Final Report

Late-season water management

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1. SUMMARY

1.1. Aims

Short-term dehydration can increase the potential for tubers to bruise and studies of commercial crops have shown that there is a tendency for those allowed to accumulate high soil moisture deficits (SMD) prior to defoliation to be associated with greater rejections from bruising despite having been well-irrigated earlier in the season. Conversely, there is a reticence among growers to continue irrigating close to harvest for fear of impacting on harvesting conditions as well as delaying skinset in excessively wet soils. The aims of the project were to establish the extent to which late season irrigation management affects a) blackspot bruising and b) skinset in crops.

1.2. Methodology

Over three seasons (2011, 2012 and 2013), tubers from six experimental and 50 commercial crops were impacted using a falling bolt to determine the sensitivity to bruising and a rumble barrel was used to assess the skinset of tubers from the detailed experiments. The experimental crops had two irrigation regimes imposed (rainfed and irrigated to maintain SMDs below the limit for yield), whilst the commercial crops had their irrigation scheduled by the CUF Potato Irrigation Scheduling Model, with the end of season irrigation management being determined by the growers. Six random areas were sampled within each commercial field and tubers impacted within 24 hours of harvesting.

1.3. Key findings

In four out of six detailed experiments assessing the effect of late-season irrigation on bruising, there was a reduction in bruising incidence where SMDs were maintained below the limiting SMD for yield in the 3 weeks prior to desiccation compared with allowing the SMDs to increase to 20-30 mm above the limiting SMD. Rainfall interceded in two of the experiments, so that a relatively small differential resulted between rainfed and irrigated treatments and there was no effect on bruising.

In commercial crops, there was no overall relationship between blackspot bruising incidence and any measure of SMD (mean, maximum, accumulated or stress SMD) during the 3-week period prior to desiccation or 50 % canopy senescence. When grouping the data by variety, there was again no relationship between bruising and

SMD in most varieties. However, in Markies there was a significant increase in bruising as the SMD maintained prior to harvest increased.

In all detailed experiments, late-season irrigation management had no effect on skin-set.

1.4. Practical recommendations

In controlled experiments, it has proved possible to reduce bruising by maintaining moderate SMD's close to desiccation or crop death when compared to rainfed crops. This should be the target for growers during August rather than switching off irrigation and allowing the crop to survive on soil reserves alone in dry periods. The concerns that maintaining small SMDs in the lead up to harvest will delay skinset have little scientific grounding and growers should concentrate on monitoring SMDs later in the season and irrigating where necessary. The crucial objective is maintaining moderate, rather than low SMDs, since the latter can adversely affect other aspects of tuber quality (e.g. rotting diseases, dry matter and lenticel eruption) and soil conditions for harvest.

2. INTRODUCTION

Whilst it has been shown that irrigation management plays an inconsistent role in susceptibility to blackspot bruising where crops have senesced completely, short-term dehydration can increase the potential for tubers to bruise. Studies of commercial crops have shown that there is a tendency for those allowed to accumulate high soil moisture deficits (SMD) prior to defoliation to be associated with greater rejections from bruising despite having been well-irrigated previously. In addition, there is evidence from experiments that mechanical defoliation of actively growing canopies can result in significant increases in bruising, particularly if the crop had been previously irrigated and then allowed to dry out prior to defoliation.

In combination with nitrogen management, water plays a large role in governing the timing and rate of canopy senescence and this is closely linked with the rate of skinset. Crops defoliated prior to active senescence can still take up water and this may slow skinset. Better information on management of water is crucial to prevent bruising and enable rapid skinset, early harvest and reduction in blemishing diseases such as black dot and silver scurf.

Over the course of this 3-year Potato Council project (R445), the incidence and severity of bruising was determined using a falling bolt impact test in 53 commercial crops, comprising some Grower Collaboration project crops, complemented by additional crops identified from commercial irrigation scheduling services offered by CUF as well as six detailed replicated-plot experiments. In the detailed experiments, tubers were also mechanically abraded using a rumble barrel to determine the effect of late-season watering on extent of skinset.

3. MATERIALS AND METHODS

3.1. Experimental crops

3.1.1. 2011 (Experiments 1 and 2)

Two controlled late-watering experiments (Expts 1 and 2) were located in commercial crops of Maris Piper grown by Greenvale AP Ltd which were irrigated with solid-set sprinkler systems (Coverline, Wroot Water). In each field, a representative area of six lines of sprinklers was selected and a randomised pattern of plots laid out with six replicates of two treatments (irrigation withheld for 3 weeks prior to intended desiccation (Dry) and irrigated according to a schedule to maintain a normal < 40 mm SMD for 3 weeks prior to desiccation (Wet)). Each 'plot' was located in the center of the over-lap patterns of four circular sprinklers. In Dry plots, once the system had been pressure-tested, the sprinklers contributing to the irrigation had their heads changed for Nelson, restricted-angle sprinkler heads which allowed the plot, through adjustment of the rotating sector, to remain unirrigated even though the rest of the line was operating. Raingauges were positioned to measure the application rates at initial irrigations to perform a calibration and subsequently irrigation quantities were based on the time each line was operating. Dry plots were not protected from rainfall. Meteorological data for running the NIAB-CUF Potato Irrigation Scheduling model was provided by the Met Office's MORECS service and daily rainfall and weekly ground covers in all plots were measured in each experiment.

Experiment 1 was located in Chapmans field, Raveningham, Norfolk on a sandy clay loam (56 % sand, 24 % silt, 19 % clay and 1.7 % organic matter). It was planted on 16 April with 35-45 mm E1 seed at a spacing of 33 cm. The crop reached 50 % plant emergence on 16 May. The Wet treatments received three doses of 12 mm irrigation during August, whilst the Dry received no irrigation during August. The crop was desiccated with split-dose Reglone at 1.5+1.5 l/ha on 19 August and 2 September and sampled on 7 September.

Experiment 2 was located in Craft field, Raveningham, Norfolk on a sandy loam (66 % sand, 20 % silt, 14 % clay and 2.0 % organic matter). It was planted on 16 April with the same seed and spacing as Expt 1. The crop emerged on 15 May. The Wet treatments received three doses of 12 mm irrigation during August, whilst the Dry received no irrigation during August. The crop was desiccated with split-dose Reglone on 2 and 9 September and sampled on 22 September.

Fifty tubers from all plots in each experiment were sampled for bruising on a single occasion 3 weeks after defoliation. After careful hand-digging and transport back to CUF, tubers were impacted 24 h after harvest at a temperature of 16 °C with 0.5 J energy using a falling bolt (Stalham 2008). Following impact, tubers were either left at 35 °C for 24 h or at 25 °C for 48 h to allow full colour development in bruises prior to assessment. Tubers were peeled at the impact site using an Oxo Good Grips peeler and bruise depth calculated from the number of peels (1.5 mm thick) taken to remove any bruise. Additionally, assessments of skinset were made on a second batch of 50 tubers per plot harvested at the same time as the bruising samples. Following the protocol of Firman & Howell (2008), the proportion of skin removed was measured after rotating tubers for 30 s in a scuffing barrel operating at 40 r.p.m. Scuffing took place 24 h after hand harvesting, with tubers stored in paper sacks overnight at 16 °C.

Two other experiments were also assessed for bruising using the same method, an experiment involving early-season restriction of watering during scab control (Potato Council Project R448 GVAP 18 Acres) and an experiment examining destoning depth (Project R452 SML Hill). No significant effects of treatments on bruising were found in either experiment mean values were added to the body of data from the commercial crops (see below).

3.1.2. 2012 (Experiments 3 and 4)

The two controlled late-watering experiments were located in commercial crops of Maris Piper grown by Greenvale AP Ltd which were irrigated with the same solid-set sprinkler systems as described in Section 3.1.1.

A randomised block design was laid out with six replicates of two treatments (irrigated withheld for 3 weeks prior to intended desiccation (Dry) and irrigated according to a schedule to maintain a moist soil (< 35 mm SMD) for 3 weeks prior to desiccation (Wet)). Dry plots were not protected from rainfall. Meteorological data for running the irrigation model was provided by the Met Office's MORECS service and daily rainfall and ground covers in all plots were measured in each experiment.

Experiment 3 was located in Beacon Hill field, Raveningham, Norfolk on a sandy loam (69 % sand, 19 % silt, 13 % clay and 1.9 % organic matter). It was planted 18 cm deep on 23 March with 30-40 mm E1 seed at a spacing of 27 cm. The crop emerged on 15 May. The Wet treatments received five doses of 10-15 mm irrigation between 12 and 22 August, whilst the Dry received no irrigation over the period. The experiment was desiccated with split-dose Reglone on 10 and 15 September. A final harvest was taken on 18 September.

Experiment 4 was located in Ashby 9 field, Somerleyton, Norfolk on a sandy loam (63 % sand, 21 % silt, 16 % clay and 1.3 % organic matter). It was planted 18 cm deep on 7 April with 40-50 mm E1 seed at a spacing of 38 cm. The crop emerged on 20 May. The Wet treatments received 15 mm irrigation on 13 and 20 August and 10 mm on 15 August, whilst the Dry received no irrigation on these dates. The experiment was harvested green-top without desiccation owing to earlier than planned commercial harvesting. A final harvest was taken on 27 August.

3.1.3. 2013 (Experiments 5 and 6)

The two controlled late-watering experiments were located in commercial crops of Maris Piper grown by Greenvale AP Ltd which were irrigated with the same solid-set sprinkler systems as described in Section 3.1.1. A randomised block design was laid out with six replicates of two treatments (irrigation withheld for 3 weeks prior to intended desiccation [Dry] and irrigated according to a schedule to maintain a moist soil (< 40 mm SMD) for 3 weeks prior to desiccation [Wet]). Dry plots were not protected from rainfall. Meteorological data for running the irrigation model was provided by the Met Office's MORECS service and daily rainfall and ground covers in all plots were measured in each experiment.

Experiment 5 was located in Red House West field, Raveningham, Norfolk on a sandy loam soil. It was planted 16 cm deep on 10 April with 35-50 mm E1 seed at a spacing of 38 cm. The crop emerged on 15 May. The Wet treatments received seven doses of 4-16 mm irrigation between 9 and 28 August (82 mm total), whilst the Dry received no irrigation over the period. The experiment was desiccated with split-dose Reglone on 31 August and 7 September. A final harvest was taken on 24 September.

Experiment 6 was located in Foxholes field, Somerleyton, Norfolk on a sandy loam soil. It was planted 16 cm deep on 12 April with 35-45 mm E1 seed at a spacing of 35 cm. The crop emerged on 19 May. The Wet treatments received seven doses of 5-16 mm irrigation between 9 and 28 August (83 mm total), whilst the Dry received no irrigation over the period. The experiment was desiccated with split-dose Reglone on 31 August and 7 September. A final harvest was taken on 24 September.

3.2. Commercial crops

The selected crops were monitored for emergence and weekly ground cover and daily inputs of rainfall and irrigation measured so that SMDs could be calculated using the CUF Irrigation Model. Crops were sampled for bruising on a single occasion *c*. 3 weeks after defoliation or *c.* 50 % crop senescence. Impacting and assessment for bruising on six replicates of 50 tubers was carried out at CUF using falling bolt impaction as detailed in Section 3.1.1.

3.2.1. 2011

Tubers were harvested from 18 commercial fields, selected to provide a range of varieties, soil types and irrigation management practices. Ground covers, rainfall and irrigation data were collected from the all except three of these commercial fields, which permitted SMDs to be calculated. Ground cover data were unavailable for the Pullen Hungerford, Branston Nocton 2 and Daw 29 Acre commercial fields, therefore it was not possible to calculate the SMD's and these fields have been excluded from the report. Impaction and assessment of bruising used the same method as detailed in Section 3.1.1. No assessments of skinset were made.

3.2.2. 2012

The protocol for 2012 was the same as for 2011 but 22 crops were selected for analysis. Additional samples for bruising were harvested from four experiments in commercial fields involved in the Potato Council projects relating to cultivation. Some of the bruising assessments were conducted by staff from Spearhead Marketing limited using the standard protocol and tools for impacting and assessment. No assessments of skinset were made.

3.2.3. 2013

The protocol for 2013 was the same as for 2011 and 2012 but 13 crops were selected for analysis. Additional samples for bruising were harvested from four experiments in commercial fields involved in the Potato Council projects relating to cultivation. Some of the bruising assessments were conducted by staff from Spearhead Marketing limited using the standard protocol and tools for impacting and assessment. No assessments of skinset were made.

4. RESULTS

4.1. 2011

4.1.1. Experiments 1 and 2

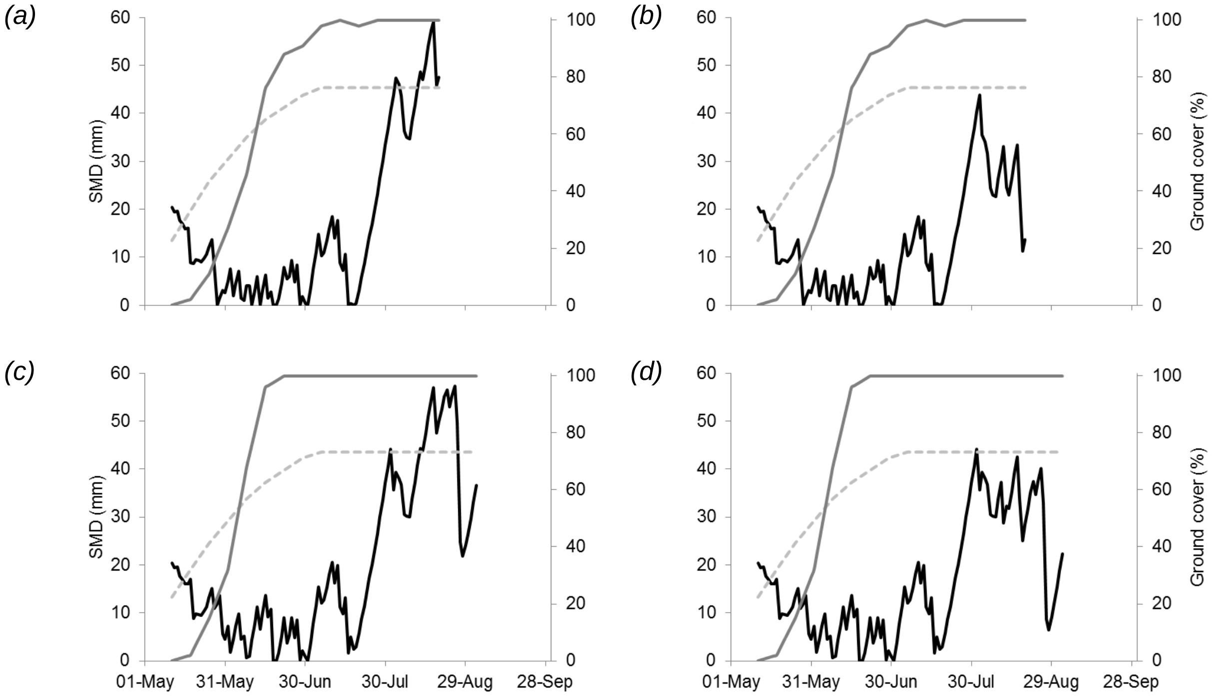
Despite differences in SMD between Dry and Wet plots during the period prior to desiccation, there was no effect of irrigation regime on blackspot bruising incidence, mean depth of bruising in damaged tubers or the degree of skinning in either experiment (Table 1). The field desiccated early (Expt 1) had a greater incidence of bruising than the one desiccated later and these differences were borne out when harvesting the commercial crop. Bruises were also deeper in Expt 1 than in Expt 2. There was substantial rainfall (Expt 1, 36 mm; Expt 2, 65 mm) in the 3 weeks prior to desiccation but SMDs in Expt 1 reached 59 mm in Dry plots and 44 mm in Wet and exceeded the Limiting SMD for growth in Dry plots in the week prior to desiccation (Figure 1). In Expt 2, SMDs reached 57 mm in Dry plots and 43 mm in Wet. The SMD in the Dry plots exceeded the Limiting SMD for 13 days but had dropped by the time of desiccation (Table 1; Figure 1).

Table 1. Effect of irrigation regime on blackspot bruising, skinning and soil moisture deficits in the 3 weeks prior to desiccation in Expts 1 and 2

		Soil moisture deficit (mm)		Blackspot bruising		Skinning
Expt	Irrigation regime	Mean	Maximum	Incidence (%)	Mean bruise depth (mm)	SA† skinned (%)
1	Dry late	43	59	61.3	4.3	12.2
	Wet late	30	44	61.0	4.3	10.2
	S.E. (5 D.F.)	-	-	2.08	0.09	0.92
2	Dry late	46	57	37.3	3.8	10.6
	Wet late	29	43	39.0	4.0	11.5
	S.E. (5 D.F.)	-	-	3.33	0.17	0.63

†Surface area

Figure 1. Soil moisture deficit (SMD) and ground cover in *(a)* Expt 1, Dry late; *(b)* Expt 1, Wet late; *(c)* Expt 2, Dry late; *(d)* Expt 2, Wet late. Modelled SMD, ——; limiting SMD, – –; ground cover, ——.



4.1.2. Commercial crops

Data collected from the commercial crops showed that bruising incidence was very high in some crops in 2011 (Table 2). The incidence of blackspot bruising was often very variable within fields (e.g. 6- 46 %) and between fields in the same variety (e.g. 22-50 % in Maris Piper, 30-55 % in Markies and 32-53 % in Saturna). The depth of bruise was generally greater in Markies and Russet Burbank than in the other varieties tested in more than one field (Table 2).

Several crops died prematurely in August (e.g. GFP Highmind Top and GFP Old Close Bottom Saturna crops) and bruising incidence was high. Although two of the Markies crops which developed large SMDs prior to bruise assessment (Figure 2*f*; *g*) had a higher incidence of blackspot bruising than one maintained much wetter during August (Figure 2*h*; Table 2), the SMD prior to desiccation or harvest in other varieties was not closely correlated with bruising incidence (Table 2 and Figure 2).

Table 2. Blackspot bruising and soil moisture deficits in the 3 weeks prior to harvest or desiccation in commercial fields in 2011

Grower/Field	Variety	Date of harvest	Soil moisture deficit Mean (mm)	Soil moisture deficit Max. (mm)	Blackspot bruising† Incidence (%)	Blackspot bruising† Mean depth of bruise (mm)
Fridlington Field 11	Hermes	31 Aug	12	19	36 (12.3)	5.2 (0.28)
SML Pins	L Rosetta	1 Sep	24	43	36 (11.7)	5.4 (0.46)
SML Hill	Linton	6 Sep	12	18	64 (10.5)	5.6 (0.77)
Manor Fresh	M Piper	19 Sep	38	54	41 (9.3)	4.0 (0.28)
GVAP 18 Acres	M Piper	14 Sep	40	53	50 (3.1)	4.7 (0.07)
SML Upper Root	Markies	8 Sep	60	73	55 (8.8)	4.9 (0.21)
SML Upper Dog	Markies	8 Sep	66	79	45 (6.9)	4.8 (0.19)
SML Bucher America	Markies	4 Sep	15	28	20 (6.2)	4.1 (0.36)
B & C Medler	R Burbank	30 Aug	37	49	60 (8.4)	4.6 (0.19)
B & C GF91	R Burbank	30 Aug	20	37	49 (4.1)	4.8 (0.25)
Bere Big Mead	Sante	24 Aug	28	38	40 (9.9)	4.7 (0.25)
GFP Highmind Top	Saturna	10 Aug	19	37	53 (6.4)	4.2 (0.26)
GFP Old Close Bottom	Saturna	10 Aug	17	34	41 (5.9	3.9 (0.19)
SML Walsingham Estate	Saturna	28 Aug	31	51	32 (6.5)	4.3 (0.22)
Westgarth Stanwick Wall	Saturna	30 Aug	30	41	45 (9.6)	4.0 (0.20)

†S.E. in ()

Figure 2. Soil moisture deficit (SMD) and ground cover in commercial crops in 2011. *(a)* Fridlington Field 11; *(b)* SML Pins; *(c)* SML Hill; *(d)* Manor Fresh; *(e)* GVAP 18 Acres; *(f)* SML Upper Root; *(g)* SML Upper Dog; *(h)* SML Bucher America. Modelled SMD, —; limiting SMD, – –; ground cover, —.

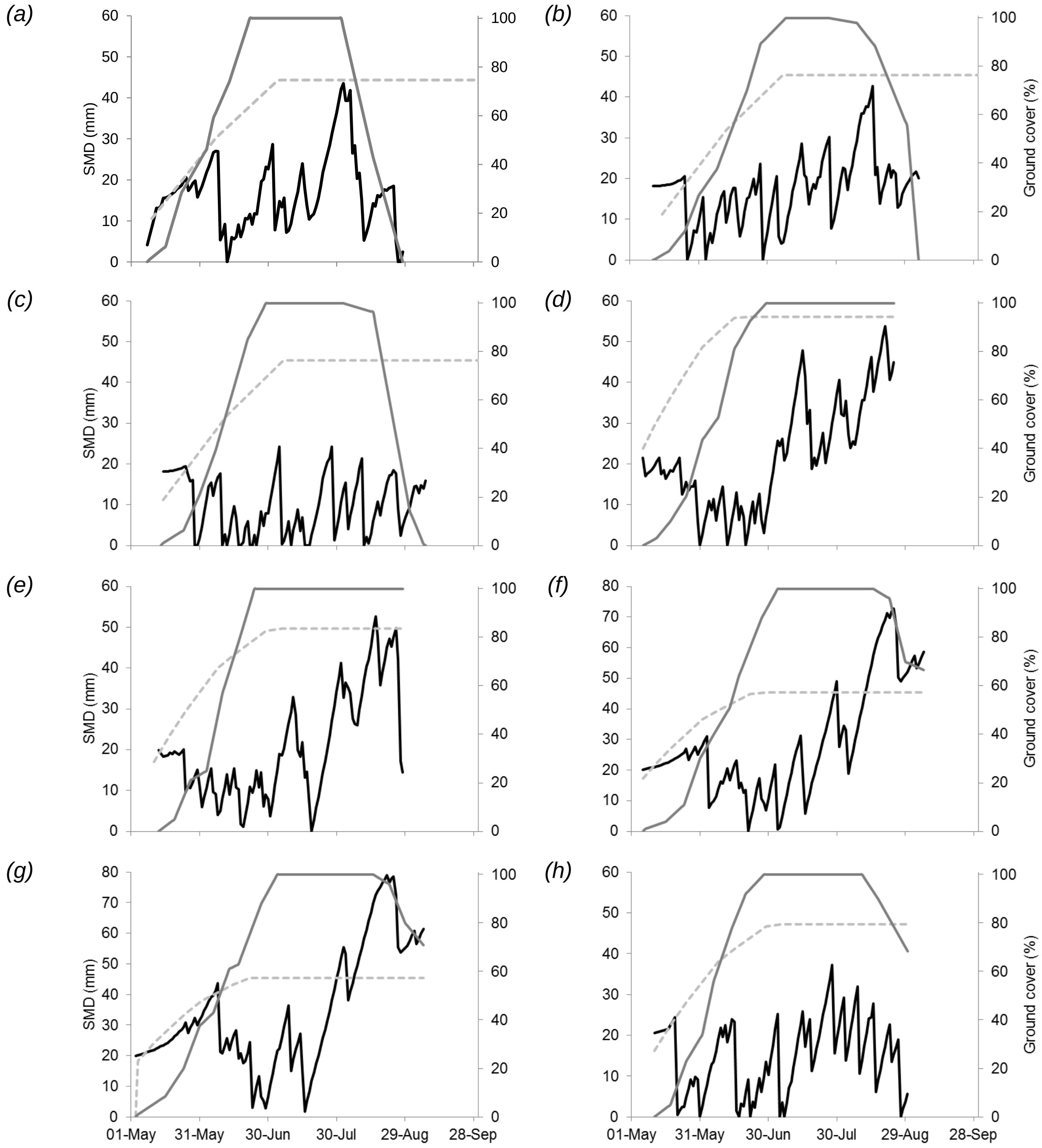
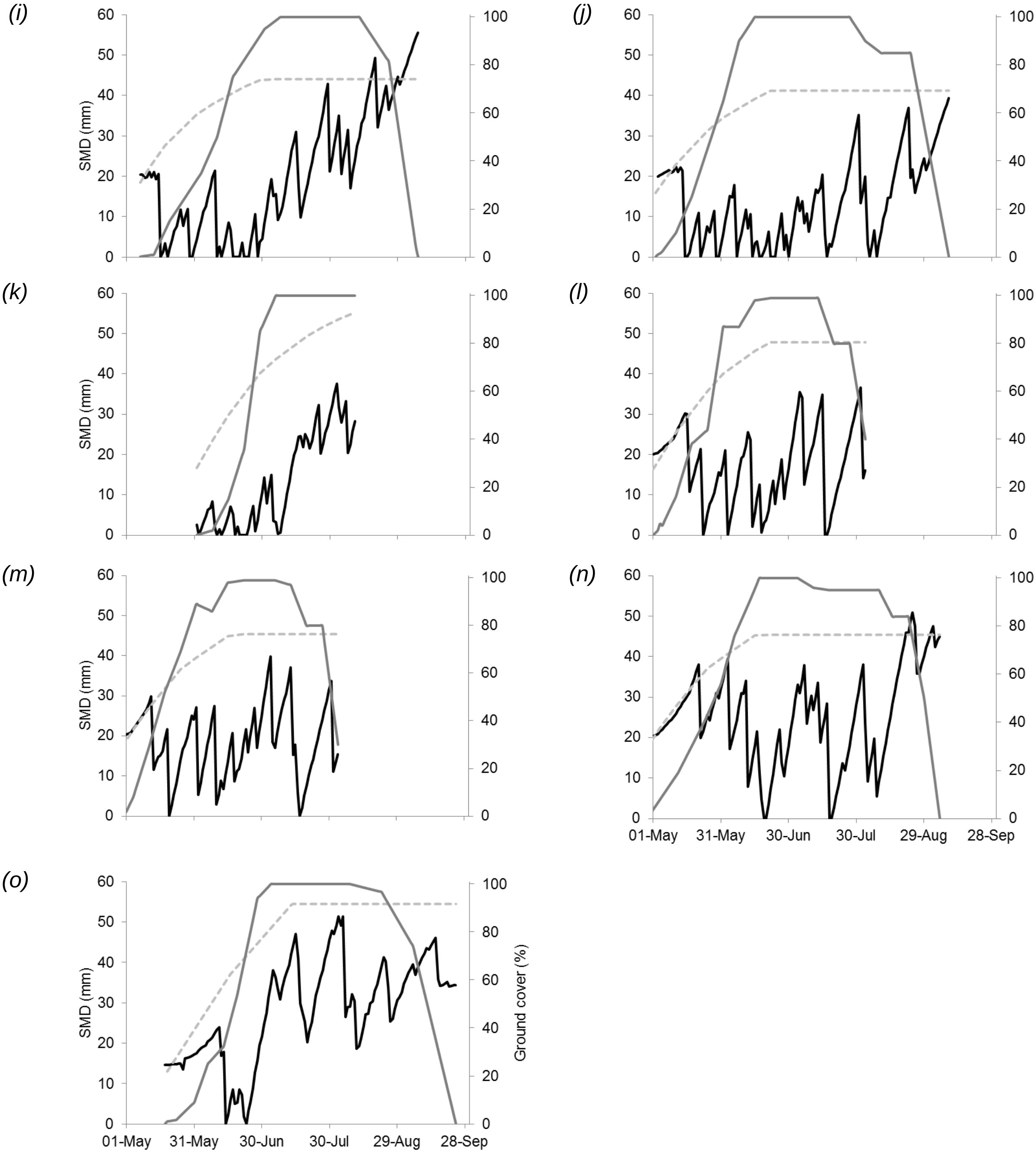


Figure 2. **(cont.) Soil moisture deficit (SMD) and ground cover in commercial crops in 2011. *(i)* B & C Medler; *(j)* B & C GF91; *(k)* Bere Big Mead; *(l)* GFP Highmind Top; *(m)* GFP Old Close Bottom; *(n)* SML Walsingham Estate; *(o)* Westgarth Stanwick Wall. Modelled SMD, —; limiting SMD, – –; ground cover, —.**



4.2. 2012

4.2.1. Experiments 3 and 4

Soil moisture deficits in both experiments reached substantial levels in Dry plots and there were considerable differences in maximum and mean SMDs between Dry and

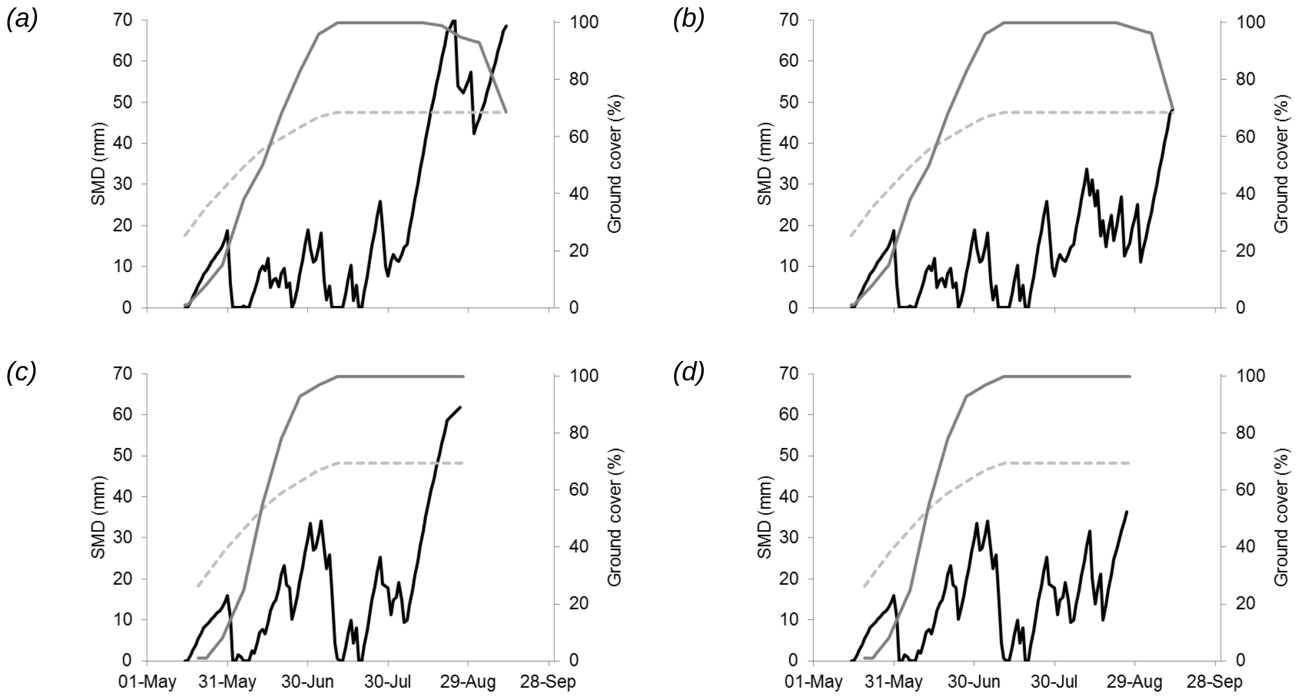
Wet treatments over the 3 weeks prior to desiccation or harvest (Table 3; Figure 3). In both experiments, there was a significant increase in blackspot bruising where soils were allowed to dry out and bruises were deeper in Dry compared to Wet treatments in Expt 2 (Table 3). There was no difference in skinning caused by maintaining soils wet or dry close to harvest or desiccation (Table 3).

Table 3. Effect of irrigation regime on blackspot bruising, skinning and soil moisture deficits in the 3 weeks prior to desiccation in Expts 3 and 4

		Soil moisture deficit (mm)		Blackspot bruising		Skinning
Expt	Irrigation regime	Mean	Maximum	Incidence (%)	Mean bruise depth (mm)	SA† skinned (%)
3	Dry late	56	71	38.0	4.2	20.0
	Wet late	22	40	29.7	4.0	20.1
	S.E. (5 D.F.)	-	-	2.41	0.06	1.28
4	Dry late	42	63	42.3	4.6	35.8
	Wet late	22	36	29.3	4.2	36.5
	S.E. (5 D.F.)	-	-	2.14	0.08	1.61

†Surface area

Figure 3. Soil moisture deficit (SMD) and ground cover in *(a)* Expt 3, Dry late; *(b)* Expt 3, Wet late; *(c)* Expt 4, Dry late; *(d)* Expt 4, Wet late. Modelled SMD, ──; limiting SMD, – –; ground cover, ──.



4.2.2. Commercial crops

Data collection from the commercial crops showed that bruising incidence was very high in some of the selected crops in 2012. The incidence of blackspot bruising was very variable within fields (e.g. 12-50 %). Where irrigation was ceased in August and SMDs exceeded the limiting SMD for yield, significant bruising was observed (Table 4; Figure 4).

Table 4. Blackspot bruising and soil moisture deficits in the 3 weeks prior to harvest or desiccation in commercial fields in 2012

			Soil moisture deficit		Blackspot bruising†	
Grower/Field	Variety	Date of harvest	Mean (mm)	Max. (mm)	Incidence (%)	Mean depth of bruise (mm)
SML Bakers 1 Light	L Rosetta	13 Sep	23	36	56 (6.3)	5.6 (0.33)
SML Bakers 1 Heavy	L Rosetta	13 Sep	23	35	62 (7.9)	5.5 (0.36)
Jolly Dyball Roadmans	L Rosetta	6 Sep	15	24	42 (5.4)	4.9 (0.33)
B & C Oxnead 3	M Piper	7 Sep	20	41	36 (4.2)	4.4 (0.16)
GVAP Norton Road Light	M Piper	13 Sep	39	42	32 (3.1)	4.3 (0.16)
GVAP Norton Road Heavy	M Piper	13 Sep	26	49	26 (2.8)	4.5 (0.19)
Jolly Larwood Concrete	M Piper	6 Sep	18	32	27 (5.1)	3.9 (0.14)
Papworth Felmingham 14	M Piper	26 Sep	69	80	35 (2.1)	4.2 (0.25)
Papworth Sco Marlers	M Piper	26 Sep	72	81	42 (4.6)	4.3 (0.21)
SML Orchard	Markies	13 Sep	19	31	12 (1.9)	3.9 (0.26)
SML Barn Breck	Markies	13 Sep	25	38	15 (3.4)	4.2 (0.22)
SML Big Field SE	Markies	13 Sep	26	46	18 (2.7)	4.3 (0.27)
B & C PF3	R Burbank	7 Sep	25	40	31 (7.9)	4.4 (0.18)
B & C Fengate 12	R Burbank	7 Sep	13	36	66 (6.6)	5.1 (0.46)
B & C Medler Crow	R Burbank	7 Sep	21	41	55 (8.9)	4.4 (0.27)
B & C Grove Farm 82	R Burbank	7 Sep	11	29	52 (6.7)	4.5 (0.33)
GFP 66 Acres	Saturna	12 Sep	49	59	60 (4.5)	4.4 (0.29)
Papworth Bungalow Light	Saturna	11 Sep	49	62	31 (2.9)	4.0 (0.21)
Papworth Bungalow Heavy	Saturna	11 Sep	47	60	28 (3.0)	3.9 (0.23)
SML Hammond Prestons	Saturna	18 Sep	60	69	39 (3.6)	4.0 (0.19)
SML Hammond H Meadow	Saturna	18 Sep	59	69	20 (2.0)	3.8 (0.20)
SML Hammond Bens Close	VR808	18 Sep	58	70	26 (2.7)	4.2 (0.30)

†S.E. in ()

Figure 4. Soil moisture deficit (SMD) and ground cover in commercial crops in 2012. *(a)* SML Bakers 1 Light; *(b)* SML Bakers 1 Heavy; *(c)* Jolly Dyball Roadmans; *(d)* B & C Oxnead 3; *(e)* GVAP Norton Road Light; *(f)* GVAP Norton Road Heavy; *(g)* Jolly Larwood Concrete; *(h)* Papworth Felmingham 14. Modelled SMD, ──; limiting SMD, – –; ground cover, ──.

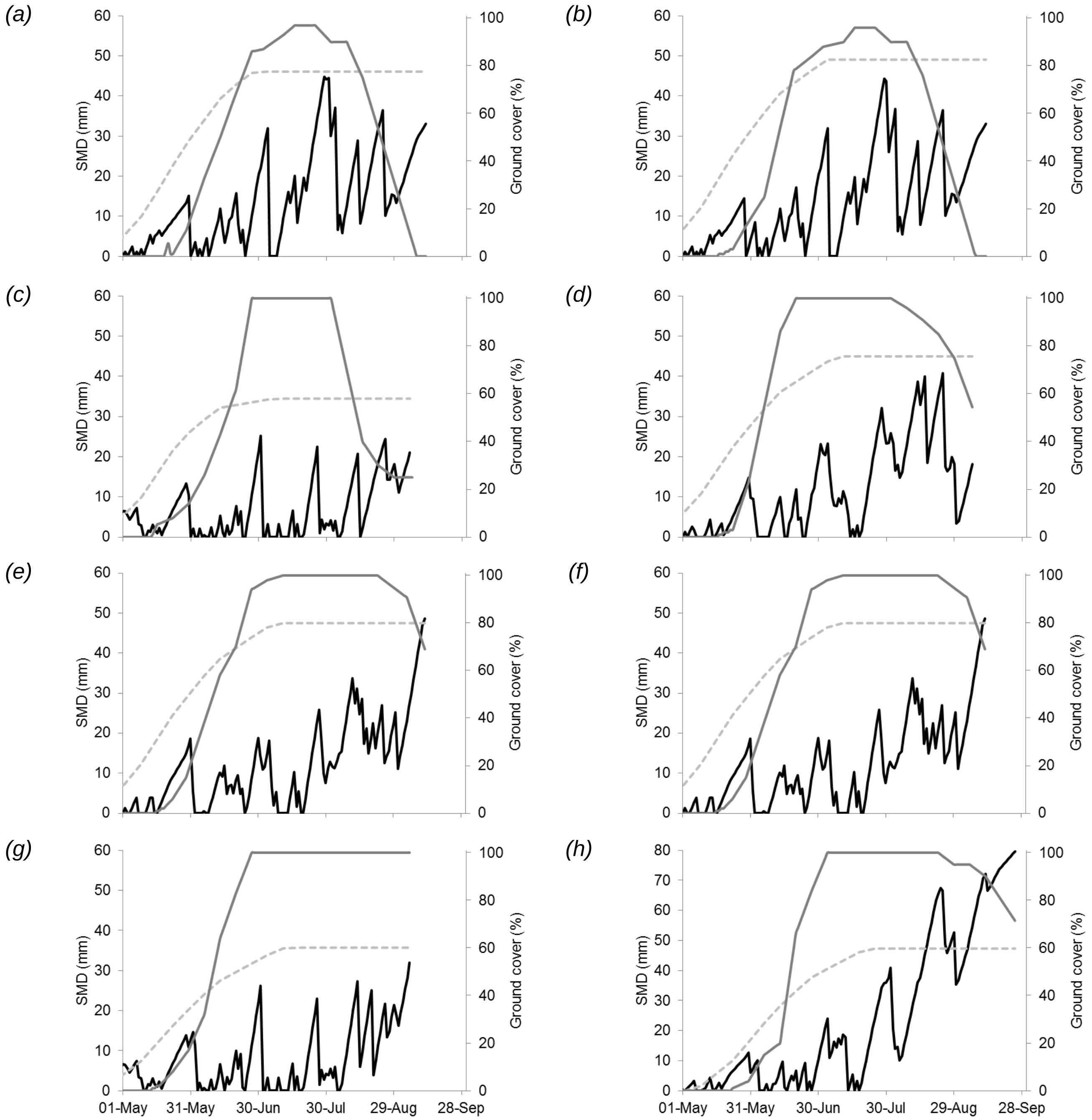


Figure 4. (cont.) Soil moisture deficit (SMD) and ground cover in commercial crops in 2012. *(i)* Papworth Sco Marlers; *(j)* SML Orchard*;* *(k)* SML Barn Breck; *(l)* SML Big Field SE; *(m)* B & C PF3; *(n)* B & C Fengate 12; *(o)* B & C Medler Crow; *(p)* B & C Grove farm 82. Modelled SMD, ——; limiting SMD, — —; ground cover, ——.

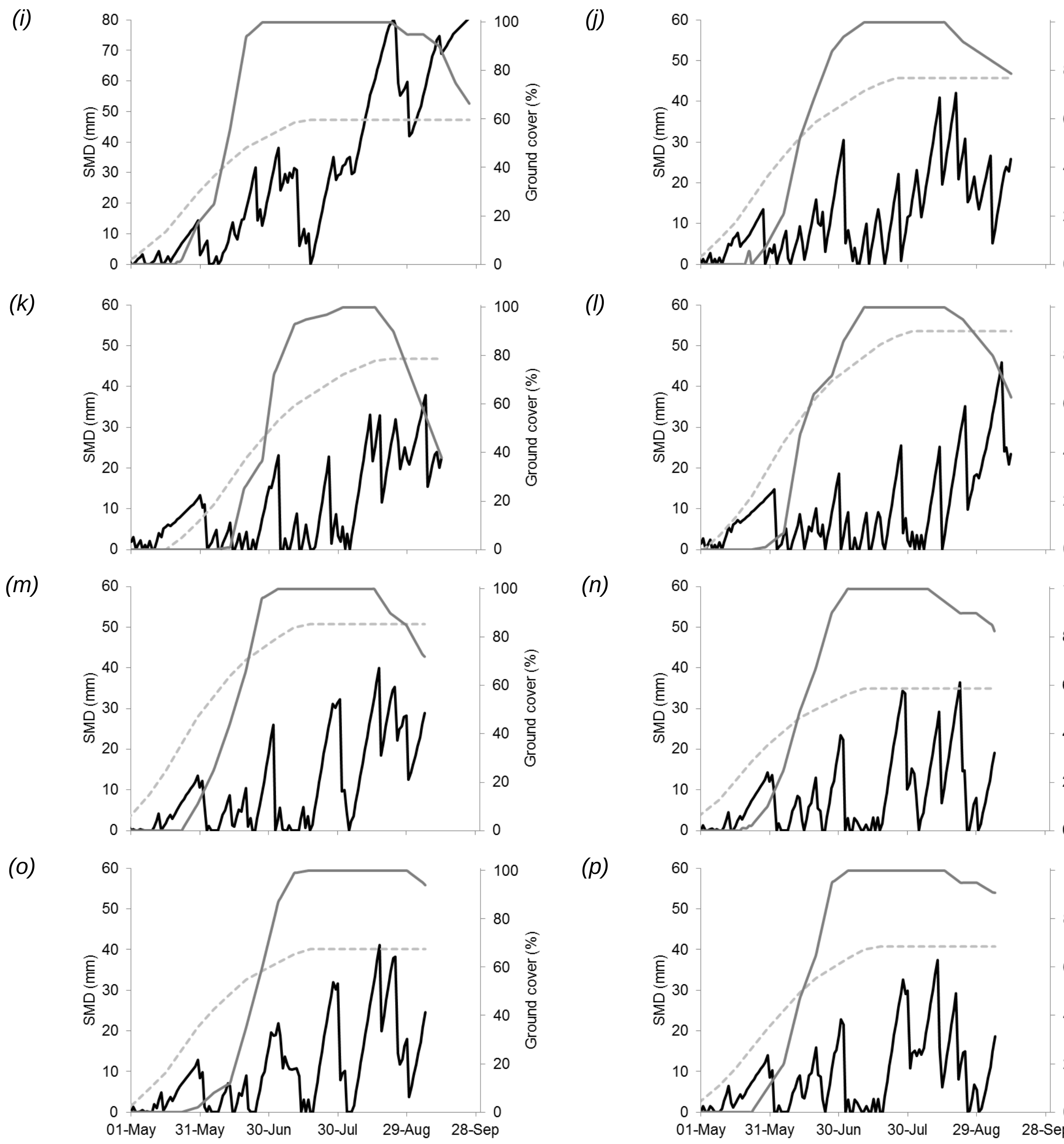
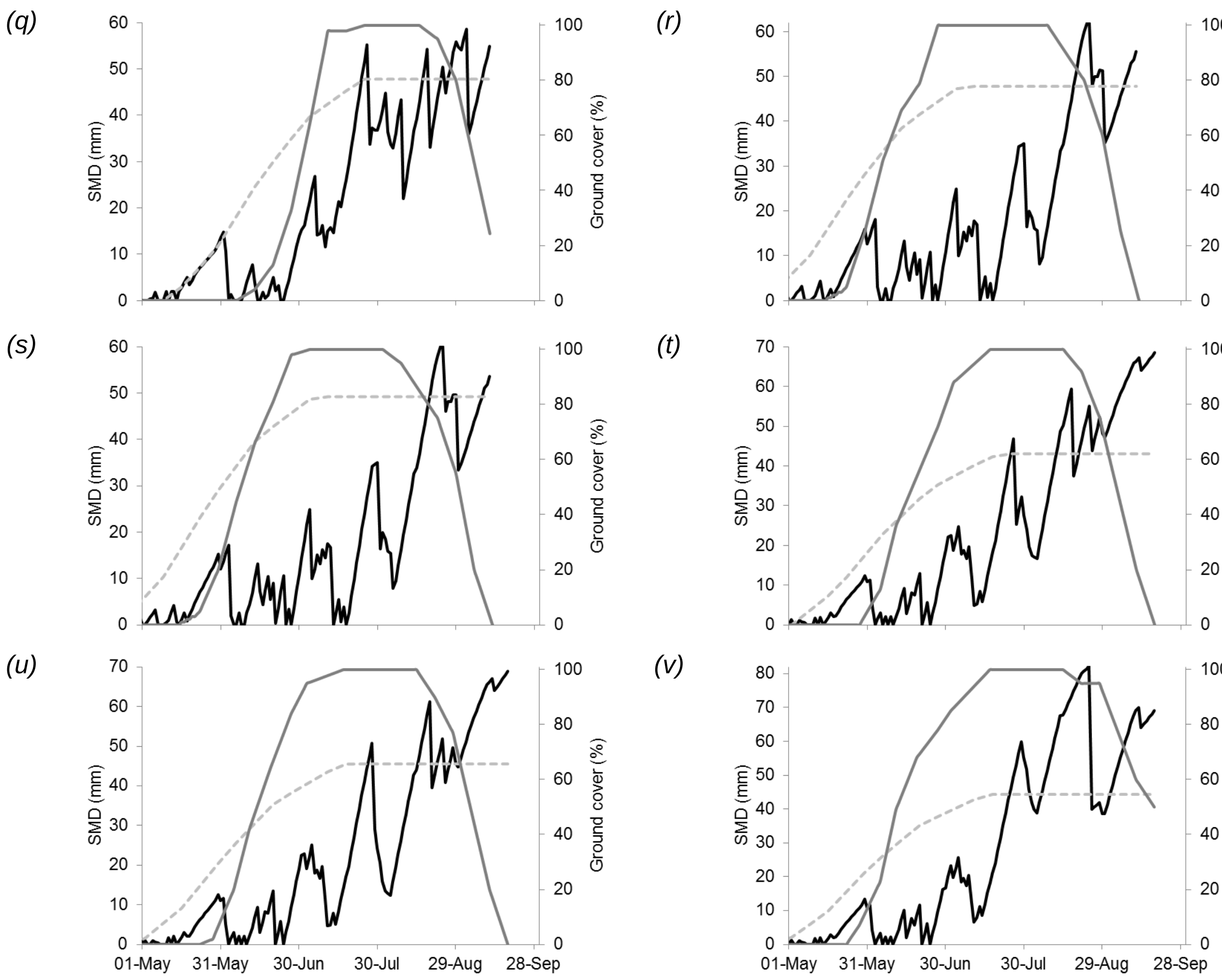


Figure 4. **(cont.) Soil moisture deficit (SMD) and ground cover in commercial crops in 2012. *(q)* GFP 66 Acres; *(r)* Papworth Bungalow Light; *(s)* Papworth Bungalow Heavy; *(t)* SML Hammond Prestons; *(u)* SML Hammond H Meadow; *(v)* SML Hammond Bens Close. Modelled SMD, ──; limiting SMD, – –; ground cover, ──.**



4.3. 2013

4.3.1. Experiments 5 and 6

Soil moisture deficits in both experiments reached substantial levels in Dry plots and there were considerable differences in maximum and mean SMDs between Dry and Wet treatments over the 3 weeks prior to desiccation or harvest (Figure 5). In both experiments, there was a significant increase in blackspot bruising where soils were allowed to dry out (Table 5). There was no difference in depth of bruising between irrigation regimes but Expt 5 had deeper bruises than Expt 6 (Table 5). The bruising results support the data from 2012.

Figure 5. Soil moisture deficit (SMD) and ground cover in *(a)* Expt 5, Dry late; *(b)* Expt 5, Wet late; *(c)* Expt 6, Dry late; *(d)* Expt 6, Wet late. Modelled SMD, ──; limiting SMD, – –; ground cover, ──.

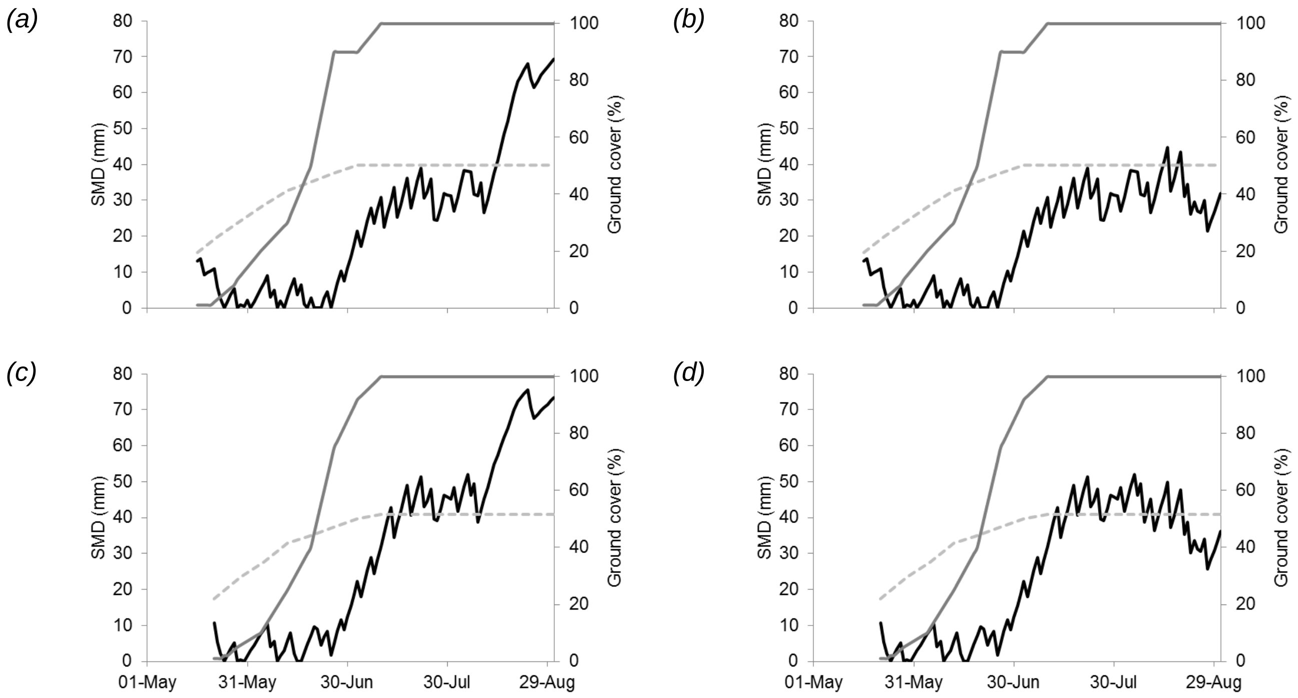


Table 5. Effect of irrigation regime on blackspot bruising, skinning and soil moisture deficits in the 3 weeks prior to desiccation in Expts 5 & 6

		Soil moisture deficit (mm)		Blackspot bruising		Skinning
Expt	Irrigation regime	Mean	Maximum	Incidence (%)	Mean bruise depth (mm)	SA† skinned (%)
5	Dry late	67	76	29.3	4.9	11.8
	Wet late	37	50	20.5	4.9	13.5
	S.E. (5 D.F.)	-	-	2.90	0.27	0.57
6	Dry late	57	69	45.3	4.5	17.9
	Wet late	32	45	31.7	4.6	19.8
	S.E. (5 D.F.)	-	-	0.99	0.16	1.31

†Surface area

There was no difference in skinning caused by maintaining soils wet or dry close to harvest or desiccation (Table 5), which supports the findings of Expts1-4 conducted in 2011 and 2012, indicating that avoiding of bruising should be the key to late-season irrigation management rather than the possibility of delayed skinset in late-watered crops.

4.3.2. Commercial crops

Data collection from the commercial crops showed that bruising incidence was again very high in some of the selected crops in 2013 (Table 6) but the range was similar to 2011-12. Similar to other seasons, the incidence of blackspot bruising was also very variable within some fields (e.g. 18-68 % in one field of Russet Burbank). Soil moisture deficits are shown in Figure 6.

Table 6. Blackspot bruising and soil moisture deficits in the 3 weeks prior to harvest or desiccation in commercial fields in 2013

			Soil moisture deficit		Blackspot bruising†	
Grower/Field	Variety	Date of harvest	Mean (mm)	Max. (mm)	Incidence (%)	Mean depth of bruise (mm)
B & C Booton 31	R Burbank	9 Sep	46	67	49 (9.0)	4.8 (0.25)
B & C Grove Farm 94	R Burbank	9 Sep	20	36	38 (17.7)	5.1 (0.46)
B & C Medlers	R Burbank	9 Sep	28	46	44 (6.9)	4.7 (0.29)
B & C Oxnead 4	M Piper	9 Sep	45	61	24 (4.5)	3.9 (0.26)
Jolly 14 E/W	M Piper	17 Sep	48	59	29 (4.8)	4.0 (0.22)
SML Below Bomb Dump	Markies	25 Sep	25	36	28 (5.6)	5.1 (0.26)
SML Cley Hall 28 Acres	Markies	25 Sep	56	67	28 (4.2)	4.9 (0.15)
SML Wace Alwyns	Markies	25 Sep	45	59	18 (3.1)	4.9 (0.28)
SML Cley Hall Clay Pit	Saturna	29 Aug	48	68	40 (7.9)	4.2 (0.31)
SML Hammond Smeeths	Saturna	29 Aug	51	67	29 (4.2)	3.8 (0.24)
GFP Big Entre Breck	VR808	31 Aug	25	44	38 (5.9)	4.4 (0.26)
GFP Barn Field	VR808	31 Aug	34	55	24 (3.6)	4.1 (0.25)
GFP Allotment Road	VR808	31 Aug	31	51	16 (4.2)	4.2 (0.29)

†S.E. in ()

Figure 6. Soil moisture deficit (SMD) and ground cover in commercial crops in 2013. *(a)* B & C Booton 31; *(b)* B & C Grove Farm 94; *(c)* B & C Medlers; *(d)* B & C Oxnead 4; *(e)* Jolly 14 E/W; *(f)* SML Below Bomb Dump; *(g)* SML Cley Hall 28 Acres; *(h)* SML Wace Alwyns. Modelled SMD, ──; limiting SMD, – –; ground cover, ──.

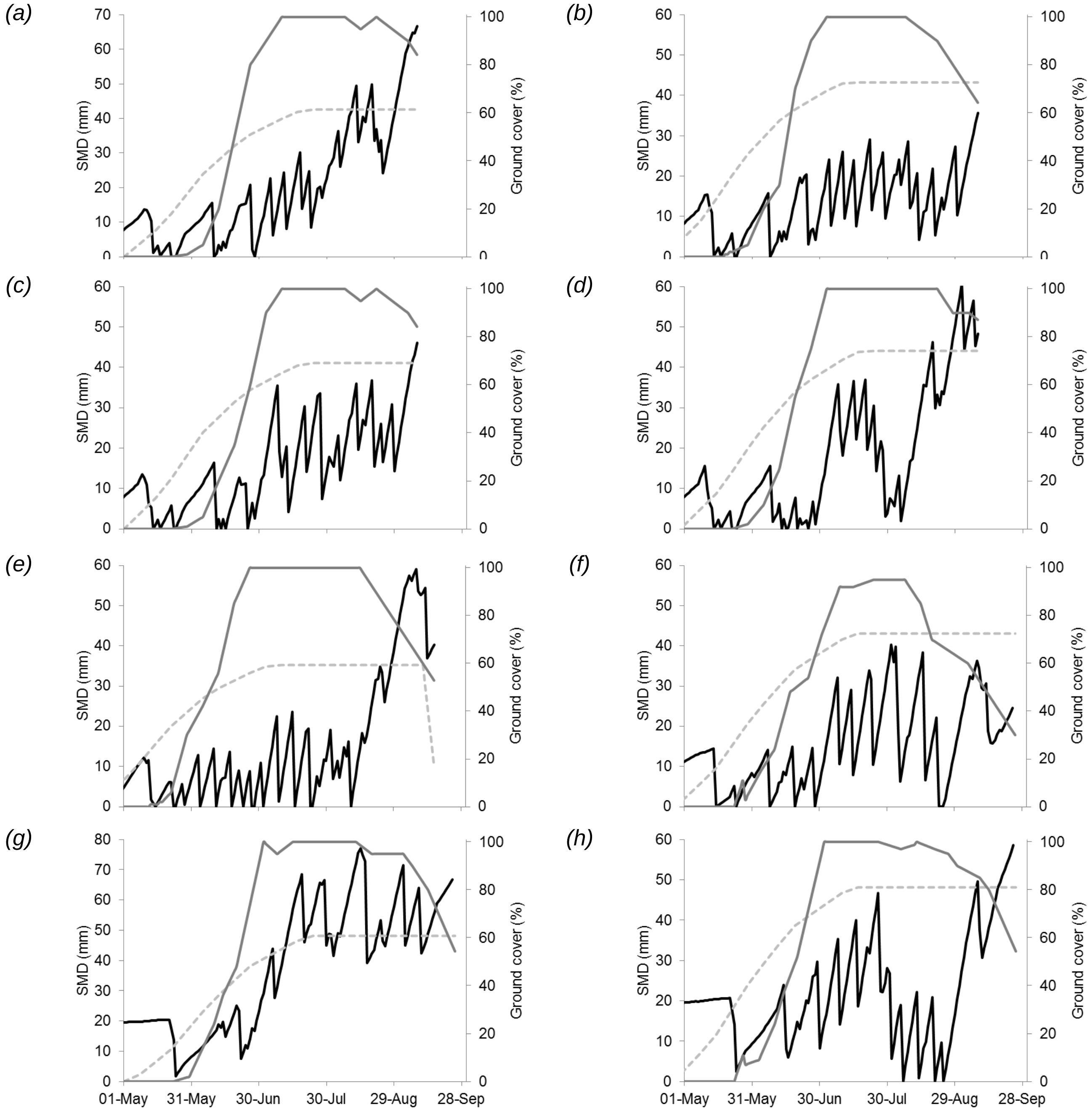
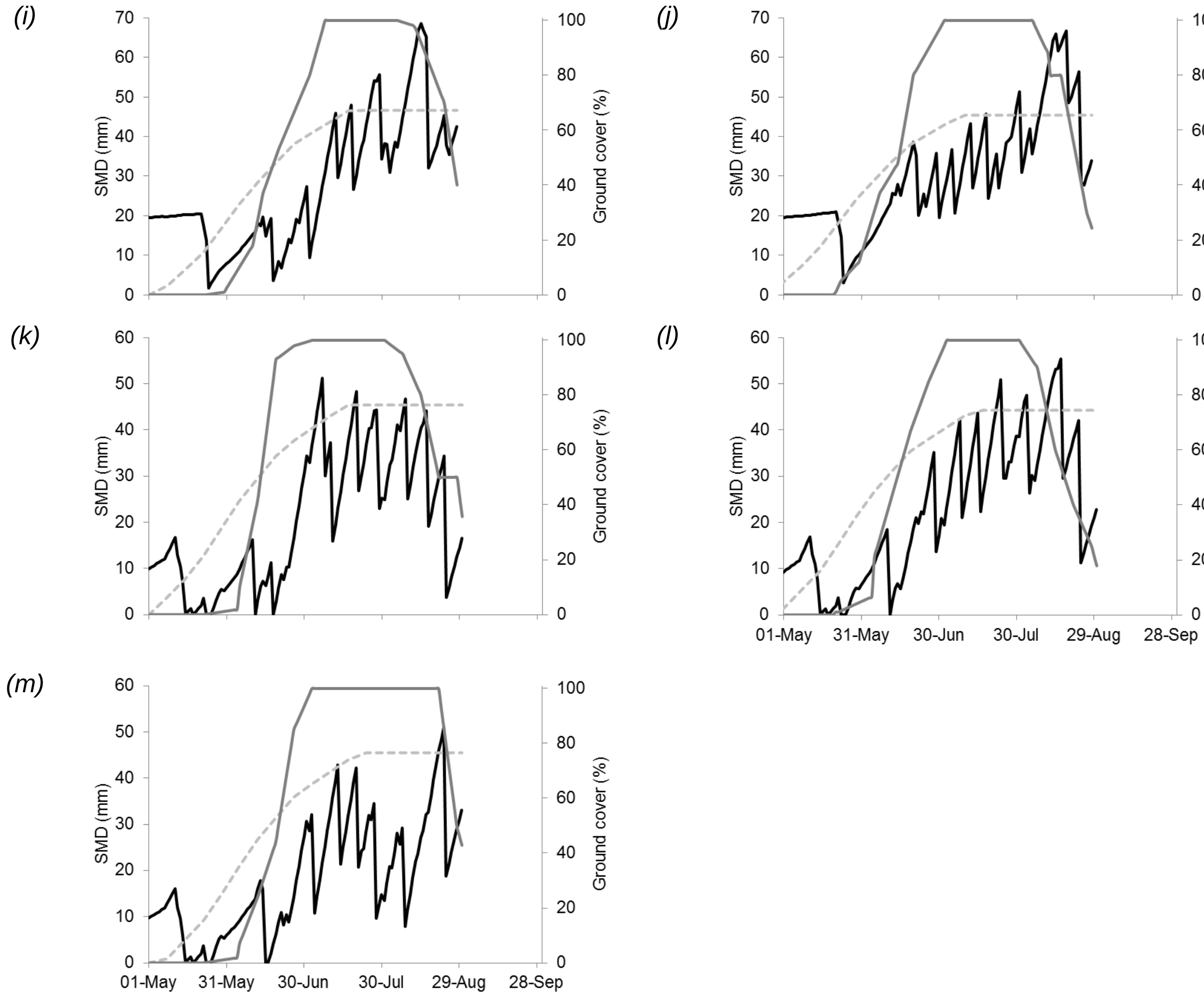


Figure 6. **(cont.) Soil moisture deficit (SMD) and ground cover in commercial crops in 2013.** ***(i)*** **SML Cley Hall Clay Pit;** ***(j)*** **SML Hammond Smeeths*;*** ***(k)*** **GFP Big Entre Breck;** ***(l)*** **GFP Barn Field;** ***(m)*** **GFP Allotment Road. Modelled SMD, ──; limiting SMD, ‒ ‒; ground cover, ──.**

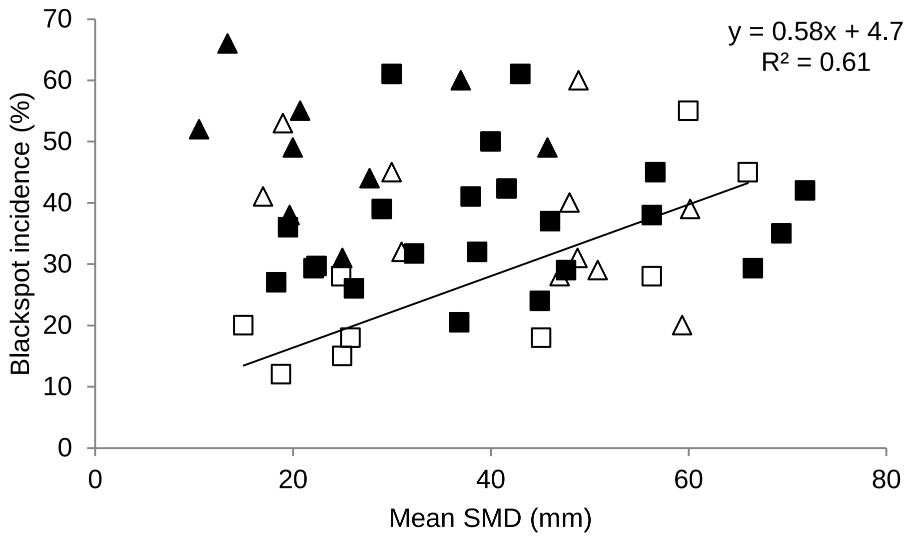


4.4. Relationship between bruising and measures of soil moisture deficit

When examining the relationship between blackspot bruise incidence and measures of soil wetness in the 3 weeks prior to desiccation or harvest (maximum SMD, mean SMD, accumulated SMD-days or “stress” SMD (the accumulated SMD above the Limiting SMD for yield)), there was no correlation when grouping all varieties used in the programme together, either within a season or using the data from all three seasons. When comparing the relationships within the four most commonly-used varieties (Maris Piper, Markies, Russet Burbank and Saturna) across all three seasons, there was again no relationship between bruising and any measure of SMD, except in Markies where there was a significant positive linear correlation between blackspot incidence and all of the four measures of SMD prior to harvest or desiccation (Figure 7; Figure 8).

Figure 7. Relationship between blackpot incidence and *a)* mean SMD; *b)* maximum SMD during the 3 weeks prior to desiccation or harvest in 2011-2013. Data from four major varieties. Maris Piper, ■; Markies, □; Russet Burbank, ▲; Saturna, △. Only significant relationship is for Markies (solid line). Relationships for Markies shown in figure.

a)



b)

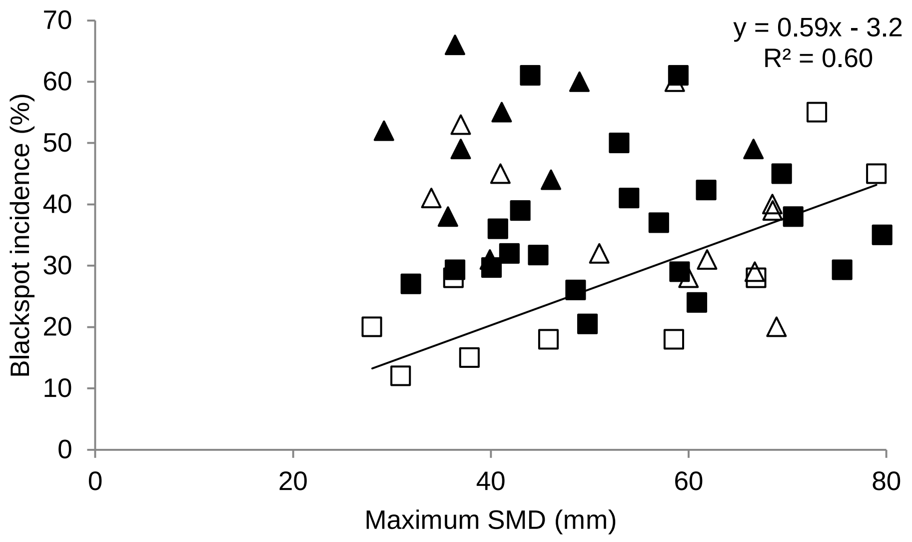
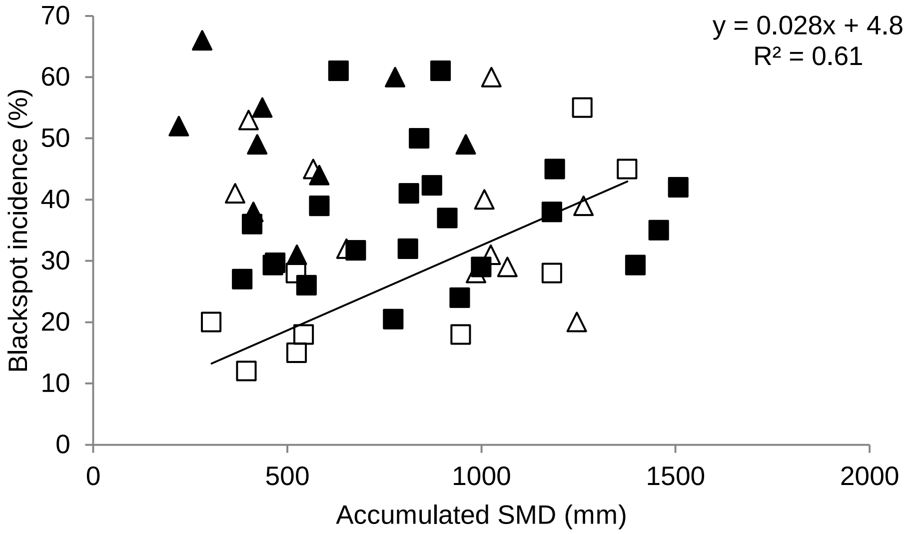
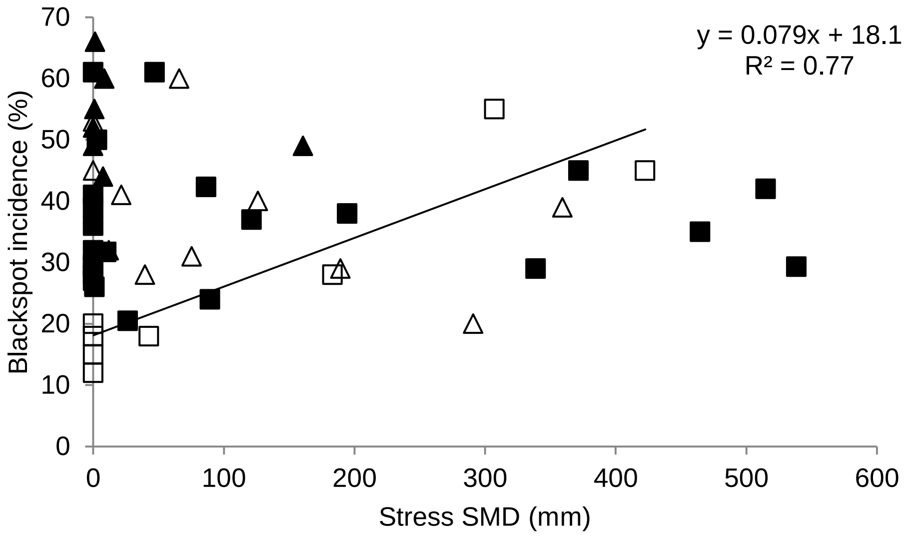


Figure 8. **Relationship between blackpot incidence and *a)* accumulated SMD; *b)* stress SMD during the 3 weeks prior to desiccation or harvest in 2011-2013. Data from four major varieties. Maris Piper, ■; Markies, □; Russet Burbank, ▲; Saturna, △,. Only significant relationship is for Markies (solid line). Relationships for Markies shown in figure.**

a)



b)



5. Discussion and Conclusions

The project hypothesis, that allowing soils to dry out excessively prior to desiccation or during canopy senescence leads to increased risk of blackspot bruising, was supported by the experimental programme in 2012 and 2013 but not in 2011 where rainfall prevented sustained periods of high SMDs prior to desiccation. There was little effect of irrigation regime on bruise depth but there were differences between sites within seasons, corroborating that an increased sensitivity to bruising results in a greater severity of cellular collapse around the impact site.

The incidence of bruising in commercial crops was variable both within and between fields and varieties. In the varieties most susceptible to bruising, damage incidence was high (e.g. 49-60 % blackspot incidence in Russet Burbank and 32-53 % in Saturna). Whilst there were large differences between crops in SMD management close to desiccation or canopy death, it was not apparent that these were the major cause of differences in bruising. However, there were a few instances where the selection of the sampling sites in commercial fields produced supporting evidence for the controlled-experiment work. For example, in 2013 B & C Grove 94 Russet Burbank, two of the sample sites were in areas that could not be reached by the irrigator and the bruising incidence was 56-68 %, whereas it was < 30 % in the irrigated areas. Another example was in 2011 Fridlington Field 11 Hermes, where three of the sites were on sandy outcrops and the canopies were completely dead at sampling. The bruising incidence was *c*. 50 % in the sandy areas where the soil was very dry and < 27 % in the heavier areas where the soil retained moisture and the crop canopies survived longer.

This project demonstrated that in controlled experiments it is possible to reduce bruising by maintaining moderate SMDs close to desiccation or crop death when compared to rainfed crops as long as large differences in SMD are maintained between dry and wet treatments. In reality, this does not mean maintaining soil close to field capacity but merely close to the limiting SMD for yield and this should reduce the extent of bruising compared to crops where the SMD increases to 30 mm or more above the limiting SMD. However, the overall poor relationships between blackspot incidence and measures of SMD found in commercial fields may be partly due to the variation in bruising within fields since the SMD data were calculated from mean ground cover data rather than individual locations in the field where bruise samples were collected and irrigation data were only supplied as the mean for the field rather than the individual sample locations. There also may be confounding factors associated with different fields which distort any relationship between bruising and some measure of soil or crop water status e.g. soil compaction, nutritional status or uneven irrigation distribution from rainguns.

Late-season irrigation did not affect the extent of skinset, indicating that avoiding of bruising should be the key to late-season irrigation management rather than the possibility of delayed skinset in late-watered crops.

6. References

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7. Acknowledgements

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