Estima*

Expt	Planting date	Seed source and size*	Plant density (000 ha^{-1})	Planting arrangement	Harvest date(s)
1	29 Apr 91	Scottish: 9–11, 14–16, 19–21, 24–26 g	35, 47, 71, 141	71 cm rows	11 Sept
2	8 May 92	Scottish: 30–35 mm (26 g) Once grown: 10–20, 20–25, 25–30, 30–35, 40–45 mm (4, 9, 16, 27, 56 g)	35, 47, 71, 141	71 cm rows	8 Sept 6 Oct
3	11 Apr 91	Scottish: 12–13, 30–35 g	35, 141	square 71 cm rows 90 cm rows	29 Aug
4	7 May 92	Scottish: 30–35 mm (26 g) Once-grown: 2–4, 9–11 g	35, 141	square 71 cm rows 90 cm rows	29 Sept
5	29 Apr 93	Scottish: 30–35 mm (26 g) Once grown: 1–3 g	35, 141	square 90 cm rows	10 Sept

*For seed graded by square mesh, mean weights are in parenthesis.

planting (the mean length of the longest sprout at planting was 10.3 mm in Expt 1 and 9.5 mm in Expt 3). In 1992 the mean length of the longest sprout at planting was greater for the Scottish 30–35 mm seed (6.6 mm) than the once-grown 1–3 g seed (2.8 mm).

Silver scurf and black scurf were assessed by washing the seed tubers and recording the percentage surface area affected on a sample of 20 (50 in 1993) tubers of each size.

In Expt 1 nine seed tubers were dug from the two extreme planting densities (35 000 and 141 000 ha^{-1}) of each seed size in all replicates at 3, 6 and 9 wk after planting. The number of conidia produced by incubated seed tubers was determined by washing them and incubating for 2 wk at 20°C on tin trays above water in plastic bags. Tubers were then shaken with water to remove conidia, and their number determined by counts on a haemocytometer slide examined under a microscope. In Expt 4 the length of the longest stolon per stem was recorded from a sample of two plants dug on 6 July (the intermediate seed size [9–11 g], and planting pattern [71 cm rows] were not sampled).

Plant emergence was recorded for each plot every 2–3 days to determine the date of 50% emergence, and the percentage foliar ground cover was assessed regularly throughout growth using a grid (Burstall & Harris, 1983). Tubers were dug by hand (harvest dates listed in Table 1) and graded in 1 cm increments over a riddle before disease assessment and storage. The area dug at each harvest (m^2 $plot^{-1}$) was 2.6 in Expts 1 & 2, 3.4 in Expts 3 & 4 and 2.3 in Expt 5.

A sample of at least 25 tubers was weighed and put into paper sacks and stored at 7°C and 95% r.h. from *c.* 1 wk after harvest. Sprout growth was controlled by application of chlorpropham (CIPC) sprout inhibitor as required. Tubers were stored at Sutton Bridge Experimental Station until 20 May for Expts 1 & 3, until 14 January for Expts 2 & 4 and until 12 May for Expt 5.

Disease on ware tubers was assessed by inspecting *c.* 25 tubers at harvest and after storage. The tubers were washed and the percentage of the surface covered by silver scurf and black scurf was noted. Silver scurf was recorded as either nil or in class intervals of 5% surface area, and the mean percentage area affected was calculated by multiplying the number of tubers in each class by the mid value of each class. Black scurf was recorded as either nil, trace, moderate or severe (0, 0–5, 5–30 or > 30% surface area affected respectively), but the incidence of black scurf infection is presented as the percentage of tubers affected. At the end of storage, samples were re-weighed and the weight loss determined.

Results

Disease on seed tubers

The mean surface area of Scottish seed affected with silver scurf in 1991–93 was 3%, 12% and 38% respectively. There was no difference between seed sizes in surface area affected by silver scurf in 1991. In 1992 the mean surface area of once-grown seed affected with silver scurf was 14% and, although the 2–4 g and 10–20 mm seed had least infection (8% and 6% surface area affected respectively), there was no trend of severity of silver scurf infection with seed size. In 1993 the mean surface area of once-grown 1–3 g seed affected with silver scurf was < 1%. There was little black scurf on Scottish seed in any year; 1% of tubers affected in 1991, 4% in 1993 and none in 1992. Black scurf affected 7% of once-grown tubers in 1992 but none of the seed tubers examined had black scurf in 1993. Too few seed tubers were examined to determine any differences in black scurf between seed sizes.

The surface area of seed affected with silver scurf in Expt 1 increased to 21% 3 wk after planting and to 80% by 9 wk after planting but there was no difference between seed sizes.

Table 2. *The effect of seed size on the number of* Helminthosporium conidia *(10^4 tuber^{-1}) produced by seed tubers*

Weeks after planting	Seed size (g) 9–11	14–16	19–21	24–26	SE (14 df)
3	74	76	96	101	13.6
6	32	56	58	60	10.4
9	28	37	37	42	6.6

At the sample 9 wk after planting *c.* 11% of seed tubers were rotten. The number of conidia produced by seed tubers after incubation decreased with delay in sampling (Table 2) and tended to increase with increase in seed size at all samples, but differences between seed sizes were not statistically significant.

Emergence, growth, yield and number of tubers

50% plant emergence was not affected by seed size in 1991 and was only 3 days earlier for 30–35 mm than 1–3 g seed in 1993. In 1992 time to emergence decreased with increase in seed size, and 50% emergence was 11 days earlier for 30–35 mm than 10–20 mm seed. All treatments attained full foliar ground cover but this was reached earlier with increase in seed size, increase in planting density and decrease in rectangularity of planting pattern, but in Expts 1, 3 & 5 this was matched by earlier senescence of these treatments.

There was little effect on total tuber yield of seed size above 15 g or planting density above 35000 ha^{-1} in any experiment. The total number of tubers increased with increase in planting density and seed size and was greater from a square planting pattern than rows in Expts 3–5, particularly at high planting density.

Stolon length

There was no difference in the length of the longest stolon per stem between different seed sizes, planting densities or planting patterns in Expt 4. The mean length of the longest stolon per stem was 90 mm and stolon length ranged from 5–165 mm.

Silver scurf

The severity of silver scurf at harvest and after storage increased with increase in seed size and planting density in all experiments (Tables 3–4). The disease increased in storage so that differences between treatments after storage were larger than at harvest. To investigate the relationship between silver scurf and the surface area of seed, the surface area of seed planted was calculated as the product of the planting density and the surface area per tuber for different planting densities and seed sizes (of common stock) in Expts 1 and 2. The surface area per tuber was estimated from the mean seed weights using the formula of Banks (1985). Linear regression of severity of silver scurf after storage on surface area of seed planted was significant in both Expts 1 and 2 (Fig. 1).

There was no effect of planting pattern on silver scurf infection at harvest in Expt 3, but after storage it was more severe from 90 cm rows than other planting patterns at high planting density (Table 4). In Expts 4 & 5 there was less silver scurf with a square planting pattern than with planting in rows at the high planting density, but there was no effect of planting pattern at the low planting density (Table 4). In Expt 2, silver scurf at harvest was slightly increased with later harvesting but there was little difference between the two harvest dates after storage (Table 3). Linear regression of severity of silver scurf after storage on severity of silver scurf at harvest was significant in all experiments (Table 5).

Table 3. *The effect of seed size, seed source and planting density on severity of silver scurf (mean % surface area affected) in Expts 1 & 2*

Seed size/source	Planting density (000 ha⁻¹) 35	47		71	141	Mean	SE
Expt 1 At harvest (30 df)							
9–11 g/Scottish	1.2	1.5		2.6	5.3	2.6	
14–16 g	2.2	2.2		2.5	3.8	2.6	0.45
19–21 g	2.3	3.1		3.5	7.9	4.2	
24–26 g	2.9	3.8		3.8	9.8	5.1	
SE			0.90				
Mean	2.1	2.7		3.1	6.7		
SE			0.45				
Expt 1 After storage (30 df)							
9–11 g/Scottish	14.9	16.6		23.0	25.9	20.1	
14–16 g	21.7	20.3		30.7	34.9	26.9	1.98
19–21 g	30.7	19.4		26.6	34.0	27.7	
24–26 g	27.4	22.1		27.5	40.6	29.4	
SE			3.95				
Mean	23.7	19.6		26.9	33.9		
SE			1.98				
Expt 2 At early harvest (46 df)							
10–20 mm/Once-grown	0.2	0.4		0.5	0.5	0.4	
20–25 mm	0.2	0.3		0.9	0.9	0.6	
25–30 mm	0.3	0.1		1.5	1.1	1.0	0.28
30–35 mm	0.8	0.9		0.9	1.5	1.0	
40–45 mm	3.1	2.4		3.5	3.7	3.2	
30–35 mm/Scottish	0.5	0.4		1.0	1.8	0.9	
SE			0.55				
Mean	0.9	0.8		1.4	1.6		
SE			0.23				
Expt 2 At late harvest (46 df)							
10–20 mm/Once-grown	0.9	0.7		1.0	0.6	0.8	
20–25 mm	0.6	1.5		2.1	3.5	1.9	
25–30 mm	0.7	0.6		2.9	2.9	2.0	0.61
30–35 mm	0.9	4.1		2.6	3.8	2.9	
40–45 mm	5.2	1.6		4.1	5.7	4.1	
30–35 mm/Scottish	0.8	0.9		5.0	3.9	2.7	
SE			1.22				
Mean	1.5	1.6		2.9	3.6		
SE			0.50				
Expt 2 After storage—early harvest (46 df)							
10–20 mm/Once-grown	1.4	1.1		2.2	3.0	1.9	
20–25 mm	1.0	1.9		1.9	4.6	2.3	
25–30 mm	1.5	1.5		4.7	6.6	3.6	0.63
30–35 mm	2.7	3.3		4.2	8.2	4.6	
40–45 mm	7.3	6.9		9.3	12.9	9.1	
30–35 mm/Scottish	1.5	2.5		6.5	9.9	5.1	
SE			1.27				
Mean	2.6	2.9		4.8	7.5		
SE			0.52				

Table 3. *Cont.*

	Planting density (000 ha^{-1})						
Seed size/source	35	47		71	141	Mean	SE
Expt 2 After storage—late harvest (46 df)							
10–20 mm/Once-grown	0.5	1.2		2.1	1.6	1.3	
20–25 mm	0.9	1.7		5.9	5.2	3.4	
25–30 mm	1.1	1.8		3.6	6.7	3.3	1.03
30–35 mm	2.2	6.5		3.9	7.0	4.9	
40–45 mm	13.8	4.0		6.0	8.9	8.2	
30–35 mm/Scottish	3.2	1.3		11.7	7.1	5.8	
SE			2.06				
Mean	3.6	2.7		5.5	6.1		
SE			0.84				

Black scurf

In all experiments, the incidence of black scurf was greatest in the produce of the largest seed size and at the highest planting density (Tables 6–7). In Expt 2 there was little black scurf in most treatments at the early harvest, but black scurf was more severe at the later harvest and increased with increasing planting density and with increase in size of once-grown seed; but there was less black scurf infection from the Scottish 30–35 mm seed than once-grown seed of this and smaller sizes (Table 6). In Expts 3 and 5 black scurf was more severe from 90 cm rows than other patterns at the high planting density, but in Expt 4 there was little black scurf and no differences between planting patterns (Table 7). There was little increase of black scurf in store in any year.

Weight loss

Weight loss in store increased with increase in seed size and planting density in Expts 1 and 3 (Tables 8–9) and was greater from 30–35 mm seed than 1–3 g seed in Expt 5 (Table 9). In Expt 5 weight loss was greatest from 30–35 mm seed planted at low planting density in 90 cm rows, and this was associated with a higher proportion ($P < 0.01$) of soft rots (10%) than for other treatments (< 1%). There was no effect of treatments on weight loss in the 1992 Expts (2 and 4) stored to January. Linear regression of weight loss on silver scurf after storage was significant in the 1991 experiments, with silver scurf accounting for 41% and 38% of the variance in weight loss in Expts 1 and 3 respectively.

Discussion

These experiments indicate that the increased production of conidia of *H. solani* with increase in seed size reported by Firman & Allen (1995) can result in more severe silver scurf on daughter tubers grown from large seed than from small seed at the same planting density. In an experiment with two seed stocks, using larger seed than for the experiments reported here, Hide, Boorer & Hall (1994) also found that silver scurf was more severe on the produce of large seed (100–160 g) than small seed (25–50 g), with or without application of the fungicide imazalil. An increase in the surface area of seed tubers results in an increase in the surface area for production of conidia of *H. solani* as the entire surface area is exploited (Jellis & Taylor, 1977; Firman & Allen, 1995) and this may explain the increase in severity of silver scurf with increase in both seed size and planting density. A linear regression of severity of silver scurf on the surface area of seed planted was significant in all years (Fig. 1), but the relationship was improved by including seed size and planting

Table 4. *The effect of seed size, seed source, planting density and arrangement on severity of silver scurf (mean % surface area affected) in Expts 3–5*

	Low density				High Density				
Seed size/source	Square	71 cm row	90 cm row		Square	71 cm row	90 cm row	Mean	SE
Expt 3 At harvest (22 df)									
12–13 g/Scottish	1.8	1.2	1.6		2.9	2.2	3.6	2.2	
30–35 g	2.4	2.2	1.9		7.4	5.9	5.7	4.2	0.16
SE				0.39					
Mean	2.1	1.7	1.8		5.1	4.1	4.7		
SE				0.27					
Mean		1.9				4.6			
SE				0.16					
Expt 3 After storage (22 df)									
12–13 g/Scottish	8.1	9.8	7.3		12.7	17.7	25.6	13.5	
30–35 g	25.5	6.3	7.3		23.2	20.7	35.9	19.8	1.55
SE				3.79					
Mean	16.8	8.1	7.3		18.0	19.2	30.8		
SE				2.68					
Mean		10.7				22.6			
SE				1.55					
Expt 4 At harvest (34 df)									
2–4 g/Once-grown	0.4	0.6	0.7		1.1	1.6	1.4	1.0	
9–11 g	1.3	0.7	1.0		2.2	3.7	4.1	2.2	0.26
30–35 mm/Scottish	1.6	1.3	2.5		1.7	3.8	5.7	2.8	
SE				0.63					
Mean	1.1	0.9	1.4		1.7	3.1	3.8		
SE				0.21					
Mean		1.1				2.8			
SE				0.21					
Expt 4 After storage (34 df)									
2–4 g/Once-grown	1.6	1.6	2.1		2.6	5.3	3.5	2.8	
9–11 g	5.2	3.2	2.2		5.8	13.7	11.8	7.0	0.58
30–35 mm/Scottish	6.5	4.8	6.2		8.1	15.9	16.9	9.7	
SE				1.42					
Mean	4.4	3.2	3.5		5.5	11.6	10.7		
SE				0.82					
Mean		3.7				9.3			
SE				0.47					
Expt 5 At harvest (14 df)									
1–3 g/Once-grown	0.3		0.3		0.6		0.8	0.5	
30–35 mm/Scottish	0.5		0.9		2.1		2.6	1.5	0.18
SE				0.36					
Mean	0.4		0.6		1.3		1.7		
SE				0.26					
Mean		0.5				1.5			
SE				0.18					
Expt 5 After storage (14 df)									
1–3 g/Once-grown	3.9		2.7		5.1		10.0	5.4	
30–35 mm/Scottish	7.1		6.0		7.9		17.5	9.6	0.94
SE				1.87					
Mean	5.5		4.3		6.5		13.7		
SE				0.32					
Mean		4.9				10.1			
SE				0.94					

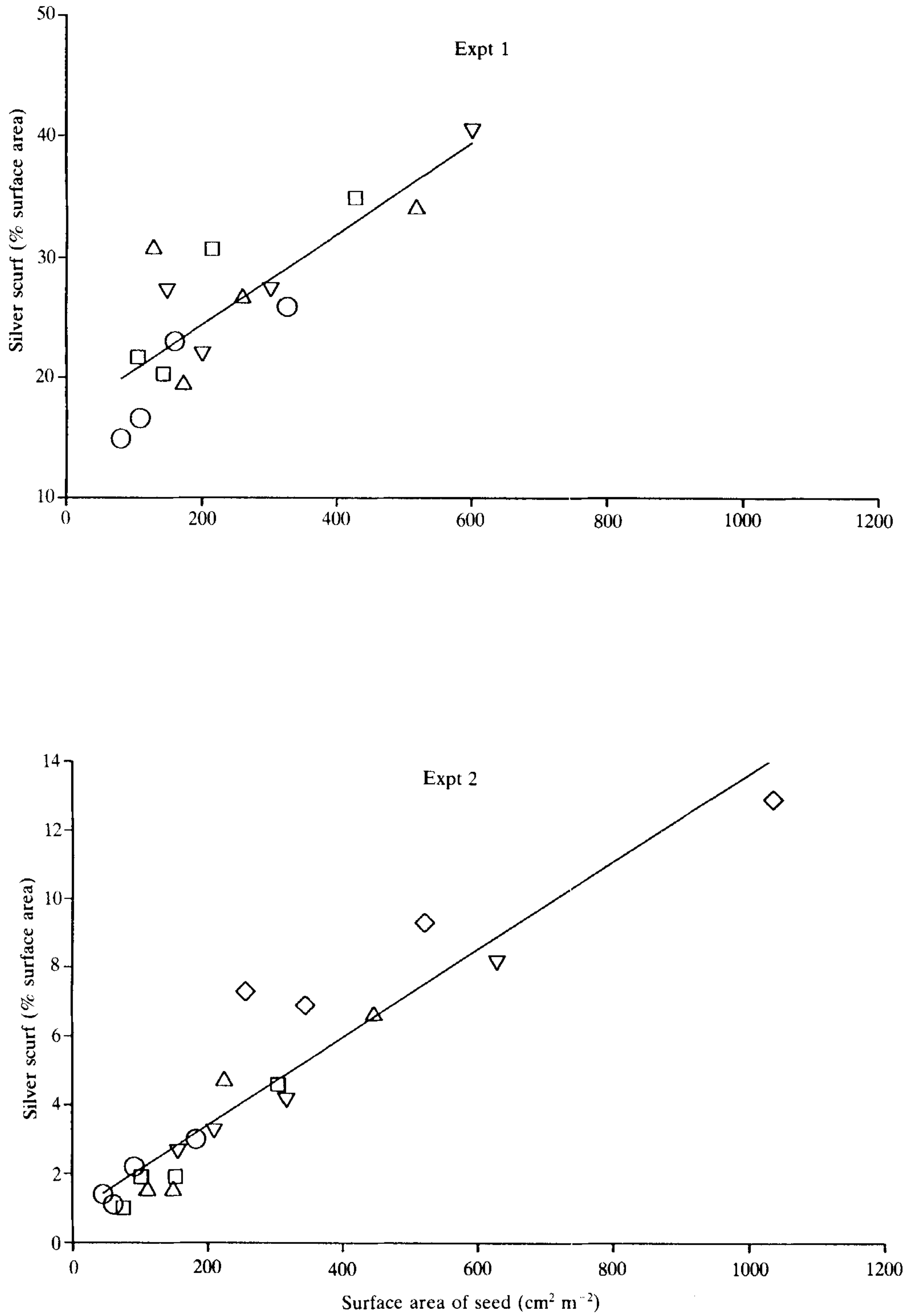

Fig. 1. Linear regression of silver scurf after storage (% surface area affected) on surface area of seed planted (cm^2 m^{-2}) in Expts 1 and 2. Expt 1: ○ 9–11 g; □ 14–16 g; △ 19–21 g; ▽ 24–26 g. Expt 2: ○ 10–20 mm; □ 20–25 mm; △ 25–30 mm; ▽ 30–35 mm; ◇ 40–45 mm. Fitted lines, $y = mx + c$. Expt 1 (14 df) $m = 0.0375 \pm 0.00675$, $c = 16.86 \pm 1.93$; Expt 2 (18 df) $m = 0.0128 \pm 0.00109$, $c = 0.0842 \pm 0.390$.

Table 5. *Parameters from regression of silver scurf infection at harvest against silver scurf after storage for Expts 1–5*

Expt (df)	Constant (SE)	Slope (SE)	Percentage variance accounted for
Expt 1 (46)	19.9 (2.04)	1.67 (0.458)	20.7
Expt 2 (70)			
Early harvest	2.1 (0.46)	2.06 (0.267)	45.1
Late harvest	1.1 (0.49)	1.41 (0.137)	59.6
Expt 3 (34)	6.7 (2.90)	3.07 (0.765)	30.2
Expt 4 (52)	2.1 (0.72)	2.23 (0.275)	55.0
Expt 5 (22)	3.7 (1.11)	3.83 (0.793)	49.2

density as regression parameters. This suggests that the effects of increased surface area by increase in seed size and by increase in planting density are not equivalent.

For *R. solani* an increase in seed size may increase the probability of infection as the area of infection sites on seed tubers increases with seed size even if the percentage surface area affected is similar for all seed sizes. Differences in the amount of infection on seed tubers of different seed sizes in these experiments cannot be excluded as a factor contributing to the differences in infection on daughter tubers because only a small sample of each size was assessed, but differences in infection on different seed sizes from the same seed stock are unlikely to be large. In Expt 2 the produce of 30–35 mm Scottish seed (26 g) had less black scurf than daughter tubers from smaller once-grown seed, which indicates that the greater incidence of *R. solani* on once-grown seed was more important than seed size in determining the incidence of black scurf. Hide, Read & Hall (1992) found no effect of seed size on black scurf, but there was little black scurf in the non-inoculated treatments and to obtain similar stem densities, small seed was planted at higher density than large seed so that seed size and planting density were confounded. Hide *et al.* (1994) found a slightly greater proportion of tubers with black scurf in the produce of small seed than large seed in one experiment. The small seed used by Hide *et al.* (1994) was larger than in these experiments, but there is no obvious explanation for a reduction in black scurf with large seed.

The effects of planting density on disease spread suggest that it may occur from neighbouring plants at least at spacings of up to 30 cm along the row; with very close spacing (10 cm) disease severity is increased markedly as a result. The reduction in disease from square planting may result from the increased separation of neighbouring plants minimising disease spread. The absence of significant effects of planting pattern on disease transmission at low planting density suggests that there is little spread of disease from neighbouring plants at spacings of *c.* 40 cm. There was no difference in stolon length between treatments, but there was a considerable range in stolon lengths. The rose end of large tubers could be 25 cm from the parent tuber and exposed to inoculum from neighbouring seed tubers. Tubers borne on very short stolons are more likely to be infected by the parent tuber than neighbouring seed tubers.

The effects of seed size, planting density and pattern on canopy development and senescence may also have affected disease expression in the daughter tubers. Early defoliation of potatoes has been shown to increase the incidence of black scurf (Spencer & Fox, 1979) and earlier senescence at high planting density and with larger seed in some experiments may have stimulated development of sclerotia of *R. solani* and thus contributed to the differences which were recorded. Firman & Allen (1993) found only a small increase in silver scurf from early defoliation and it seems unlikely that the differences in canopy senescence had much effect on the severity of silver scurf.

Table 6. *The effect of seed size, seed source and planting density on severity of black scurf (% tubers affected) in Expts 1 & 2*

	Planting density (000 ha⁻¹)					
Seed size/source	35	47	71	141	Mean	SE
Expt 1 At harvest (30 df)						
9–11 g/Scottish	0	0	4	12	4	
14–16 g	1	3	6	35	11	3.0
19–21 g	1	13	1	27	11	
24–26 g	25	4	12	54	24	
SE		6.0				
Mean	7	5	6	32		
SE		3.0				
Expt 1 After storage (30 df)						
9–11 g/Scottish	0	1	8	10	5	
14–16 g	0	1	15	29	11	3.4
19–21 g	1	5	6	18	8	
24–26 g	24	4	21	40	22	
SE		6.8				
Mean	6	3	13	24		
SE		3.4				
Expt 2 At early harvest (46 df)						
10–20 mm/Once-grown	0	0	0	0	0	
20–25 mm	0	0	0	3	1	
25–30 mm	1	0	0	0	0	1.0
30–35 mm	0	3	0	0	1	
40–45 mm	0	8	1	14	6	
30–35 mm/Scottish	0	4	0	0	1	
SE		2.1				
Mean	0	2	0	3		
SE		0.8				
Expt 2 After storage—early harvest (46 df)						
10–20 mm/Once-grown	0	0	0	1	0	
20–25 mm	0	1	1	2	1	
25–30 mm	5	1	2	8	4	1.7
30–35 mm	3	11	1	3	4	
40–45 mm	11	2	6	43	16	
30–35 mm/Scottish	1	10	0	0	3	
SE		3.3				
Mean	3	4	2	9		
SE		1.4				
Expt 2 At late harvest (46 df)						
10–20 mm/Once-grown	20	0	7	21	12	
20–25 mm	0	20	21	26	17	
25–30 mm	14	12	11	37	19	4.7
30–35 mm	7	5	20	44	19	
40–45 mm	9	25	25	60	30	
30–35 mm/Scottish	1	7	4	18	8	
SE		9.5				
Mean	9	12	15	34		
SE		3.9				

Table 6. *Cont.*

Seed size/source	Planting density (000 ha^{-1}) 35	47		71	141	Mean	SE
Expt 2 After storage—late harvest (46 df)							
10–20 mm/Once-grown	3	0		2	25	7	
20–25 mm	0	11		15	35	15	
25–30 mm	8	22		12	55	24	4.9
30–35 mm	17	8		27	65	29	
40–45 mm	16	35		32	65	37	
30–35 mm/Scottish	3	2		2	26	8	
SE			9.7				
Mean	8	13		15	45		
SE			4.0				

Table 7. *The effect of seed size, seed source, planting density and arrangement on severity of black scurf (% tubers affected) in Expts 3–5*

Seed size/source	Low density Square	71 cm row	90 cm row		High density Square	71 cm row	90 cm row	Mean	SE
Expt 3 At harvest (22 df)									
12–13 g/Scottish	1	0	0		4	4	11	3	
30–35 g	1	7	1		4	23	21	10	2.5
SE				6.2					
Mean	1	4	1		4	13	16		
SE				4.4					
Mean		2				11			
SE				2.5					
Expt 3 After storage (22 df)									
12–13 g/Scottish	6	3	1		6	4	12	5	
30–35 g	3	1	3		14	14	37	12	1.4
SE				3.4					
Mean	4	2	2		10	9	25		
SE				2.4					
Mean		2.6				14.4			
SE				1.4					
Expt 4 At harvest (34 df)									
2–4 g/Once-grown	0	0	0		0	0	0	0	
9–11 g	0	0	0		0	8	4	2	1.0
30–35 mm/Scottish	0	1	0		0	13	4	3	
SE				2.5					
Mean	0	0	0		0	7	3		
SE				1.8					
Mean		0				3			
SE				0.8					
Expt 4 After storage (34 df)									
2–4 g/Once-grown	0	0	3		0	0	10	2	
9–11 g	1	0	0		0	14	3	3	1.8
30–35 mm/Scottish	1	10	1		7	15	3	6	
SE				4.5					
Mean	1	3	1		2	10	5		
SE				2.6					
Mean		2				6			
SE				1.5					

Table 7. *Cont.*

Seed size/source	Low density Square	Low density 71 cm row	Low density 90 cm row		High density Square	High density 71 cm row	High density 90 cm row	Mean	SE
Expt 5 At harvest (14 df)									
1–3 g/Once-grown	0		7		3		11	5	
30–35 mm/Scottish	19		0		27		46	23	4.2
SE				8.3					
Mean	9		4		15		29		
SE				5.9					
Mean		6				22			
SE				4.2					
Expt 5 After storage (14 df)									
1–3 g/Once-grown	3		8		3		24	9	
30–35 mm/Scottish	28		3		39		53	30	5.9
SE				11.9					
Mean	16		6		21		38		
SE				8.4					
Mean		11				30			
SE					5.9				

Table 8. *The effect of seed size and planting density on weight loss (%) during storage in Expt 1*

Seed size (g)	Planting density ($000\ ha^{-1}$) 35	47		71	141	Mean	SE (30 df)
9–11	7.4	8.3		8.2	8.7	8.2	
14–16	7.9	8.5		9.0	9.4	8.7	0.22
19–21	8.2	8.7		9.5	10.0	9.1	
24–26	8.2	8.2		8.8	10.4	8.9	
SE (30 df)			0.44				
Mean	7.9	8.4		8.9	9.6		
SE (30 df)			0.22				

Table 9. *The effect of seed size, planting density and arrangement on weight loss (%) during storage in Expts 3 & 5*

Seed size/source	Low density Square	Low density 71 cm row	Low density 90 cm row		High Density Square	High Density 71 cm row	High Density 90 cm row	Mean	SE
Expt 3 (22 df)									
12–13 g/Scottish	6.8	6.9	6.8		8.5	8.5	8.4	7.6	
30–35 g	8.3	6.8	7.1		9.2	8.1	9.5	8.2	0.15
SE				0.37					
Mean	7.6	6.9	6.9		8.8	8.3	8.9		
SE				0.21					
Mean		7.1				8.7			
SE				0.15					
Expt 5 (14 df)									
1–3 g/Once-grown	4.7		4.2		3.8		4.2		4.2
30–35 mm/Scottish	4.6		6.3		4.2		4.7	0.18	
SE				0.37					
Mean	4.6		5.3		4.0		4.4		
SE				0.26					
Mean		4.9				4.2			
SE				0.18					

The increase in severity of disease with increasing planting density is particularly relevant for seed production, as high planting densities are used to maximise multiplication rates. However, very high planting densities could increase the spread of disease. Square planting patterns are beneficial for seed production as the increase in early ground cover is combined with a reduction in disease at high planting density and an increase in the number of tubers produced.

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References

Allen E J, Wurr D C E. 1992. Plant density. In *The Potato Crop*, pp. 292–333. Ed. P Harris. London: Chapman & Hall.

Banks N H. 1985. Surface area estimation of potato tubers. *Potato Research* **28**:487–496.

Burstall L, Harris P M. 1983. Estimation of percentage light interception from leaf area index and percentage ground cover in potatoes. *Journal of Agricultural Science, Cambridge* **100**:241–244.

Carnegie S F. 1992. Improving seed tuber health. *Aspects of Applied Biology* **33**, *Production and Protection of Potatoes*, pp. 93–100.

Firman D M, Allen E J. 1993. Effects of windrowing, irrigation and defoliation of potatoes on silver scurf (*Helminthosporium solani*) disease. *Journal of Agricultural Science, Cambridge* **122**:47–53.

Firman D M, Allen E J. 1995. Transmission of *Helminthosporium solani* from potato seed tubers and effects of soil conditions, seed inoculum and seed physiology on silver scurf disease. *Journal of Agricultural Science, Cambridge* **124**:219–234.

Hide G A, Boorer K J, Hall S M. 1994. Controlling potato tuber blemish diseases on cv. Estima with chemical and non-chemical methods. *Annals of Applied Biology* **124**:253–265.

Hide G A, Read P J, Hall S M. 1992. Stem canker (*Rhizoctonia solani*) on three early and three maincrop potato cultivars: effects of seed tuber size on growth and yield. *Annals of Applied Biology* **120**:391–403.

Jellis G J, Taylor G S. 1977. The development of silver scurf (*Helminthosporium solani*) disease of potato. *Annals of Applied Biology* **86**:19–28.

Spencer D, Fox R A. 1979. The development of *Rhizoctonia solani* Kühn on the underground parts of the potato plant. *Potato Research* **22**:29–39.

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