Final Report

Factors affecting tuber numbers per stem leading to improved seed rate recommendations

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CONTENTS

1. SUMMARY 4

2. INTRODUCTION 5

3. MATERIALS AND METHODS 5

3.1. Seed production 5
3.2. Field experiments in 2010 7
3.3. Experiments 1-4 9
3.4. Experiments 5-8 9
3.5. Experiments 9-11 9
3.6. Experiments 12-13 9
3.7. Experiment 14 9
3.8. Experiment 15 10
3.9. Experiment 16 10
3.10. Experiment 17 10
3.11. Experiments 18-30 11
3.12. Experiment 31 12
3.13. Soil survey 2010 12
3.14. Soil analysis of 2009 experiments 12
3.15. Investigation of radiation absorption during tuber initiation 13

4. RESULTS AND DISCUSSION 15

4.1. Experiments 1-4 Seed size and stock 15
4.2. Experiment 5 Density - King Edward 18
4.3. Experiment 6 Density - Marfona 21
4.4. Experiment 7 Density - Pentland Dell 23
4.5. Experiment 8 Density - Russet Burbank 25
4.6. Experiment 9 Planting and density - Estima 27
4.7. Experiment 10 Planting and density - Lady Rosetta 30
4.8. Experiment 11 Planting and density - Maris Peer 33
4.9. Experiment 12 Multiple date of planting - Maris Peer 36
4.10. Experiment 13 Multiple date of planting - Estima 38
4.11. Experiment 14 Soil condition - Maris Peer 39
4.12. Experiment 15 Clod size and soil type - Estima 46
4.13. Experiment 16 Soil temperature - Estima and Hermes 50
4.14. Experiment 17 Soil type - Maris Peer 54
4.15. Experiment 18-30 Sites - Estima, Maris Piper and Lady Rosetta 57
4.16. Experiment 31 Cultivation and irrigation - Lady Rosetta and Maris Piper 61
4.17. Soil survey Frontier 2010 63
4.18. Soil analysis of 2009 experiments 65
4.18.1. Experiment 14 Soil condition - Maris Peer 65
4.18.2. Experiment 15 Clod size and soil type - Estima 65
4.18.3. Experiments 18-31 Sites - Estima, Maris Piper and Lady Rosetta 67
4.19. Investigation of radiation absorption during tuber initiation 69

5. CONCLUSIONS 80

6. REFERENCES 82

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1. SUMMARY

Factors affecting the number of tubers per stem were investigated in a series of experiments and in commercial crops with a range of varieties over three years. Experiments were also conducted to enable new seed rate recommendations to be developed for King Edward, Marfona, Pentland Dell and Russet Burbank by quantifying the relationship between stem production, seed age and seed size.

Effects of seed age on the number of stems were smaller for King Edward, Marfona, Pentland Dell and Russet Burbank than most varieties studied previously but have been used together with the other varietal characters quantified to derive new seed rate recommendations and a simplified system for determining seed rates from these characters.

Raising soil temperature during tuber initiation had no consistent effect on either the number of tubers initiated or retained in any year. Manipulating soil conditions by cultivation generated relatively small differences in bulk density, soil resistance and ped size and there were limited effects on the number of tubers. There was however some data to support the hypothesis that an increase in bulk density can inhibit stolon growth and reduce the number of tubers. Data from other experiments including those where ped size was manipulated indicated that large mean ped size can also reduce the number of tubers. The number of tubers from clay was consistently much lower than for other soil types and much of this effect may be attributable to large mean ped size. No consistent substantial differences in the number of tubers between sand, sandy clay loam, silt and peat were found.

There was considerable variation in the number of tubers between planting dates in each year and the number of tubers per stem varied between plantings and years. Some of the variation between years may be attributable to soil conditions. The number of tubers per stem tended to increase with incident radiation and much of the variation in number of tubers per stem was accounted for by linear regression against the absorbed radiation per stem that differed to some extent between plantings and years. Plantings in March and April produced more tubers per stem for a given amount of absorbed radiation per stem than later plantings.

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2. INTRODUCTION

Following improved understanding of effects of seed age on stem production, research has been completed on six potato varieties (Estima, Hermes, Lady Rosetta, Maris Peer, Maris Piper and Saturna) to develop new seed rate recommendations. To complement this work, the current project initiated in 2008 has produced data to provide recommendations for the four additional varieties, King Edward, Marfona, Pentland Dell and Russet Burbank and investigated the extent to which more crop-specific recommendations can be provided to account for variation in the number of tubers per stem. The project has also allowed for development of a system to enable seed rate recommendations for new varieties to be provided with limited requirement for extensive field experiments.

For the development of new seed rate recommendations, the relationship between stem production, seed age and seed size was derived from a series of experiments conducted over 3 years. The relationship between the number of tubers, yield and stem population was investigated in a similar way quantifying experimentally the effect of factors that may affect the number of tubers per stem and through the extended collation and analysis of historic data sets (Firman et al. 2007).

This report provides results for the series of experiments carried out in Cambridge and other sites in 2010 with reference to the results obtained in 2009 and 2008, and analysis of meteorological data for current and historic data sets.

3. MATERIALS AND METHODS

Full materials and methods are given here for 2010. In many cases the 2010 experiments follow similar experiments conducted in 2008 and 2009 for which full materials and methods have been reported previously (Firman & Daniels 2008-2009).

3.1. Seed production

Details of the production for 2009 seed crops are given in Table 1. Mean tubers weights were determined at grading prior to cold storage (Table 2). Following harvests, all seed was initially held in commercial stores (with final holding temperature of c. 3 °C) then following grading held in experimental stores at 2 °C until just prior to planting. For Experiments 9-11 and 12-13, 200 and 260 tubers, respectively, were weighed at each planting, any rots were noted and where any sprouts were visible, the length of the longest sprout was recorded on each of 20 tubers per lot.

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Variety	Stock	Date of Planting	Emergence	Initiation	Defoliation	Harvest
King Edward	Wilts	25 May	26 Jun†	14 Jul	16 Aug	10 Sep
	Wales P2	19 Jun	5 Jul	22 Jul	1 Sep	9 Oct
Marfona	Wales P1	11 Apr	12 May	1 Jun	4 Jul	18 Aug
	Wales P2	24 Jun	10 Jul	27 Jul	1 Sep	3 Oct
Pentland Dell	Wilts	8 May	23 May†	10 Jun	16 Jul	4 Sep
	Wales P2	19 Jun	5 Jul	22 Jul	1 Sep	9 Oct
Russet Burbank	Wilts	25 May	26 Jun†	14 Jul	16 Aug	10 Sep
	Wales P2	19 Jun	5 Jul	22 Jul	1 Sep	9 Oct
Estima	Wales P1	22 Apr	20 May	6 Jun	14 Jul	6 Sep
Hermes	Wilts	25 May	27 Jun	14 Jul	16 Aug	10 Sep
Lady Rosetta	Wilts	8 May	26 May	15 Jun	16 Jul	4 Sep
	Greenseed	20 Apr	16 May	-	-	15 Sep
Maris Peer	Wales P1	21-22 Apr	22 May	9 Jun	20 Jul	8 Sep
Maris Piper	Wales P1	14 Apr	20 May	7 Jun	25 Jul	20Aug
	B&C	13 May	2 Jun	-	24 Aug	15 Oct

† Emergence data not available, emergence dates calculated as 18 days before tuber initiation.

TABLE 1. TIMING OF KEY EVENTS IN THE SEED CROPS IN 2009

Variety	Stock	Seed size (mm) 25-30	25-35	30-35	35-40	35-45	40-45	45-50	50-55
King Edward	Wilts	15.0	-	25.4	44.5	44.0	57.2	77.6	117.0
	Wales P2	19.8	-	28.0	44.2	46.6	64.7	92.0	116.0
Marfona	Wales P1	17.1	-	24.2	43.3	45.1	56.8	80.7	105.0
	Wales P2	17.6	-	23.6	43.3	42.7	63.9	95.5	116.4
Pentland Dell	Wilts	19.2	-	28.9	51.2	52.4	65.8	107.4	135.8
	Wales P2	22.9	-	35.5	59.5	60.7	76.5	118.2	-
Russet Burbank	Wilts	15.5	-	25.3	51.4	46.5	68.8	100.3	137.3
	Wales P2	21.1	-	31.0	50.0	50.8	61.3	101.4	126.7
Estima	Wales P1	-	23.6	26.2	-	47.4	-	-	-
Hermes	Wilts	-	15.7	-	-	-	-	-	-
Lady Rosetta	Wilts	-	-	-	-	40.1	-	-	-
	Greenseed	-	-	-	36.2	-	-	-	-
Maris Peer	Wales P1	-	23.3	-	-	43.8	-	-	-
Maris Piper	Wales P1	-	-	-	-	43.0	-	-	-
	B&C	20.8	-	-	-	-	-	-	-

TABLE 2. MEAN SEED WEIGHTS (G PER TUBER) PRIOR TO COLD STORAGE OF 2009-PRODUCED SEED

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3.2. Field experiments in 2010

The experiments listed in Table 3 were conducted at Cambridge, Holbeach Hurn (Lincolnshire) and at two sites in Norfolk, Thetford and Methwold Hythe. Treatments in each experiment consisted of all combinations of the factors listed in Table 3 arranged in randomised blocks with either six (Experiments 18-30), four (Experiments 9-11 and 16), three (Experiments 1-8, 12-13, 15, 17 and 31), or two replicates (Experiment 14). For Experiments 14 and 16, a split-plot design was used and for Experiment 15 a factorial design with an additional control was used (see below).

All experiments were planted by hand with a row width of 76 cm at Cambridge, or 91 cm at other sites. A liquid application of nitrogen was applied by a tractor-mounted sprayer to Experiments 1-8, 16, 18-19, 23-24, 28-29 at Cambridge between 26-29 April at c. 200 kg/ha. For all other experiments at Cambridge 200 kg/ha was applied by hand as prills of ammonium nitrate at planting, except Experiment 17 where 50 or 200 kg/ha was applied by hand according to treatment and Experiment 31 where 180 kg/ha was applied by hand to appropriate plots. Fertilizer applications on outside sites were as per the commercial crop.

A pre-emergence herbicide application of Artist (flufenacet + metribuzin) and Basta (glufosinate ammonium) was applied on 23 April (Experiments 9-13), 29 April (Experiments 5-8, 16-17), 7 May (Experiments 1-4, 15, 19, 24, 29), or 10 May (Experiments 18, 23, 28, 31). Experiment 31 was sprayed with Basta on 7 May followed by Artist and Basta on 10 May. For Experiments 9-13, a pre-emergence herbicide was applied to all plots prior to emergence of the first plantings and late plantings were after herbicide application. Herbicides on outside sites were as the commercial crop.

Soil samples were taken at planting to determine bulk density and aggregate (ped) size at planting in Experiments 9-13, or planting and tuber initiation in Experiments 14, 15, 17-30, with at least two samples per experiment, or two (Experiment 14) or three (Experiments 15 and 17) samples per soil treatment. At least one sample was taken from Experiments 18-30 and at least three samples at each external site. A sampling tool (205 mm diameter and 100 mm deep) was used to remove a core of soil which was weighed and then dried at 105 °C for 24 hours, then re-weighed, except for Experiments 15 and 17 where a smaller tool (200 mm length × 100 mm breadth × 100 mm width) was used to sample between plants during tuber initiation. Dried soil was sieved into 20 grades (< 2, 2-6, 6-10, then in 5 mm increments to 75 mm and above this in 10 mm increments to 145 mm) with the stones removed and weighed separately for each grade, except for the smallest two (< 2 and 2-6 mm) where the stones were washed from the soil, dried, graded and weighed. The water content (% gravimetric) was determined for each sample.

Soil resistance and water content were measured in Experiments 9-15 and 17 using a soil penetrometer (Pesola 80098) and ML-2 Theta Probe (Delta-T Devices), respectively. Three or four soil resistance readings were taken across each sample ridge at a depth of c. 10 cm, together with a single Theta probe reading at a depth of c. 6 cm, the latter calibrated to either mineral or organic soils as appropriate. Readings were taken at tuber initiation except in Experiment 14 where readings were taken weekly from planting until 28 June and then fortnightly until 9 August. To prevent damage to harvest plants, readings were taken from the end of a row, and to avoid anomalous results from repeated soil disturbance in Experiment 14 rows were

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sampled in turn on each occasion. Vertical penetrometer readings were taken in Experiment 14 on 2 July using an Eijkelkamp penetrometer (2 cm2 cone) in four plots of each treatment with four readings taken in the unplanted area of each plot.

Expt	Variety	Seed size (mm)	Seed stock	Planting date	Other treatments and details
1	King Edward	25-30, 30-35, 35-40, 40-45, 45-50, 50-55	Wilts, Welsh P2	14 Apr	
2	Marfona	As Expt 1	Welsh P1, P2	15 Apr	
3	Pentland Dell	As Expt 1	As Expt 1	15 Apr	
4	Russet Burbank	As Expt 1	As Expt 1	14 Apr	
5	King Edward	35-45	Wilts, Welsh P2	9 Apr	5 within-row spacings: 19, 24, 31, 44, 80 cm
6	Marfona	35-45	Welsh P1, P2	12 Apr	As Expt 5
7	Pentland Dell	35-45	As Expt 5	12 Apr	As Expt 5
8	Russet Burbank	35-45	As Expt 5	9 Apr	As Expt 5
9	Estima	35-45	Welsh P1	25 Mar, 22 Apr, 20 May, 17 Jun	2 within-row spacings: 20, 40 cm
10	Lady Rosetta	35-45	Wilts	As Expt 9	As Expt 9
11	Maris Peer	35-45	Welsh P1	As Expt 9	2 within-row spacings: 15, 30 cm
12	Maris Peer	25-35	Welsh P1	18 Mar, 1, 15, 29 Apr, 13, 27 May, 10, 24 Jun, 8, 15, 22, 29 Jul	2 within-row spacings: 15, 30 cm
13	Estima	25-35	Welsh P1	As Expt 12	2 within-row spacings: 20, 40 cm
14	Maris Peer	35-45	Welsh P1	13 May	4 cultivations; 2 within-row spacings: 15, 30 cm; 2 planting methods
15	Estima	30-35	Welsh P1	28 Apr	4 soil grades and 2 soil types
16	Estima Hermes	25-35 25-35	Welsh P1 Wilts	8 Apr	2 soil temperature treatments; 2 within-row spacings: 10, 20 cm
17	Maris Peer	25-35	Welsh P1	20 Apr	6 soil type and 2 nitrogen treatments
18	Estima	35-45	Welsh P1	30 Apr	2 within-row spacings: 20, 40 cm
19	Estima	35-45	Welsh P1	30 Apr	As Expt 18 (CUF fine loam) †
20	Estima	35-45	Welsh P1	30 Apr	As Expt 18 (Holbeach Hurn site)
21	Estima	35-45	Welsh P1	30 Apr	As Expt 18 (Methwold Hythe site)
22	Estima	35-45	Welsh P1	30 Apr	As Expt 18 (Thetford site)
23	Maris Piper	35-45	Welsh P1	30 Apr	As Expt 18 (CUF fine loam)
24	Maris Piper	35-45	Welsh P1	30 Apr	As Expt 18 (CUF fine loam) †
25	Maris Piper	35-45	Welsh P1	30 Apr	As Expt 18 (Holbeach Hurn site)
26	Maris Piper	35-45	Welsh P1	30 Apr	As Expt 18 (Methwold Hythe site)
27	Maris Piper	35-45	Welsh P1	30 Apr	As Expt 18 (Thetford site)
28	Lady Rosetta	35-45	Wilts	30 Apr	As Expt 18 (CUF fine loam)
29	Lady Rosetta	35-45	Wilts	30 Apr	As Expt 18 (CUF fine loam) †
30	Lady Rosetta	35-45	Wilts	30 Apr	As Expt 18 (Thetford site)
31	Maris Piper Lady Rosetta	25-30 35-40	B&C Greenseed	19 Apr	4 soil cultivations, 2 nitrogen treatments

† Cloddy soil structure.

TABLE 3. LIST OF FIELD EXPERIMENTS IN 2010

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Soil temperatures were recorded in Experiments 16 and 17 using calibrated thermistors inserted into ridges at a depth of c. 10 cm and logged hourly on a data logger (Delta-T Devices DL2).

3.3. Experiments 1-4

These experiments consisted of plots 4 rows wide and 1.5 m long with tubers spaced 30 cm apart as indicated in Table 3 but 50-55 mm seed of the Welsh P2 stock of Pentland Dell was unobtainable. Stems were removed and counted on 21-23 June but no tubers were harvested.

3.4. Experiments 5-8

Plots three rows wide and 5.6 m long were used for the five density treatments in these experiments. A final harvest of 4 m was taken from the central row comprising 5, 9, 13, 17, or 21 plants depending on spacing (Table 3).

3.5. Experiments 9-11

In Experiments 9 and 10, plots four rows wide and 5.2 m long were used with spacings of 20 and 40 cm. In Experiment 11 plot length was 3.9 m and spacings were 15 and 30 cm (Table 3). Three consecutive harvests were taken from the two central rows of each plot with harvests of four or eight plants for wide and narrow spacings respectively, c. 5 and 7 weeks after 50 % emergence and a final harvest of eight or 16 plants (Table 4).

3.6. Experiments 12-13

These experiments consisted of plots four rows wide and 2.1 or 2.8 m long (Experiments 12 and 13, respectively). Plots were separated by an unplanted row to avoid interference between plots planted on widely contrasting dates. Spacings were at either 15 and 30 cm (Experiment 12), or 20 and 40 cm (Experiment 13) apart as indicated in Table 3. A final harvest was taken from the two central rows of each plot with harvests of six or 12 plants for wide and narrow spacings, respectively.

3.7. Experiment 14

Plots were arranged in a split-plot design with soil condition treatments as main plots and other treatment combinations as sub-plots. The sub-plots were four rows wide and 5.0 m long, comprising a planted area of 3.9 m with spacings of 15 or 30 cm, and 1.1 m for soil sampling (0.5 m of undisturbed ridge and 0.6 m of ridge where the soil was disturbed by simulating the planting process but no seed was planted). Four soil conditions were created by different cultivations; all plots were initially roto-ridged on 24 March then subsequent cultivations applied on 11 May with plots either: left to consolidate; rotovated and re-ridged or flattened. The experiment was then irrigated with 10.8 mm of water. On 12 May the flattened plots were further compacted and half the flattened plots re-ridged according to the randomisation. The experiment was planted on 13 May and three consecutive harvests were taken from the two central rows of each plot with harvests of four or eight plants for wide and narrow spacings respectively, c. 5 and 7 weeks after 50 % emergence and a final harvest of eight or 16 plants c. 12 weeks after 50 % emergence (Table 4).

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3.8. Experiment 15

Plots were arranged in a factorial design with an extra control. Plots three rows wide and 2.4 m long were used with spacings of 20 cm. Treatments consisted of a control with ridges formed by standard roto-ridging or the removal of the central ridge of each plot prior to planting and replacement with all combinations of clay or sandy clay loam and four clod size grades fine (< 10 mm), medium (10-20 mm), cloddy (> 20 mm) or ungraded. A final harvest was taken from the central row of each plot with a harvest of eight plants.

3.9. Experiment 16

Plots were arranged in a split plot design with soil temperature as the main plots and other treatment combinations as sub-plots. The sub-plots were four rows wide and 2.6 m long with spacings of 10 or 20 cm. Soil temperature was increased during tuber initiation (4 June-21 June) by the use of electric soil warming cables installed in the harvest rows of the appropriate plots. Slits were made in the ridges to a depth of 14 cm for the installation of the cables prior to planting. Ridges in control plots were also slit but no cables installed. Three consecutive harvests were taken from the two central rows of each plot with harvests of four or eight plants for wide and narrow spacings respectively, c. 5 and 7 weeks after 50 % emergence and a final harvest of eight or 16 plants c. 13 weeks after 50 % emergence (Table 4).

3.10. Experiment 17

Plots were three rows wide and 2.4 m long and the within-row spacing was 20 cm. Treatments consisted of all combinations of two nitrogen treatments and six soil types. Nitrogen was applied at either 50 or 200 kg/ha after planting and soil types (taken from field soils) were sand, silt, clay, peat and experimental field soil (sandy clay loam). The central ridge of each plot was removed prior to planting and replaced with the appropriate soil type, except for field soil which was either dug over and re-ridged by hand, or undisturbed ridges formed by roto-ridging. A final harvest of eight plants was taken from the central row of each plot.

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Experiment	Variety	Planting	Harvest date(s)
1	King Edward	1	22 Jun
2	Marfona	1	22 Jun
3	Pentland Dell	1	23 Jun
4	Russet Burbank	1	21 Jun
5	King Edward	1	30 Sep
6	Marfona	1	17 Sep
7	Pentland Dell	1	30 Sep
8	Russet Burbank	1	6 Oct
9	Estima	1	11 Jun, 25 Jun, 6 Aug
		2	25 Jun, 9 Jul, 11 Aug
		3	14 Jul, 28 Jul, 2 Sep
		4	6 Aug, 20 Aug, 4 Oct
10	Lady Rosetta	1	11 Jun, 25 Jun, 11 Aug
		2	25 Jun, 9 Jul, 13 Sep
		3	14 Jul, 28 Jul, 5 Oct
		4	6 Aug, 20 Aug, 8 Oct
11	Maris Peer	1	11 Jun, 25 Jun, 11 Aug
		2	25 Jun, 9 Jul, 18 Aug
		3	14 Jul, 28 Jul, 1 Sep
		4	6 Aug, 20 Aug, 16 Sep
12	Maris Peer	1-12	5, 11, 11, 12, 24 Aug, 2, 9 Sep, 4,5,6,13,15 Oct
13	Estima	1-12	5, 11, 11, 12, 12 Aug, 1,16 Sep, 4,7,7,13,15 Oct
14	Maris Peer	1	12 Jul, 23 Jul, 9 Sep
15	Estima	1	10 Sep
16	Estima, Hermes	1	24 Jun, 8 Jul, 18 Aug
17	Maris Peer	1	18 Aug
18	Estima	1	25 Aug
19	Estima	1	27 Aug
20	Estima	1	25 Aug
21	Estima	1	25 Aug
22	Estima	1	27 Aug
23	Maris Piper	1	25 Aug
24	Maris Piper	1	27 Aug
25	Maris Piper	1	25 Aug
26	Maris Piper	1	25 Aug
27	Maris Piper	1	27 Aug
28	Lady Rosetta	1	25 Aug
29	Lady Rosetta	1	27 Aug
30	Lady Rosetta	1	27 Aug
32	Maris Piper, Lady Rosetta	1	18 Jun, 7, 22 Jul, 23 Aug, 27 Sep

TABLE 4. HARVEST DATES FOR THE 2010 EXPERIMENTS

3.11. Experiments 18-30

These experiments consisted of a series of paired plantings at Cambridge and sites at Holbeach Hurn, Thetford and Methwold Hythe, in each case plots four rows wide and 2 m long were used with spacings of 20 or 40 cm. A final harvest was taken from the two central rows of each plot with harvests of six or 12 plants for wide and narrow spacings, respectively.

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3.12. Experiment 31

This experiment forms part of the Potato Council funded projects on water use (R406) and full materials and methods are detailed in Stalham & Allison (2011).

3.13. Soil survey 2010

As part of a collaboration project with Frontier Agriculture, six fields each of Maris Piper and Markies and three fields of Lady Rosetta were sampled at three locations 100 m apart in each field, each with four replicates 50 m apart in the direction of planting. The sample area was defined as a 5 m length of bed in the direction of planting between two adjacent wheelings. Emergence, ground cover, tuber initiation and harvests were recorded at replicate one of all three locations. The number of plants emerged in both rows within the 5 m length was recorded weekly until near full emergence was achieved and ground cover measured weekly from the first week after first emergence until the eighth week or until full ground cover was achieved, whichever was the sooner. Generally, a 2 m length of two rows was harvested at least 6 weeks after first emergence and the number of plants, stems and tubers recorded but at two sites (Palgrave Ireland 16 Acres and Gravel Pit) a 3 m length of a single row was harvested.

Soil samples at six locations in two different areas of the field were sampled avoiding excessively stony areas. At each location, a pit c. 30 x 30 cm was excavated and approximately 300 g of soil and stones taken for texture analysis. A Theta probe was inserted into the soil face at 25 cm or vertically in a hole 22 cm deep to record soil water content, but for deep or de-stoned beds 20 or 10 cm respectively was removed to create an equivalent level to flat soil then excavated to 25 cm to insert the probe so that sampling depth was equivalent.

3.14. Soil analysis of 2009 experiments

These analyses complement the data presented previously (Firman & Daniels, 2009) for 2009 experiments listed in Table 5. In Experiment 14 two soil samples were taken from each plot both at planting and tuber initiation to determine bulk density and ped size. In Experiments 15 and 18-31 soil samples were taken at planting with three samples per treatment in Experiment 15 and at least one sample was taken from Experiments 18-31 with at least two samples at each external site or adjoining experiments at Cambridge. A soil sampling tool (205 mm diameter and 100 mm deep) was used to remove a core of soil which was weighed and dried at 105 °C for 24 hours, before being reweighed. The sample was sieved into twelve grades (< 2, 2-6, 6-10, then in 5 mm increments to 65 mm) with the stones removed and weighed separately for each grade, except for the smallest two grades (< 2 and 2-6 mm) where the stones were washed from the soil, dried, graded and weighed. The water content (% gravimetric) was determined for each sample.

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3.15. Investigation of radiation absorption during tuber initiation

The period of tuber initiation was defined as the 7 days following the expected date of onset of initiation and incident radiation and ground cover data collated for that period. The onset of tuber initiation was estimated as 17 days after 50 % emergence for Lady Rosetta and 18 days after 50 % emergence for Estima, Maris Peer, Maris Piper and Hermes (values derived from previous studies including BPC Reference Crops). Daily ground cover values were estimated using an exponential curve fitted to weekly measurements, or for experiments at external sites where less frequent ground cover measurements were made (e.g. Holbeach Hurn, Methwold Hythe and Thetford) a straight line interpolation of the available data was made. Daily incident radiation data were collected from pyranometers installed at Cambridge, Holbeach Hurn and Methwold Hythe, while data from Broom's Barn meteorological station was used for the Thetford site. Absorbed radiation was calculated for each day of tuber initiation as the product of ground cover and incident radiation. The relationship between tuber and stem populations fitted to the historical datasets by Firman et al. (2007) was used to calculate expected tuber populations from stem populations for the 2008-2010 experiments. The difference and percentage difference between the actual and predicted tuber populations was then examined in relation to the values calculated for absorbed radiation during tuber initiation.

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Expt	Variety	Seed size (mm)	Seed stock	Planting date	Other treatments and details
1	King Edward	25-30, 30-35, 35-40, 40-45, 45-50, 50-55	Wilts or Welsh P2	16 Apr	
2	Marfona	As Expt 1	As Expt 1	16 Apr	
3	Pentland Dell	As Expt 1	As Expt 1	16 Apr	
4	Russet Burbank	As Expt 1	As Expt 1	16 Apr	
5	King Edward	35-45	Wilts, Welsh P2	3 Apr	5 within-row spacings: 19, 24, 31, 44, 80 cm
6	Marfona	35-45	As Expt 2	6 Apr	As Expt 5
7	Pentland Dell	35-45	As Expt 2	6 Apr	As Expt 5
8	Russet Burbank	35-45	As Expt 2	3 Apr	As Expt 5
9	Estima	35-45	Wilts	18 Mar, 15 Apr, 13 May, 10 Jun	2 within-row spacings: 20, 40 cm
10	Lady Rosetta	35-45	Wilts	As Expt 10	As Expt 9
11	Maris Peer	35-45	Welsh P1	As Expt 10	2 within-row spacings: 15, 30 cm
12	Maris Peer	30-35	Welsh P1	11, 24 Mar, 8, 22 Apr, 6, 20 May, 3, 17 Jun, 1, 15, 29 Jul, 12 Aug	2 within-row spacings: 15, 30 cm
13	Estima	30-35	Wilts	As Expt 12	2 within-row spacings: 20, 40 cm
14	Maris Peer	35-45	Welsh P1	11 May	4 soil cultivation treatments; 2 within-row spacings: 15, 30 cm
15	Estima	30-35	Welsh P2	1 May	4 soil grades and 2 soil types
16	Estima Hermes	30-35 30-35	Wilts Wilts	2 Apr	2 soil temperature treatments; 2 within-row spacings: 10, 20 cm
17	Maris Peer	30-35	Welsh P1	27 Apr	6 soil type and 2 nitrogen treatments
18	Maris Piper	30-35	Greenseed	9 Apr	2 within-row spacings: 20, 40 cm
19	Maris Piper	30-35	Greenseed	9 Apr	As Expt 18 (Holbeach Hurn site)
20	Estima	35-45	Wilts	9 Apr	As Expt 18 (Cambridge sandy loam)
21	Estima	35-45	Wilts	9 Apr	As Expt 18 (Holbeach Hurn site)
22	Maris Piper	30-35	Greenseed	29 Apr	As Expt 18 (Cambridge sandy loam)
23	Maris Piper	30-35	Greenseed	29 Apr	As Expt 18 (Cambridge sandy clay loam)
24	Maris Piper	30-35	Greenseed	29 Apr	As Expt 18 (Methwold Hythe site)
25	Maris Piper	30-35	Greenseed	29 Apr	As Expt 18 (Thetford site)
26	Estima	35-45	Wilts	29 Apr	As Expt 18 (Cambridge sandy loam)
27	Estima	35-45	Wilts	29 Apr	As Expt 18 (Cambridge sandy clay loam)
28	Estima	35-45	Wilts	29 Apr	As Expt 18 (Methwold Hythe site)
29	Estima	35-45	Wilts	29 Apr	As Expt 18 (Thetford site)
30	Lady Rosetta	35-45	Wilts	29 Apr	As Expt 18 (Cambridge sandy loam)
31	Lady Rosetta	35-45	Wilts	29 Apr	As Expt 18 (Thetford site)
32	Maris Piper	35-40	B&C	15, 29 Apr	4 soil cultivations, 2 irrigation regimes

TABLE 5. LIST OF FIELD EXPERIMENTS IN 2009

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4. Results and Discussion

4.1. Experiments 1-4 Seed size and stock

The earlier-produced stock (Wiltshire stock for King Edward, Pentland Dell and Russet Burbank or Welsh P1 stock for Marfona) reached 50 % emergence c. 0.5-2 days before the later-produced Welsh stock in all varieties (Table 6). The number of days to 50 % emergence tended to decrease with increasing seed size in both Pentland Dell and Russet Burbank but there was no difference in emergence in either King Edward or Marfona.

Variety	Stock	Seed size (mm)						Mean
		25-30	**30-35**	**35-40**	**40-45**	**45-50**	**50-55**	
King Edward	Wiltshire	37.6	38.3	37.5	37.7	38.6	38.6	38.0
	Welsh P2	39.3	40.2	39.2	39.6	39.2	39.3	39.5
	S.E. (22 D.F.)	0.57						0.23
Marfona	Welsh P1	36.9	36.9	36.9	38.0	38.5	37.7	37.5
	Welsh P2	37.9	38.0	37.8	38.2	38.1	38.1	38.0
	S.E. (22 D.F.)	0.51						0.21
Pentland Dell	Wiltshire	38.6	38.1	36.2	36.8	35.7	35.4	37.1†
	Welsh P2	37.8	38.0	37.9	37.4	37.6	-	37.7†
	S.E. (18 D.F.) †	0.37†						0.16†
Russet Burbank	Wiltshire	37.7	37.9	35.9	36.2	36.2	35.4	36.5
	Welsh P2	39.4	38.8	38.8	38.8	38.2	37.8	38.6
	S.E. (22 D.F.)	0.33						0.13

† Mean and S.E. excluding seed sizes not represented by both stocks.

Table 6. Effect of stock and seed size in King Edward, Marfona, Pentland Dell and Russet Burbank in Experiments 1-4 on the interval from planting to 50 % emergence (days)

There were few secondary stems produced in any treatment (< 0.25 per plant) and the number of main stems increased linearly with increasing seed size in most varieties in 2010 (Figure 1a and b and Figure 2a and b), except for the later-produced Welsh stocks in King Edward and Marfona (Figure 1a and b) where there was little increase in the number of stems at seed weights greater than c. 100 g. In Pentland Dell, the earlier-produced Wiltshire stock produced a greater number of main stems than the later-produced Welsh stock for a comparable seed size up to c. 100 g (Figure 2a) but in Russet Burbank and notably in the large seed of King Edward the earlier-produced Wiltshire stock produced a smaller number of main stems for a comparable seed size than the later-produced Welsh stock (Figure 1a, Figure 2b). In Marfona seed sizes < c. 45 g produced more main stems in the earlier-produced Welsh stock than the later-produced Welsh seed but above c. 105 g the later-produced Welsh stock produced more stems than the earlier produced Welsh seed (Figure 1b). Rotting occurred in the 50-55 mm grade of the earlier-produced Marfona stock and later-produced stock for all varieties except Pentland Dell, and may have been associated with the stable number of tubers at the larger seed sizes of both stocks of Marfona and the later-produced stock of King Edward.

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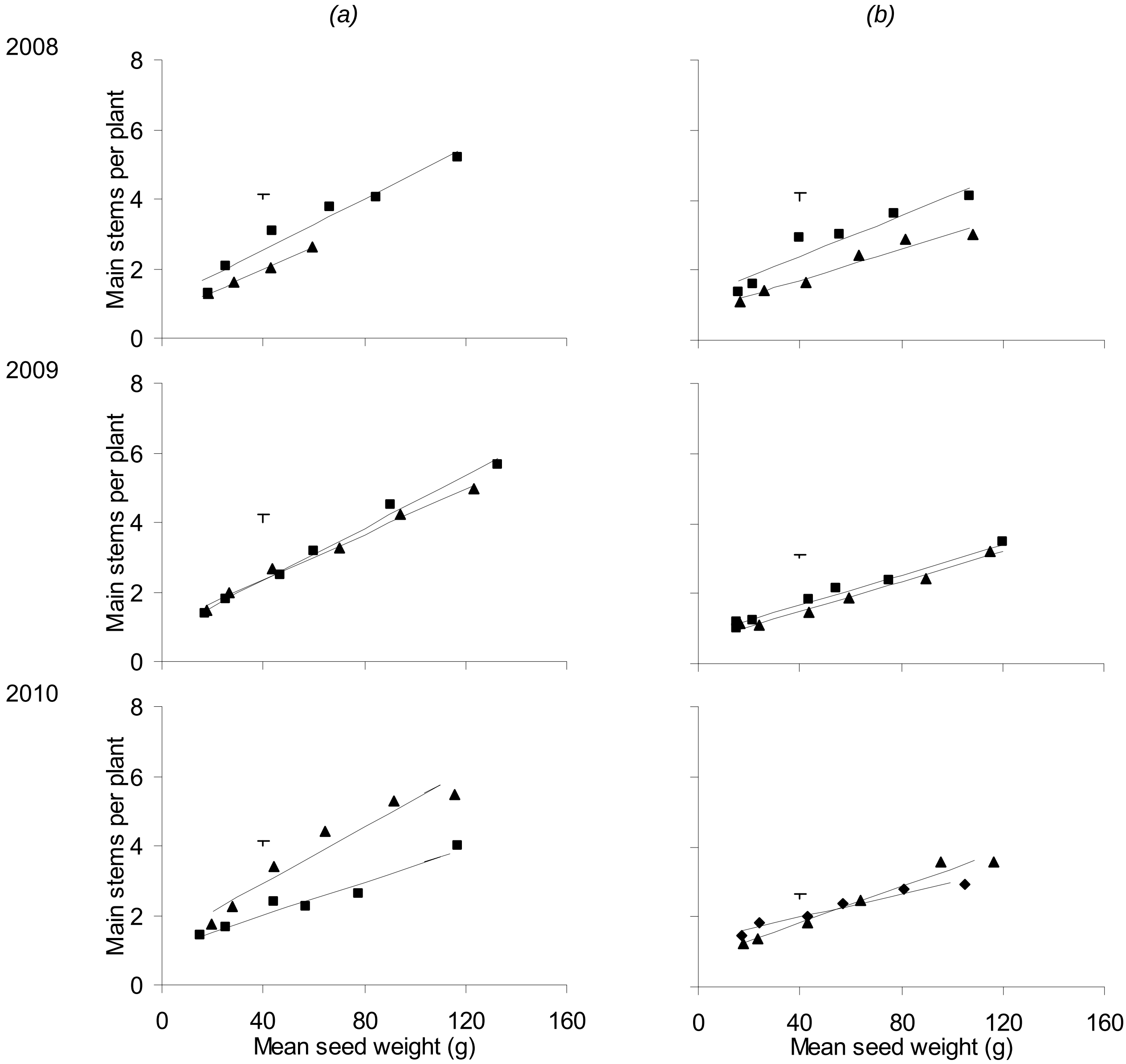

FIGURE 1 LINEAR RELATIONSHIPS BETWEEN THE NUMBER OF MAIN STEMS PER PLANT AND MEAN SEED WEIGHT OVER 3 YEARS (2008-2010) FOR *(A)* KING EDWARD, *(B)* MARFONA. SEED STOCKS: WELSH LATE, ▲;WILTSHIRE, ■; WELSH EARLY, ◆.

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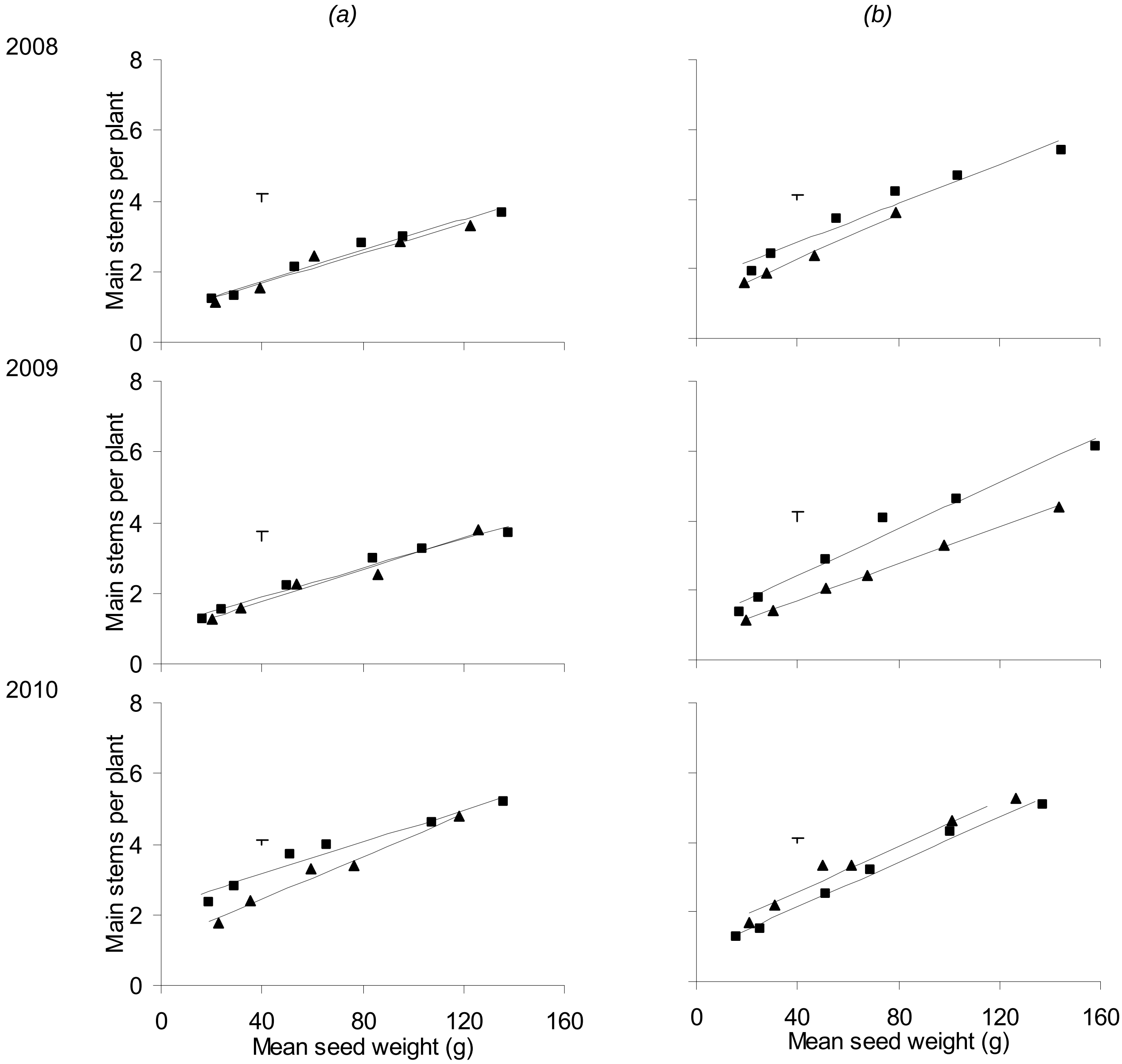

FIGURE 2 LINEAR RELATIONSHIPS BETWEEN THE NUMBER OF MAIN STEMS PER PLANT AND MEAN SEED WEIGHT OVER 3 YEARS (2008-2010) FOR (A) PENTLAND DELL, (B) RUSSET BURBANK. SEED STOCKS: WELSH LATE, ▲;WILTSHIRE, ■.

For the 2009 seed stocks, the number of days to replanting (emergence of stock to replanting of seed) was substantially greater for the early-produced than the late-produced stock in Marfona and Pentland Dell but in King Edward and Russet Burbank differences between stocks were small (Table 7). In all varieties the differences in seed production cycles in 2008 were similar to those in 2007 (Table 7), but the number of days to replanting in 2009 stocks was relatively long in King Edward, Pentland Dell and Russet Burbank in the Welsh late stock and relatively short in the Wiltshire stock of King Edward and Russet Burbank in 2009 compared to 2007 and 2008.

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Stock	Early Wiltshire			Early Welsh		Late Welsh	
Year of production	2007	2008	2009	2007	2009	2008	2009
Variety							
King Edward	307	320	292†	254	-	258	283
Marfona	308	320		256	338	272	279
Pentland Dell	323	319	327†	255	-	260	284
Russet Burbank	308	320	292†	255	-	258	283

† Emergence data not available, emergence dates calculated as 18 days before tuber initiation.

TABLE 7. THE NUMBER OF DAYS FROM SEED EMERGENCE TO REPLANTING IN SEED SIZE AND STOCK EXPERIMENTS IN KING EDWARD, MARFONA, PENTLAND DELL, AND RUSSET BURBANK IN 2010 EXPERIMENTS 1-4 AND SIMILAR EXPERIMENTS IN 2008 AND 2009

Generally, stem production in the earlier-produced stocks was similar in 2008 and 2009, except for Marfona (Figure 1b) where fewer stems for a comparable seed weight were produced in 2009. In 2010, Pentland Dell produced a greater number of stems and King Edward and Russet Burbank fewer stems for a comparable seed weight than in 2008 and 2009 (Figure 1a and Figure 2ab), while in Marfona the number of stems produced in 2010 for a comparable seed weight was similar to 2009 but fewer than in 2008 (Figure 1b). In the late-produced Welsh stock King Edward produced slightly more stems for a comparable seed weight in 2009 than 2008 (Figure 1a) but in 2010 late-produced seed of all varieties produced more stems than in either 2008 or 2009 (Figure 1a and b, Figure 2a and b) consistent with a relatively long interval to replanting compared to previous years (Table 7).

4.2. Experiment 5 Density - King Edward

The later-produced Welsh stock reached 50 % emergence c. 1 day later than the Wiltshire stock. All treatments reached near full emergence (> 98 %) and near complete ground cover (> 98 %). Near complete ground cover was achieved later at wider than closer spacings (Figure 3) and canopies persisted slightly longer at the wider than the closer spacings (Figure 3).

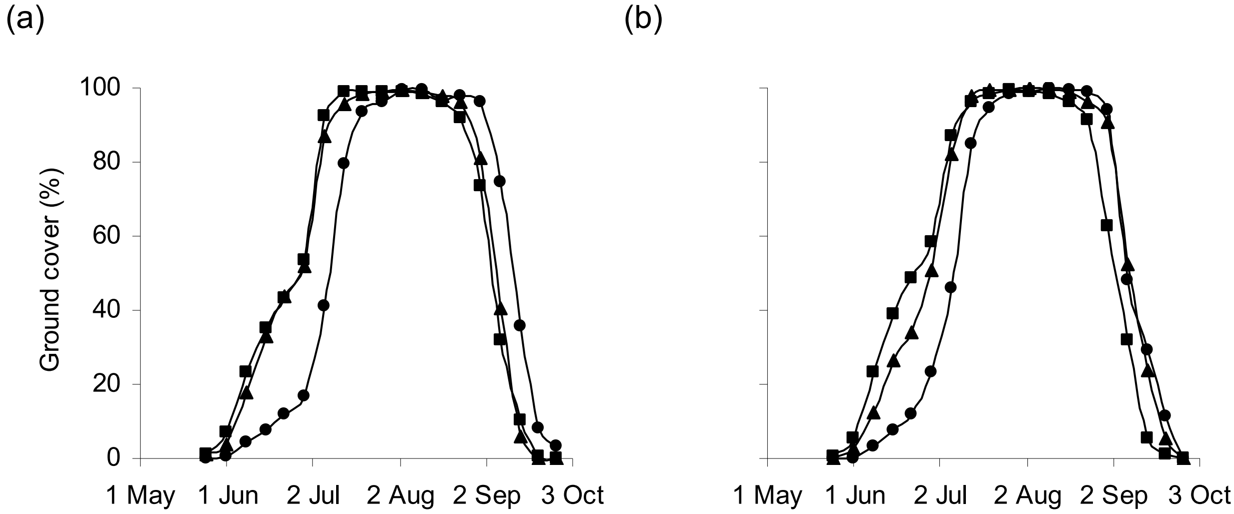

FIGURE 3. EFFECT OF PLANT DENSITY ON GROUND COVER FOR *(A)* WILTSHIRE AND *(B)* WELSH LATE STOCKS OF KING EDWARD IN EXPERIMENT 5. PLANT SPACING (CM): 80, ●; 31, ▲; 19, ■. (INTERMEDIATE DENSITIES NOT SHOWN).

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Consistent with the seed size experiment (Experiment 1) the number of main stems per plant was greater for the late-produced Welsh stock (3.3 ± 0.14) than the early-produced Wiltshire stock (2.5) and there were few secondary stems in either stock (< 0.07 per plant). Stem populations varied from 43 700/ha for the earlier-produced Wiltshire stock planted at the 80 cm spacing to 239 500/ha for the later-produced Welsh stock planted at 19 cm. The number of tubers > 10 mm increased with increasing stem density (Figure 4a) and the number of tubers was greater in the later-produced Welsh stock (686 ± 19.7) than the earlier-produced Wiltshire stock (594). There was little effect of stem density on total yield (Figure 4b) but the mean tuber size decreased with an increase in stem density and on average was least for the later-produced Welsh stock at the closer spacings while the mean tuber size was greater for the earlier-produced Wiltshire stock (53.2 ± 0.57) than the later-produced Welsh stock (49.8) (Figure 4c). Yield > 60 mm generally decreased with increase in stem density and was numerically least for the later-produced Welsh stock at the closer spacings (Figure 4d) and averaged over density greater for the earlier-produced Wiltshire stock (15.2 ± 1.18) than the later-produced Welsh stock (8.6) (Figure 4d).

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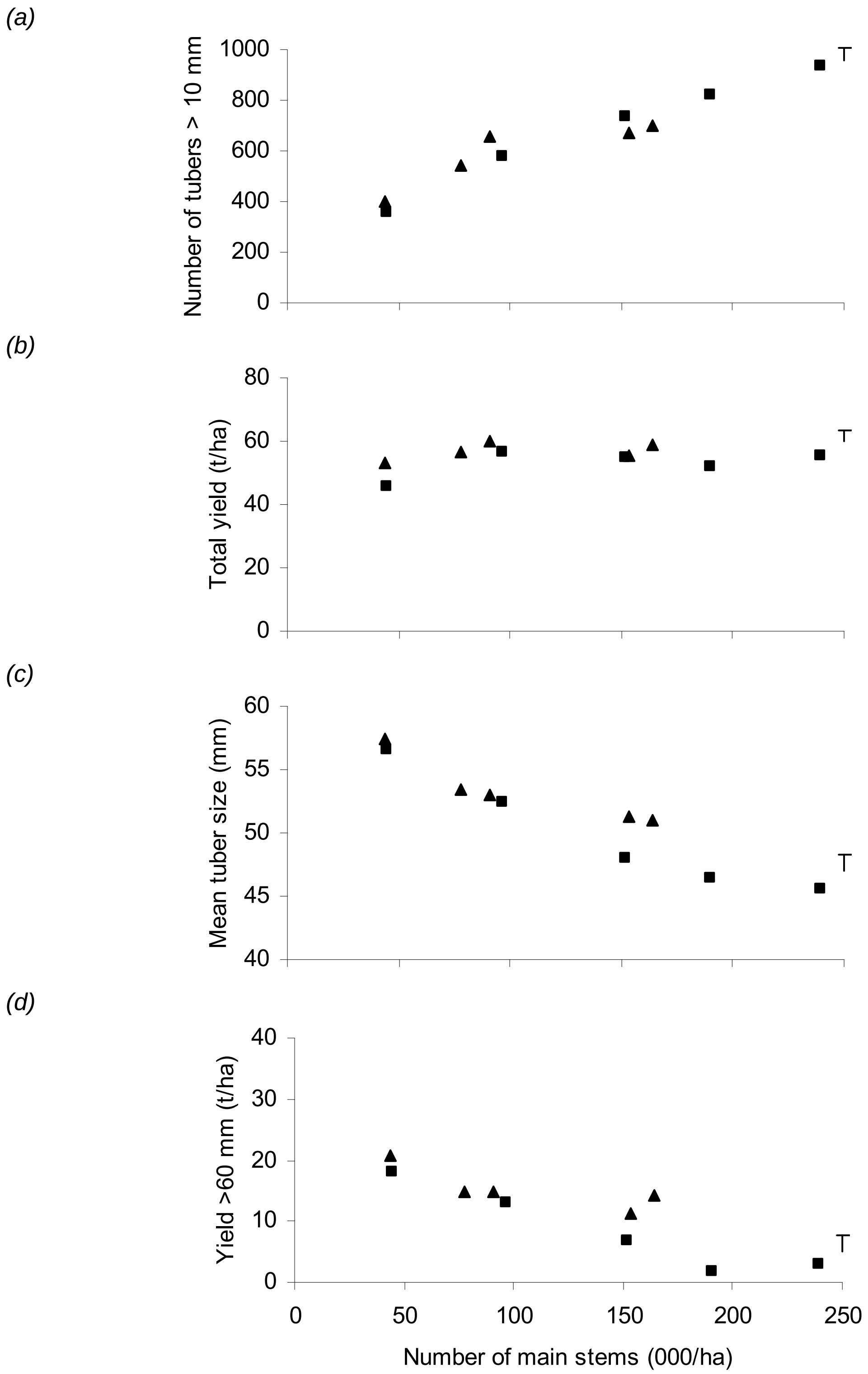

FIGURE 4. RELATIONSHIP BETWEEN *(A)* NUMBER OF TUBERS > 10 MM (000/HA), *(B)* TUBER YIELD, *(C)* MEAN TUBER SIZE, AND *(D)* YIELD OF TUBERS > 60 MM AND NUMBER OF MAIN STEMS OF KING EDWARD IN EXPERIMENT 5. STOCKS: WELSH LATE, ■; WILTSHIRE, ▲.

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4.3. Experiment 6 Density - Marfona

The later-produced Welsh stock reached 50 % emergence < 1 day after the earlier-produced Welsh stock and final emergence was compete in the later-produced Welsh stock and > 96 % for the earlier-produced Welsh stock . All treatments reached near complete ground cover (> 97 %) except for the earlier-produced Welsh stock at the wider spacings of 80 and 44 cm where ground cover reached c. 92 and 94 %, respectively. Maximum ground cover was reached later at wider than closer spacings but there was little difference in the persistence of canopies (Figure 5).

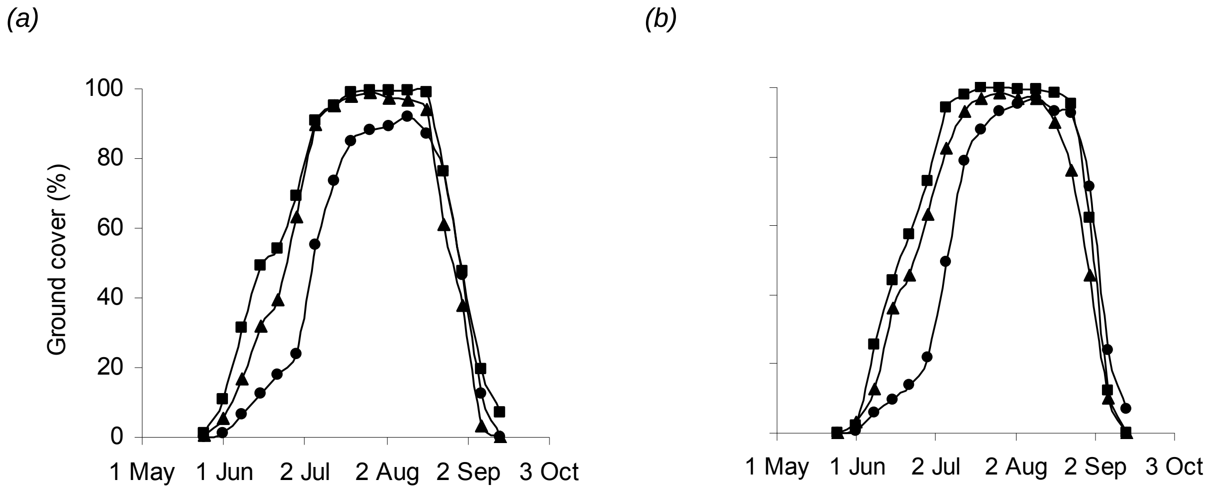

FIGURE 5. EFFECT OF PLANT DENSITY ON GROUND COVER FOR (*A*) WELSH EARLY AND (*B*) WELSH LATE STOCKS OF MARFONA IN EXPERIMENT 6 PLANT SPACING (CM): 80, ●; 31, ▲; 19, ■. (INTERMEDIATE DENSITIES NOT SHOWN).

Consistent with the seed size experiment (Experiment 2) for seed weights c. 45 g the number of main stems per plant was greater for the earlier-produced Welsh stock (2.1 ± 0.06) than the later-produced Welsh stock (1.7), with few secondary stems produced in either stock (< 0.06 per plant). Stem populations varied from 25 200/ha for the later-produced Welsh stock planted at the 80 cm spacing to 147 600/ha for the earlier-produced Welsh stock planted at 19 cm. The number of tubers > 10 mm increased with increasing stem density (Figure 6a) while total yield increased with increasing stem density up to c. 100 000 main stems per ha and averaged over density greater for the later-produced Welsh stock (59.0 ± 1.38) than the earlier-produced Welsh stock (51.5 t/ha) (Figure 6b). The mean tuber size decreased with increasing stem density (Figure 6c) but stem population had relatively little effect on yield > 60 mm (Figure 6d) which averaged over density was greater for the later-produced Welsh stock (46.0 ± 1.58 t/ha) than the earlier-produced Welsh stock (38.6). Seed weights (c. 43-45 g) were similar to the 35-40 mm grade of Experiment 2 (c. 43 g) where rots occurred in the earlier-produced Welsh stock but weight loss in both stocks was < 3 %.

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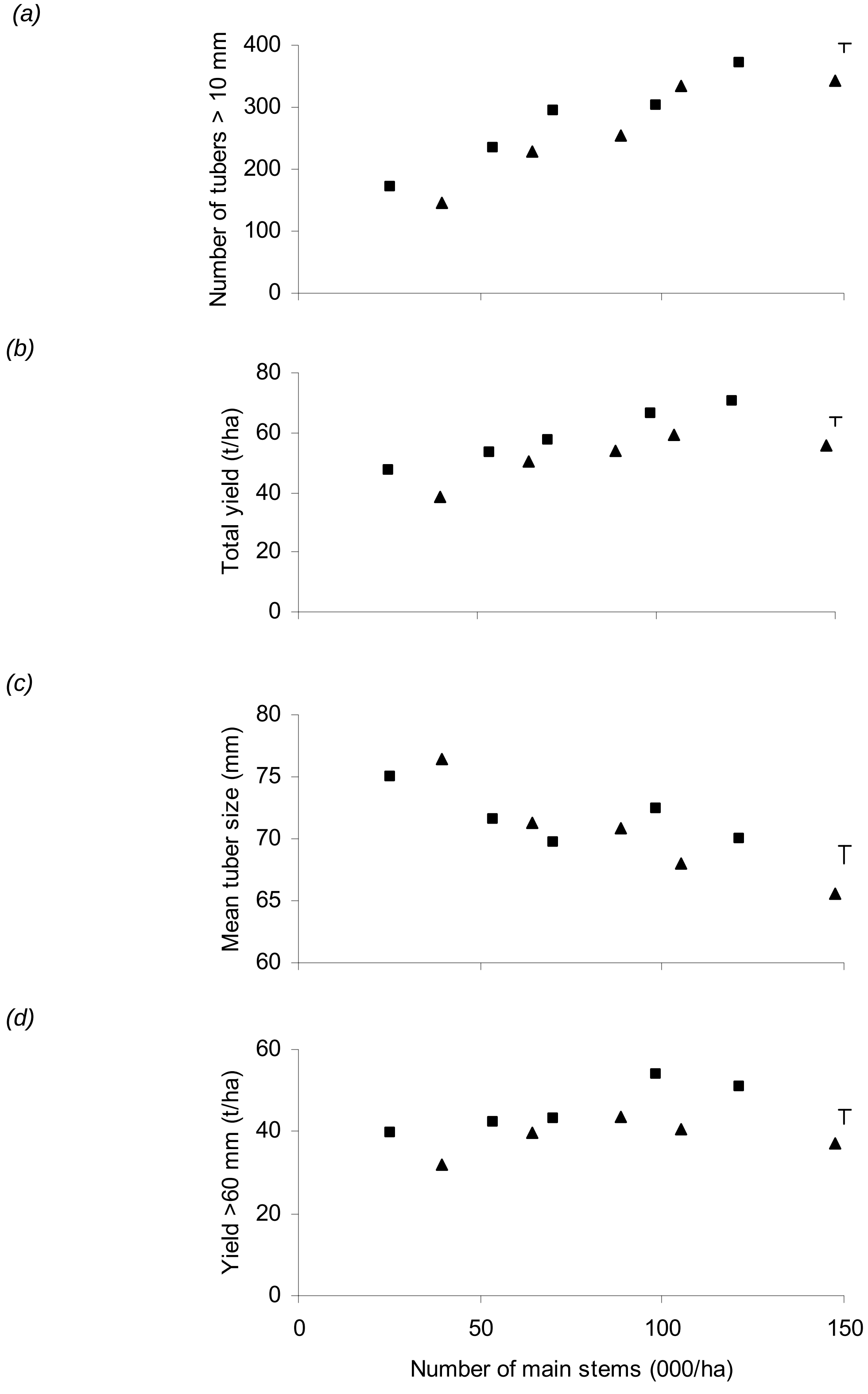

FIGURE 6. RELATIONSHIP BETWEEN *(A)* NUMBER OF TUBERS > 10 MM (000/HA), *(B)* TUBER YIELD, *(C)* MEAN TUBER SIZE, AND *(D)* YIELD OF TUBERS > 60 MM AND NUMBER OF MAIN STEMS OF MARFONA IN EXPERIMENT 6. STOCKS: WELSH LATE, ■; WELSH EARLY, ▲.

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4.4. Experiment 7 Density - Pentland Dell

The later-produced Welsh stock reached 50 % emergence < 1 day after the Wiltshire stock and final emergence was > 98 % for both stocks. All treatments reached near complete ground cover (> 97 %) and the widest spacing reached near complete ground cover later than the closer spacings but there was little difference in the persistence of canopies (Figure 7).

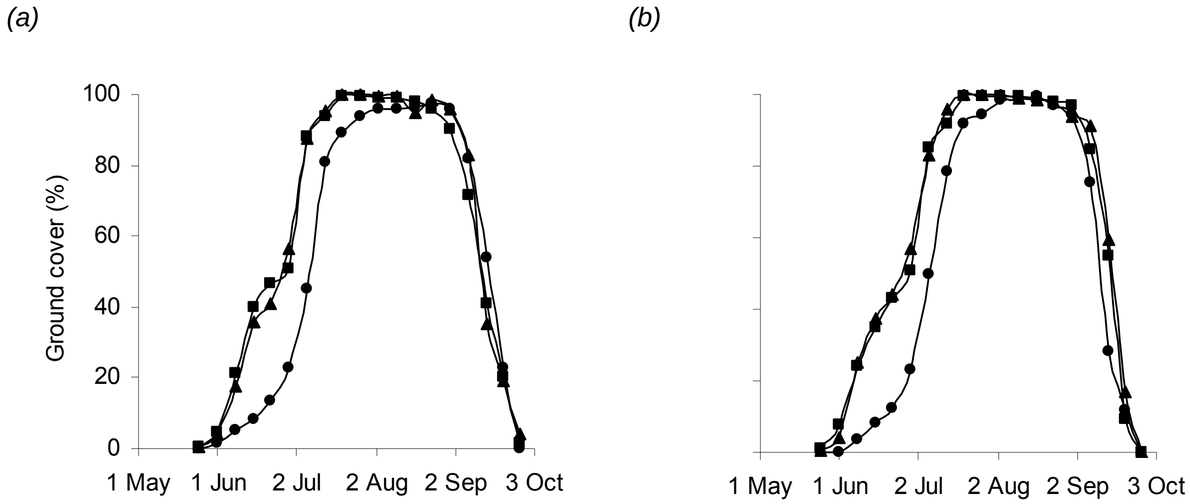

FIGURE 7. EFFECT OF PLANT DENSITY ON GROUND COVER FOR (A) WILTSHIRE AND (B) WELSH LATE STOCKS OF PENTLAND DELL IN EXPERIMENT 7. PLANT SPACING (CM): 80, ●; 31, ▲; 19, ■. (INTERMEDIATE DENSITIES NOT SHOWN).

Consistent with the seed size experiment (Experiment 3) the number of main stems per plant was greater for the earlier-produced Wiltshire stock (3.1 ± 0.12) than the later-produced Welsh stock (2.6) with few secondary stems produced in either stock (< 0.02 per plant). Stem populations varied from 41 600 main stems per ha for the later-produced Welsh stock planted at 80 cm spacing to 202 300 main stems per ha for the earlier-produced Wiltshire stock planted at 19 cm.

The number of tubers > 10 mm and the total yield increased with increase in stem density up to c. 110 000 main stems per ha (Figure 8a and b). The mean tuber size decreased with an increase in stem density up to c. 110 000 main stems per ha (Figure 8c) and averaged over density was greater for the later-produced Welsh stock (52.3 ± 0.32 mm) than the earlier-produced Wiltshire stock (50.5) (Figure 8c) but stem density had little effect on the yield > 50 mm which averaged over density was greater for the later-produced Welsh stock (32.6 ± 1.31 t/ha) than the earlier-produced Wiltshire stock (27.2) (Figure 8d).

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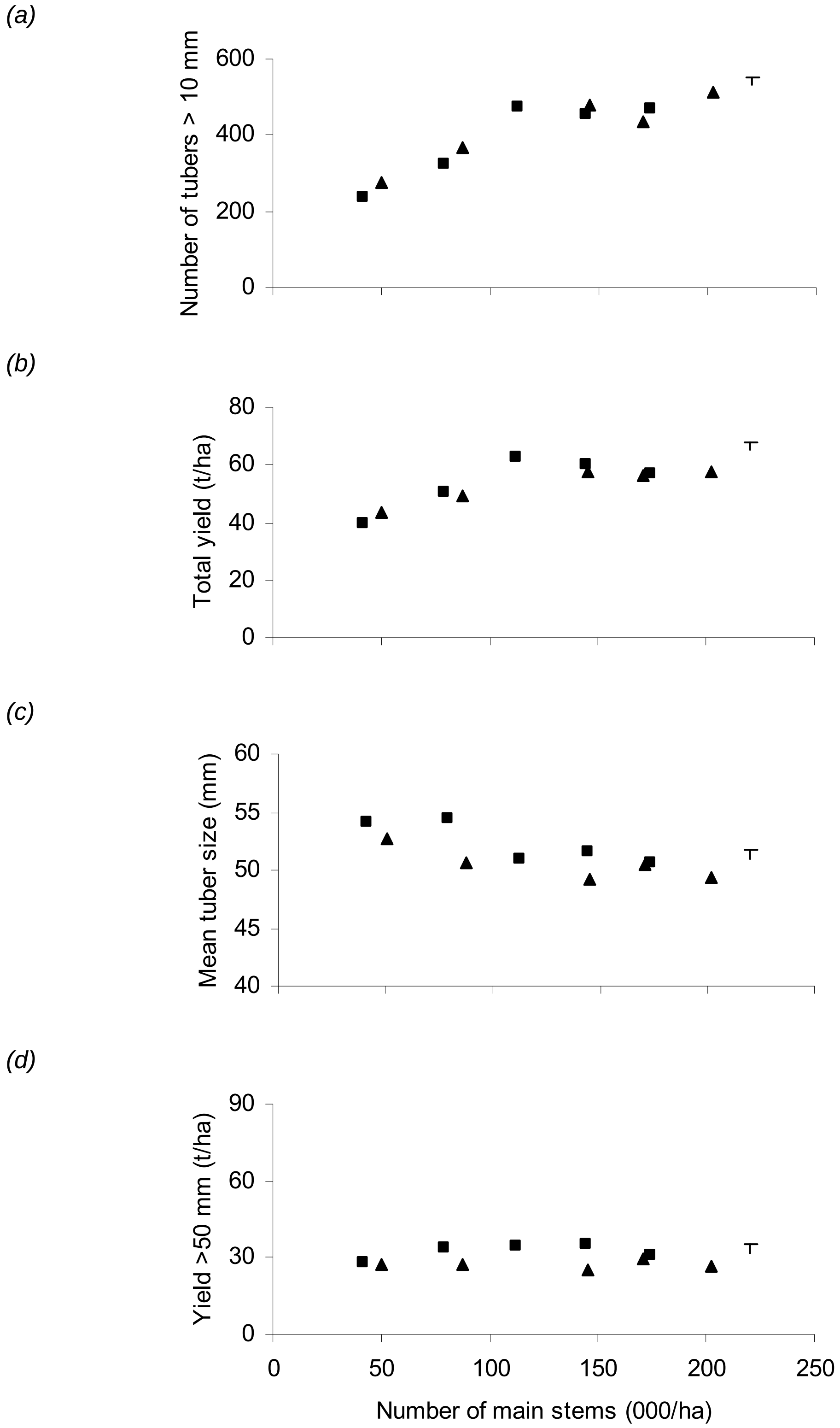

FIGURE 8. RELATIONSHIP BETWEEN (A) NUMBER OF TUBERS > 10 MM (000/HA), (B) TUBER YIELD, (C) MEAN TUBER SIZE, AND (D) YIELD OF TUBERS > 50 MM AND NUMBER OF MAIN STEMS OF PENTLAND DELL IN EXPERIMENT 7. STOCKS: WELSH LATE, ■; WILTSHIRE, ▲.

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4.5. Experiment 8 Density - Russet Burbank

The Wiltshire stock reached 50 % emergence c. 1 day before the later-produced Welsh stock, and final emergence was > 98 % for both stocks. Ground cover was complete in both stocks and achieved later at the widest than the closer spacings but there was little difference in the persistence of canopies (Figure 9).

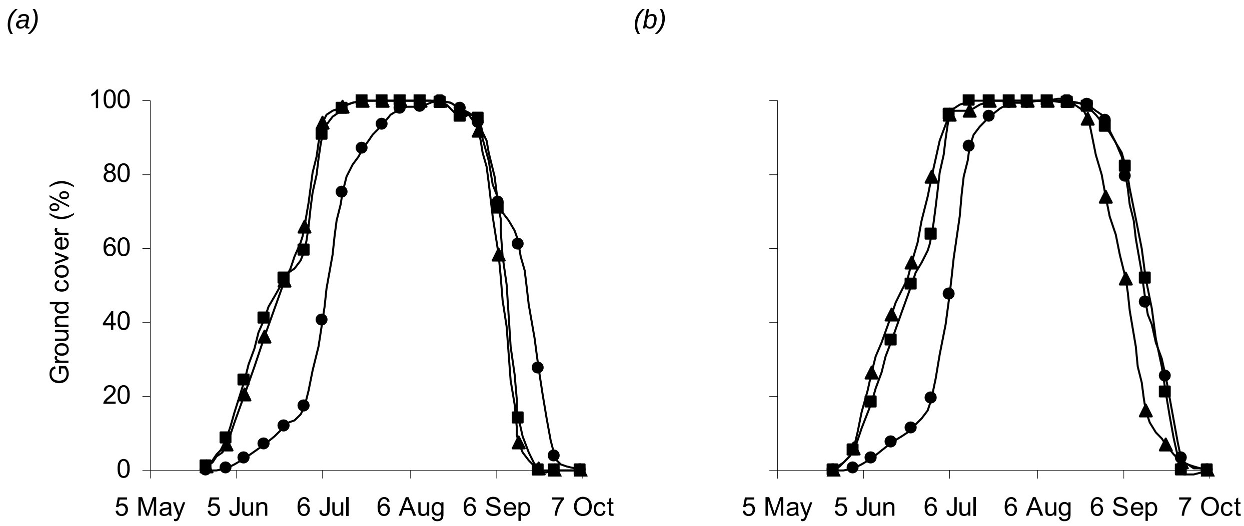

FIGURE 9. EFFECT OF PLANT DENSITY ON GROUND COVER FOR (*A*) WILTSHIRE AND (*B*) WELSH LATE STOCKS OF RUSSET BURBANK IN EXPERIMENT 8. PLANT SPACING (CM): 80, ●; 31, ▲; 19, ■. (INTERMEDIATE DENSITIES NOT SHOWN).

Consistent with the seed size experiment (Experiment 4) the number of main stems per plant was greater for later-produced Welsh stock (2.5 ± 0.07) than the earlier-produced Wiltshire stock (2.1) and few secondary stems were formed in either stock (< 0.02 per plant). Stem populations varied from 33 900 main stems per ha for the earlier-produced Wiltshire stock planted at the 80 cm spacing to 177 200 main stems per ha for the later-produced Welsh stock planted at 19 cm.

The number of tubers > 10 mm increased with an increase in stem density with a greater number of tubers in the later-produced Welsh stock (342 500 ± 8 330/ha) than the earlier-produced Wiltshire stock (289 300) (Figure 10a). Total yield increased with increase in stem density up to c. 100 000 main stems per ha (Figure 10b) but mean tuber size decreased with increasing stem density and averaged over density was greater for the earlier-produced Wiltshire stock (58.4 ± 1.09 mm) than the later-produced Welsh stock (54.4) (Figure 10c). There was little effect of stem density on yield > 50 mm (Figure 10d) but the yield was greater in the earlier-produced Wiltshire stock (40.2 ± 2.03 t/ha) than the later-produced Welsh stock (32.5).

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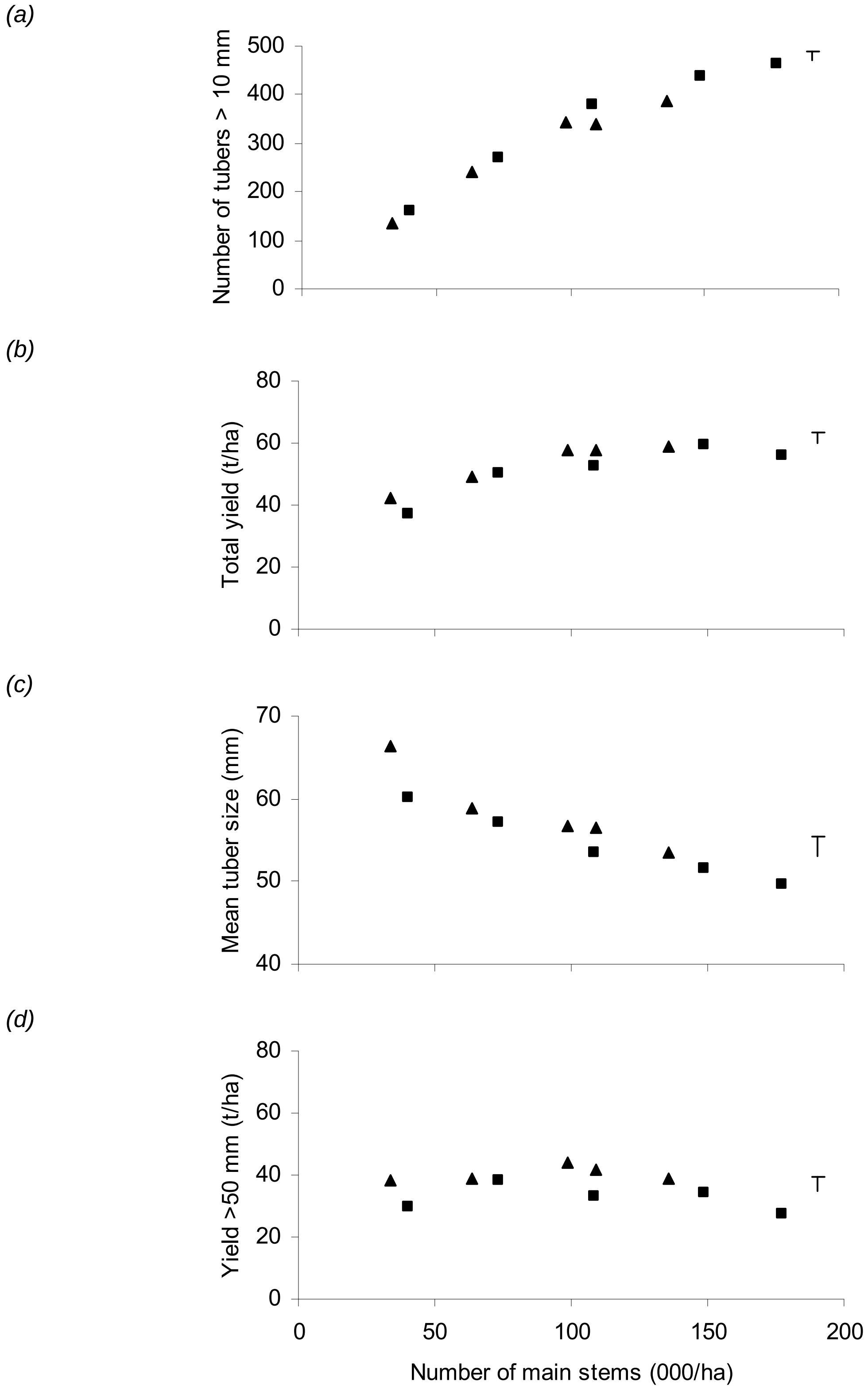

FIGURE 10. RELATIONSHIP BETWEEN (A) NUMBER OF TUBERS > 10 MM (000/HA), (B) TUBER YIELD, (C) MEAN TUBER SIZE, AND (D) YIELD OF TUBERS > 50 MM AND NUMBER OF MAIN STEMS OF RUSSET BURBANK IN EXPERIMENT 8. STOCKS: WELSH LATE, ■; WILTSHIRE, ▲.

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4.6. Experiment 9 Planting and density - Estima

No sprouting was visible on seed tubers at the first three planting dates but at the final planting 35 % of the tubers had sprouts of c. 1 mm in length. The interval from planting to 50 % emergence decreased progressively with sequential plantings (49, 35, 24 and 19 ± 0.5 days) and emergence was fairly complete at all plantings (> 97 %). Complete ground cover was achieved in most treatments (> 99 %) except for the wider spacing of the final three plantings (95, 96 and 91 % ground cover respectively). Frost damage on 11-12 May affected 4 and 8 % of all plants in the harvest rows at the first planting at the wider and closer spacings, respectively but all plants re-grew.

Between the first two harvests, the total number of tubers was stable or decreased except for the closer plant spacing at the first two plantings where the number of tubers increased (Figure 11a-d). The number of tubers > 10 mm generally changed little between the first two harvests except at the closer spacing of the first two plantings and the wider spacing of the final planting where the number of tubers increased (Figure 11a-d). Between the second and final harvests the total number of tubers generally decreased except at the wider spacing of the first planting and both spacings of the penultimate planting where the number of tubers was stable. The number of tubers > 10 mm generally changed little between the second and final harvests except for the closer spacing of the second planting where the number of tubers decreased (Figure 11a-d). Substantially more tubers were initiated than retained at the first two plantings at the higher plant density but there was little change in the number of tubers at the penultimate planting (Figure 11a-d).

In 2010 a delay in planting had little effect on the numbers of main stems per plant at the final harvest (Table 8) and few secondary stems were formed in any treatment (< 0.04 per plant). At the final harvest the effects on the total number of tubers reflected the number of tubers > 10 mm which were numerically greatest at the second and third plantings and least at the final planting (Table 8) and greater at the closer spacing (536 200 ± 9 650/ha) than the wider spacing (343 400). At the wider spacing, the greatest number of tubers formed at the second planting (415 200 ± 9 650/ha) and least at the final planting (245 000) while at the closer spacing a greater number of tubers formed at the second and penultimate planting (614 100 and 621 300 ± 19 290/ha, respectively) than the first and final plantings (479 800 and 429 600, respectively).

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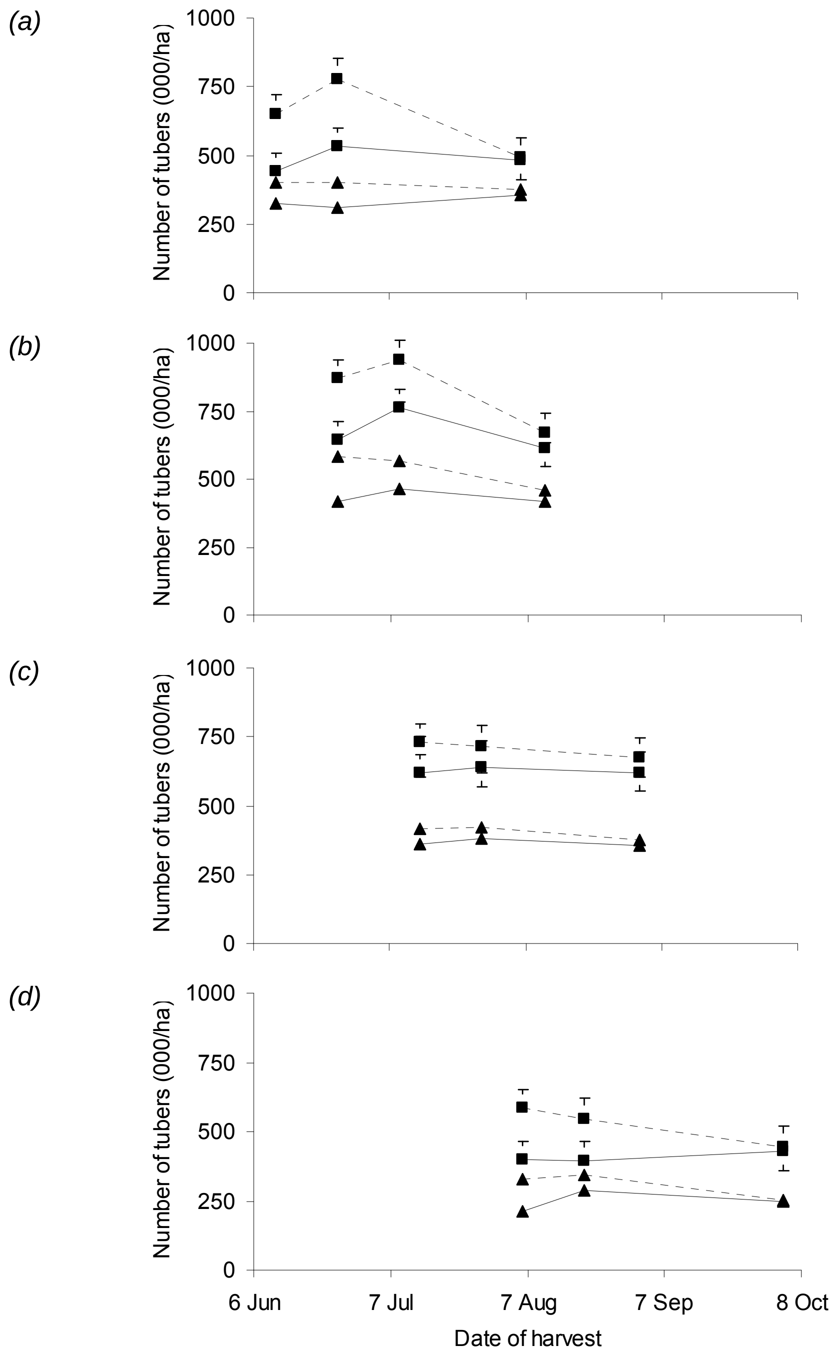

FIGURE 11. EFFECT OF PLANTING DENSITY ON THE NUMBER OF TUBERS AT FOUR PLANTING DATES *(A)* 25 MARCH, *(B)* 22 APRIL, *(C)* 20 MAY, *(D)* 17 JUNE FOR ESTIMA IN EXPERIMENT 9. PLANT SPACING: 20 CM, ■; 40 CM, ▲. NUMBER OF TUBERS > 10 MM, SOLID LINE; TOTAL NUMBER OF TUBERS, BROKEN LINE.

Averaged over the 3 years, planting date generally had little effect on the number of main stems per plant (Table 9) except at the final planting where the number of main stems increased but in 2009 the greatest number of stems was produced at the first and final plantings and fewest at the penultimate planting while in 2010 there was little effect of planting date (Table 9).

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Variety	Main stems/plant				Total number of tubers (000/ha)				Tubers > 10 mm (000/ha)			
Planting	**P1**	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**	**P4**	**P1**	**P2**	**P3**	**P4**
Estima	2.35	2.53	2.45	2.39	432	564	524	348	419	515	489	337
S.E. (21 D.F.)	0.087				16.8				13.6			
Lady Rosetta	2.19	2.50	2.59	2.69	512	687	507	383	435	584	495	364
S.E. (21 D.F.)	0.120				21.4				17.9			
Maris Peer	2.77	3.20	3.99	4.12	498	757	501	655	489	731	481	640
S.E. (21 D.F.)	0.110				18.5				17.1			

TABLE 8. THE EFFECT OF PLANTING DATE (P1-P4, MEAN OF PLANT DENSITY) ON THE NUMBER OF MAIN STEMS, THE TOTAL NUMBER OF TUBERS AND THE NUMBER OF TUBERS > 10 MM IN ESTIMA, LADY ROSETTA AND MARIS PEER AT THE FINAL HARVEST. PLANTING DATE: P1, 25 MARCH; P2, 22 APRIL; P3, 20 MAY; P4, 17 JUNE

Variety	Planting Year	Main stems/plant P1	P2	P3	P4	Tubers > 10 mm P1	P2	P3	P4
Estima									
	2008	2.08	2.29	2.23	2.87	478	498	523	648
	2009	2.51	2.22	1.74	2.58	460	440	454	437
	2010	2.35	2.53	2.45	2.39	419	515	489	337
S.E.			0.124				19.5		
Mean		2.31	2.35	2.14	2.61	452	484	489	474
S.E. mean			0.072				11.2		
Lady Rosetta									
	2008	2.16	2.46	2.80	3.54	617	754	663	915
	2009	2.17	2.37	2.34	2.79	505	445	523	488
	2010	2.19	2.50	2.59	2.69	435	585	495	364
S.E.			0.117				18.4		
Mean		2.17	2.44	2.58	3.00	519	595	561	589
S.E. mean			0.068				10.7		
Maris Peer									
	2008	3.10	3.82	3.58	-	997	1217	1113	-
	2009	2.48	2.36	3.14	3.44	560	566	571	599
	2010	2.77	3.20	3.99	4.12	489	731	481	640
S.E†			0.114				44.7		
Mean		2.78	3.13	3.57	3.78	682	838	722	800
S.E†			0.081				25.8		

† Mean and S.E. exclude planting dates not represented by all years. S.E. based on 60 D.F. for Estima, 63 D.F. for Lady Rosetta and 45 D.F. for Maris Peer.

TABLE 9. THE EFFECT OF PLANTING DATE (P1-P4) ON THE NUMBER OF MAIN STEMS PER PLANT AND TUBERS > 10 MM IN THREE VARIETIES (MEAN OF PLANT SPACING) OVER 3 YEARS. PLANTING DATE: P1 (18-25 MARCH), P2 (15-22 APRIL), P3 (13-20 MAY, P4 (10-17 JUNE)

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Averaged over all years, planting date had little effect on the number of tubers > 10 mm (Table 9) but more tubers were formed at the closer plant spacing (567 300 ± 7 950/ha) than the wider spacing (382 200) and at the closer spacings the greatest number of tubers formed at the second planting (403 800 ± 19 470/ha) and least at the penultimate planting (351 000) while at the wider spacing the greatest number of tubers formed at the penultimate planting (626 100 ± 19 470/ha) and least at the first planting (520 200).

The number of tubers > 10 mm at the final harvest was generally similar to the values fitted to the historical data sets by Firman et al. (2007) (Figure 12). Generally the peak total number of tubers was substantially higher than the retained number of tubers > 10 mm at the final harvest except at the first planting at the wider spacing in 2009 and 2010, and the penultimate planting at both spacings in 2010 where the difference was < 30 % of the retained number of tubers (Figure 12).

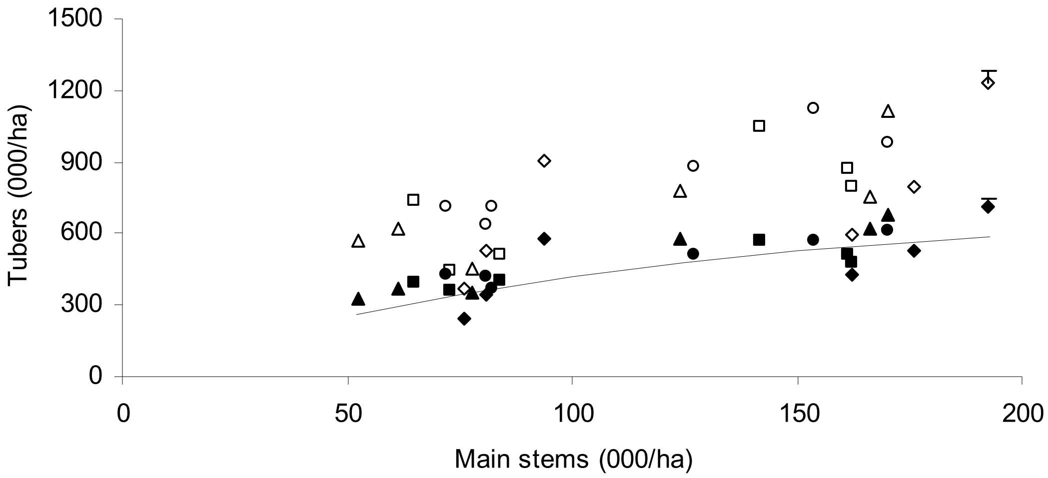

FIGURE 12. EFFECT OF PLANTING DATE AND PLANT SPACING ON THE FINAL NUMBERS OF TUBERS > 10 MM AND PEAK TOTAL NUMBER OF TUBERS IN ESTIMA OVER 3 YEARS. PLANTING DATE: P1 (18-25 MARCH), ■; P2 (15-22 APRIL), ●; P3 (13-20 MAY), ▲; P4 (10-17 JUNE), ◆. FINAL HARVEST: CLOSED SYMBOLS, PEAK NUMBERS, OPEN SYMBOLS. LINE, EXPECTED NUMBER OF TUBERS BASED ON HISTORIC DATA SET AVERAGE.

4.7. Experiment 10 Planting and density - Lady Rosetta

Sprouting was visible on seed tubers at all four planting dates with 55, 90, 55 and 100 %, respectively of tubers with sprouts of c. 1 mm length. The interval from planting to 50 % emergence decreased with sequential plantings (47, 34, 21 and 19 ± 0.4 days). Emergence was fairly complete at all plantings (> 99 %) and near full ground cover was achieved in all treatments (> 99 %). Frost damage on 11-12 May affected 3 and 11 % of all plants in the harvest rows at the first planting at the wider and closer spacings, respectively but all plants re-grew.

Between the first two harvests there was generally little change in the total number of tubers except at the closer spacing of the first two plantings and the wider spacing of the penultimate planting where the number of tubers decreased (Figure 13a-d). There was generally little change in the number of tubers > 10 mm between the first two harvests except at the wider spacing of the first planting where the number of tubers increased and at the closer spacing of the second planting where the number of tubers decreased (Figure 13a-d). Between the second and final harvest, the total number of tubers generally decreased except at the closer spacing of the penultimate

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planting where the number of tubers was stable (Figure 13a-d). There was generally little change in the number of tubers > 10 mm between the second and final harvest harvests except at the closer spacing of the second planting where the number of tubers decreased slightly (Figure 13a-d). Similar to the results for Estima, substantially more tubers were initiated than retained at the first two plantings at the higher plant density with much less difference in the number of tubers initiated and retained at the penultimate planting (Figure 11a-d).

The numbers of main stems per plant tended to increase with a delay in planting (Table 8) and generally very few secondary stems were formed in any treatment (< 0.08 per plant) except for the penultimate planting at the wider spacing where 1.3 secondary stems per plant were formed. At the final harvest the effects on the total number of tubers reflected the number of tubers > 10 mm which were greatest at the second planting and least at the final planting (Table 8) and greater at the closer spacing (538 300 ± 12 630/ha) than the wider spacing (401 000).

Averaged over the 3 years, the numbers of main stems per plant tended to increase with a delay in planting but in 2009 there was little difference in the number of stems except at the final planting (Table 9). Overall the greatest number of tubers > 10 mm was produced at the second planting and least at the first planting and more tubers formed at the closer spacing (661 600 ± 7 530/ha) than the wider spacing (469 700) (Table 9). More tubers > 10 mm were formed in 2008 than either 2009 or 2010, but in 2008 the greatest number of tubers formed at the final planting and least at the first planting while in 2009 the greatest number of tubers formed at the penultimate planting and least at the second planting and in 2010 the greatest number of tubers formed at the second planting and least at the final planting (Table 9).

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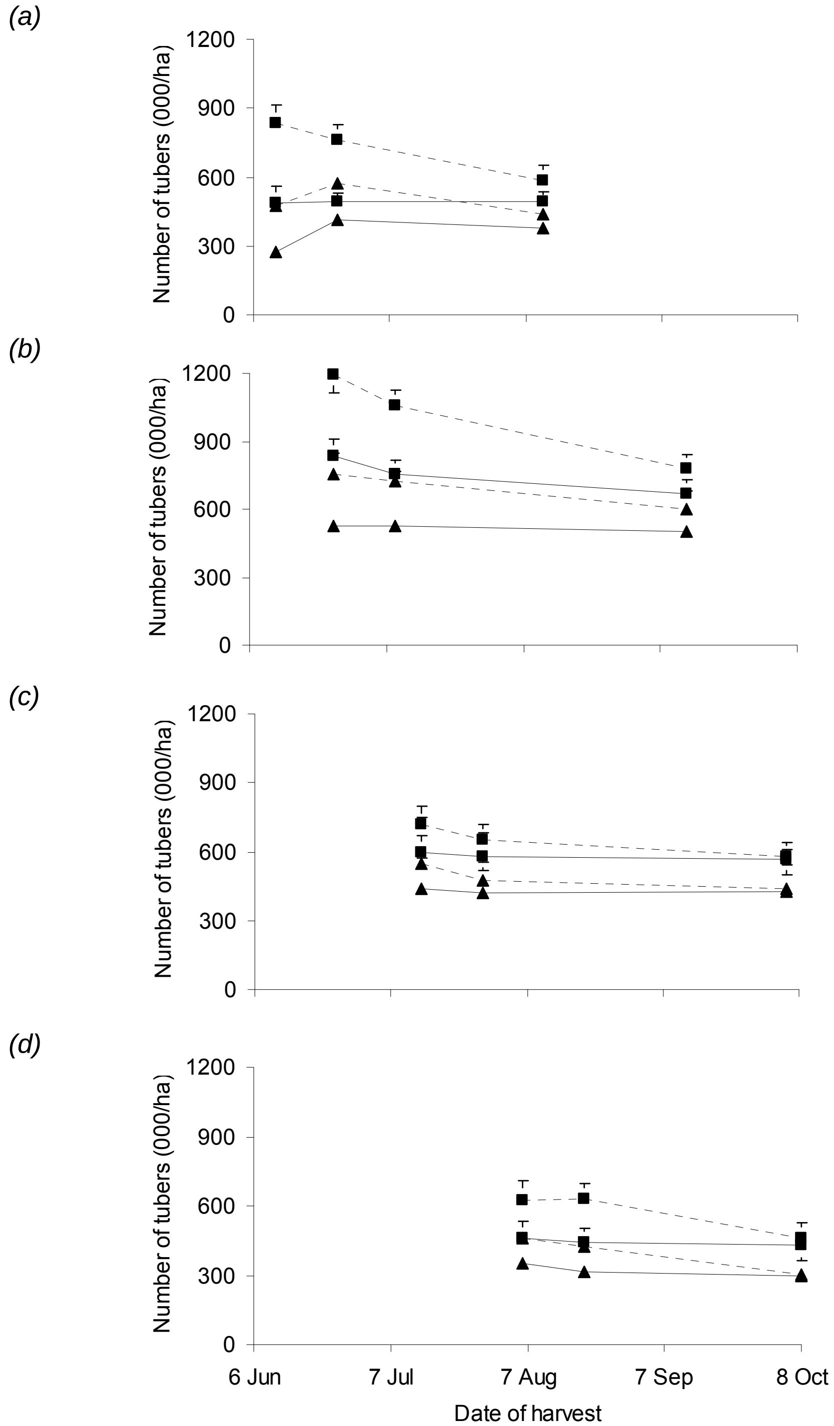

FIGURE 13. THE EFFECT OF PLANTING DENSITY ON THE NUMBER OF TUBERS AT FOUR PLANTING DATES *(A)* 25 MARCH, *(B)* 22 APRIL, *(C)* 20 MAY, *(D)* 17 JUNE FOR LADY ROSETTA IN EXPERIMENT 10. PLANT SPACING: 20 CM, ■; 40 CM, ▲. NUMBER OF TUBERS > 10 MM, SOLID LINE; TOTAL NUMBER OF TUBERS, BROKEN LINE.

The number of tubers > 10 mm at final harvest was generally similar to the values fitted to the historical data sets by Firman et al. (2007) (Figure 14). The peak total number of tubers was substantially higher than the retained number of tubers > 10 mm at the final harvest except at the first and second planting at the wider spacing in 2009, the penultimate planting at both spacings in 2009 and the closer spacing in 2010, and the final planting at the closer spacing in 2009 where the difference was < 30 % of the retained number of tubers (Figure 14). In these cases, the final number of tubers were often below those fitted to the historical data sets.

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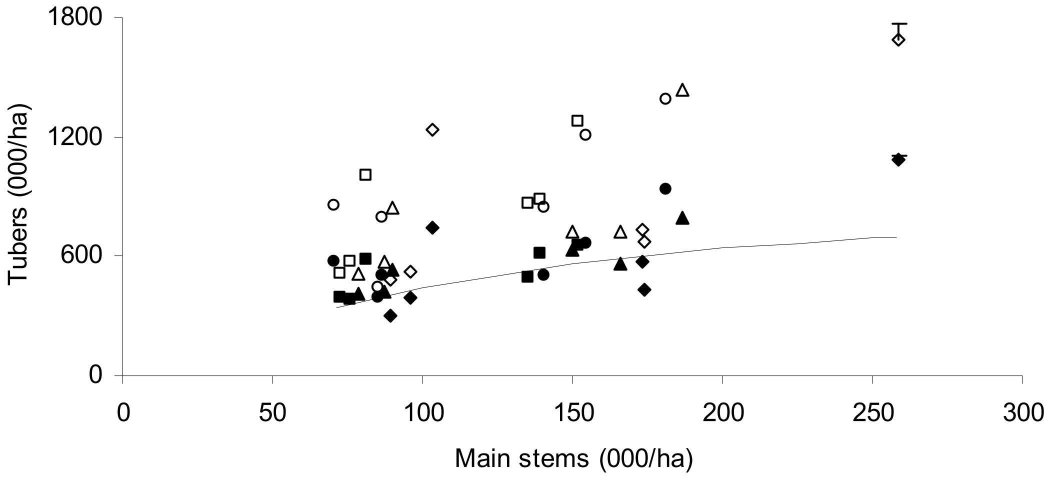

FIGURE 14. EFFECT OF PLANTING DATE AND PLANT SPACING ON THE FINAL NUMBERS OF TUBERS > 10 MM AND PEAK TOTAL NUMBER OF TUBERS IN LADY ROSETTA OVER 3 YEARS. PLANTING DATE: P1 (18-25 MARCH), ■; P2 (15-22 APRIL), ●; P3 (13-20 MAY), ▲; P4 (10-17 JUNE), ◆. FINAL HARVEST: CLOSED SYMBOLS, PEAK NUMBERS, OPEN SYMBOLS. LINE, EXPECTED NUMBER OF TUBERS BASED ON HISTORIC DATA SET AVERAGE.

4.8. Experiment 11 Planting and density - Maris Peer

Sprouting was visible on seed tubers on all four planting dates with 10, 35, 5 and 30 %, respectively of tubers with sprouts of c. 1 mm length. The interval from planting to 50 % emergence decreased progressively with sequential plantings (47, 32, 23, 19 ± 0.5 days) and emergence was fairly complete at all plantings (> 96 %). Near-complete ground cover was achieved at the first three plantings (> 97 %) but at the final planting 53 and 94 % ground cover was achieved at the wider spacing and closer spacings, respectively. Frost damage on 11-12 May affected 22 and 25 % of all plants in the harvest rows at the first planting at the wider and closer spacings, respectively, but all plants re-grew.

Generally between the first two harvests the total number of tubers was stable except at the wider plant spacing of the second planting and the closer spacing of the final planting where the number of tubers decreased, while the number of tubers > 10 mm was generally stable or increased between the first two harvests (Figure 15a-d). Between the penultimate and final harvests the total number of tubers generally decreased except at the closer spacing of the final harvest where the number of tubers was stable. Generally there was little change in the number of tubers > 10 mm between the penultimate and final harvests except at the closer spacing of first and final plantings where the number of tubers increased and at the closer spacing of the second planting where the number of tubers increased (Figure 15a-d). Similar to the results for Estima and Lady Rosetta substantially more tubers were initiated than retained at the second planting at the higher plant density but in Maris Peer there was less difference between the initiated and retained number of tubers at the first planting than in Estima and Lady Rosetta but a greater difference between the number of tubers initiated and retained at the penultimate planting (Figure 15a-d). At the final plantings of Estima and Lady Rosetta there was a moderate difference between the number of tubers initiated and retained while at the final planting of Maris Peer there was a substantial increase in the number of tubers > 10 mm with sequential harvests at the closer spacing (Figure 15d).

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The numbers of main stems per plant increased with a delay in planting (Table 8) and few secondary stems were formed (< 0.04 per plant) in any treatment. At the final harvest the effects on the total number of tubers reflected the number of tubers > 10 mm which was greatest at the second planting and least at the first and penultimate at plantings (Table 8). More tubers > 10 mm formed at the closer (682 600 ± 12 080/ha) than the wider spacing (487 700) and at the wider spacing the greatest number of tubers > 10 mm formed at the second planting (667 100 ± 24 160/ha) and least at the first and third planting (380 000 and 425 100, respectively), while at the closer spacing the number of tubers > 10 mm was greatest at the final and second plantings (802 100 and 794 700 ± 24 160/ha, respectively) and least at the penultimate and first planting (536 100 and 597 400, respectively). Averaged over the 3 years the numbers of main stems per plant tended to increase with a delay in planting and overall the number of tubers > 10 mm was greatest at the second planting and least at the first planting (Table 9). At the closer plant spacing more tubers > 10 mm formed at the second planting (755 000 ± 36 500/ha) and least at the first planting (602 000) with the third planting being intermediate (670 000) while at the wider plant spacing more tubers formed at the second planting (921 000 ± 36 500/ha) than either the first or third plantings (762 000 and 774 000, respectively). More tubers > 10 mm formed in 2008 than either 2009 or 2010 and in 2008 the greatest number of tubers formed at the second planting and least at the first planting while in 2010 the greatest number of tubers formed at the second planting and least at the penultimate and first plantings but in 2009 planting date had little effect on the number of tubers (Table 9).

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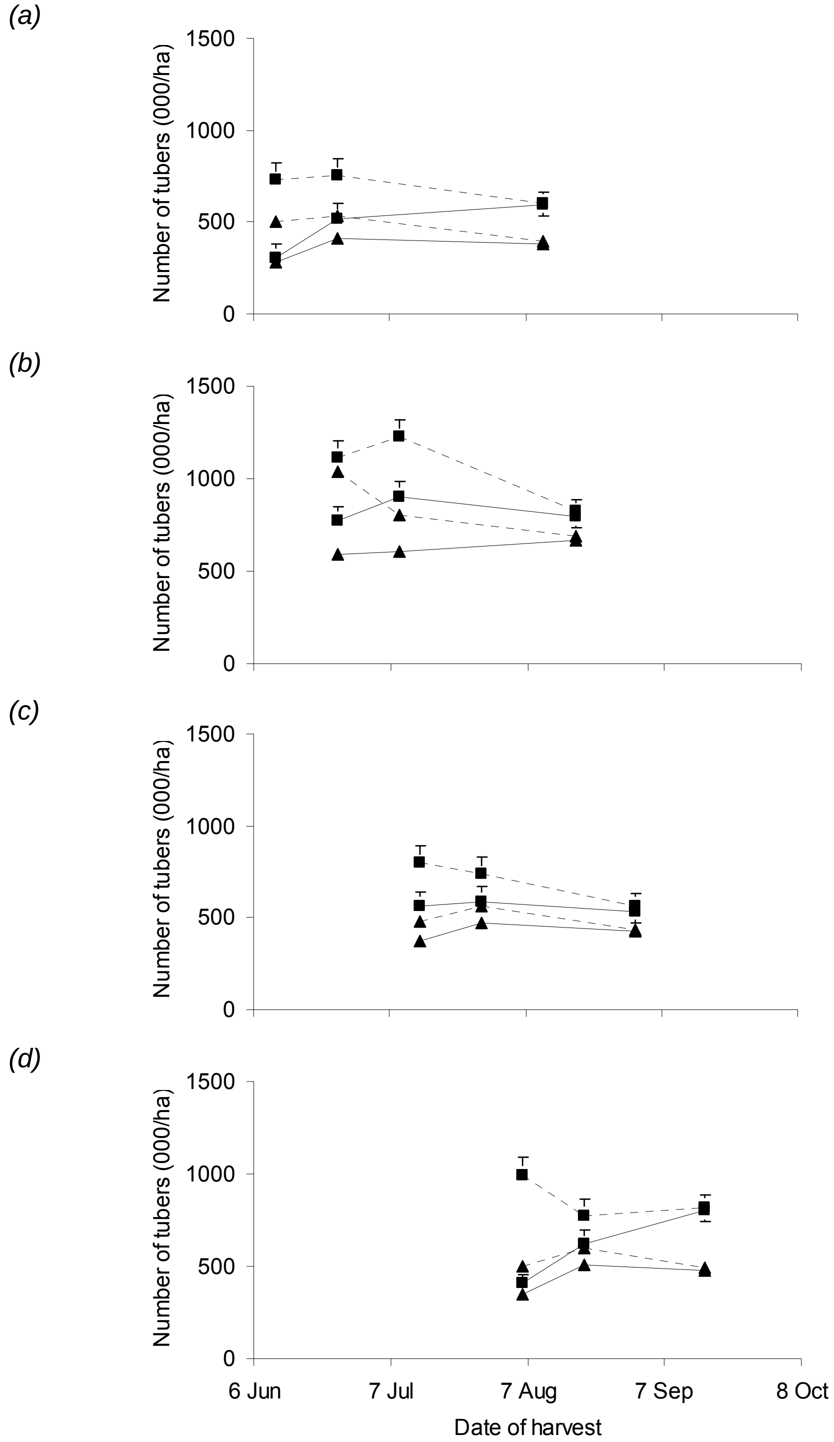

FIGURE 15. EFFECT OF PLANTING DENSITY ON THE NUMBER OF TUBERS AT FOUR PLANTING DATES (A) 25 MARCH, (B) 22 APRIL, (C) 20 MAY, (D) 17 JUNE FOR MARIS PEER IN EXPERIMENT 11. PLANT SPACING: 20 CM, ■; 40 CM, ▲. NUMBER OF TUBERS > 10 MM, SOLID LINE; TOTAL NUMBER OF TUBERS, BROKEN LINE.

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The number of tubers > 10 mm at the final harvest were generally similar to the values fitted to the historical data sets by Firman et al. (2007) (Figure 16). The peak total number of tubers were substantially higher than the retained number of tubers at the final harvest except at the penultimate planting at the wider spacing in 2009 and the final planting at the closer spacing in 2010 where the where the difference was < 30 % of the retained number of tubers (Figure 16). Small differences between the peak and retained number of tubers tended to be associated with cases when the final number of tubers were fewer than those fitted to the historical data set (Figure 16).

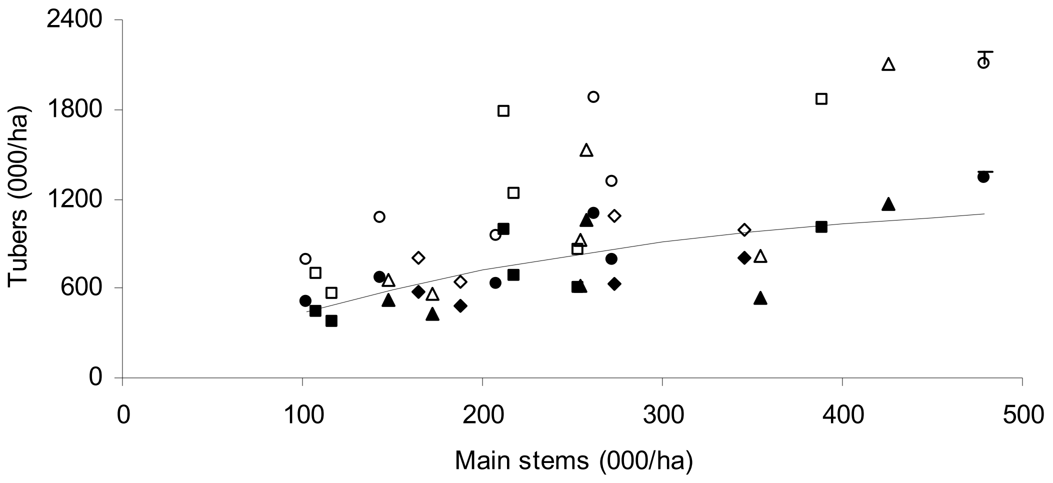

FIGURE 16. EFFECT OF PLANTING DATE AND PLANT SPACING ON THE FINAL NUMBERS OF TUBERS > 10 MM AND PEAK TOTAL NUMBER OF TUBERS IN MARIS PEER OVER 3 YEARS. PLANTING DATE: P1 (18-25 MARCH), ■; P2 (15-22 APRIL), ●; P3 (13-20 MAY), ▲; P4 (10-17 JUNE), ◆. FINAL HARVEST: CLOSED SYMBOLS, PEAK NUMBERS, OPEN SYMBOLS. LINE, EXPECTED NUMBER OF TUBERS BASED ON HISTORIC DATA SET AVERAGE.

4.9. Experiment 12 Multiple date of planting - Maris Peer

No sprouting was visible on seed tubers at the first five planting dates and generally at later plantings ≤ 25 % of tubers had sprouts of c. 1 mm length except at the ninth planting where 60 % of tubers had sprouts of c. 1 mm length. At the first eight plantings near complete emergence (> 98 %) was achieved but at the final four plantings emergence was 90, 95, 97 and 93 %, respectively. The number of days from planting to 50 % emergence decreased with the first eight sequential plantings (Table 10) but increased at the final three plantings. While near full ground cover (> 95 %) was achieved at the wider spacing of the first and second plantings, the closer spacing of the sixth planting and both spacings of the fourth, fifth and final plantings generally ground cover was less than complete (80-95 %) with a maximum ground cover of 65-72 % achieved at the wider spacing of the seventh to tenth plantings. Frost damage on 11-12 May affected 43 and ≤ 2 % of all plants in the harvest rows at the first and second planting, respectively but all plants re-grew.

Consistent with Experiment 11 the average number of main stems per plant tended to increase with delay in planting (Table 10) and very few secondary stems were produced at any planting (< 0.09 per plant). Consistent with Experiment 11 the number of tubers > 10 mm was greater at the eighth to eleventh plantings (24 June to 22 July) than at the first three and the fifth to seventh plantings (18 March to 15 April and 13 May to 10 June, respectively) (Table 10) but in contrast the greatest number of tubers > 10 mm in Experiment 11 were produced at the second planting (22 April).

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Planting date	Planting to 50 % emergence (days)	Main stems/plant			Main stems (000/ha)			Tubers > 10 mm (000/ha)		
	Mean	D1	D2	Mean	D1	D2	Mean	D1	D2	Mean
18 Mar	50.5	2.11	1.92	2.01	92	168	130	362	462	412
1 Apr	45.7	2.06	2.16	2.11	90	189	139	345	476	411
15 Apr	38.1	1.94	1.97	1.96	85	172	129	433	552	492
29 Apr	34.0	2.34	2.50	2.42	103	219	161	458	714	586
13 May	26.2	2.50	2.14	2.32	109	188	149	350	529	440
27 May	25.9	2.67	2.36	2.51	117	207	162	311	420	366
10 Jun	22.0	2.72	2.89	2.81	119	253	186	343	583	463
24 Jun	18.6	3.44	3.06	3.25	151	267	209	464	671	568
8 Jul	18.7	3.41	3.47	3.44	149	304	227	517	732	624
15 Jul	20.4	3.39	3.08	3.24	148	270	209	642	756	699
22 Jul	22.3	3.67	2.94	3.30	160	257	209	588	776	682
29 Jul	24.0	2.81	3.06	2.93	123	267	195	406	617	512
S.E. (45 D.F.)	0.40	0.189		0.134	11.1		7.9	36.2		25.6

TABLE 10. EFFECT OF PLANTING DATE ON EMERGENCE AND THE NUMBER OF MAIN STEMS AND TUBERS > 10 MM AT TWO PLANT DENSITIES (SPACING D1, 30 CM; D2, 15 CM) IN MARIS PEER

In 2009 the relationship between the number of stems and tubers was close to the values fitted to the historical data sets by Firman et al. (2007) (Figure 17) with 19 % of treatments producing substantially more tubers than expected (difference between the observed and the expected greater than three standard errors) including both spacings at the fourth planting (Figure 17). In 2008, 45 % of treatments produced a greater number of tubers than expected from the historic data set including both stocks and spacings at the fourth planting and in 2010 50 % of treatments produced fewer tubers than expected from the historic data analysis including the fifth to eighth plantings at both spacings (Figure 17).

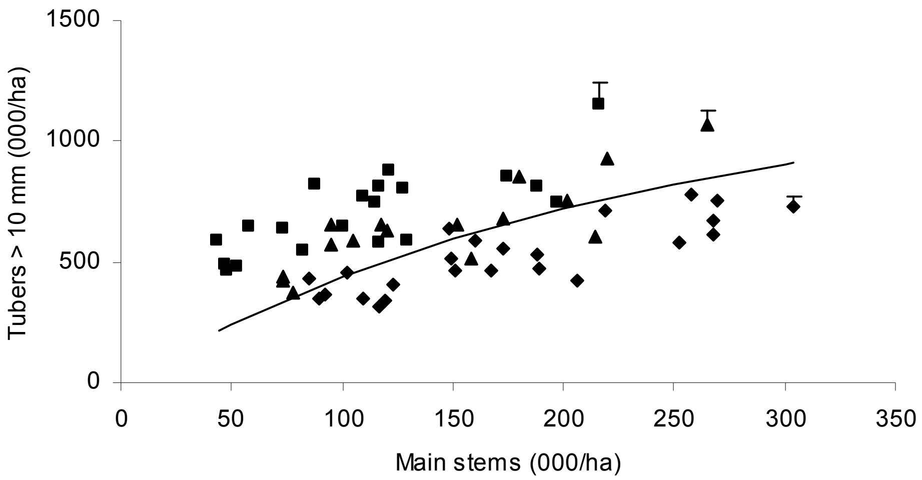

FIGURE 17. RELATIONSHIP BETWEEN THE NUMBER OF MAIN STEMS AND TUBERS > 10 MM AT MULTIPLE PLANTINGS IN MARIS PEER OVER 3 YEARS. YEAR: ■, 2008; ▲, 2009; ◆, 2010. LINE, EXPECTED NUMBER OF TUBERS BASED ON HISTORIC DATA SET AVERAGE.

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4.10. Experiment 13 Multiple date of planting - Estima

No sprouting was visible on seed tubers at planting except at the fourth and tenth planting where 5 % of the seed tubers had sprouts of c. 1 mm length, and the ninth planting where 40 % had sprouts of c. 1 mm length. At the first seven plantings near complete emergence (> 95 %) was achieved but generally at subsequent plantings emergence was 86-95 %. Frost damage on 11-12 May affected 19 and 7 % of all plants in the harvest rows at the first planting at the wider and closer spacing, respectively, and < 5 % of plants at the second planting but all plants re-grew.

Consistent with Maris Peer the number of days from planting to 50 % emergence decreased with the first eight sequential plantings in Estima but increased at the final four plantings (Table 11). While near complete ground cover (> 95 %) was achieved at the first, fourth, fifth, ninth and tenth plantings at the closer spacings and the third planting at the wider spacing generally ground cover was less than complete (80-95 %) with maximum ground cover of 62-77 % achieved at the wider spacing of the seventh to tenth planting and the final planting.

In contrast to Experiment 9, from the fifth planting the average number of main stems per plant tended to increase with delay in planting whereas at the first four plantings there was no trend in number of stems with delay in planting (Table 11). Few secondary stems (< 0.03 per plant) were formed at any planting.

Planting date	Planting to 50 % emergence (days)	Main stems/plant			Main stems (000/ha)			Tubers > 10 mm (000/ha)		
	Mean	D1	D2	Mean	D1	D2	Mean	D1	D2	Mean
18 Mar	49.7	1.78	1.75	1.76	58	115	87	275	445	360
1 Apr	44.6	2.28	1.97	2.12	75	129	102	292	428	360
15 Apr	37.8	1.67	1.92	1.79	55	126	90	275	507	391
29 Apr	33.1	2.00	1.92	1.96	66	126	96	275	454	364
13 May	25.9	1.56	1.44	1.50	51	95	73	248	436	342
27 May	25.3	1.78	1.75	1.76	58	115	87	237	348	292
10 Jun	22.0	1.54	1.94	1.74	51	128	89	191	348	269
24 Jun	19.5	1.82	1.75	1.79	60	115	87	215	368	292
8 Jul	20.0	1.63	2.11	1.87	53	139	96	181	390	285
15 Jul	20.9	1.94	2.13	2.04	64	140	102	208	395	301
22 Jul	22.7	2.22	2.08	2.15	73	137	105	253	372	313
29 Jul	24.1	2.00	2.39	2.19	66	157	111	213	379	296
S.E. (46 D.F.)	0.38	0.162		0.114		8.6	6.1	30.4		21.5

TABLE 11. THE EFFECT OF PLANTING DATE ON THE NUMBER OF MAIN STEMS AND TUBERS > 10 MM, AT TWO PLANT DENSITIES (SPACING D1, 30 CM; D2, 15 CM) IN ESTIMA

On average, the number of tubers > 10 mm was greater at the first four plantings (18 March to 29 April) than the sixth to ninth plantings (27 May to 8 July) with the greatest number of tubers formed at the third planting (15 April) and least at the seventh planting (10 June) (Table 11). In Experiment 9 the second planting (22 May) produced the greatest number of tubers whilst the first (25 March) and third plantings (20 May) produced the least, and the final planting (17 June) was intermediate (Table 8).

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Consistent with the results for Maris Peer the relationship between the number of stems and tubers for the majority of treatments in 2009 was similar to the values fitted to the historical data sets by Firman et al. (2007) (Figure 18) with 8 % of treatments each producing a greater or smaller number of tubers than expected from the historic data (difference between the observed and the expected greater than three standard errors), but in 2010, 33 % of treatments produced fewer tubers than expected including both spacings at the tenth and twelfth planting (Figure 18). The lower than expected number of tubers for both Maris Peer and Estima in 2010 is consistent with the 2001 reference crop data grown in the same area and it is possible that in both cases poor soil conditions associated with a relatively high clay content limited the number of tubers formed.

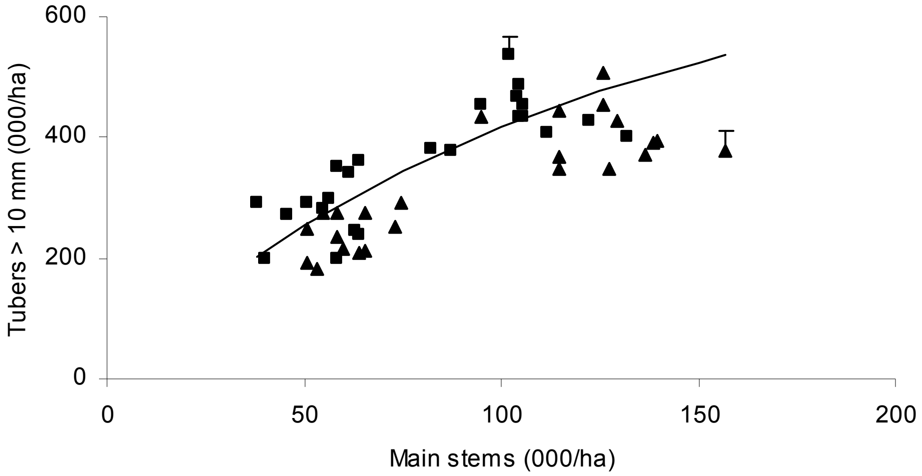

FIGURE 18. RELATIONSHIP BETWEEN THE NUMBER OF MAIN STEMS AND TUBERS > 10 MM AT MULTIPLE PLANTINGS IN ESTIMA OVER 2 YEARS. YEAR: ■, 2009; ▲, 2010. LINE, EXPECTED NUMBER OF TUBERS BASED ON HISTORIC DATA SET AVERAGE.

4.11. Experiment 14 Soil condition - Maris Peer

The interval from planting to 50 % emergence was similar for all treatments (c. 25-27 days). Although on average planting depth was deeper with the bulb planter (12.4 ± 0.40 cm) than the dibber (9.8) planting depth on flattened plots was similar (10.6 cm) and near-complete emergence was achieved in all treatments (> 98 %). Full ground cover was achieved later at the wider compared to the closer plant spacing and generally persisted slightly longer at the wider spacing. Generally there was little difference in ground cover with different planting methods except between the end of June and the beginning of July where ground cover was c. 5 % greater in the dibber-planted plots compared to the bulb planter method.

The total number of tubers averaged over planting method was generally stable between the first and second harvests except at the wider spacing of the flat+ridge plots and the closer spacing of the roto+ridge plots where the number of tubers decreased (Figure 19a). The number of tubers > 10 mm was generally stable between the first and second harvests except at the wider plant spacing of the flat+ridge plots where the number of tubers decreased and at the closer spacing of the flat+ridge plots where the number of tubers > 10 mm increased (Figure 19b). Between the second and final harvest the total number of tubers was generally stable

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at the wider spacing except for the flat+ridge plots where the number of tubers increased but at the closer spacing the number of tubers decreased in all treatments (Figure 19a). The number of tubers > 10 mm generally increased between the second and final harvest at the wider spacing except in the roto+ridge plots where the number of tubers was stable, but at the closer spacing, the number of tubers decreases in the flat and flat+ridge plots was stable in the roto+ridge plots and increased in the ridged treatment (Figure 19b).

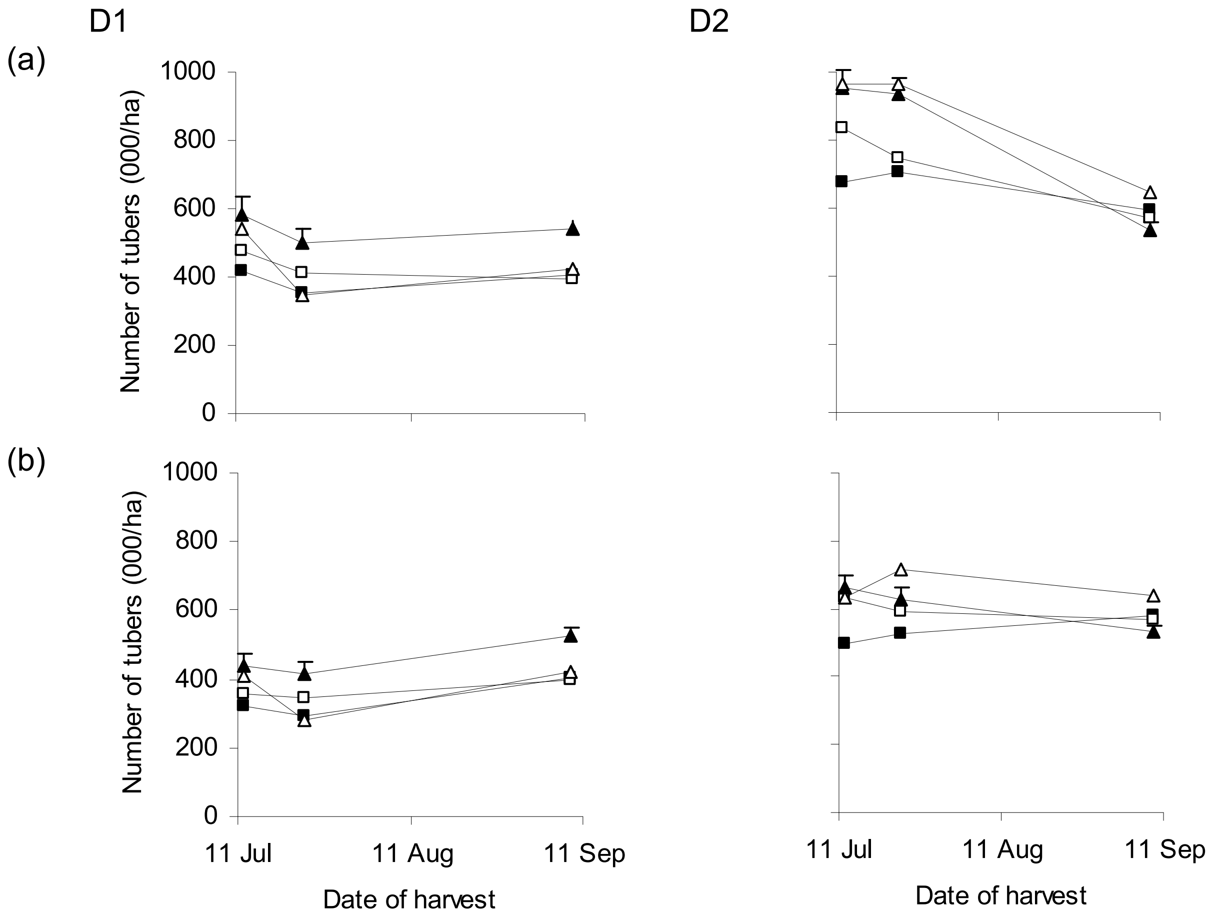

FIGURE 19. EFFECT OF SOIL CONDITIONS ON (A) TOTAL NUMBER OF TUBERS, (B) THE NUMBER OF TUBERS >10 MM AT THREE HARVESTS IN MARIS PEER WITH TWO PLANT SPACINGS: D1 30 CM, D2 15 CM. MEAN OF PLANTING METHOD. MEAN OF PLANTING METHOD. SOIL CULTIVATIONS: RIDGE, ■; ROTO+RIDGE, □; FLAT, ▲; FLAT+RIDGE, △.

In 2010 there was no effect of soil condition, method of planting or density on the interval from planting to 50 % emergence (Table 12) and there was little difference in the number of main stems per plant at the final harvest (Table 13) with few secondary stems produced in any treatment (< 0.05 per plant). The number of tubers > 10 mm was greater at the closer than the wider plant spacing at the final harvest but not in the flattened plots where at wide spacing there were more tubers than other treatments (Table 13). On average, the final number of tubers was greater with the dibber planting method (534 000 ± 14 400/ha) than the bulb planter (483 000). There was little difference in the total yield at the final harvest but the mean tuber size was greater at the wider than the closer plant spacing (Table 13).

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Planting method	Density	Soil Ridge	Roto+ridge	Flat	Flat+ridge	S.E. (15 D.F.)
Dibber	D1	26.2	26.8	25.3	24.5	0.82
	D2	26.4	26.1	24.3	24.5	
Mean of density		26.3	26.5	24.8	24.5	0.58
Bulb planter	D1	26.0	27.3	24.5	27.3	0.82
	D2	27.0	26.0	25.9	26.0	
Mean of density		26.5	26.6	25.2	26.6	0.58
Mean of D1		26.1	27.1	24.9	25.9	0.58
Mean of D2		26.7	26.0	25.1	25.2	

TABLE 12. THE EFFECT OF SOIL CONDITION AND PLANTING METHOD ON THE NUMBER OF DAYS TO 50 % EMERGENCE AT TWO PLANT DENSITIES (SPACING: D1, 30 CM; D2, 15 CM)

Generally over the 3 years there was little effect of soil condition or plant density on the number of main stems per plant (Table 14) except in 2008 when more main stems were formed at the wider plant spacing (3.93 ± 0.079) than the closer spacing (3.65). The number of tubers > 10 mm was lower at the wider than the closer spacing in all 3 years (679 000 and 947 000 ± 21 000/ha, respectively in 2008) and (462 000 and 630 100 ± 11 000/ha, averaged for 2009 & 2010). In 2009 and 2010 the flat plots produced more tubers at the wider spacing than other treatments but fewer at the closer spacing (Table 14). The total yield was similar for all treatments in 2008 with little effect of soil or plant density but in 2009 and 2010 the yield was lower on the flattened plots than other treatments (Table 14). There was little effect of soil or plant density on mean tuber size in 2008 and 2009 (Table 14).

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Planting method		Density	Ridge	Roto+ridge	Flat	Flat+ridge	S.E. (15 D.F.)
Main stems per plant	Dibber	D1	3.5	2.9	3.2	3.4	0.22
		D2	3.0	3.0	2.9	2.9	
		Mean	3.2	3.0	3.1	3.2	0.16
	Bulb planter	D1	2.9	3.2	3.2	3.1	0.22
		D2	2.9	3.2	3.2	3.3	
		Mean	2.9	3.2	3.2	3.2	0.16
		Mean of D1	3.2	3.1	3.2	3.3	0.16
		Mean of D2	3.0	3.1	3.1	3.1	
Tubers > 10 mm (000/ha)	Dibber	D1	459	405	529	487	40.6
		D2	563	571	573	689	
		Mean	511	488	551	588	28.7
	Bulb planter	D1	350	388	525	358	40.6
		D2	599	560	487	593	
		Mean	474	474	506	476	28.7
		Mean of D1	404	396	527	422	28.7
		Mean of D2	581	566	530	641	
Yield (t/ha)	Dibber	D1	50.4	46.6	48.1	45.6	5.49
		D2	43.8	44.1	47.5	43.8	
		Mean	47.1	45.4	47.8	44.7	3.88
	Bulb planter	D1	43.8	50.5	41.8	41.9	5.49
		D2	51.0	36.6	30.6	47.7	
		Mean	47.4	43.5	36.2	44.8	3.88
		Mean of D1	47.1	48.6	45.0	43.8	3.88
		Mean of D2	47.4	40.3	39.0	45.8	
Mean tuber size (mm)	Dibber	D1	54.7	58.0	54.5	52.2	2.18
		D2	48.3	48.5	51.0	45.8	
		Mean	51.5	53.3	52.8	49.0	1.54
	Bulb planter	D1	59.9	59.2	51.2	56.2	2.18
		D2	49.8	46.3	46.3	49.8	
		Mean	54.8	52.7	48.7	53.0	1.54
		Mean of D1	57.3	58.6	52.8	54.2	1.54
		Mean of D2	49.0	47.4	48.7	47.8	

TABLE 13. THE EFFECT OF SOIL CONDITION AND PLANTING METHOD AT THE FINAL HARVEST ON THE NUMBER OF MAIN STEMS, NUMBER OF TUBERS (TOTAL AND > 10 MM), TOTAL YIELD AND MEAN TUBER SIZE AT TWO PLANT DENSITIES (SPACING: D1, 30 CM; D2, 15 CM)

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	Soil	Ridge		Roto+ridge		Flat		Flat+ridge		
	Density Year	D1	D2	D1	D2	D1	D2	D1	D2	S.E. (33 D.F)
Main stems per plant	2008	4.09	3.80	4.01	3.73	3.88	3.60	3.72	3.48	0.172†
	2009	3.00	2.81	3.09	2.86	3.22	2.93	2.97	3.02	0.173
	2010	3.20	2.95	3.06	3.09	3.20	3.08	3.25	3.11	
	Mean ‡	2.99		3.03		3.11		3.09		0.086
Tubers > 10 mm (000/ha)	2008	699	967	671	1008	640	936	708	876	54.5†
	2009	463	686	537	670	496	651	449	716	15.6
	2010	404	581	396	566	527	530	422	641	
	Mean ‡	534		542		551		557		15.6
Total yield (t/ha)	2008	53.2	58.1	57.1	56.4	46.8	49.3	52.6	51.4	3.61†
	2009	69.5	74.8	65.1	67.6	55.4	62.9	61.4	65.0	3.73
	2010	47.1	47.4	48.6	40.3	45.0	39.0	43.8	45.8	
	Mean ‡	59.7		55.4		50.6		54.0		1.86
Mean tuber size (mm)	2008	-	-	-	-	-	-	-	-	
	2009	61.5	55.5	58.3	55.0	55.8	51.5	59.2	53.1	0.87
	2010	57.4	49.0	58.7	47.4	52.8	48.7	54.2	47.8	
	Mean ‡	55.9		54.9		52.2		53.6		0.62

‡ Means of 2009 and 2010 data. † S.E. based on 20 D.F.

TABLE 14. THE EFFECT OF SOIL CONDITION AND PLANT DENSITY OVER 3 YEARS AT THE FINAL HARVEST ON THE NUMBER OF MAIN STEMS, NUMBER OF TUBERS > 10 MM, TOTAL YIELD AND MEAN TUBER SIZE. MEAN OF STOCK 2008 (SPACING: D1, 20 CM; D2, 10 CM), MEAN OF PLANTING METHOD (SPACING: D1, 30 CM; D2, 15 CM) 2009 AND 2010

At the first harvest stolon length (mean of the three longest stolons per plant) was greatest in the roto+ridge and least in the ridge soil (Table 15) and greater with the dibber planting method (74.6 ± 2.04 cm) than the bulb planter (56.7). Stolon length was greatest in the flat+ridge and roto+ridge treatments with the dibber planting method at the widest plant spacing and least with the planter at both spacings in the ridge treatment, the roto+ridge and flat treatments at the closer spacing and the flat+ridge treatment at the widest spacing (Table 15).

		Soil				
Planting method	Density	Ridge	Roto+ridge	Flat	Flat+ridge	S.E. (15 D.F.)
Dibber	D1 30 cm	63.2	90.0	79.0	101.1	5.77
	D2 15cm	61.6	72.6	66.9	61.9	
Bulb planter	D1 30 cm	42.5	80.7	61.4	49.9	
	D2 15 cm	52.1	57.1	49.1	60.9	
	Mean	54.9	75.1	64.1	68.4	2.88

TABLE 15. THE EFFECT OF SOIL CONDITION AND PLANTING METHOD ON THE MEAN STOLON LENGTH (MM) AT THE FIRST HARVEST WITH TWO PLANT DENSITIES (SPACING: D1, 30 CM; D2, 15 CM)

At planting, bulk density in the unplanted areas was greatest in the flat and least in the ridge and roto+ridge plots and where planting was simulated a similar pattern was found (Table 16). At tuber initiation, bulk density in the unplanted areas was greatest in the flat and flat+ridge treatments and least in the ridge and roto+ridge plots and where planting was simulated greatest in the flat and least in the ridge and roto+ridge plots (Table 16). Generally there was little difference between bulk density at planting compared to tuber initiation in unplanted areas except for the flat+ridge plots where bulk density increased, but where planting was simulated bulk density was generally

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greater at tuber initiation than at planting except for the flat+ridge treatment where there was little difference in bulk density (Table 16). There was no difference in the bulk density between simulated and unplanted areas at planting irrespective of planting method in either the ridged or roto+ridge areas (0.029 and 0.029 ± 0.0517, mean of the value of each plot where simulated bulk density was subtracted from the unplanted bulk density) but bulk density was greater in the unplanted flattened plots (0.078) compared to the simulated planting and lower in the unplanted flat+ridge plots (-0.056) than the simulated planting areas. There was little difference in the bulk density of simulated and unplanted areas at tuber initiation (Table 16).

	Bulk Density			
	Planting		**TI**	
Soil condition	**Unplanted**	**Simulated**	**Unplanted**	**Simulated**
Ridge	1.07	1.04	1.10	1.11
Roto+ridge	1.08	1.05	1.14	1.12
Flat	1.27	1.19	1.30	1.30
Flat+ridge	1.16	1.22	1.26	1.24
S.E. (15 D.F.)	0.017	0.018	0.018	0.017

TABLE 16. THE EFFECT ON BULK DENSITY (G/CM^3) OF FOUR SOIL CONDITIONS AT PLANTING AND TUBER INITIATION (TI) WITH RIDGES UNPLANTED OR WITH SIMULATED PLANTING

At planting there was little difference in the mean ped size in the unplanted areas except for the flattened treatment which was greater than the other cultivation methods whereas where planting was simulated mean ped size was numerically greater in the flat and flat+ridge and least in the ridged or roto+ridge plots (Figure 20).

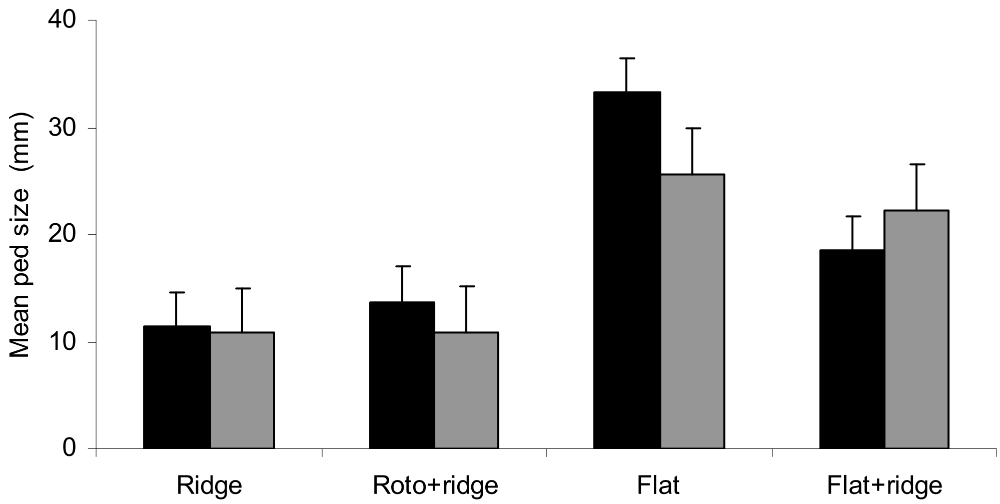

FIGURE 20. EFFECT OF FOUR SOIL CONDITIONS ON MEAN PED SIZE AT PLANTING WITH RIDGES UNDISTURBED OR SIMULATED PLANTING. PLANTING: UNPLANTED, ■; SIMULATED PLANTING, ■.

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Soil resistance at tuber initiation increased with increasing soil profile depth except for the flattened treatment which was stable (Figure 21). The flattened treatment showed highest resistance and the ridged treatment numerically the least except at a depth of 30 cm where resistance was greatest in the roto+ridge and flat+ridged plots (Figure 21). Resistance was similar in the ridged and roto+ridged plots to a depth of 15 cm but below 20 cm the increase in resistance with increasing depth was greater in the roto+ridged than the ridged treatments. Resistance was numerically greater in the flat+ridged than the roto+ridge treatment to 20 cm but was similar below 25 cm (Figure 21).

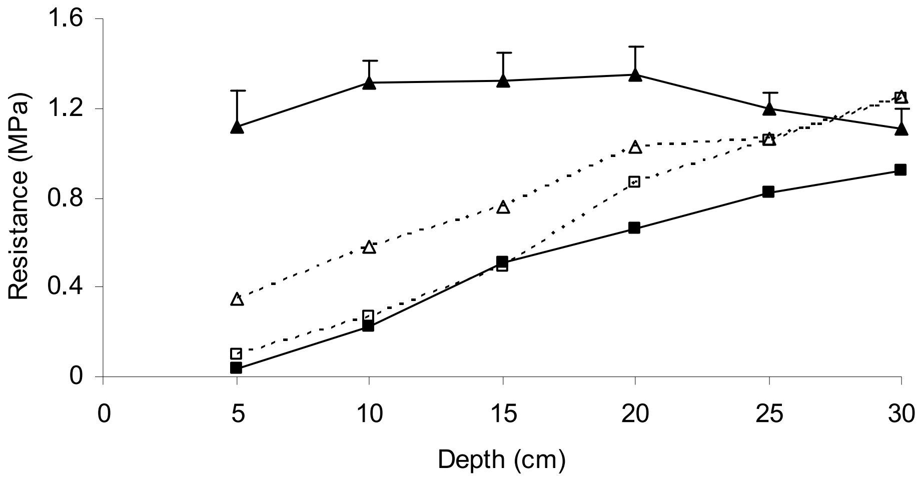

FIGURE 21. EFFECT OF SOIL CULTIVATIONS ON VERTICAL SOIL RESISTANCE. SOIL CULTIVATIONS: RIDGE, ■; ROTO+RIDGE, □; FLAT, ▲; FLAT+RIDGE, △.

Soil resistance at 10 cm was numerically greatest in the flattened treatments except on 7, 21 and 28 June when the flat+ridged treatment was numerically greater (Figure 22a). Resistance was numerically lower in the ridge and roto+ridged plots compared to the flat and flat+ridged treatments, and generally resistance was lowest in the roto+ridged plots except for 17, 24 May, 28 June and 12 July were the ridged plots were numerically the lowest (Figure 22a). Moisture content was greatest in the flat and flat+ridged plots except on 7 and 28 June where moisture content in the roto+ridged plots was greater than in the ridge and flat+ridged plots (Figure 22b).

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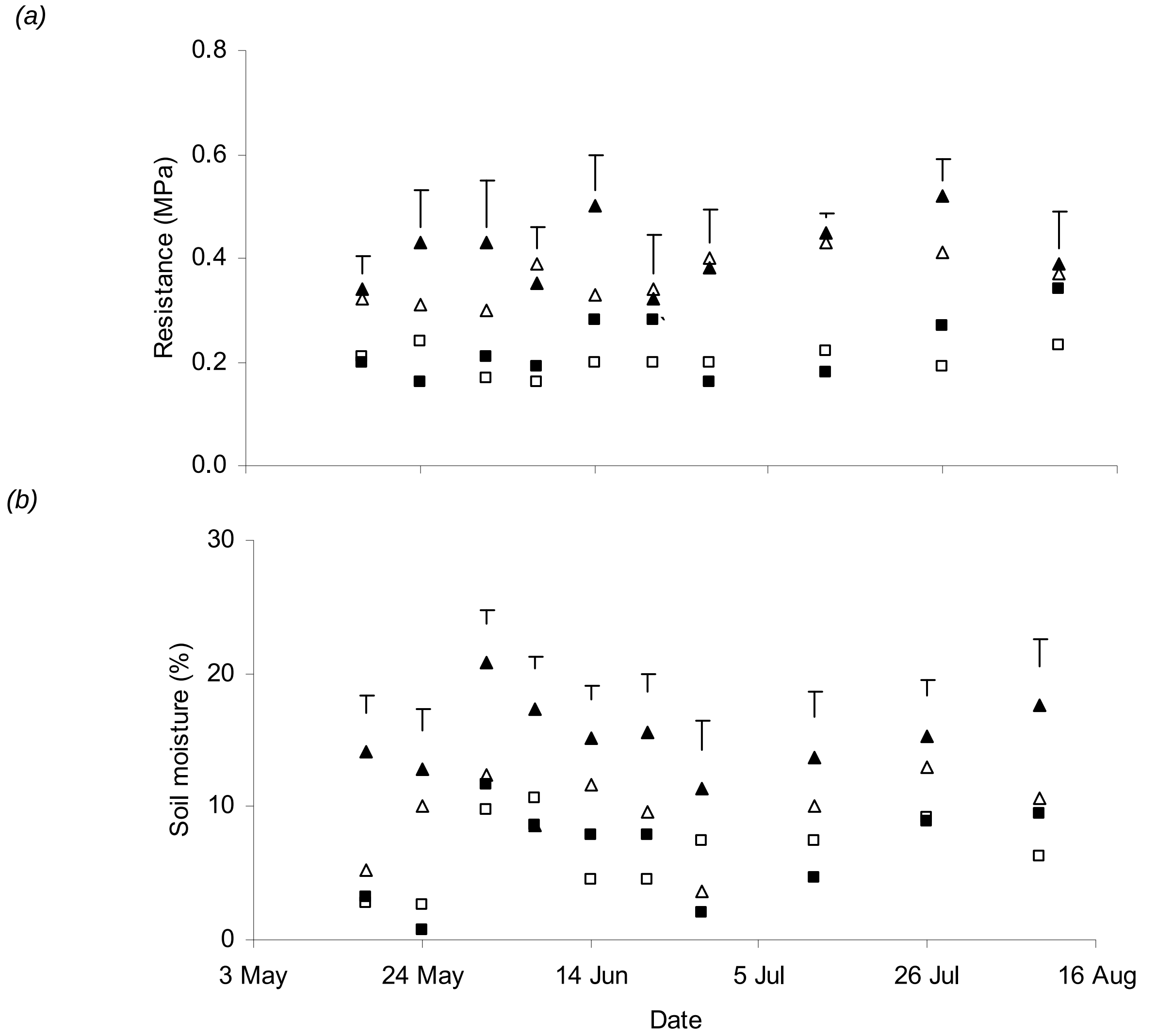

FIGURE 22. EFFECT OF SOIL CULTIVATIONS ON (*A*) SOIL RESISTANCE AT 10 CM (MPA), (*B*) SOIL WATER CONTENT AT 10 CM (%). SOIL CULTIVATIONS: RIDGE, ■; ROTO+RIDGE, □; FLAT, ▲; FLAT+RIDGE, △.

4.12. Experiment 15 Clod size and soil type - Estima

On average, the interval from planting to 50 % emergence in reformed ridges was 11 days later in the clay than the sandy clay loam but similar for the undisturbed control and ungraded sandy clay loam (Table 17). Fine soil advanced emergence in the sandy clay loam but not in the clay whilst cloddy soil delayed emergence markedly in the sandy clay loam but had less effect in the clay (Table 17). For the clay soil emergence was advanced most by grading to medium size aggregates in contrast to the sandy clay loam (Table 17).

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Soil	Grade	Days to 50 % emergence	Main stems per plant	Tubers > 10 mm	Total number of tubers	Yield (t/ha)
Sandy clay loam	Control	37.8	1.88	442	472	52.2
	S.E.	1.63	0.119	22.7	26.8	2.35
	S.E.†		0.113	28.5	33.7	2.87
	Ungraded	37.9	1.92	424	454	49.9
	Fine	32.4	2.04	530	555	58.8
	Medium	41.8	1.96	385	448	47.5
	Cloddy	51.1	1.75	342	396	35.9
Clay	Ungraded	55.7	1.75	128	156	6.7
	Fine	52.3	1.92	109	153	2.6
	Medium	47.7	1.63	170	238	21.2
	Cloddy	51.1	1.69	283	352	28.5
	S.E.	2.30	0.168	32.2	37.9	3.33
	S.E.†		0.160	40.3	47.6	4.06
Sandy clay loam	Mean	40.8	1.92	420	463	48.0
Clay	Mean	51.7	1.75	173	225	14.7
	S.E	1.15	0.084	16.1	18.9	1.67

S.E. based on 19 D.F. except † based on 11 D.F. excluding clay.

TABLE 17. THE EFFECT OF SOIL TYPE AND GRADING ON EMERGENCE, NUMBERS OF STEMS PER PLANT, TUBERS > 10 MM (000/HA), TOTAL NUMBER OF TUBERS (000/HA) AND YIELD

All treatments reached near full emergence (> 97 %) except for the ungraded clay (94 %). In the sandy clay loam near complete ground cover (> 97 %) was achieved except for the cloddy grade (93 %), and near complete ground cover occurred earlier in the fine than the cloddy grade (Figure 23). Ground cover developed later in the clay than the sandy clay loam (Figure 23) and initially developed more rapidly in the cloddy and medium than the ungraded and fine clay with maximum ground covers of c. 87, 68, 38, 4 %, respectively. All plants in the fine clay soils and most plants in the ungraded clay developed little after emergence with fewer than six expanded leaves but there was little difference in the persistence of ground cover in any treatment.

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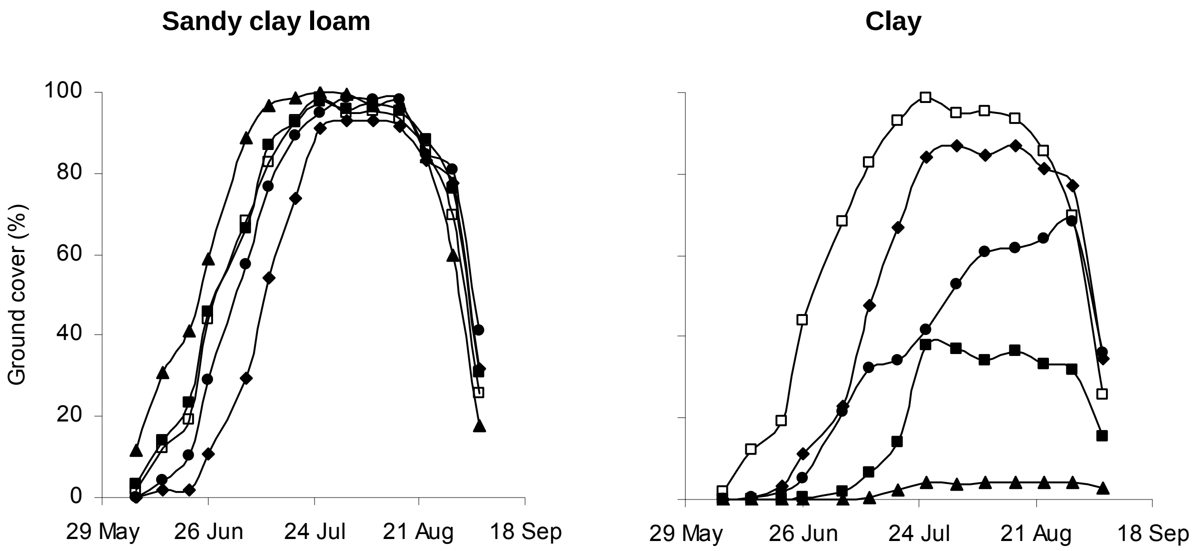

FIGURE 23. EFFECT OF SOIL TYPE AND GRADING ON GROUND COVER FOR ESTIMA IN EXPERIMENT 15. SOIL GRADES: □, SANDY CLAY LOAM CONTROL; ■, UNGRADED; ▲, FINE; ●, MEDIUM; ◆, CLODDY.

The number of main stems per plant was unaffected by treatment (Table 17) and few secondary stems (< 0.05 per plant) were produced. The total number of tubers in the control and the ungraded field soil were similar but there were more tubers in the undisturbed control (472 000 ± 26 800/ha) than the disturbed soils (344 000) and numerically the fine grade of the field soil produced the greatest number of tubers and the cloddy grade the least (Table 17). Fewer tubers formed in the clay than the sandy clay loam and very few tubers were formed in the ungraded and fine clay where plant growth was severely affected compared to the medium and cloddy grades (Table 17). Analysis of variance was conducted excluding the clay soil to allow an appropriate test of effects in the field soil. The number of tubers > 10 mm in the control and the ungraded field soil was similar but there were more tubers in the undisturbed control soil (442 000 ± 22 700/ha) than the average of the disturbed soils (296 000) and more tubers were produced in the fine grade of field soil than in the medium and cloddy grades. More tubers > 10 mm were produced in the sandy clay loam than the clay and very few tubers were formed in the ungraded, fine and medium clay compared to the cloddy clay (Table 17). The total yield of tubers in the ungraded sandy clay loam was similar to the undisturbed control and the fine grade produced numerically the greatest yield while the cloddy produced the least with the medium grade intermediate. Yields in the clay were lower than the sandy clay loam and negligible in the ungraded and fine clays (Table 17).

At planting the bulk density of the clay was lower than the sandy clay loam but soil grading had no effect on bulk density (Table 18). Moisture content was greater in the disturbed (11.2 ± 0.38 %) than undisturbed soil (2.6), greater in the clay on average than the sandy clay loam and least in the control (Table 18). Averaged over soils the fine grade had the greater moisture content but in the sandy clay loam the fine and cloddy grades were wetter than the ungraded and medium soils while for the clay the moisture content was greatest in ungraded and fine and least in the medium grade (Table 18).

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Soil	Grade	Bulk density (g/cm3)	Soil moisture (% volumetric)
Sandy clay loam	Control	0.88	2.6
	S.E.	0.024	0.38
	Ungraded	0.82	5.2
	Fine	0.94	8.0
	Medium	0.85	5.9
	Cloddy	0.86	7.2
Clay	Ungraded	0.64	16.7
	Fine	0.64	16.4
	Medium	0.60	14.9
	Cloddy	0.59	15.4
	S.E.	0.033	0.54
Sandy clay loam	Mean	0.87	6.6
Clay	Mean	0.62	15.8
	S.E	0.017	0.27

S.E. based on 19 D.F.

TABLE 18. THE EFFECT OF SOIL TYPE AND GRADING ON BULK DENSITY AND SOIL MOISTURE CONTENT AT PLANTING

The mean ped size was greater in the undisturbed (19.6 ± 0.83 mm) than the disturbed soil (14.0) but the mean ped size of the sandy clay loam and the clay were similar (Table 19). Mean ped size increased with increasing grade size in both soils with the ungraded soil being intermediate between the medium and cloddy grades (Table 19). There were more stones in the sandy clay loam than the clay but grading did not affect the distribution of stones (Table 19). Soil resistance at tuber initiation was greater in the undisturbed (0.24 ± 0.010 MPa) than the disturbed soil (0.13) and least in the clay (Table 19). On average resistance increased with increasing grade size and resistance in the disturbed sandy clay loam was greatest in the cloddy and least in the fine grade while the ungraded and medium soils were intermediate. Resistance was greatest in the cloddy and ungraded clays and greater in the medium clay than the fine grade which had the lowest resistance (Table 19). Soil moisture content was greater in the disturbed (6.9 ± 1.10 %) than the undisturbed soil (4.2) and greater in the clay than the sandy clay loam (Table 19). Grading had no effect on soil moisture content which was numerically greatest in the fine grade of both soil types and least in the medium sandy clay loam and the fine clay (Table 19).

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Soil	Grade	Mean ped size (mm)	Stones (%)	Resistance (MPa)	Moisture content (%)
Sandy clay loam	Control	19.6	13.3	0.24	4.2
	S.E.	0.83	0.86	0.010	1.10
	Ungraded	16.2	12.5	0.16	4.7
	Fine	4.4	9.4	0.12	6.4
	Medium	12.6	14.6	0.16	1.9
	Cloddy	26.4	9.3	0.19	4.2
Clay	Ungraded	15.5	1.1	0.14	7.0
	Fine	3.4	1.4	0.02	10.7
	Medium	10.2	1.4	0.10	10.4
	Cloddy	23.0	1.6	0.15	9.9
	S.E.	1.18	1.21	0.014	1.56
Sandy clay loam	Mean	14.9	11.5	0.16	4.3
Clay	Mean	13.0	1.4	0.10	9.5
	S.E	0.59	0.61	0.007	0.78

S.E. based on 19 D.F.

TABLE 19. THE EFFECT OF SOIL TYPE AND GRADING ON THE MEAN PED SIZE AND STONE CONTENT AT PLANTING AND RESISTANCE AND SOIL WATER CONTENT AT TUBER INITIATION

The number of tubers > 10 mm for the clay was greatest in the fine grade in 2009 (388 000 ± 36 400/ha) but least in 2010 (Table 17) while for the field soil the fine grade produced the fewest tubers in 2009 (298 000 ± 36 400/ha) but most in 2010 (Table 17). There was little difference between the mean ped sizes of the fine clay and fine field soil in either 2009 (4.2 and 3.9 ± 0.76 mm respectively) or 2010 (Table 19) but there was a difference in the percentage of particles < 2 mm in the fine clay and fine field soil in 2009 (24.6 and 54.5 ± 4.02 %, respectively) and a numerical difference in 2010 (41.0 and 33.9 ± 2.69 %, respectively). Generally in 2010, maximum ground cover in the clay was achieved c. 60 days after first emergence (except for the medium clay at c. 95 days) when root growth would generally have been complete. At harvest, no roots penetrated the underlying sandy clay loam in the fine clay and few roots penetrated beyond the ungraded clay and restricted moisture may have limited ground cover development. Little development after emergence occurred on plots with a higher proportion of smaller soil particles and it is possible that these particles formed a barrier to limit root penetration in the underlying soil.

4.13. Experiment 16 Soil temperature - Estima and Hermes

The interval from planting to 50 % emergence was c. 5 days longer in Hermes (46.6 ± 0.15 days) than Estima (45.6). Emergence was nearly complete in Estima (> 98 %) but less complete in Hermes (> 89 %) and fairly complete ground cover (> 95 %) was achieved in all treatments.

Soil temperature was recorded in eight ridges of both treatments from 16 April to 20 July but a logger failure between 16-23 June resulted in a loss of data. On average, the soil temperature was 2.5 °C greater in the warmed plots than the control over the period of warming and the maximum difference was 3.6 °C with a similar diurnal cycle for warmed and control plots (Figure 24). Soil temperature had no effect on the number of stems, the number of tubers, total yield or mean tuber size at any harvest except at the first harvest where the number of tubers > 10 mm was lower in the warmed soil at closer spacing (372 000 ± 39 800/ha) than the control (506) and at the final harvest where the mean tuber size from warmed soil (58.9 ± 0.59 mm) was greater than the control (56.3).

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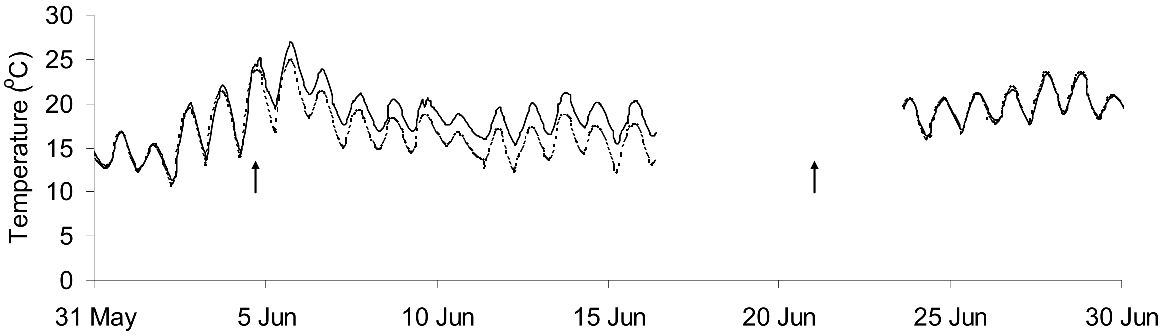

FIGURE 24. SOIL TEMPERATURE DURING TUBER INITIATION IN EXPERIMENT 16. WARMED SOIL, SOLID LINE; CONTROL PLOTS, BROKEN LINE. ARROWS INDICATE START AND END OF THE PERIOD WHEN SOIL WARMING CABLES WERE OPERATING.

The total number of tubers was generally stable between the first and second harvests for Estima at both temperatures (Figure 25a and b) but in Hermes the total number of tubers generally increased between the first and second harvests except at the wider spacing of the warmed plots and at the closer spacing of the control plots where the number of tubers was stable (Figure 25c and d). The number of tubers > 10 mm was generally stable for Estima between the first and second harvests at the wider spacing for both temperatures but at the closer spacing the number of tubers > 10 mm increased in the warmed and decreased in the control plots (Figure 25a and b). In Hermes, the number of tubers > 10 mm generally increased between the first and second harvests except at the wider spacing of the warmed plots where the number of tubers was stable (Figure 25c and d).

Between the second and final harvests the total number of tubers generally decreased in both varieties and at both temperatures except in Hermes at the wider spacing where there was little change in the number of tubers at either temperature (Figure 25a-d). The number of tubers > 10 mm generally decreased in Estima between the second and final harvests except at the wider spacing of the control plots were there was little change (Figure 25a and b). In Hermes there was little change in the number of tubers > 10 mm at either spacing or temperature (Figure 25c and d).

At the final harvest Estima had a greater number of main stems (1.9 ± 0.05 per plant) than Hermes (1.1) and very few secondary stems were formed (< 0.03 per plant). There was little difference in the number of tubers > 10 mm between varieties (Table 20) but on average the number of tubers > 10 mm was greater at the closer (480 000/ha ± 22 800) than wider spacings (331 000). There was little difference in yield between treatments (Table 20).

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Variety	Soil warming Density	Number of tubers > 10 mm (000/ha) D1	D2	Mean	Total yield of tubers (t/ha) D1	D2	Mean
Estima	Control	349	456	402	47.0	44.5	45.8
	Warm	310	499	405	47.9	48.5	48.2
	Mean	329	478	403	47.5	46.5	47.0
Hermes	Control	373	522	448	42.5	47.8	45.2
	Warm	293	443	368	42.0	46.0	44.0
	Mean	333	483	408	42.3	46.9	44.6
S.E. (17 D.F.)	Temperature	38.4		27.1	3.60		2.54
S.E. (17 D.F.)	Mean	27.1		14.7†	2.54		1.50 †

† S.E based on 12 D.F.

TABLE 20. THE EFFECT OF SOIL WARMING DURING THE PERIOD OF TUBERISATION ON THE NUMBER OF STEMS, TUBERS > 10 MM, AND YIELD, AT TWO PLANT DENSITIES (SPACING: D1, 20 CM; D2, 10 CM) IN ESTIMA AND HERMES AT FINAL HARVEST

Generally over the 3 years the largest number of tubers occurred at the second harvest but there was no effect of soil temperature on the number of main stems per plant, the number of tubers > 10 mm, the total number of tubers, total yield or mean tuber size except in 2008 at the closer plant spacing where there were fewer tubers > 10 mm in warmed soil (560 000 ± 43.400) than the control (699 000).

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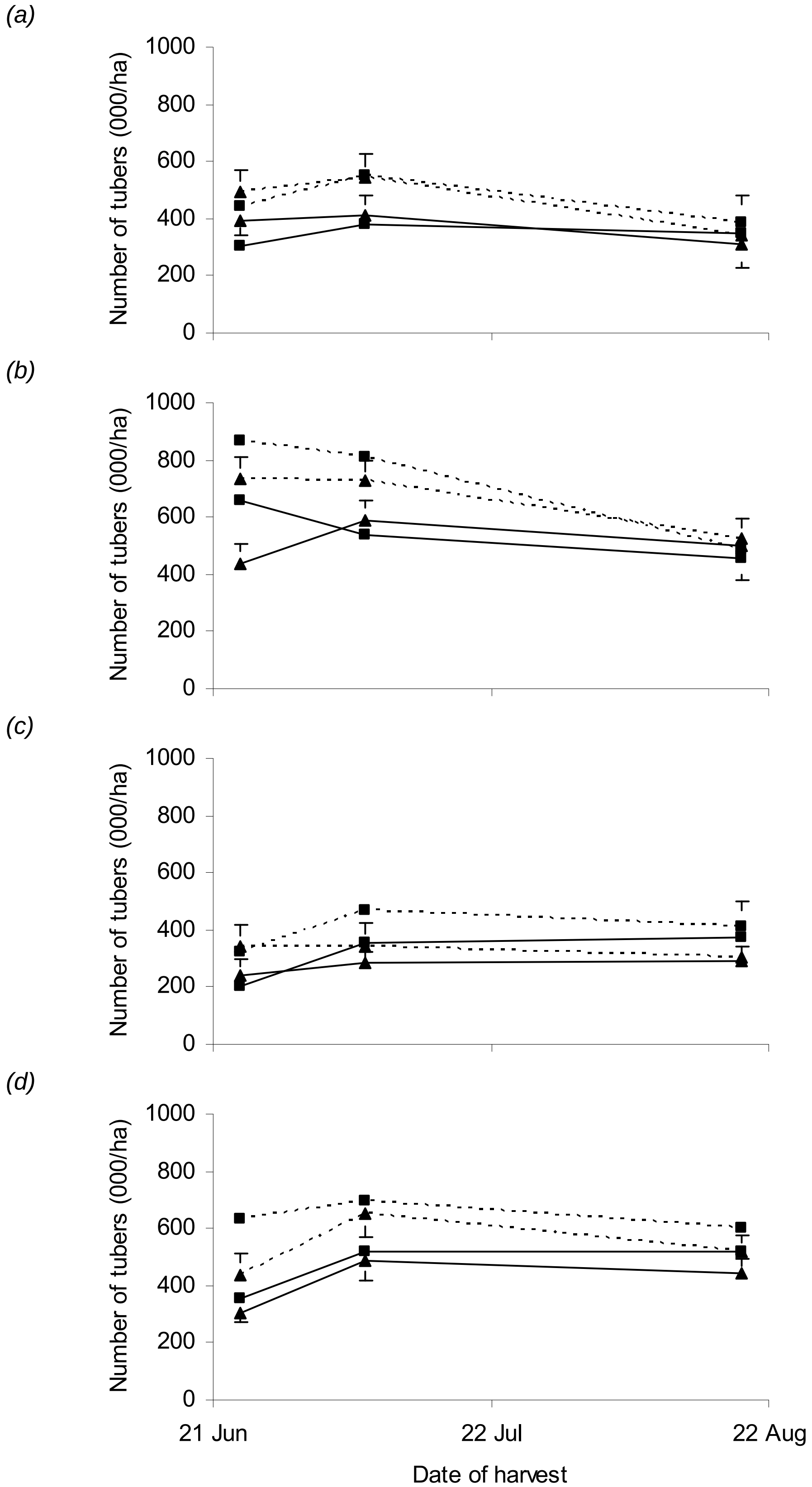

FIGURE 25. EFFECT OF SOIL TEMPERATURE ON THE NUMBER OF TUBERS AT THREE HARVESTS IN TWO VARIETIES WITH TWO PLANTING DENSITIES (A) ESTIMA, 20 CM SPACING; (B) ESTIMA, 10 CM SPACING; (C) HERMES, 20 CM SPACING; (D) HERMES, 10 CM SPACING. TEMPERATURE: CONTROL, ■; WARM, ▲. NUMBER OF TUBERS > 10 MM SOLID LINE; TOTAL NUMBER OF TUBERS, BROKEN LINE.

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Over the 3 years at the final harvest there was no effect of soil temperature on the number of main stems per plant, the number of tubers > 10 mm, the total number of tubers, total yield or mean tuber size at the final harvest (Table 21) except in 2010 when the mean tuber size from warmed soil (59.0 ± 0.69 mm) was greater than the control (56.3). Overall, Estima produced a greater number of main stems per plant (1.6 ± 0.03) than Hermes (1.1) particularly in 2010 where Estima and Hermes produced 1.9 and 1.1 (± 0.05) main stems per plant, respectively. Generally mean tuber size was greater in Estima (57.6 ± 0.40 mm) than in Hermes (61.0) except in 2009 where mean tuber size was greater in Hermes (62.0 ± 0.69 mm) than Estima (60.1).

	Variety	Estima		Hermes		
Year Temperature		Control	Warm	Control	Warm	S.E.
Main stems per plant	2008	1.33	1.28	1.11	1.10	0.052
	2009	1.54	1.63	1.20	1.22	0.061
	2010	1.98	1.82	1.04	1.12	0.082
	Mean	1.61	1.58	1.12	1.15	0.037
Tubers > 10 mm (000/ha)	2008	521	520	495	532	27.3
	2009	504	481	572	504	53.4
	2010	402	405	448	368	27.1
	Mean	476	469	505	468	21.4
Total number of tubers (000/ha)	2008	521	524	495	535	27.2
	2009	505	481	576	506	53.2
	2010	439	433	506	413	33.9
	Mean	488	479	526	485	22.3
Total yield (t/ha)	2008	62.6	60.6	58.8	63.3	3.45
	2009	70.2	66.0	74.8	65.4	5.56
	2010	45.8	48.2	45.2	44.0	2.54
	Mean	59.5	58.3	59.6	57.6	2.38
Mean tuber size (mm)	2008	57.9	58.0	60.5	60.4	1.04
	2009	61.0	59.1	62.7	61.3	1.00
	2010	54.2	55.5	58.4	62.6	0.83
	Mean	57.7	57.5	60.6	61.4	0.57

S.E. based on 19 D.F. except means based on 65 D.F.

TABLE 211. THE EFFECT OVER 3 YEARS OF SOIL WARMING DURING THE PERIOD OF TUBERISATION ON THE NUMBER OF STEMS, TUBERS > 10 MM, TOTAL YIELD AND MEAN TUBER SIZE, MEAN OF PLANT DENSITY IN ESTIMA AND HERMES AT FINAL HARVEST

4.14. Experiment 17 Soil type - Maris Peer

The interval from planting to 50 % emergence in 2010 was c. 32-35 days for all treatments except for the sandy clay loam where 50 % emergence was slightly later (c. 38-40 days) (Table 22). Generally the interval from planting to 50 % emergence was similar in 2008 and 2009 except for the silt and clay which emerged earlier and later respectively in 2009 compared to 2008 (Table 22). The interval from planting to 50 % emergence was notably greater for field and field-dug soil in 2010 than in either 2008 or 2009 but less so for other soil types (Table 22).

The final percentage of emerged plants was > 94 % in all treatments and 100 % in the silt, peat and clay. Near complete ground cover (> 95 %) was achieved in the higher nitrogen plots but maximum ground cover was lower at the lower nitrogen rate (> 89 %).

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The number of main stems per plant in 2010 was greatest in the sand and silt and numerically lowest in the field-dug soil (Table 22) and few secondary stems (< 0.15 per plant) were produced in any treatment. Between 2008 and 2010 the number of main stems per plant remained fairly consistent in the field and silt soils but varied more in other soil types. On average, over the 3 years the silt produced the greatest number of main stems per plant numerically and clay fewer stems than other soils associated with relatively large differences in 2008 and 2009 but not in 2010 (Table 22).

In 2010 the sand produced the greatest number of tubers (total and > 10 mm) and the field and field-dug soil numerically the least (Table 22). There was a wide variation in the number of tubers between soil types and between years with the peat and silt producing the greatest number of tubers (total and > 10 mm) in 2008 and 2009, respectively, but overall the sand produced the greatest numbers of tubers (total and > 10 mm) and the clay the least (Table 22).

Total yields were greater in the sand and numerically least in the field-dug soil in 2010 (Table 22). Overall between 2008 and 2010 yields were only slightly greater at the higher rate of nitrogen (54.7 ± 1.10 t/ha) than the lower rate (50.9) and were greatest in the sand, peat and silt and least in the clay (Table 22).

Year	**Field**	**Field-dug**	**Sand**	**Silt**	**Peat**	**Clay**	**S.E.**	**D.F.**
Days to 50 % emergence								
2008	28.6	29.6	29.9	33.0	28.3	34.6	0.58	21
2009	28.2	28.6	28.5	30.2	29.9	49.5	0.90	22
2010	38.5	40.3	32.5	33.7	32.8	34.7	0.73	22
Mean	31.8	32.8	30.3	32.3	30.3	39.6	0.43	65
Main stems per plant								
2008	2.06	2.24	1.79	2.30	2.22	1.85	0.191	20
2009	2.28	2.08	2.16	2.23	2.40	1.57	0.086	22
2010	2.00	1.83	2.38	2.33	2.00	2.05	0.106	22
Mean	2.11	2.05	2.11	2.30	2.21	1.82	0.077	64
Tubers > 10 mm (000/ha)								
2008	920	857	906	696	1025	644	59.4	20
2009	745	675	850	997	661	380	40.3	22
2010	511	453	943	708	596	542	47.6	22
Mean	725	662	900	799	760	522	28.5	64
Total number of tubers (000/ha)								
2008	926	858	907	698	1026	644	60.3	20
2009	746	676	853	1032	667	432	41.4	22
2010	560	511	1074	743	679	594	54.1	22
Mean	744	682	945	823	790	557	30.2	64
Yield (t/ha)								
2008	45.3	47.1	61.3	53.6	61.1	41.3	4.03	20
2009	61.1	61.3	57.8	65.6	70.1	43.9	3.22	22
2010	41.5	36.4	64.3	51.2	42.3	45.3	2.60	22
Mean	49.3	48.3	61.1	57.0	58.0	43.5	1.91	64
Bulk density (g/cm3)								
2008	1.03	1.03	0.92	0.92	0.33	0.69	0.013	6
2009	0.86	0.93	0.98	0.90	0.33	0.71	0.032	10
2010	0.83	0.81	1.03	0.83	0.42	0.70	0.032	10
Mean	0.91	0.96	0.98	0.88	0.36	0.70	0.020	30
Moisture content (% volumetric)								
2008	16.0	11.3	17.5	19.3	39.4	20.2	1.4	6
2009	5.8	8.7	7.0	12.6	32.1	8.2	1.1	10
2010	12.0	2.3	5.6	23.0	23.1	13.8	6.2	10
Mean	10.7	7.0	9.1	18.1	30.5	13.3	2.3	30

TABLE 22. THE EFFECT OF SOIL TYPE ON EMERGENCE, NUMBERS OF MAIN STEMS PER PLANT, NUMBER OF TUBERS > 10 MM, TOTAL NUMBER OF TUBERS, YIELD AND BULK DENSITY AT PLANTING IN YEARS 2008-2010

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Bulk density in 2010 was greatest in the sand and least in the peat (Table 22) and generally over the 3 years bulk density was relatively high in the field-dug soil, field soil and sand, least in the peat and relatively low in the clay (Table 22). Moisture content at planting in 2010 was greatest in the peat and least in the field-dug soil (Table 22) while over the 3 years the moisture content was greatest in the peat and least (< 10 % moisture) in the field-dug soil and sand in 2009 and 2010 and the field soil and clay in 2009 (Table 22).

Mean ped size in 2010 was greatest in the field and field-dug treatments and numerically least in the sand (Table 23) but over the 3 years mean ped size was generally greatest in the clay and numerically least in the sand except in 2010 when the mean ped size of the field and field-dug soils were much greater than any other soil (Table 23).

	Soil						
Year	**Field**	**Field-dug**	**Sand**	**Silt**	**Peat**	**Clay**	**S.E. †**
2008	4.8	4.1	2.3	3.6	4.2	11.0	0.43
2009	2.0	2.3	1.2	6.2	8.9	17.6	0.45
2010	22.9	24.3	1.0	4.3	3.3	12.6	2.85

† S.E. based on 10 D.F. except 2009, 9 D.F. and 2008, 6 D.F.

TABLE 23. THE EFFECT OF SIX SOIL TYPES ON MEAN PED SIZE (MM) AT PLANTING OVER 3 YEARS 2008-2010

Resistance was lowest in the peat, sand and silt and highest in the field soil in 2010 whereas the water content was generally greatest in the peat and lowest in the sand (Table 24). The peat and silt soils had relatively low resistance and high water content, the field and field-dug soils high resistance and low water contents but the sand had low resistance and low water content (Table 24). The high resistance in the field and field-dug soils was associated with low bulk densities (Table 22) and large mean ped size (Table 23) while the sand had a high bulk density (Table 22) and a small mean ped size (Table 23). Water content was determined c. 2 days before the first irrigation on the 16 June and 21.2 mm of rainfall was recorded in the preceding 8 days.

Soil	**Field**	**Field-dug**	**Sand**	**Silt**	**Peat**	**Clay**	**S.E. (10 D.F.)**
Resistance	0.177	0.132	0.003	0.011	0.004	0.064	0.0171
Moisture	4.3	4.6	2.0	11.6	17.2	11.6	1.70

TABLE 22. THE EFFECT OF SOIL TYPE ON RESISTANCE (MPA) AT *C.* 10 CM AND SOIL MOISTURE CONTENT (%) AT *C.* 6 CM ON 14 JUNE (DURING TUBER INITIATION)

Soil temperature was recorded from two ridges for all soil types from 20 April to 20 July but a logger failure between 16-23 June resulted in a loss of data. Differences between soil types during the same period were relatively small (< 1 °C) and mean soil temperatures generally increased from April to July (Table 25) except during tuber initiation where soil temperatures were lower than the periods after initiation and between 50 % emergence and initiation.

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	Soil							
	Field†		**Field-dug†**		**Peat**	**Sand**	**Silt**	**Clay**
(a) Planting to 50 % emergence	13.2	(12.3)	12.5	(11.6)	11.8	12.4	11.8	11.9
(b) 50 % emergence to TI	16.6	(17.3)	16.1	(16.7)	16.9	17.5	17.2	16.9
(c) During tuber initiation	*	(16.0)*	*	(15.4)*	15.6*	15.5*	15.3*	16.0*
(d) After tuber initiation	19.7*	(19.7)*	19.4*	(19.4)*	18.8*	18.9*	19.3*	19.5*

(a) 20 April to 22 May, (b) 23 May to 9 June, (c) 10 June to 16 June, (d) 17 June to 20 July.
† (a) 20 April to 28 May, (b) 29 May to 15 June, (c) 16 June to 22 June, (d) 23 June to 20 July. Figures in parentheses: mean temperatures at the same dates as other soils.
A logger failure between 16-23 June resulting in the loss of data for part or all of the specified period.

TABLE 23. MEAN SOIL TEMPERATURES (°C) DURING PLANT DEVELOPMENT. PERIODS RELATING TO: (A) PLANTING TO 50 % EMERGENCE, (B) 50 % EMERGENCE TO TUBER INITIATION (TI), (C) DURING TUBER INITIATION, (D) AFTER TUBER INITIATION

4.15. Experiment 18-30 Sites - Estima, Maris Piper and Lady Rosetta

The interval from planting to emergence in Estima was 29-33 days except for the cloddy sandy clay loam at Cambridge where emergence was 6 days later than the fine sandy clay loam (30 and 36 days, respectively). For Maris Piper the interval from planting to emergence was 28-31 days except for the cloddy sandy clay loam at Cambridge where emergence was 6 days later than the fine sandy clay loam (30 and 36 days, respectively). The interval from planting to emergence in Lady Rosetta was c. 29, 30 and 31 days for the sandy Thetford soil, and the fine and cloddy soils at Cambridge, respectively. Near-complete emergence (< 96 %) was achieved in all experiments.

There was little effect of density on the number of main stems per plant in any variety (Table 26) but the number of main stems was greatest for the peat and generally least for the cloddy sandy clay loam except at the wider spacing of Estima where the sand produced the fewest stems (Table 26). Fewer main stems were produced on the cloddy than the fine sandy clay loam for all varieties (Table 26) and there were few secondary stems (< 0.15 per plant) formed in any treatment.

For all experiments the number of tubers > 10 mm was much greater at closer plant spacing than the wider spacing (Table 26). Numerically the greatest number of tubers were formed in the fine sandy clay loam and fewest in the cloddy sandy clay loam for all varieties at both spacings except for Lady Rosetta where the number of tubers in the cloddy sandy clay loam was similar to the sand (Table 26).

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Site	Soil type	Main stems per plant D1	D2	S.E.	Tubers > 10 mm (000/ha) D1	D2	S.E.
Estima							
Cambridge	Fine sandy clay loam	2.8	2.6	0.11	514	732	19.1
Cambridge	Cloddy sandy clay loam	2.3	2.3	0.10	298	486	17.2
Thetford	Sand	2.1	2.5	0.19	355	543	17.7
Methwold Hythe	Peat	2.8	2.9	0.09	363	574	20.3
Holbeach Hurn	Silt	2.6	2.6	0.10	360	565	24.5
Maris Piper							
Cambridge	Fine sandy clay loam	3.6	3.2	0.28	639	955	42.2
Cambridge	Cloddy sandy clay loam	2.5	2.9	0.19	270	513	25.9
Thetford	Sand	3.2	3.4	0.22	400	731	13.5
Methwold Hythe	Peat	4.0	3.8	0.18	515	804	40.1
Holbeach Hurn	Silt	3.5	3.4	0.14	450	765	17.0
Lady Rosetta							
Cambridge	Fine sandy clay loam	3.0	3.1	0.13	731	956	26.6
Cambridge	Cloddy sandy clay loam	2.7	2.5	0.08	455	729	16.8
Thetford	Sand	2.4	2.8	0.03	449	706	24.1

S.E.'s based on 8 D.F.

TABLE 26. NUMBER OF MAIN STEMS AND TUBERS > 10 MM IN ESTIMA, MARIS PIPER AND LADY ROSETTA AT SITES WITH CONTRASTING SOIL TYPES AT TWO PLANT DENSITIES (SPACINGS D1, 40 CM; D2, 20 CM)

Over the 3 years the number of tubers > 10 mm was generally similar to or greater than the values fitted to the historical data sets by Firman et al. (2007) (Figure 26a-d) except for Maris Piper and Estima on the silt Figure 26b) and the cloddy sandy clay loam (Figure 26d) where fewer tubers were produced. Although Lady Rosetta produced more tubers for the cloddy sandy clay loam than predicted from the historic data this was still fewer than for the fine sandy clay loam (Figure 27).

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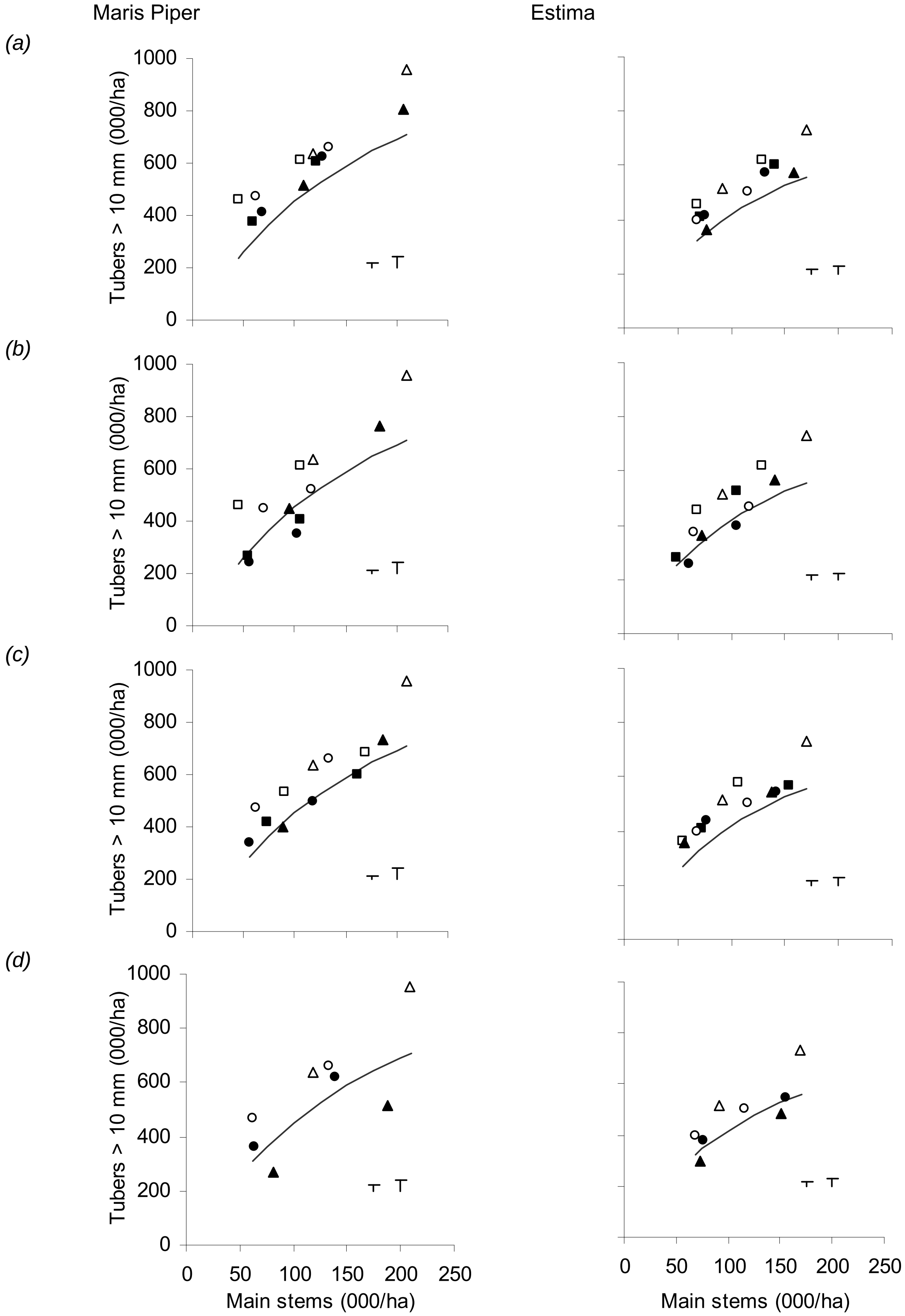

FIGURE 26. RELATIONSHIP BETWEEN THE NUMBER OF STEMS AND TUBERS FOR FOUR SOIL TYPES (A) PEAT, (B) SILT, (C) SAND, (D) CLODDY SANDY CLAY LOAM, WITH A CAMBRIDGE COMPARISON PLANTED ON THE SAME DAY, OVER 3 YEARS. OPEN SYMBOLS CAMBRIDGE COMPARISON (SANDY LOAM OR SANDY CLAY LOAM), CLOSED SYMBOLS CONTRASTING SOIL TYPE. YEARS: 2008, ■; 2009, ●; 2010, ▲. LINE, EXPECTED NUMBERS BASED ON HISTORIC AVERAGE. S.E., MAXIMUM AND MINIMUM FOR PAIRED SOILS.

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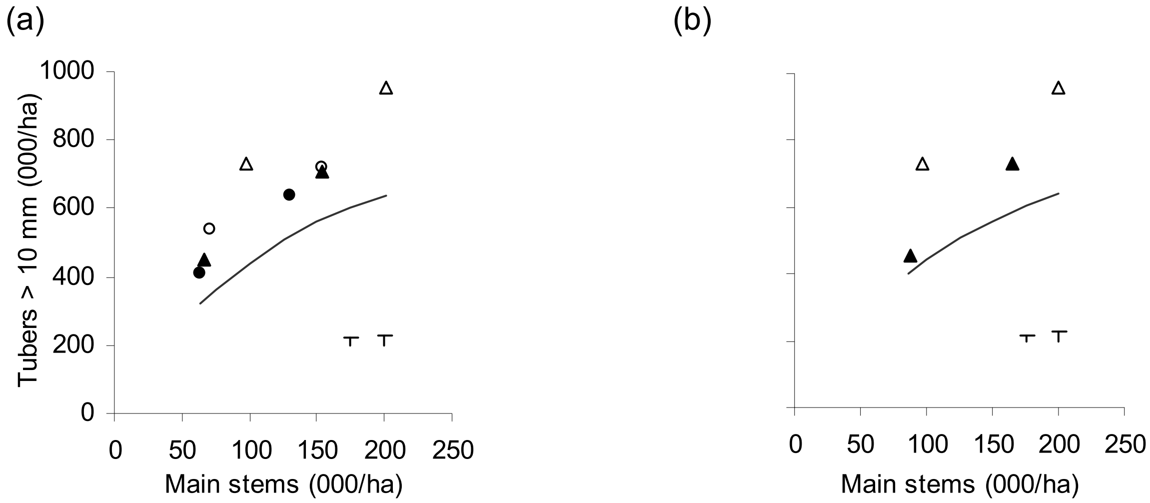

FIGURE 27. RELATIONSHIP BETWEEN THE NUMBER OF STEMS AND TUBERS IN LADY ROSETTA FOR TWO SOIL TYPES (A) SAND, (B) CLODDY SANDY CLAY LOAM, WITH A CAMBRIDGE COMPARISON PLANTED ON THE SAME DAY, OVER 3 YEARS. OPEN SYMBOLS CAMBRIDGE COMPARISON (SANDY LOAM OR SANDY CLAY LOAM), CLOSED SYMBOLS CONTRASTING SOIL TYPE. YEARS: 2008, ■; 2009, ●; 2010, ▲. LINE, EXPECTED NUMBER OF TUBERS BASED ON HISTORIC AVERAGE. S.E., MAXIMUM AND MINIMUM FOR PAIRED SOILS.

Bulk density at planting and tuber initiation were least in the peat and numerically greatest in the sand (Table 27). Generally there was little difference between the silt and fine and cloddy sandy clay loams except at planting when the cloddy sandy clay loam for Estima and Maris Piper were lower than the other loams and silt (Table 27). Mean ped size at tuber initiation was greater for the cloddy sandy clay loam in Estima and Maris Piper than for the Lady Rosetta (13.7 ± 0.69 and 9.2 ± 1.04 mm, respectively) and least in the fine sandy clay loam (7.9 ± 0.28 mm).

	Bulk density	
Soil	**Planting**	**TI**
Sandy clay loam	1.07 (0.022)	1.02 (0.015)
Sandy clay loam cloddy †	0.96 (0.019)	1.02 (0.035)
Sandy clay loam cloddy ‡	1.08 (0.009)	1.06 (0.024)
Silt	1.05 (0.020)	1.07 (0.006)
Peat	0.40 (0.020)	0.40 (0.015)
Sand	1.12 (0.023)	1.13 (0.020)

Samples from: †Estima and Maris Piper, ‡Lady Rosetta.

TABLE 27. BULK DENSITY (G/CM3) AT PLANTING AND TUBER INITIATION (TI) FOR SIX DIFFERENT SOILS. S.E. IN PARENTHESES

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4.16. Experiment 31 Cultivation and irrigation - Lady Rosetta and Maris Piper

There was little difference in the number of days from planting to 50 % emergence between the Early and Late Plough cultivations (35 days) but the Non-plough treatments emerged 3 days earlier in the Early cultivated than the Late cultivated soil (33 and 36 days, respectively). Maximum ground cover was 93-94 % except for the Early Plough and Late Plough cultivations in Lady Rosetta where the maximum ground cover was 91 and 96 %, respectively. Ground cover persisted longer in Maris Piper than Lady Rosetta and slightly longer in the Early Plough and Non-plough treatments of Maris Piper compared to other treatments.

Between the first and second harvest the total number of tubers in Lady Rosetta increased except in the Late Plough and Early Non-plough treatments where the number of tubers was stable (Figure 28a) while in Maris Piper there was a large increase in the total number of tubers for all cultivations (Figure 28b). Between the second and third harvest the total number of tubers decreased in both Lady Rosetta and Maris Piper for all cultivations (Figure 28a and b). Between the third and penultimate harvests the total number of tubers decreased in Lady Rosetta except for the Late cultivations where the number of tubers was stable (Figure 28a) while in Maris Piper the number of tubers decreased for all cultivations (Figure 28b). Between the penultimate and final harvests the total number of tubers was generally stable for both Lady Rosetta and Maris Piper except for the Late Non-plough treatment where the number of tubers decreased for both varieties (Figure 28a and b). There was a large increase in the number of tubers > 10 mm between the first and second harvest in Lady Rosetta for all cultivations except for the Early Non-plough treatment where the number of tubers was stable while in Maris Piper there was a large increase in the number of tubers for all cultivations (Figure 28a and b). Between the second and third harvest the number of tubers > 10 mm increased in Lady Rosetta for both the Early cultivation treatments, but the number of tubers was stable for the Late Plough and decreased for the Late Non-plough treatment (Figure 28a). The number of tubers > 10 mm in Maris Piper was generally stable between the second and third harvests except for the Early Non-plough treatment where the number of tubers decreased (Figure 28b). There was little difference in the number of tubers > 10 mm in either Lady Rosetta or Maris Piper between the third and penultimate harvests (Figure 28a and b) and between the penultimate and final harvests the number of tubers > 10 mm was generally stable for both Lady Rosetta and Maris Piper except for the Late Non-plough treatment where the number of tubers decreased for both varieties (Figure 28a and b).

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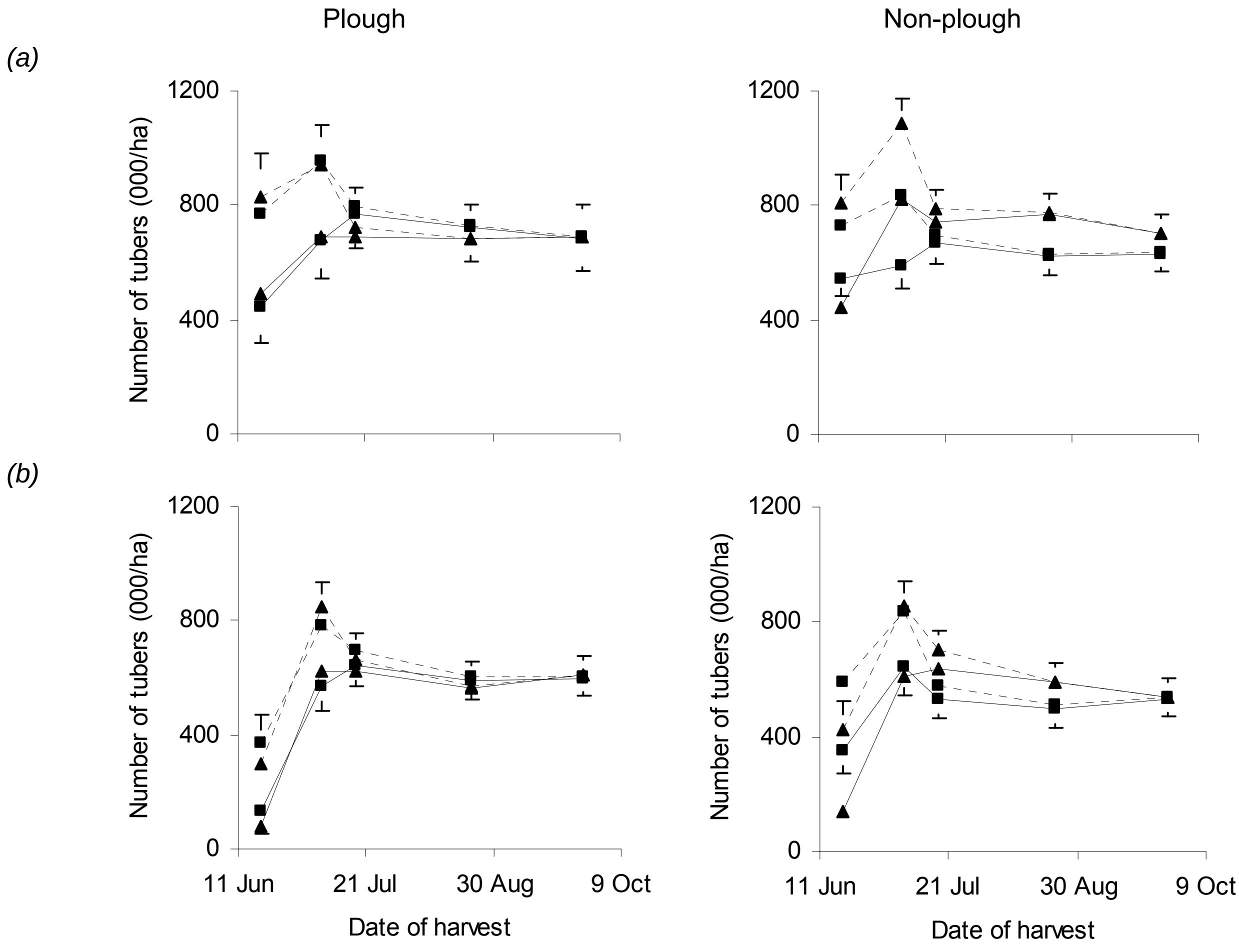

FIGURE 28. EFFECT OF CULTIVATION AND WATER CONTENT ON THE NUMBER OF TUBERS (> 10 MM AND TOTAL) WITH TWO CULTIVARS AT FIVE HARVESTS, FOR (A) LADY ROSETTA, (B) MARIS PIPER IN EXPERIMENT 32. DATE OF CULTIVATION: EARLY, ■; LATE, ▲. NUMBER OF TUBERS > 10 MM, SOLID LINE; TOTAL NUMBER OF TUBERS, BROKEN LINE.

At the final harvest, cultivation regime had no effect on either the numbers of main stems per plant or yield but the number of tubers > 10 mm was greatest for the Plough treatments (645 000 ± 13 300/ha, respectively) and least for the Early Non-plough (582 000) while the Late Non-plough treatment was intermediate (620 000). The bulk density below 20 cm was greater for the Early Non-plough treatment than other cultivations and it is possible this may have limited root penetration and the uptake of water.

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4.17. Soil survey Frontier 2010

The number of tubers in Maris Piper was not clearly different from the expected number based on the historic average (difference between the observed and the expected less than three standard errors) except for one clay loam site (Reckerby 10) where fewer tubers were produced compared to the historic average. For the sandy silt loam/clay loam sites relatively few tubers were recorded but these estimates were associated with a high standard error (Figure 29a).

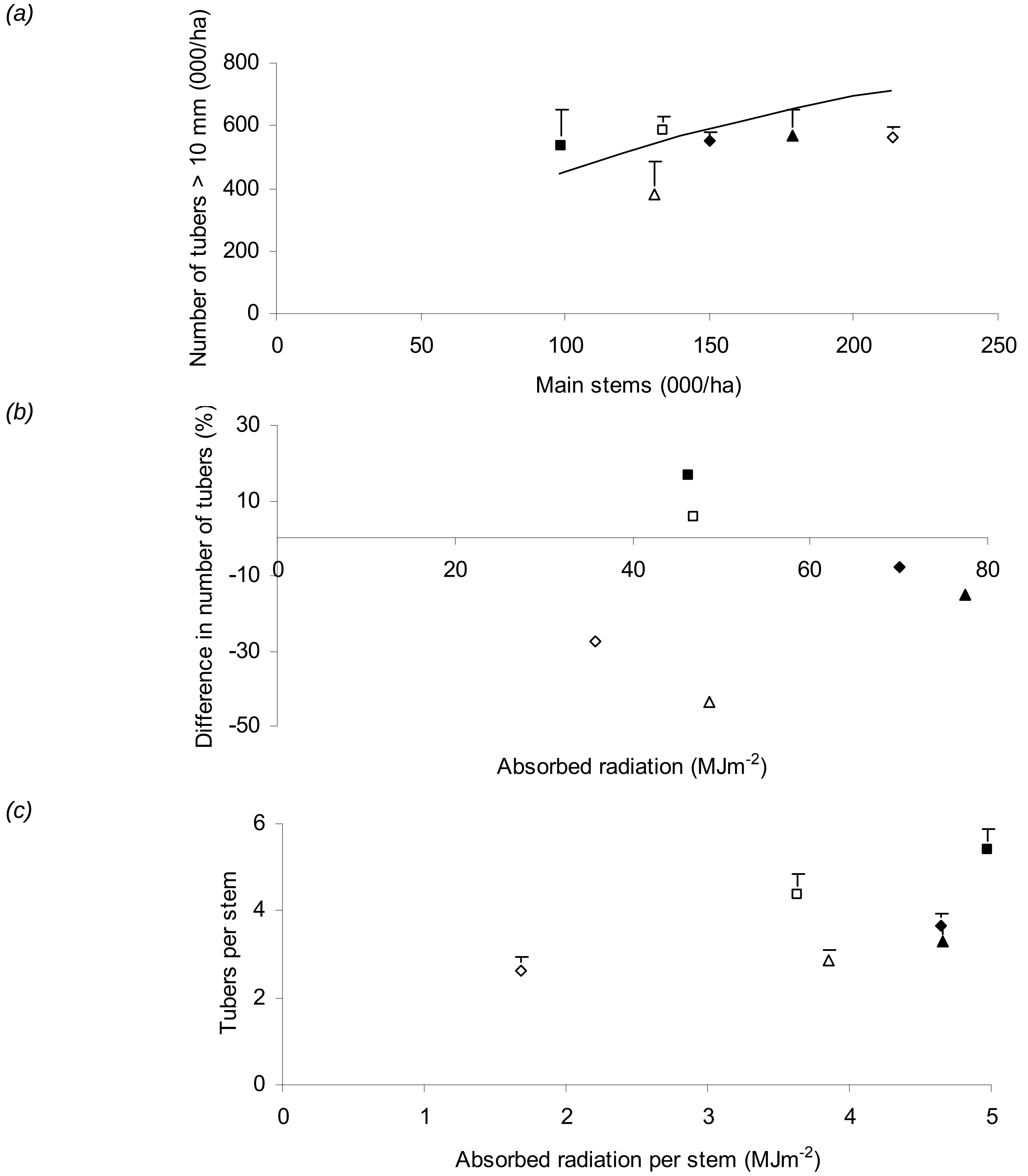

FIGURE 29. RELATIONSHIP BETWEEN (A) NUMBER OF TUBERS > 10 MM AND MAIN STEMS (000/HA), (B) % DIFFERENCE BETWEEN THE OBSERVED AND THE EXPECTED NUMBER OF TUBERS > 10 MM AND ABSORBED RADIATION, (C) TUBERS > 10 MM PER STEM AND ABSORBED RADIATION PER STEM, FOR MARIS PIPER WITH THREE SOIL TYPES: SANDY LOAM, SQUARE; SANDY SILT LOAM/CLAY LOAM, TRIANGLE; CLAY LOAM, DIAMOND. FIELDS: ◆, HORSE CLOSE; ◇, RECKERBY 10; ▲, CRANE 6; △, GROVE 62; ■, OXNEAD 2; □, BOOTON 32. LINE, EXPECTED NUMBER OF TUBERS BASED ON HISTORIC AVERAGE.

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For the heavier soil types the percentage difference between the observed and the expected number of tubers increased with increasing absorbed radiation but for the sandy loam the number of tubers was relatively high although absorbed radiation was intermediate (Figure 29b). The Reckerby 10 clay loam field which had been compacted (mean bulk density at 25-35 cm depth at harvest 1.37 g/cm3 compared to 1.22 g/m3 at Grove 62) had fewer tubers than expected based on the historic average but many fewer than the comparable uncompacted clay loam Horse Close field (Figure 29a). At the Reckerby 10 clay loam field relatively poor ground cover development associated with compaction resulted in relatively low levels of absorbed radiation and few tubers per stem. More tubers per stem were formed on sandy loam than other soil types (Figure 29c). For Markies there was little difference in either the number of tubers > 10 mm, the number of tubers per stem or absorbed radiation per stem in any field which were all sandy loams (Figure 30a and b).

(a)

(b)

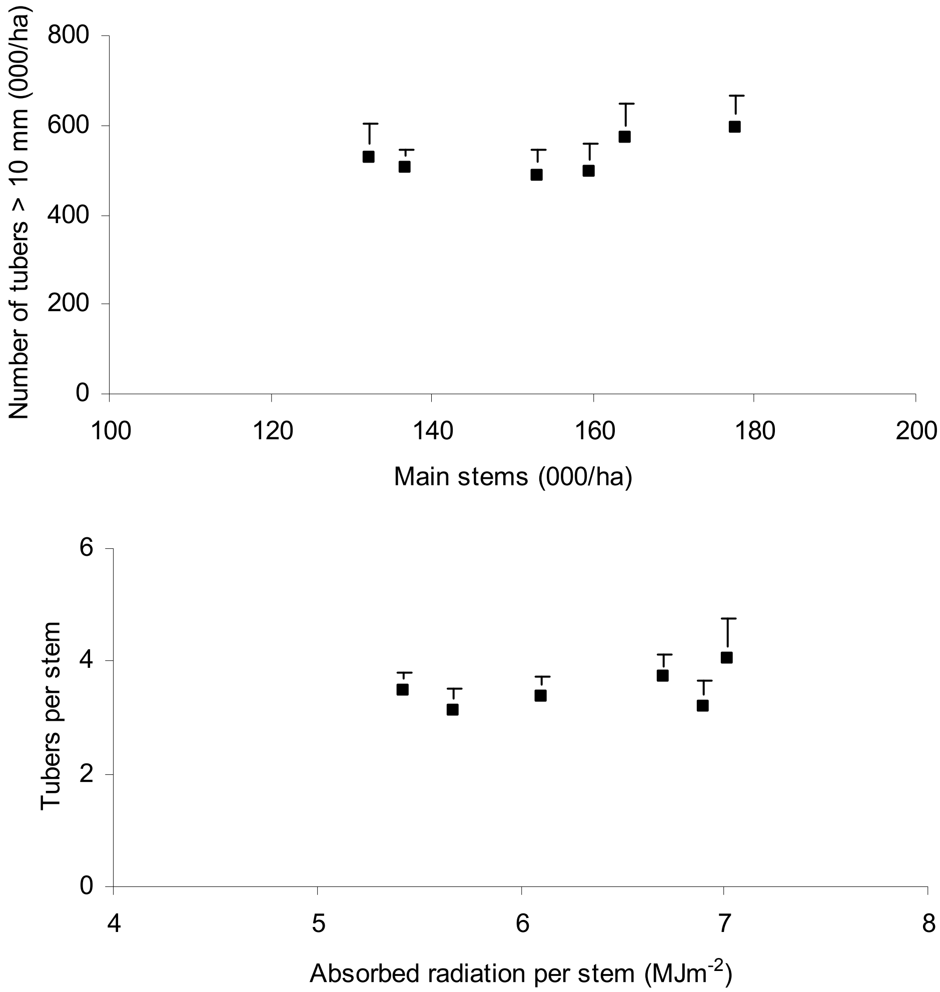

FIGURE 30. RELATIONSHIP BETWEEN *(A)* NUMBER OF TUBERS > 10 MM AND MAIN STEMS (000/HA), *(B)* TUBERS > 10 MM PER STEM AND ABSORBED RADIATION PER STEM FOR MARKIES.

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4.18. Soil analysis of 2009 experiments

4.18.1. Experiment 14 Soil condition - Maris Peer

At tuber initiation mean ped size was greater in the flattened treatment than in other cultivation methods both in the unplanted and simulated planted areas and there was little difference in the mean ped size between unplanted area and areas where planting was simulated (Figure 31).

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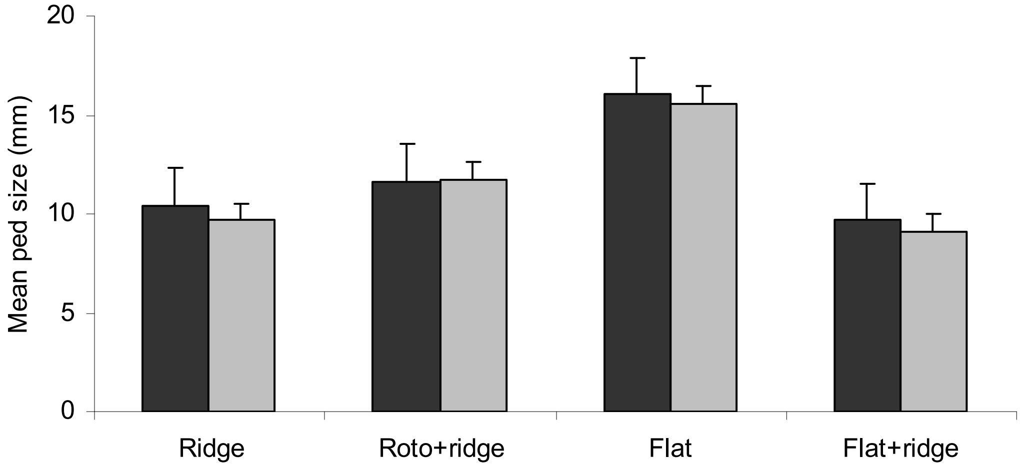

FIGURE 31. EFFECT OF FOUR SOIL CONDITIONS ON MEAN PED SIZE AT TUBER INITIATION WITH RIDGES UNDISTURBED OR SIMULATED PLANTING. PLANTING: UNPLANTED, ■; SIMULATED PLANTING, ■

4.18.2. Experiment 15 Clod size and soil type - Estima

At planting bulk density was similar in the disturbed field soil and the undisturbed control whilst grading had no effect on bulk density it was lower in the clay than the field soil (Table 28). Soil moisture was greater in the disturbed field soil than the undisturbed control and on average lower in the field soil than the clay (Table 28). Grading had little effect on the moisture content of the clay but the graded field soil was dryer than the ungraded soil particularly for the fine grade (Table 28). At tuber initiation bulk density was greater than at planting but remained similar to the disturbed field soil and greater in the field soil than the clay (Table 28). Bulk density in the field soil tended to be greater at coarser than finer grades but in the clay bulk density was greater in the ungraded clay (Table 28). Soil moisture was similar in all the field soils and greater in the clay and grading had little effect on the moisture content (Table 28).

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Soil	Grade	Planting Bulk density (g/cm3)	Soil moisture (% volumetric)	Tuber initiation Bulk density (g/cm3)	Soil moisture (% volumetric)
Sandy clay loam	Control	1.06	10.2	1.18	12.8
	S.E.	0.025	0.69	0.013	0.83
	Ungraded	1.01	14.4	1.21	12.3
	Fine	1.14	4.5	1.26	13.3
	Medium	1.11	10.5	1.29	12.6
	Cloddy	1.20	8.0	1.30	11.7
Clay	Ungraded	0.66	17.7	0.88	20.8
	Fine	0.67	16.8	0.81	16.7
	Medium	0.63	16.8	0.81	18.0
	Cloddy	0.66	17.3	0.83	19.6
	S.E.	0.036	0.97	0.018	1.17
Sandy clay loam	Mean	1.11	9.4	1.27	12.5
Clay	Mean	0.66	17.2	0.83	18.8
	S.E	0.02	0.49	0.01	0.59

S.E Based on 19 D.F.

TABLE 24. THE EFFECT OF FOUR SOIL GRADES AND TWO SOIL TYPES ON BULK DENSITY AND SOIL MOISTURE CONTENT AT PLANTING AND TUBER INITIATION IN ESTIMA

At planting mean ped size of ungraded soil was similar in the disturbed soil and the undisturbed control (6.6) but greater in the clay (Table 29). Mean ped size increased with increasing grade size in both soils with the ungraded soil being similar to the medium grade in the sandy clay loam and intermediate between the medium and cloddy grades in the clay (Table 29). The stone content was greater in the sandy clay loam than the clay (Table 29) and there were more stones in the medium and cloddy sandy clay loam than other treatments (Table 29).

At tuber initiation the field soil was similar to the control values at planting but decreased in the clay except for the finely graded soil (Table 29). Mean ped size averaged over soil type was greatest in the cloddy grade (10.3 ± 1.02 mm) and least in the fine grade (4.6) with the ungraded and medium grade soils being intermediate (7.6 and 6.7 mm, respectively).

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Soil	Grade	Planting Mean ped size (mm)	Planting Stone content (%)	Tuber initiation Mean ped size (mm)	Tuber initiation Stone content (%)
Sandy clay loam	Control	6.6	18	6.0	18
	S.E.	0.50	1.3	1.03	1.7
	Ungraded	6.5	15	5.6	16
	Fine	3.3	19	3.1	15
	Medium	6.8	30	5.7	32
	Cloddy	14.7	26	10.3	32
Clay	Ungraded	15.8	5	1.0	2
	Fine	4.2	0	6.0	0
	Medium	11.2	1	7.8	1
	Cloddy	22.8	1	10.4	1
	S.E.	0.71	1.8	1.5	2.5
Sandy clay loam	Mean	7.8	23	6.2	24
Clay	Mean	13.5	2	8.5	1
	S.E	0.35	0.9	1.03	1.2

S.E. based on: Planting, 16 D.F.; Tuber initiation, 18 D.F.

TABLE 29. THE EFFECT OF FOUR SOIL GRADES AND TWO SOIL TYPES ON MEAN PED SIZE AND STONE CONTENT AT PLANTING AND TUBER INITIATION IN ESTIMA

4.18.3. Experiments 18-31 Sites - Estima, Maris Piper and Lady Rosetta

At planting bulk density was greatest in the sand and least in the peat (Figure 32a). Generally there was little difference in bulk density between planting and tuber initiation except at the first planting where there was an increase in the bulk density of the silt and a decrease in the sandy loam (Figure 32a). At planting water content was greatest in the peat and least in the sand (Figure 32b) and was generally greater at tuber initiation than at planting except for the sandy loam and sandy clay loams which contained less water at tuber initiation than at planting (Figure 32b).

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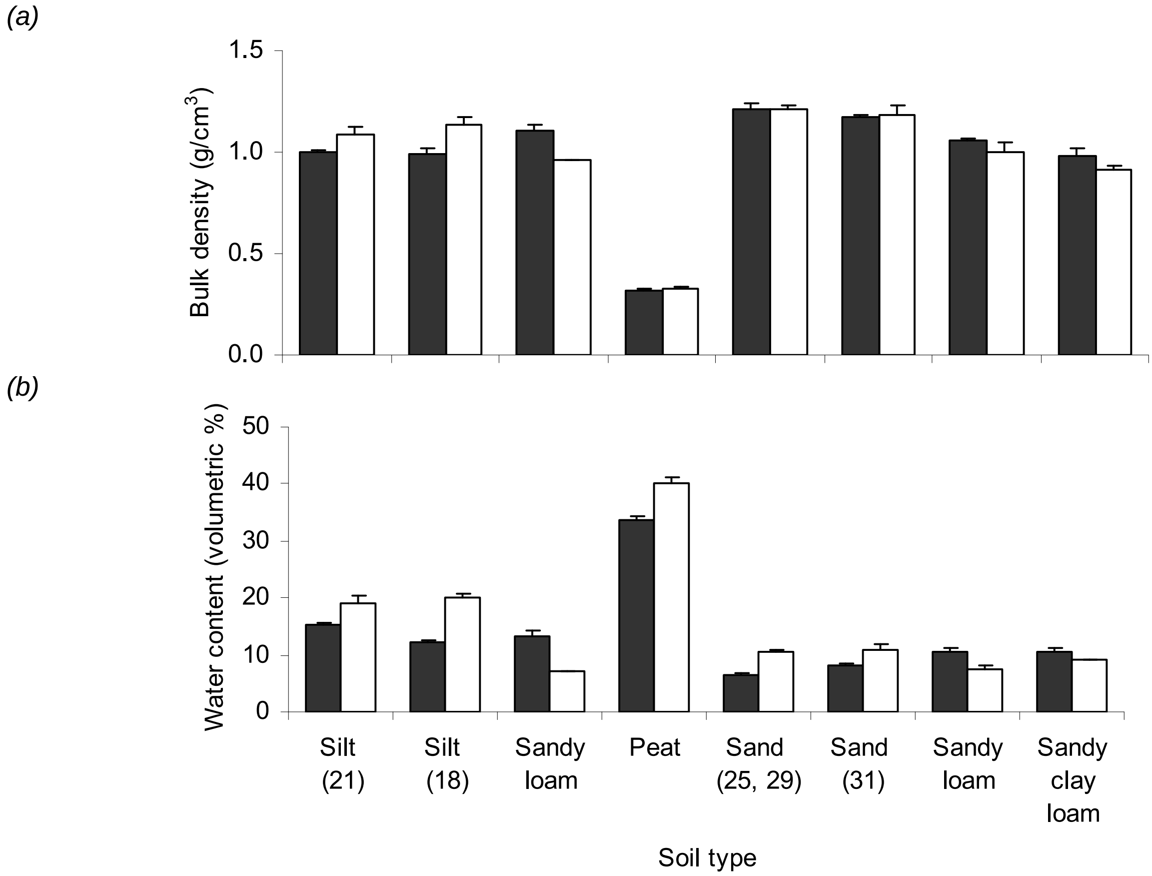

FIGURE 32. EFFECT OF FIVE SOIL TYPES AT TWO PLANTING DATES ON (A) BULK DENSITY AND (B) WATER CONTENT AT PLANTING AND TUBER INITIATION (TI) IN EXPERIMENTS 18-31. PLANTING DATES: SILT AND SANDY LOAM 1 PLANTED ON 9 APRIL ALL OTHERS 29 APRIL. CLOSED BARS, PLANTING; OPEN BARS, TUBER INITIATION. NUMBERS IN PARENTHESIS, EXPERIMENT NUMBER.

At planting mean ped size was greatest on the silt and the sandy clay loam and least on the peat, sand and sandy loam (Figure 33a). Mean ped size decreased between planting and tuber initiation on the sandy clay loam and the earlier planted sandy loam but changed little on other soils (Figure 33a).

There were very few stones in the silt and peat soils with most stones found in the sandy loam (Figure 33b). The sand in Experiments 25 and 29 contained a greater number of stones than in Experiment 31 while the sandy clay loam had a stone content intermediate between the sand and the sandy loam soils (Figure 33b).

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(a)

(b)

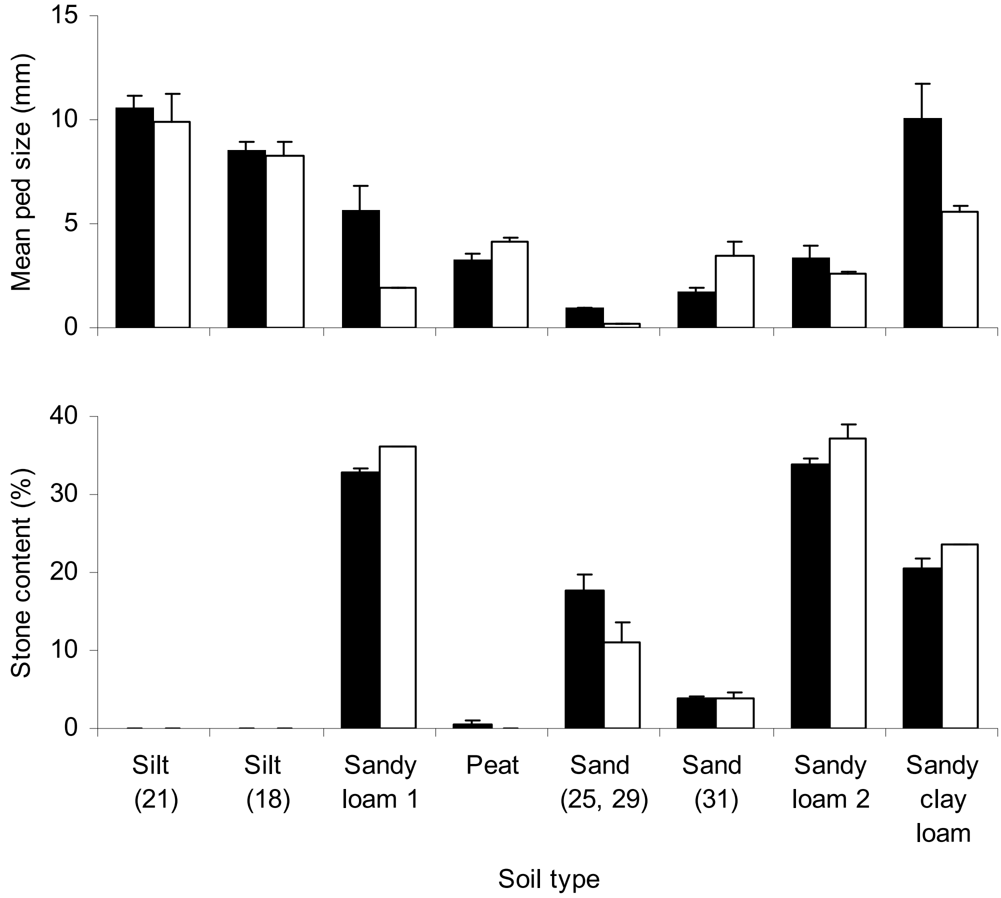

FIGURE 33. EFFECT OF 5 SOIL TYPES AT 2 PLANTING DATES ON *(A)* MEAN PED SIZE (MM), *(B)* STONE CONTENT (%) AT PLANTING AND TUBER INITIATION IN EXPERIMENTS 18-31. PLANTING DATES: SILT AND SANDY LOAM 1 PLANTED ON 9 APRIL ALL OTHERS 29 APRIL. CLOSED BARS, PLANTING; OPEN BARS, TUBER INITIATION. NUMBERS IN PARENTHESIS, EXPERIMENT NUMBER.

4.19. Investigation of radiation absorption during tuber initiation

The relationship between tuber and stem populations fitted to the historical datasets by Firman et al. (2007) was used to calculate expected tuber populations from stem populations for the 2008 to 2010 experiments. In 2010 there were fewer tubers than expected in Estima and Maris Peer (Figure 34a and d) but the number of tubers was similar to the historic average for Lady Rosetta and Maris Piper (Figure 34b and c). Over the 3 years the difference between actual and expected tuber populations was relatively small in Estima and Maris Piper over a wide range in stem populations (Figure 34a and c) although there was greater variation in Estima in 2010 compared to 2008-2009. More tubers than expected were found in Lady Rosetta at high stem populations (Figure 34b) but in Maris Peer more tubers were found at low stem populations and at intermediate stem densities there were fewer than expected (Figure 34d). Over the 3 years in Maris Peer and with the addition of an historic 1998 data set in Estima, experiments with a wide range of planting dates had a large spread of absorbed radiation values c. 20-130 MJ m-2 but the difference between the actual and expected number of tubers was greater for Maris Peer (Figure 35a) than Estima (Figure 36a). Simple linear regression analysis showed no overall effect of absorbed radiation on the difference between the observed and expected number of tubers in Maris Peer and only accounted for 23 % of the variance in Estima but in both Estima and particularly Maris Peer, including year of planting as a factor increased the

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variance accounted for (Figure 35a, Figure 36a, Table 30) consistent with the relatively high and low numbers of tubers in 2008 and 2010, respectively. In Estima, including planting date as a factor also increased the variance accounted for consistent with relatively few tubers from late plantings but this was not so for Maris Peer (Table 30).

The effect of absorbed radiation per stem on the number of tubers per stem in Maris Peer and in Estima accounted for 55 and 50 % of the variance, respectively, overall and including planting date categorised by month of planting as a factor increased the variance accounted for (Figure 35b, Figure 36b, Table 30). In Maris Peer, March plantings produced significantly more tubers per stem at similar levels of absorbed radiation per stem than those in April, May or June with the least number of tubers per stem in May while the number of tubers per stem in July was similar to March (Figure 35b, Table 30). In Estima, March plantings also produced significantly more tubers per stem at similar levels of absorbed radiation per stem than April, May, June, July and August (Figure 36b*,* Table 30).

Where data was interpolated to a common stem density, the number of tubers per stem increased with an increase in the absorbed radiation per stem and accounted for 8 and 40 % of the variance in Maris Peer and Estima, respectively, but overall and including planting date categorised by month of planting as a factor increased the variance accounted for (Table 30). Interpolation resulted in the exclusion of 32 and 21 % of the data points in Maris Peer and Estima, respectively, where the interpolated stem density lay outside the actual stem range and this may have contributed to the difference in variance accounted for between the interpolated and overall stem analysis (Table 30). In Maris Peer there were fewer tubers per stem at similar levels of absorbed radiation per stem in May than in March while for overall stem data there were fewer tubers per stem in April, May and June than in March (Table 30). In Estima the effect of absorbed radiation on the number of tubers per stem was similar in both analyses where fewer tubers per stem were formed in May, June, July and August compared to March except for the overall stem data where fewer tubers per stem were also formed in April than in March (Table 30).

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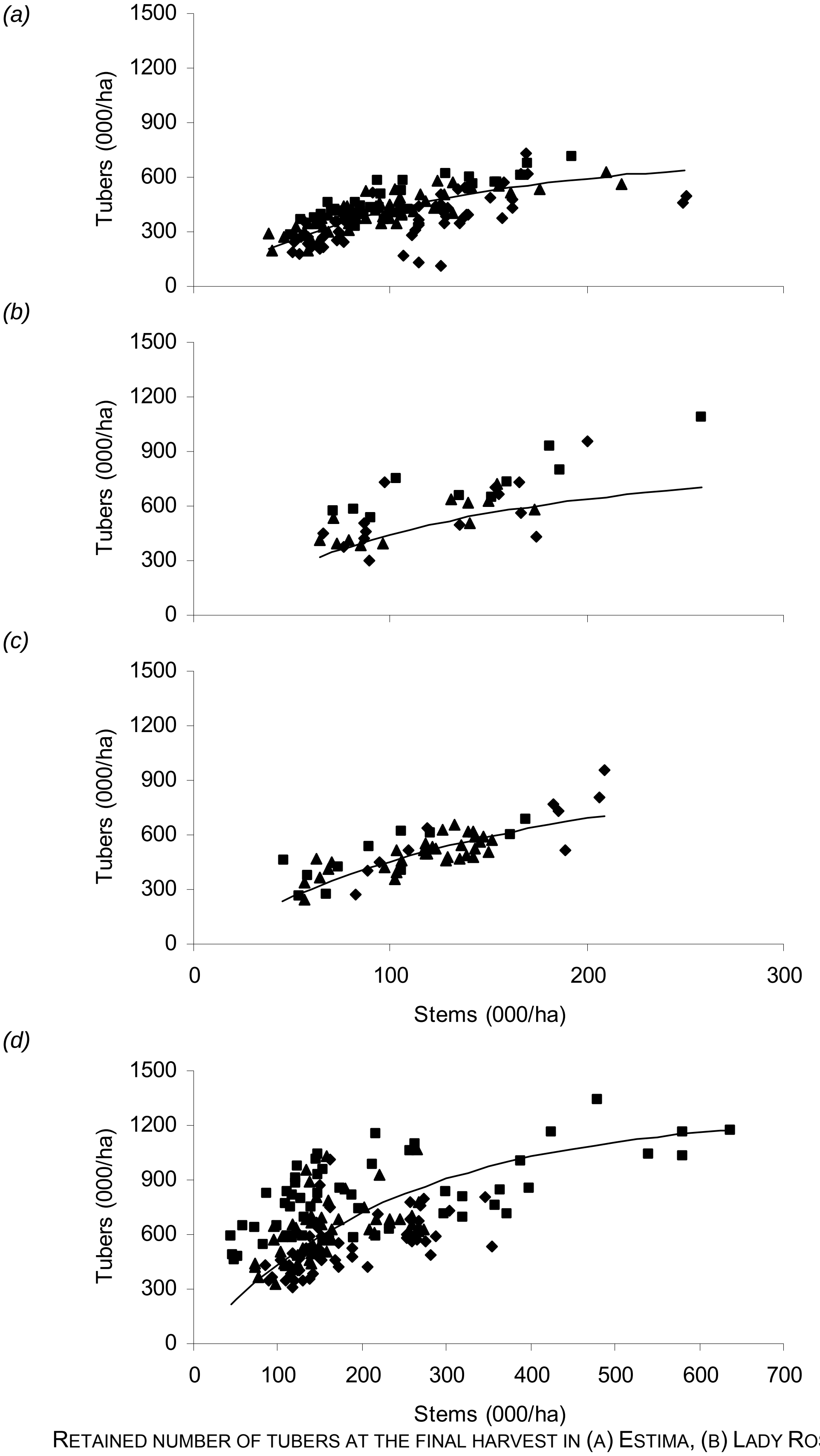

FIGURE 34. RETAINED NUMBER OF TUBERS AT THE FINAL HARVEST IN (A) ESTIMA, (B) LADY ROSETTA, (C) MARIS PIPER, (D) MARIS PEER OVER 3 YEARS. ACTUAL NUMBER OF TUBERS: 2008, ■; 2009, ▲; 2010, ◆. LINE, EXPECTED NUMBER OF TUBERS BASED ON HISTORIC AVERAGE.

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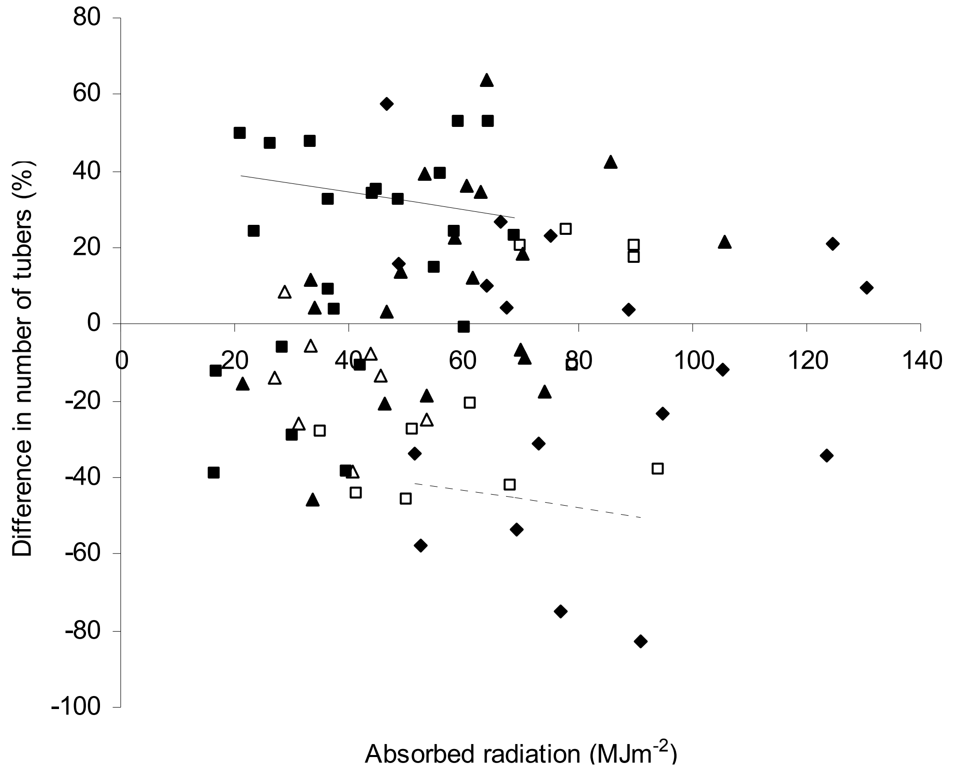
(a)



(b)

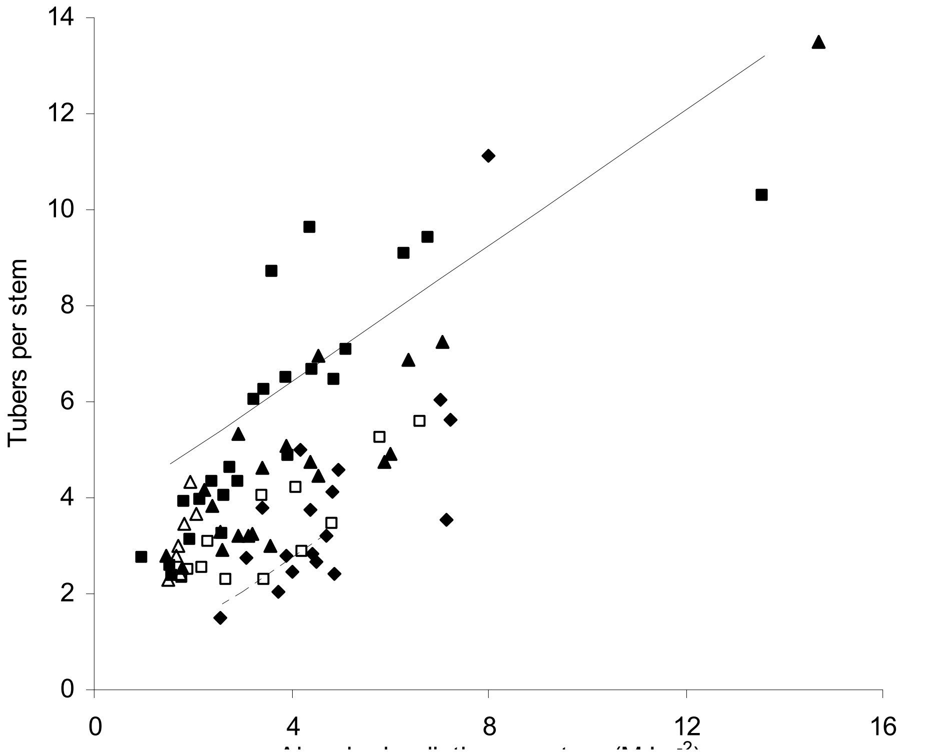


Figure 35. Effect of planting date in Maris Peer over 3 years on (a) absorbed radiation during tuber initiation (TI) plotted against the difference between the actual and expected number tubers, (b) absorbed radiation per stem during TI plotted against the number of tubers per stem. Planting dates: March, ■; April, ▲; May, ◆; June, □; July, △. Solid line, March 2008 regression; broken line, May 2010 regression. Other regression lines not shown.

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(a)

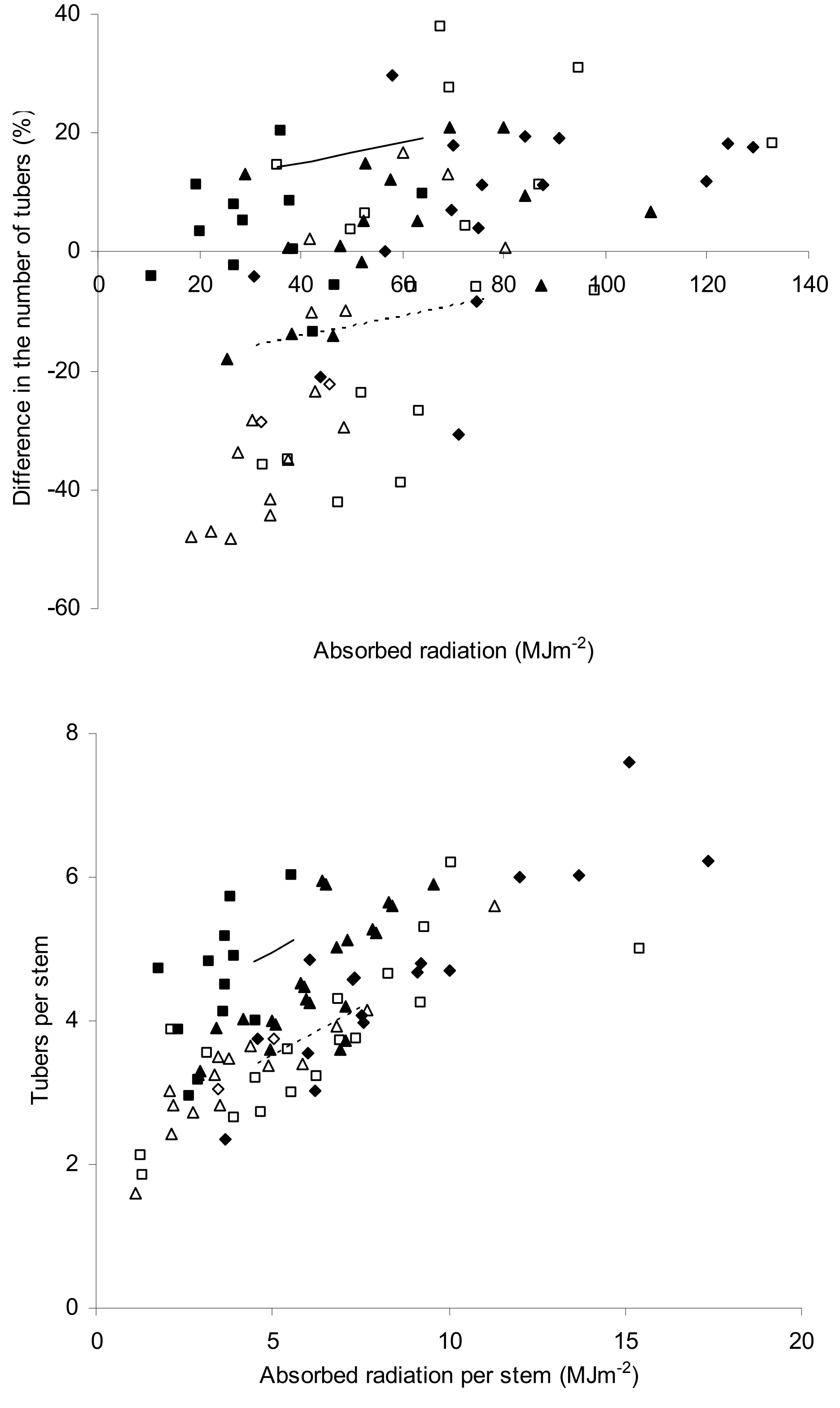

FIGURE 36. EFFECT OF PLANTING DATE IN ESTIMA OVER 4 YEARS (1998, 2008-2010) ON (A) ABSORBED RADIATION DURING TUBER INITIATION (TI) PLOTTED AGAINST THE DIFFERENCE BETWEEN THE ACTUAL AND EXPECTED NUMBER TUBERS, (B) ABSORBED RADIATION PER STEM DURING TI PLOTTED AGAINST THE NUMBER OF TUBERS PER STEM. PLANTING DATES: MARCH, ■; APRIL, ▲; MAY, ◆; JUNE, □; JULY, △; AUGUST, ◇. SOLID LINE, MARCH 2008 REGRESSION; BROKEN LINE, MAY 2010 REGRESSION. OTHER REGRESSION LINES NOT SHOWN.

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		Maris Peer				Estima			
Year	Planting	Parameter	Estimate	S.E.		Parameter	Estimate	S.E.	
Difference in number of tubers (%)									
Variance accounted for (%)			67.1			Variance accounted for (%)	64.1		
All	All	Slope	-0.23	0.121	NS	Slope	0.17	0.082	
1998†	Mar					Constant	17.9	6.65	
2008	Mar	Constant	43.6	6.94		Constant difference	-9.7	7.00	NS
2009	Mar	Constant difference	-27.5	5.66		Constant difference	-14.9	5.22	
2010	Mar	Constant difference	-66.5	6.20		Constant difference	-33.2	5.29	
	Apr	Constant difference	13.8	6.39		Constant difference	-0.9	5.40	NS
	May	Constant difference	-6.9	7.90	NS	Constant difference	-5.7	6.26	NS
	Jun	Constant difference	4.1	8.26	NS	Constant difference	-15.8	5.63	
	Jul	Constant difference	16.2	8.78	NS	Constant difference	-25.7	5.11	
	Aug					Constant difference	-35.2	9.77	
Tubers per stem (overall stem density)									
Variance accounted for (%)			79.3			Variance accounted for (%)	69.4		
All	All	Slope	0.70	0.059		Slope	0.27	0.037	
1998†	Mar					Constant	3.43	0.311	
2008	Mar	Constant	3.60	0.353		Constant difference	0.20	0.399	NS
2009	Mar	Constant difference	-1.50	0.322		Constant difference	0.24	0.340	NS
2010	Mar	Constant difference	-1.58	0.349		Constant difference	0.00	0.280	NS
	Apr	Constant difference	-0.72	0.337		Constant difference	-0.68	0.270	
	May	Constant difference	-2.08	0.347		Constant difference	-1.24	0.336	
	Jun	Constant difference	-1.23	0.410		Constant difference	-1.46	0.284	
	Jul	Constant difference	-0.18	0.486	NS	Constant difference	-1.34	0.258	
	Aug					Constant difference	-1.40	0.487	
Tubers at 150 000 stems/ha						Tubers at 100 000 stems/ha			
	Variance accounted for (%)		64.7			Variance accounted for (%)	75.3		
All	All	Slope	0.30	0.142		Slope	0.21	0.065	
1998†	Mar								
2008	Mar	Constant	4.40	0.511		Constant	3.89	0.414	
2009	Mar	Constant difference	-1.27	0.339		Constant difference	-0.27	0.242	NS
2010	Mar	Constant difference	-1.95	0.388		Constant difference	-0.65	0.315	NS
	Apr	Constant difference	0.05	0.358	NS	Constant difference	-0.39	0.301	NS
	May	Constant difference	-1.05	0.473		Constant difference	-1.01	0.427	
	Jun	Constant difference	-0.15	0.504	NS	Constant difference	-0.99	0.322	
	Jul	Constant difference	0.59	0.399	NS	Constant difference	-1.0	0.24	
	Aug					Constant difference	-1.3	0.42	

† Data from historical data set.

TABLE 30. REGRESSION PARAMETERS FOR THE RELATIONSHIP BETWEEN THE DIFFERENCE BETWEEN THE OBSERVED AND EXPECTED NUMBER OF TUBERS AND ABSORBED RADIATION, THE RELATIONSHIP BETWEEN TUBERS PER STEM AND ABSORBED RADIATION PER STEM AND FOR THE RELATIONSHIP BETWEEN THE NUMBER OF TUBERS AND ABSORBED RADIATION INTERPOLATED TO A COMMON STEM DENSITY FROM PLANTING DATE EXPERIMENTS IN MARIS PEER AND ESTIMA

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For overall stem data (covering a wide range of stem density) the mean percentage ground cover during tuber initiation (TI) was generally lower in 2010 than other years and there was little relationship evident between the number of tubers per stem and ground cover in either variety (Figure 37a). Incident radiation during TI had little effect on the number of tubers per stem in Maris Peer but in Estima more tubers per stem were formed at higher levels of incident radiation accounting for 18 % of the variance (Figure 37b). It would appear that incident radiation in Estima was a more important influence on the relationship between the number of tubers per stem and absorbed radiation per stem than percentage ground cover, but this was not the case in Maris Peer (Figure 37a-c). For the interpolated data the mean percentage ground cover during TI was lower in 2010 compared to other years and was often lower from March plantings than later plantings (Figure 38a, Figure 39a and b), but in contrast to the overall stem data there was a small increase in the number of tubers per stem with an increase in mean ground cover accounting for 15 and 11 % of the variance in Maris Peer and Estima, respectively (Figure 38a). Consistent with the overall stem data, incident radiation during TI had little effect on the number of tubers per stem in Maris Peer but in Estima incident radiation accounted for 40 % of the variance (Figure 38b) and would appear to be a more important influence than ground cover on the relationship between the number of tubers per stem and absorbed radiation per stem (Figure 38a-c).

For the analysis of absorbed radiation per stem on the number of tubers per stem, the inclusion of planting date categorised by month of planting and year of experiment as factors increased the variance accounted for above that of absorbed radiation per stem alone (Figure 35b and Figure 36b, Table 30). Year as a factor included differences in soil conditions between years with generally coarser loams in the Cambridge experiments of 2008 and 2009 compared to the finer loam in 2010 as well as soil type experiments and experiments on external sites with a diverse range of soils with soil samples taken across a range of experiments to determine bulk density and mean ped size. Bulk density at planting was generally least in the peat and clay soils and greatest in the silt, fine and coarse loams and sand (Figure 40) but delay in planting had little effect on bulk density (Figure 41) and bulk density had no effect on the number of tubers per stem. The number of tubers per stem decreased with increasing mean ped size in both Maris Peer and Estima (Figure 42a and b) accounting for 19 and 26 % of the variance, respectively. In Maris Peer the number of tubers per stem varied greatly in soils with a mean ped size of less than 10 mm but was consistently low with ped sizes above 10 mm (Figure 42a) but in Estima the relationship between the number of tubers per stem and mean ped size was linear across the range of ped sizes (Figure 42b). There was no relationship between mean ped size and absorbed radiation or absorbed radiation per stem.

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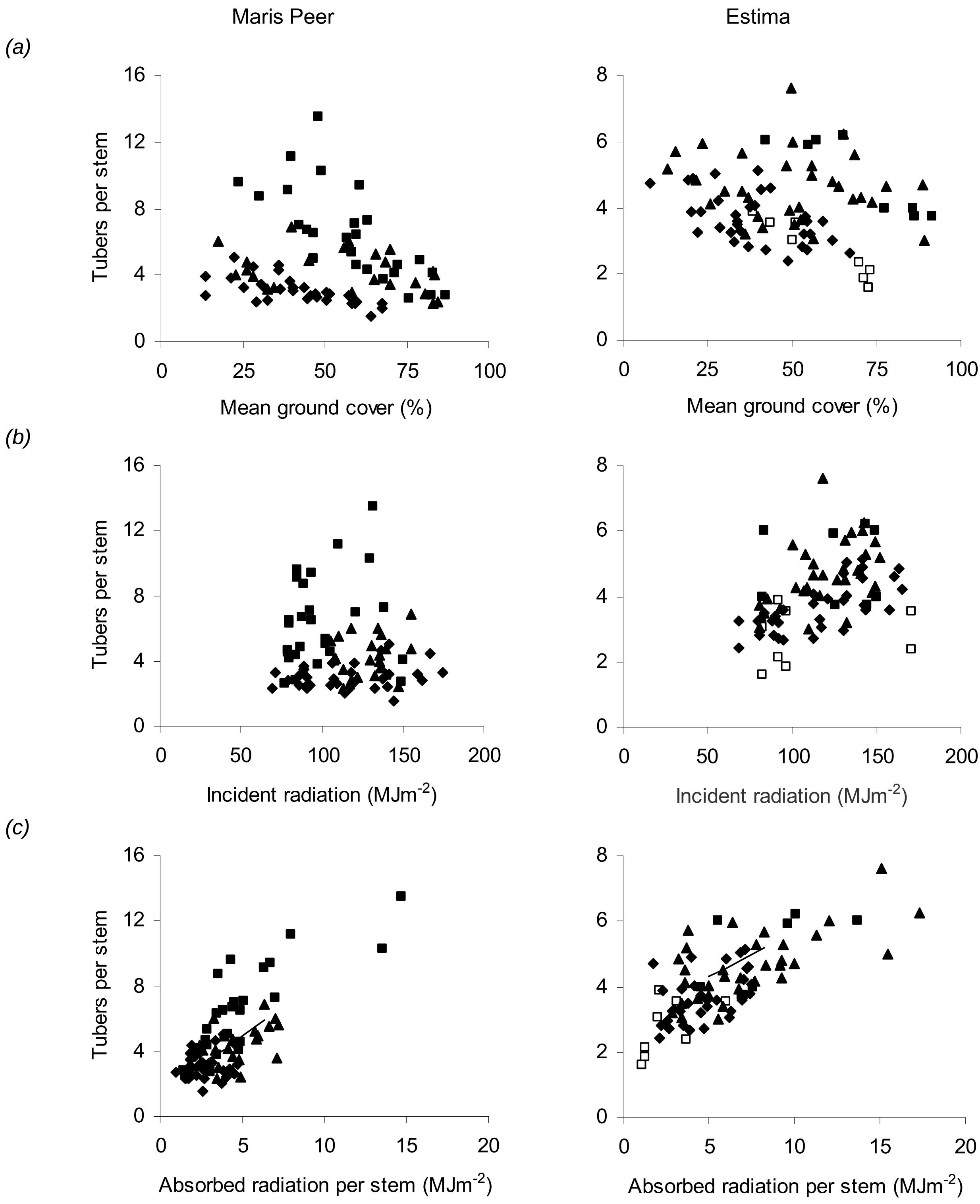

Figure 37. Effect of (a) mean ground cover, (b) incident radiation, (c) absorbed radiation at tuber initiation over 3 years for planting date experiments in Maris Peer and Estima. Years: 1998, □; 2008, ■; 2009, ▲; 2010, ◆. Regression lines for planting date April 2009, other regression lines not shown.

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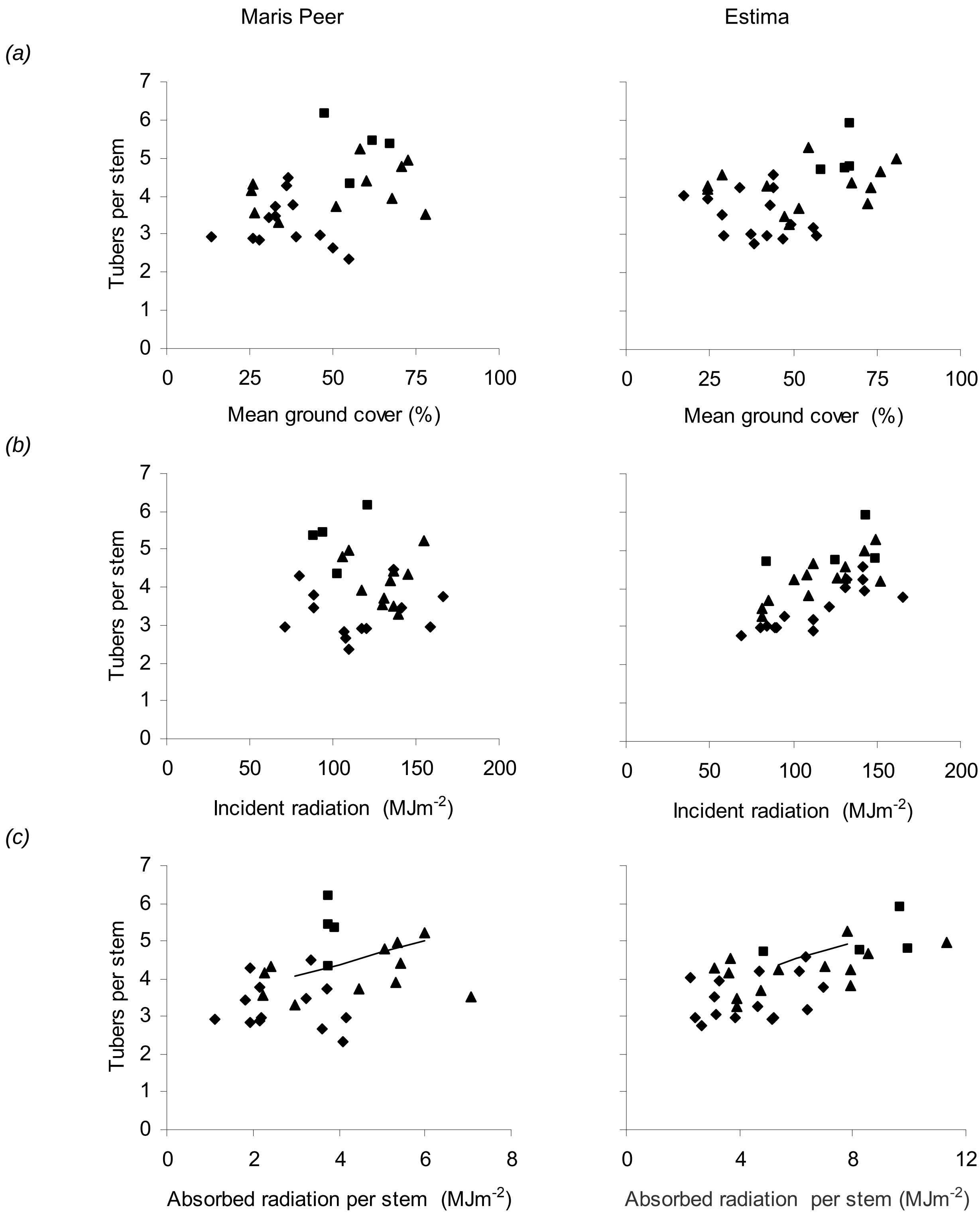

FIGURE 38. EFFECT OF (A) MEAN GROUND COVER, (B) INCIDENT RADIATION, (C) ABSORBED RADIATION AT TUBER INITIATION OVER 3 YEARS FOR PLANTING DATE EXPERIMENTS IN MARIS PEER INTERPOLATED TO 150 000 STEMS/HA AND ESTIMA INTERPOLATED TO 100 000 STEMS/HA. YEARS: 2008, ■; 2009, ▲; 2010, ◆. REGRESSION LINES FOR PLANTING DATE APRIL 2009, OTHER REGRESSION LINES NOT SHOWN.

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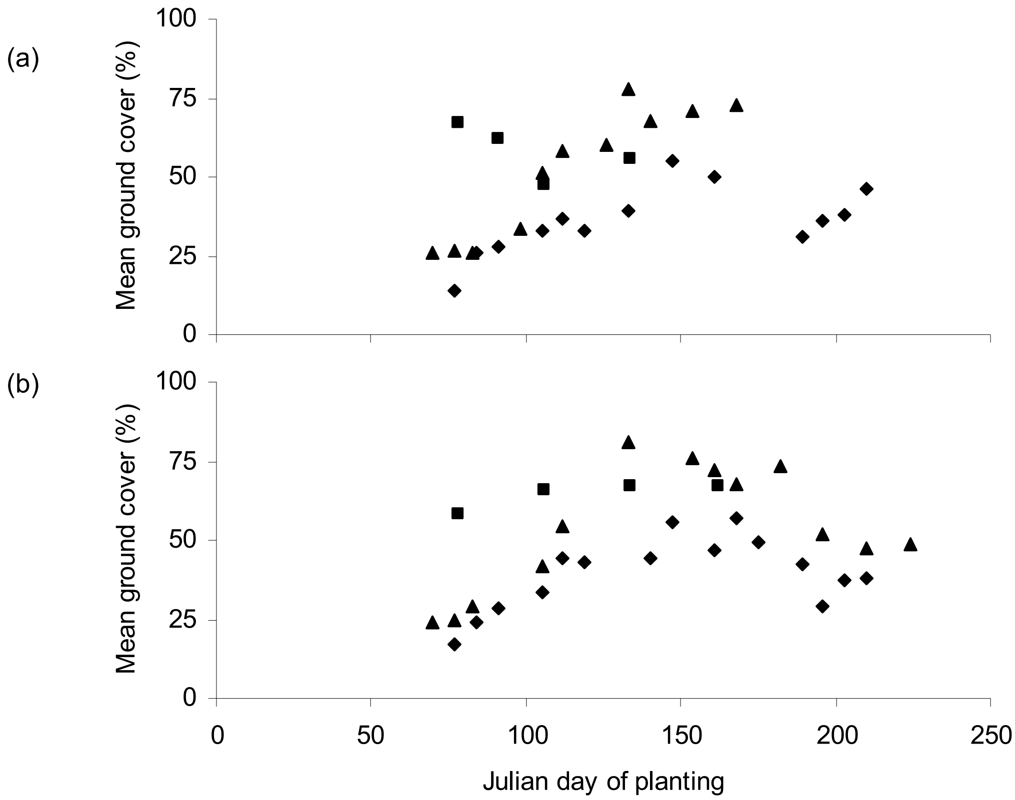

FIGURE 39 EFFECT OF PLANTING DATE ON MEAN GROUND COVER AT TUBER INITIATION OVER 3 YEARS IN (A) MARIS PEER INTERPOLATED TO 150 000 STEMS/HA, (B) ESTIMA INTERPOLATED TO 100 000 STEMS/HA. YEARS: 2008, ■; 2009, ▲; 2010, ◆.

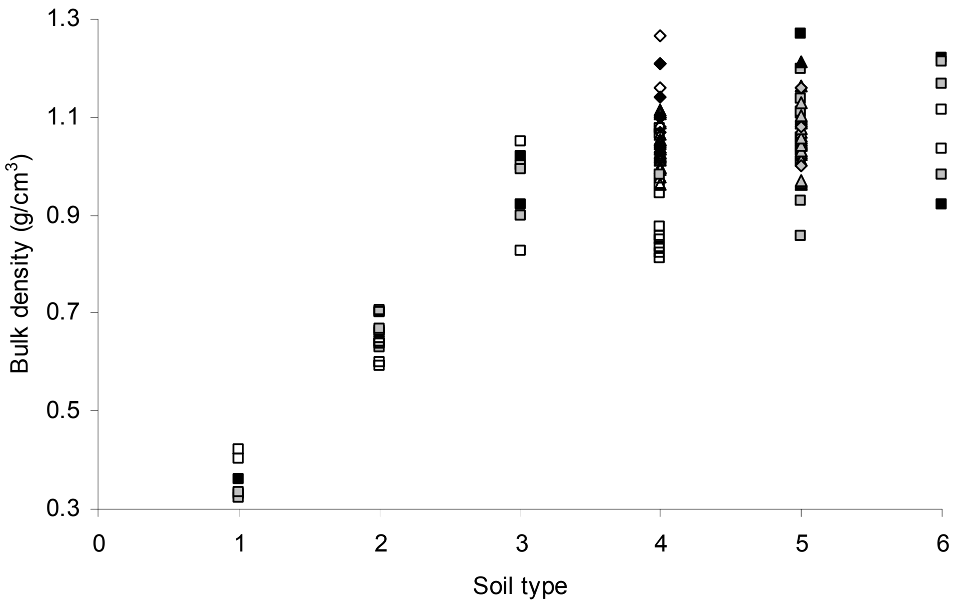

FIGURE 40. BULK DENSITY AT PLANTING FOR SIX SOIL TYPES OVER 3 YEARS AND THREE EXPERIMENT TYPES. SOILS: 1, PEAT; 2, CLAY, 3, SILT; 4, FINE LOAM; 5, COARSE LOAM; 6, SAND. YEARS: 2008, ■; 2009, ■; 2010, □. EXPERIMENTS: SOIL EXPERIMENTS (SOIL TYPE, PAIRED SITES, SOIL X CLOD), SQUARE; PLANTING DATE EXPERIMENTS (PLANTING & DENSITY, PLANTING & STOCK, MULTIPLE DATE OF PLANTING), TRIANGLE; CULTIVATION EXPERIMENTS (SOIL CONDITION), DIAMOND.

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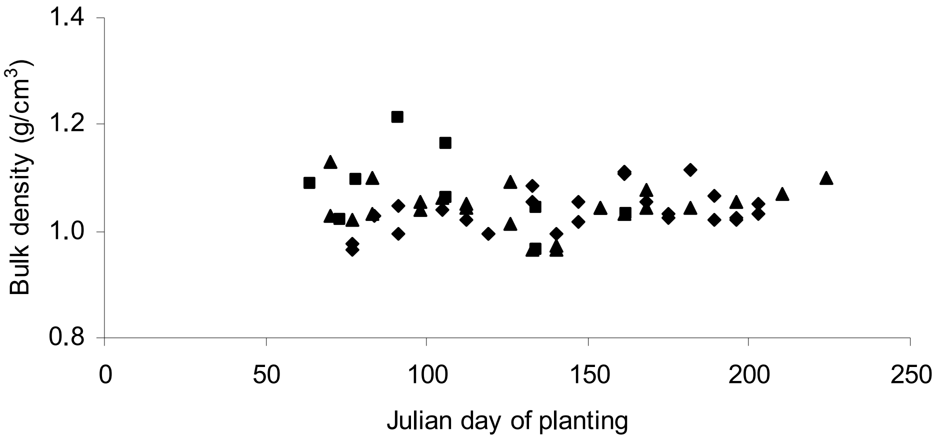
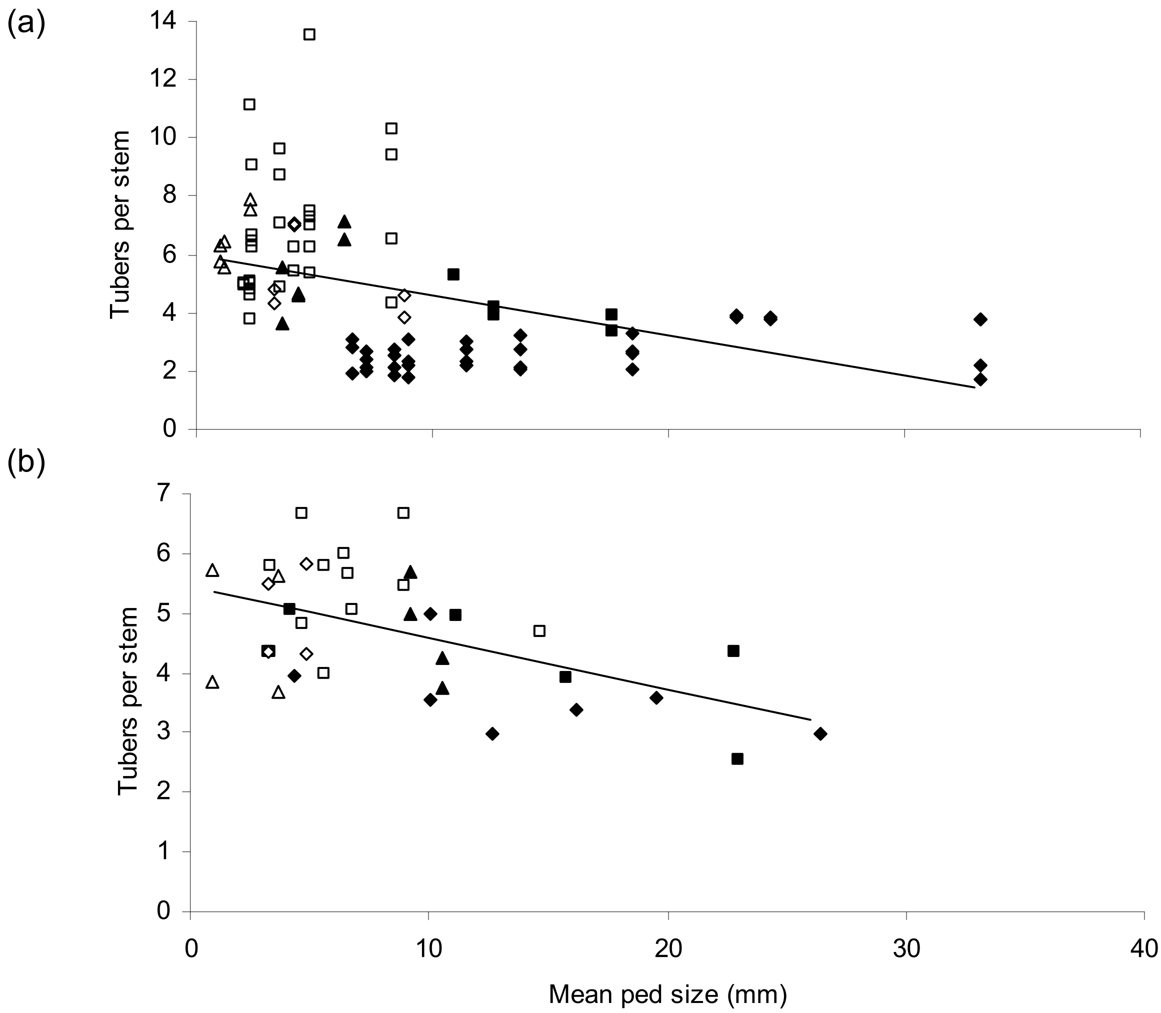


FIGURE 41. EFFECT OF DELAY IN PLANTING ON BULK DENSITY AT PLANTING OVER 3 YEARS. YEARS: 2008, ■; 2009, ▲; 2010, ◆.



†2008, soils graded, dried then regraded; 2009-2010 soils dried then graded. ‡ Excluding clays from clod size and soil type experiment 2010 except cloddy clay treatment.

FIGURE 42. EFFECT OF MEAN PED SIZE† AT PLANTING AND SOIL TYPE ON THE NUMBER OF TUBERS PER STEM OVER 3 YEARS IN (A) MARIS PEER (B) ESTIMA‡. SOIL TYPE: CLAY, ■; SILT, ▲; FINE LOAM, ◆; COARSE LOAM, □; SAND, △; PEAT, ◇. REGRESSION LINE: MEAN PED SIZE FOR ALL SOILS TYPES.

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5. CONCLUSIONS

Experiments conducted to determine seed rates for King Edward, Marfona, Pentland Dell and Russet Burbank have enabled varietal differences in key parameters to be established and the derivation of seed rate recommendations (Firman & Daniels 2010). Effects of seed age on the number of stems in 2009 and 2010 were small and in some cases inconsistent indicating the latest set of varieties studied are relatively unresponsive to difference in seed production cycle compared with most of the varieties studied previously. The combined datasets from all varieties studied has now enabled a simplified system for determining seed rates from these characters to be derived (Firman, 2010). The datasets have demonstrated that stem density is more important as a determinant of tuber size and marketable yield than total yield so that the requirement to establish effects of seed rate on total yield for different varieties is secondary to determining the effects on tuber size.

In each of 3 years, experiments were carried out to manipulate soil temperature and soil conditions and examine how differences in these variables between dates of planting and seasons may contribute to variation in the number of tubers initiated or retained. Raising soil temperature during tuber initiation by 2.4-3.1°C had no consistent effect on either the number of tubers initiated or retained in any year. Whilst greater differences in soil temperature than those generated in the experiments occur between very early and late plantings, the differences in soil temperature examined were representative of a range likely to be experienced by a high proportion of commercial crops in the UK so the data do not suggest variation in soil temperature is an important contributor to variation in the number of tubers for many crops.

Experiments designed to manipulate soil conditions generated little difference in ridge bulk density (generally ≤ 0.1 g/cm3) between ridges left to consolidate after preparation (representative of those in experiments with a wide range of planting dates) and freshly prepared ridges in all years. There was no evidence that these differences affected the number of tubers initiated or retained. Bulk density in flattened soil was up to c. 0.2 g/cm3 greater than that of freshly prepared ridges and whilst some effects on the number of tubers were found, these were inconsistent and overall soil cultivation treatments provided no evidence for a simple association between initiation and retention of tubers and bulk density or soil resistance. Comparison of planting tubers using a hand dibber, where soil surrounding the seed tuber was disturbed, with use of a bulb planter where little disturbance resulted did however provide some evidence that soil disturbance encouraged longer stolons to form and increased the number of tubers. These data suggest that soil resistance to stolon growth could contribute to variation in the number of tubers but that such effects are not simply associated with small differences in overall bulk density of the ridge. Cultivations generally had limited effect on mean ped size and whilst this tended to be greater for flattened than ridged soil there was no evidence that these relatively small differences affected the number of tubers.

The influence of soil type was investigated both by importing different soil types to compare at a common site and by planting paired site experiments on different soil types. Although both of these approaches have limitations, taken together they provide useful information. With imported soil, large differences in the number of tubers were found between soil types and whilst effects were not the same in all years, the number of tubers was consistently considerably lower with clay than other soil types and on average greatest with sand. Compared to the undisturbed sandy clay loam field soil, on average the effects of clay and sand were a 25 % decrease

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and a 27 % increase respectively in the number of tubers. The paired site comparisons did not include clay soils and the number of tubers tended to be relatively high from the sand, as found in an analysis of historic datasets (Firman et al. 2007) but there was no clear evidence for a substantial, consistent difference between sandy clay loam, silt, peat or sand on the number of tubers. The reduction in the number of tubers in clay was not associated with a high bulk density but mean ped size was high in the clay (c. 11-18 mm) and relatively low numbers of tubers in paired site experiments on cloddy soil with a large mean ped size indicate large peds may reduce the number of tubers per stem. Experiments over two years where mean ped size was manipulated by grading clay and sandy clay loam showed that substantial delays in emergence could result from both very fine (mean ped size of c. 3 mm) or cloddy soil (mean ped size > 20 mm). These effects on emergence confounded direct effects of ped size on the number of tubers and complicated interpretation of the results but there was evidence in both years that where these extreme effects were avoided, in soil of both types without a high proportion of very fine particles, low mean ped size was associated with higher numbers of tubers than large mean ped size (> 10 mm).

In all years, there was considerable variation in the number of tubers between planting dates but the differences between plantings did not change in a systematic way with delay in planting over the wide range of plantings examined. As previously found, the number of stems per plant generally increased with delay in planting so that stem populations were greater at later plantings. However, this did not account for differences in the number of tubers and the number of tubers per stem also varied considerably between plantings and years. In 2010, relatively low numbers of tubers per stem were associated with poor soil conditions and some of the variation between years may be attributable to soil conditions, particularly differences in mean ped size.

Analysis of the combined datasets showed ground cover during tuber initiation was low following early plantings (c. 25 %) and tended to increase with delay in planting to > 50 % in mid-May with relatively low values for plantings in July. Overall there was little relationship between absorbed radiation during tuber initiation and the number of tubers expected from stem populations but separate relationships were found for data grouped by planting period and year. The number of tubers per stem tended to increase with incident radiation and much of the variation in number of tubers per stem was accounted for by linear regression against the absorbed radiation per stem. This analysis indicated that plantings in March and April produced more tubers per stem for a given amount of absorbed radiation per stem than later plantings. This is consistent with more efficient use of incident radiation to produce assimilate for tuber formation at earlier plantings where ground cover during tuber initiation is relatively low. The analysis also showed that the relationship differed between years and this may reflect differences in soil conditions between years having direct physical effects on the number of tubers independent of indirect effects on canopy size and light absorption.

This project has provided a considerable body of information to inform seed rate requirements for potato crops. Variety specific recommendations have been produced and quantitative data provided on the effects of soil type, soil conditions and planting date on the number of tubers per stem. The findings should be useful in highlighting circumstances where modifying generic seed rates might be considered but suggest in many cases this may not be worthwhile as effects are sometimes inconsistent and often relatively small.

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