FV 39/39a
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Research Report

FV 39/39a

Timing of irrigation during vegetable crop establishment

Final report 1991/94

Working for Growers

Horticultural Development Council
18 Lavant Street, Petersfield, Hampshire GU32 3EW
Tel:(0730) 263736 Fax:(0730) 265394

Report to HDC

FV39 & FV39a - Timing irrigation

during vegetable crop establishment

HORTICULTURE RESEARCH INTERNATIONAL

WELLESBOURNE

Timing irrigation during vegetable crop establishment.

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Project leader	: W.E. Finch-Savage
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CONTENTS

RELEVANCE TO GROWERS AND PRACTICAL APPLICATION

Application

This 3-year study at HRI Wellesbourne was carried out to provide a basis on which useful and effective guidelines for timing irrigation during seedling establishment could be determined. The summary below describes the background and methodology of the technique developed for timing irrigation. A grower fact sheet is currently being prepared which provides information to growers.

Summary

Why is irrigation needed

There is an increasing need to establish the correct number of uniformly-sized seedlings to achieve efficient and profitable vegetable production. This is because the number of seedlings established determines both individual plant size and total crop yield. In addition the uniformity of plant size at harvest, which determines graded yields, is greatly influenced by the uniformity of seedling emergence.

Arguably the greatest cause of poor and variable seedling emergence, during a large part of the season, is inadequate and variable seed-bed moisture. Clearly, irrigation could overcome this problem, but there have been no guidelines for irrigation during crop establishment of vegetables. Previous studies supported by MAFF have shown that there may be optimum times to apply irrigation following sowing to improve the predictability and uniformity of seedling stands.

When is irrigation needed:

Following sowing the seed rapidly takes up moisture and begins the processes of germination leading to growth of the radicle (root). Sowing the seed into moisture and establishing good seed-soil contact will allow this to occur uniformly in the seed population. After this initial imbibition the seed takes up little further water until radicle growth is initiated. Growth initiation, in many species, is more sensitive to low moisture than the processes of germination leading up to it or subsequent growth. This acts as a natural mechanism that prevents radicle growth into a drying seed bed. Therefore for each seed, radicle growth is prevented if the soil moisture falls below a critical level (base water potential) at the time when growth should be initiated. To prevent delay in germination and subsequent emergence irrigation is required at this point.

The time from sowing to the initiation of radicle growth differs between seeds. In a lot, there are fast and slow germinators and germination of the whole seed lot may take several days. Figure 1. illustrates how soil moisture can determine the pattern of germination and subsequent emergence.

Figure 1 shows the soil drying after sowing. In this example, drying is slow and so soil moisture remains above the base water potential long enough to allow faster germinating seeds to initiate radicle growth and germinate. As the soil continues to dry below the base water potential radicle growth is not initiated in the remaining seeds until rainfall once again raises soil moisture. In this way two flushes of emergence occur which reduces plant uniformity.

Of course the pattern of soil moisture is different at each sowing and therefore different patterns of germination and emergence will occur. In principle however, if water is available from rain or irrigation near to the time when radicle growth is initiated all the seeds should progress to germination and seedling emergence without delay to give uniform emergence. Irrigation before or after this point is progressively less effective.

How do you decide when to irrigate:

In order to time when to irrigate it is necessary to predict when radicle growth would be initiated in the majority of seeds. If the seed is adequately imbibed, temperature determines the rate of progress towards radicle initiation and germination. Therefore it is not possible to use a set time (in days, see example below) to irrigate following sowing because the processes of germination proceed faster when it is warm than when it is cold. However, the nature of this relationship makes it possible to use thermal time (day degrees, °Cd) to predict radicle initiation and therefore when to irrigate. The equation below can be used to calculate thermal time above a base temperature (*c.* 2 °C for many vegetable species in the UK) for each day. Seeds will not germinate below this base temperature. The values from each day are added to indicate the passage of thermal time.

$$\text{Day degrees (°Cd)} = \frac{\text{max + min temperature}}{2} - \text{base temperature}$$

Each species, and often cultivar, have different characteristic thermal times to germination. However, it is possible to generalise into three categories:

1. Fast germinators with thermal times to 50% germination (T50) less than 40 °Cd, i.e. lettuce, radish, calabrese and other more rapid Brassicas

2. Medium-rate germinators with T50 greater than 40 and less than 80 °Cd, i.e. onions, carrot, leek and slower Brassicas

3. Slow germinators with T50 greater than 80 °Cd, i.e. parsnips.

A single thermal time recommendation for irrigation in the first two categories can be used as a rough guide. Check if irrigation is required at 30-40 °Cd and 80-90 °CD for fast and medium rate species. Examples are given below for spring and autumn sown bulb onion crops (medium rate).

Sown 24 March 1993

Day	1	2	***	14	15	16	17	18	19
Max temp (°C)	10.6	10.1	***	11.9	9.2	11.4	10.2	13.3	12.1
Min temp (°C	0.4	0.2	***	5.8	3.9	7.4	7.0	2.3	5.7
Day degrees (°Cd)	3.5	6.7	***	71.3	78.2	85.6	92.2	98.0	104.9
Time to irrigate						______	______		

Sown 22 August 1993

Day	1	2	3	4	5	6	7	8	9
Max temp (°C)	15.8	15.9	17.1	17.6	17.1	16.4	18.5	21.7	21.4
Min temp (°C)	11.2	6.3	4.4	8.3	5.6	3.9	11.2	7.5	14.3
Day degrees (°Cd)	11.5	20.6	29.4	40.4	49.8	58.0	70.9	83.5	99.4
Time to irrigate								—	—

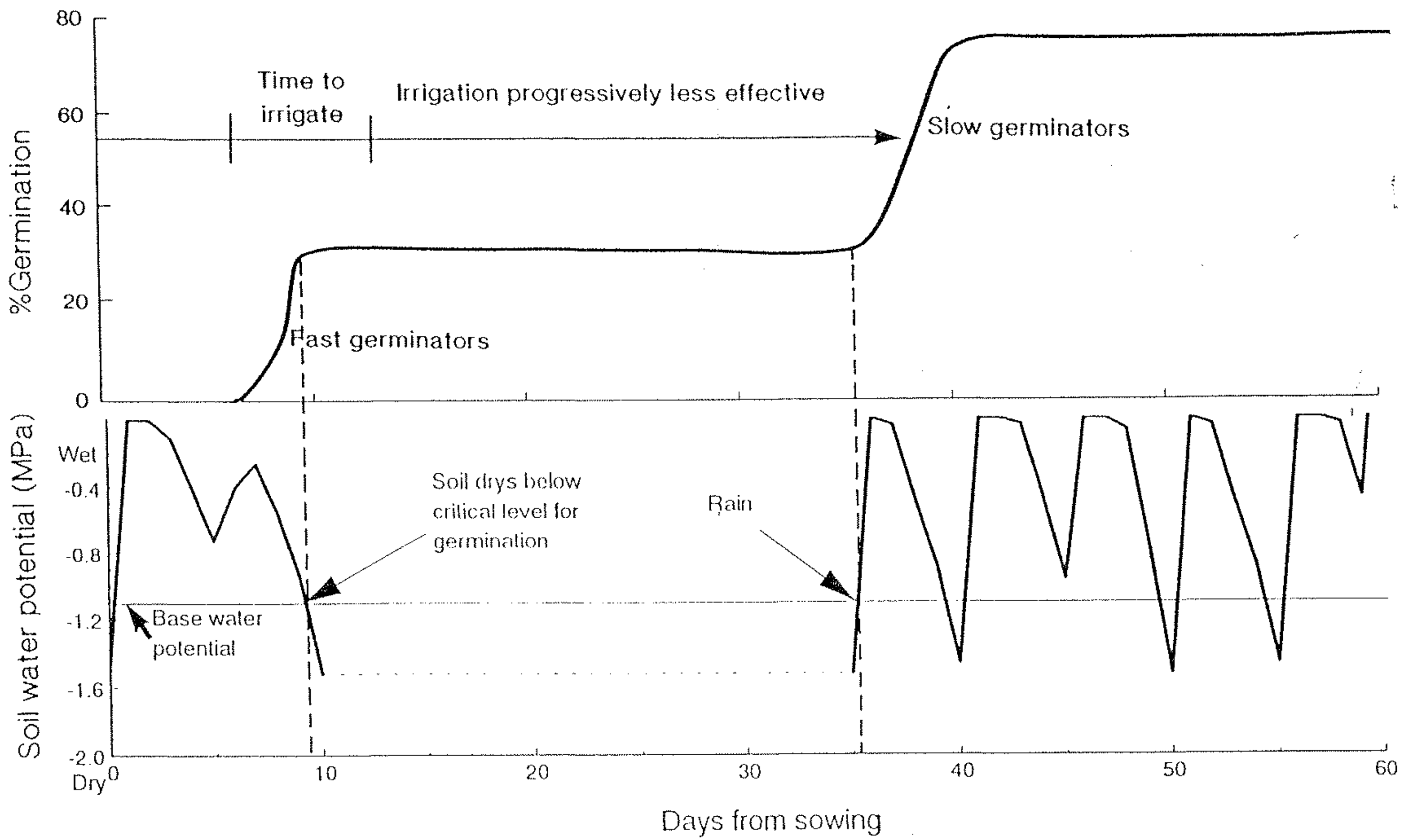
Further funding from HDC may allow an approximate guide to be produced in days, based on average temperatures for the time of year and location.

In the slow category, timing will depend on the seed lot. We have used 12.5 mm of irrigation in our experiments, but clearly if it has just rained significantly or imminent rain is forecasted irrigation is unnecessary. In these experiments seeds were sown into moist soil. Results will vary more if seeds are sown into very dry soils where initial imbibition is limited or delayed.

What benefits result from timing irrigation:

Only a limited number of experiments have been carried out and this method of timing has not been tested on a large scale. Also the impact of timed irrigation on soil impedance in soils which are very prone to capping has not been evaluated. However, the results so far show that a single correctly timed irrigation can reduce the spread of seedling emergence times, increase percentage emergence and improve predictability across sowings. Figure 2 provides an example of the improved seedling emergence and the greater uniformity of seedlings resulting from timed irrigation of onions. We estimate, using a computer model, that over the last 20 years, onion crops (medium-rate species) would have benefited from a timed irrigation on an average of more than 35% of potential sowing occasions and up to 60% of occasions in one year.

As with all experimental protocols it is prudent to carry out a comparative test on a small representative area of crop.



%Germination
80
60
40
20
0
Time to irrigate
Irrigation progressively less effective
Slow germinators
Fast germinators
Soil water potential (MPa)
Wet
-0.4
-0.8
-1.2
-1.6
-2.0
Dry
Soil drys below critical level for germination
Rain
Base water potential
0
10
20
30
40
50
60
Days from sowing

Figure 1

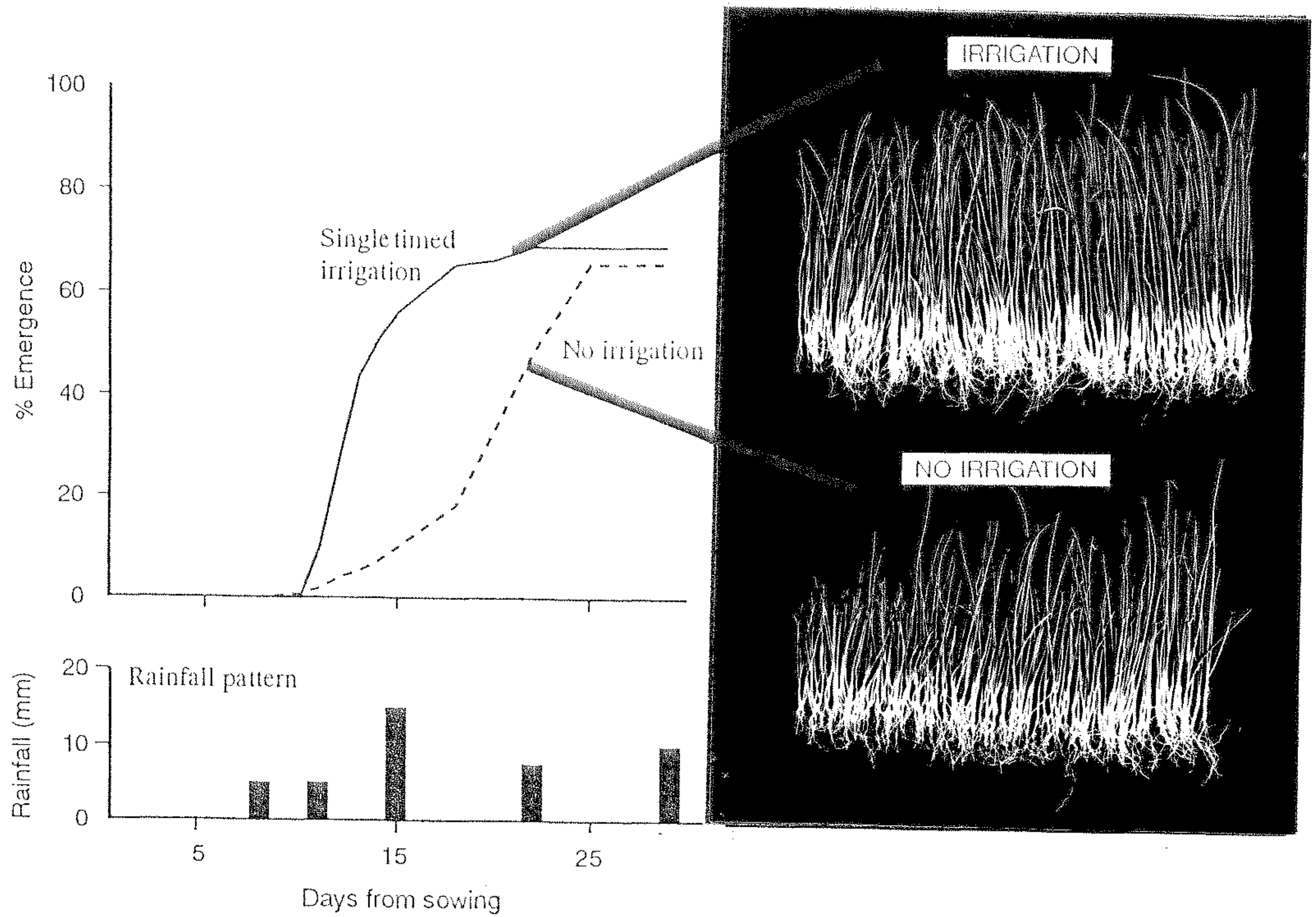

100
80
60
40
20
0
% Emergence
Single timed
irrigation
No irrigation
20
10
0
Rainfall (mm)
Rainfall pattern
5
15
25
Days from sowing
IRRIGATION
NO IRRIGATION

Figure 2

EXPERIMENTAL SECTION

Introduction

Experiments were carried out over a three year period at HRI Wellesbourne to develop and test techniques for timing irrigation during seedling emergence to improve vegetable crop establishment.

Previously under MAFF funding, a model to describe the influence of variable conditions of temperature and soil moisture on the pattern of seedling emergence in the field had been developed. Work on the model suggested that there was a critical moisture-requiring step at the point following sowing when radicle growth was initiated in the majority of seeds. Inadequate soil moisture at this stage resulted in delayed and non-uniform seedling emergence. Thus emergence may be improved by providing irrigation at this time. In theory, thermal time could be used to indicate when radicle growth would be initiated following sowing.

In the first year of experiments a thermal time method of predicting optimum irrigation timing was tested at ten sowing occasions using two crops, carrot and onion. The basic method was then further developed and in the second year experiments were carried out to determine if the same technique could be used with other species that covered the full range of vegetable crops sown in the UK. In the third year the efficacy of timed irrigation was tested on a further three crops in a range of seed-bed conditions. In all these experiments it was essential to carry out detailed recording of seedling emergence and to fully characterise seed germination. The data from all experiments were subjected to analyses of variance.

In order to achieve uniform emergence and increase the benefits of timed irrigation it is necessary to get rapid and uniform seed imbibition following sowing. It is thought that seed/soil contact to aid imbibition is better when a seed press wheel or the dibber-drill technique is used. Experiments in 1992 and 1993 investigated the potential benefits of combining these drilling techniques with timed irrigation.

(1991 Expts. 1-3)

Experiment 1

Site	Wellesbourne - Field experiments
Treatments	
Irrigation	1.Restored to field capacity 2 days before drilling + timed irrigation @ 90°Cd >1°C. 2.Restored to field capacity 2 days before drilling 3.Timed irrigation @ 90°Cd >1°C. 4.No irrigation
Species	Carrot c.v. Nandor Onion c.v. Hysam
Sowing dates	1. 9 April 2. 15 April 3. 23 May 4. 4 June 5. 5 July 6. 14 August 7. 4 September
Experimental design	There were separate experiments for each species. Sowings were randomised on the experimental area ; Each sowing had a randomised block design with 3 replications. There were 24 plots with 2 x 3m. rows each containing 100 seeds sown with a hand-pushed drill
Fertiliser	Basal 240kg ha^{-1} P and K
Pest and disease control	1.Pre-emergence herbicide - Carrot - Linuron @ 1.1l ha^{-1} in 500l. water Onion - Albrass @ 9l ha^{-1} + Dacthal @ 6 kg ha^{-1} in 500l. water 2.Sowing 3 to Onions - Bravo @ 2l ha^{-1} in 220-1000l water & Decis @ 300ml ha^{-1} in >400l water against Damping-off and Bean seed fly respectively 3.Sowings 6 & 7 - Fubol 58WP @ 12kg ha^{-1} in 500-1000l water against Damping-off 4.Sowing 7 - seeds dressed with Metaxaine @ 1g a.i. kg^{-1} against Damping-off
Soil conditioner	Soiltex L1@ 125l ha^{-1} in >1000l water
Records taken	1.Seedling emergence 2.Soil moisture contents 3.Soil temperatures at seed depth 4.Germination in laboratory Carrot 5° - 25°C., Onion 1° - 35°C. (@ 5°C. intervals)

Experiment 2

Site	Wellesbourne - Mobile covers
Treatments	
Irrigation	1.Restored to field capacity 2 days before drilling + timed irrigation @ 90°Cd >1°C. 2.Restored to field capacity 2 days before drilling 3.Timed irrigation @ 90°Cd >1°C. 4.No irrigation
Species	Carrot c.v. Nandor Onion c.v. Hysam
Sowing dates	1. 11 March 2. 2 May
Experimental design	There were separate experiments for each species and sowing. Each sowing had a randomised block design with 3 replicates. There were 24 plots with 2 x 3 m. rows each containing 100 seeds sown with a hand-pushed drill
Fertiliser	Basal 240kg ha^{-1} P and K
Pest and disease control	1.Pre-emergence herbicide - Carrot - Linuron @ 1.1l ha^{-1} in 500l. water Onion - Albrass @ 9l ha^{-1} + Dacthal @ 6 kg ha^{-1} in 500l. water
Soil conditioner	Soiltex L1@ 125l ha^{-1} in >1000l water
Records taken	1.Seedling emergence 2.Soil moisture contents 3.Soil temperatures at seed depth 4.Germinations in laboratory Carrot 5 - 25°C. , Onion 1 - 35°C. (@ 5°C. intervals)

Experiment 3

Site	Wellesbourne - Polytunnel
Treatments	
Irrigation	1.Restored to field capacity 2 days before drilling + timed irrigation @ 90°Cd >1°C. 2.Restored to field capacity 2 days before drilling 3.Timed irrigation @ 90°Cd >1°C. 4.No irrigation
Species	Carrot c.v. Nandor Onion c.v. Hysam
Sowing date	22 August
Experimental design	There were separate experiments for each species which had a randomised block design with 3 replicates. There were 24 plots with 2 x 3 m. rows each containing 100 seeds sown with a hand-pushed drill
Fertiliser	Basal 240kg ha^{-1} P and K
Pest and disease control	1.Pre-sowing seed dressing of Metaxaine @ 1g a.i. kg^{-1} against Damping-off 2.Pre-emergence herbicide - Carrot - Linuron @ 1.1l ha^{-1} in 500l. water Onion - Albrass @ 9l ha^{-1} + Dacthal @ 6 kg ha^{-1} in 500l. water 3.Fubol 58WP 12kg ha^{-1} in 500-1000l water against Damping-off
Soil conditioner	Soiltex L1@ 125l ha^{-1} in >1000l water
Harvest	1 October
Records taken	1.Seedling emergence 2.Soil moisture contents 3.Soil temperatures at seed depth 4.Harvest - individual seedling weights 5.Germinations in laboratory Carrot 5° - 25°C. , Onion 1° - 35°C. (@ 5°C. intervals)

Results (1991 Expts. 1-3)

Mean values of percentage emergence, spread of emergence times and time to 50% emergence across sowings for each of the four irrigation treatments are presented in Table 1. In general, percentage seedling emergence was increased and both the time to 50% emergence and the spread in times to emergence of individual seedlings were reduced on carrot and onion plots when post-sowing timed irrigation was applied, compared to that on plots which received pre-sowing irrigation or just ambient rainfall. As expected, the benefits of post-sowing timed irrigation were greatest at sowings where soil moisture was limiting due to lack of rainfall. An example of the greater predictability of seedling emergence that can be achieved from timed irrigation is given in Figure 3.

Pre-sowing irrigation was found to be inadequate to give predictable seedling emergence when post-sowing rainfall was significantly delayed. A combination of both pre-sowing and post-sowing timed irrigation gave the most predictable time to seedling emergence, but post-sowing timed irrigation on its own gave the most predictable percentage seedling emergence across sowings compared to other treatments. Figure 3 clearly shows that with onions a very similar percentage emergence was achieved at each sowing occasion with post-sowing timed irrigation, whereas, a more variable percentage seedling emergence resulted from the other irrigation regimes. Further evidence that timed irrigation improves the predictability of seedling emergence in the open field (Expt. 1) is given in Figure 4.

The data presented provides a brief overview of the experiments carried out, further results showing seedling emergence patterns at individual sowings are presented in appendix 3.

Conclusions from 1991 experiments

The timing of irrigation following sowing using simple thermal time models was shown to be an effective method of improving the level and predictability of onion and carrot crop establishment under a range of environmental conditions.

Table 1. Seedling emergence characters for four irrigation treatments meaned across ten sowing occasions in 1991.

Seedling emergence character	Irrigation treatment Pre + post sowing	Pre-sowing	Post-sowing	None	LSD
ONION					
Percentage	65	62	70	62	
Angular transformation of percentage	54	52	57	53	2.8
Spread (days)	7.7	9.5	7.4	9.9	1.0
Time to 50% (days)	15	17	17	21	1.1
Time to 50% (°Cd)	176	202	199	247	14
CARROT					
Percentage	67	63	71	68	
Angular transformation of percentage	55	53	58	56	2.7
Spread (days)	8.8	10.3	9.7	12.0	0.8
Time to 50% (days)	14	16	17	19	0.8
Time to 50% (°Cd)	160	186	187	235	12

**Base-temp for ONION = 2.77°C.
" " CARROT = 2.25°C.

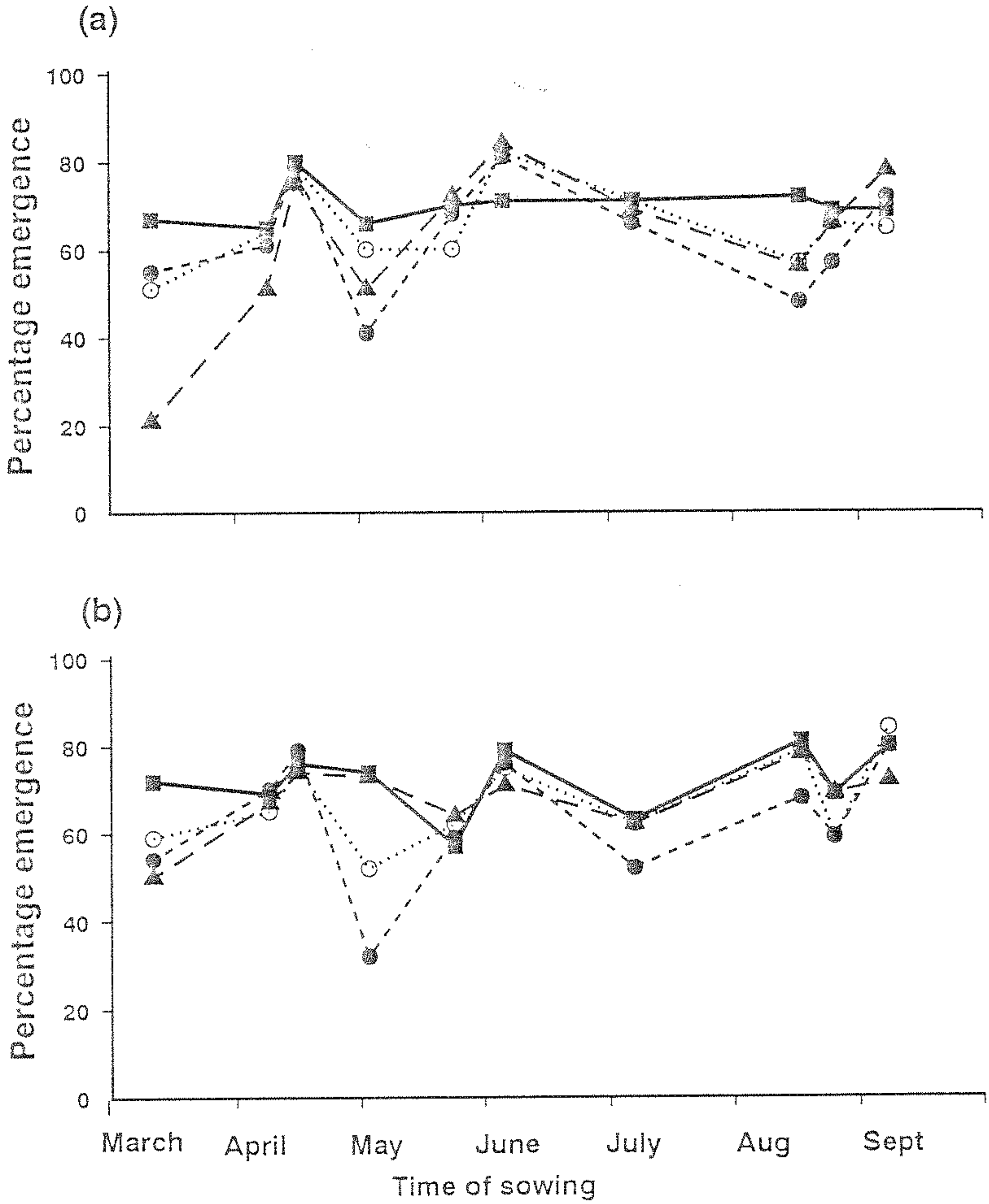


Figure 3. Percentage onion (a) and carrot (b) seedling emergence in four irrigation treatments on ten sowing occasions in 1991. ○,pre+post-sowing irrigation; ●,pre-sowing irrigation; ■,timed post sowing irrigation; ▲,no irrigation

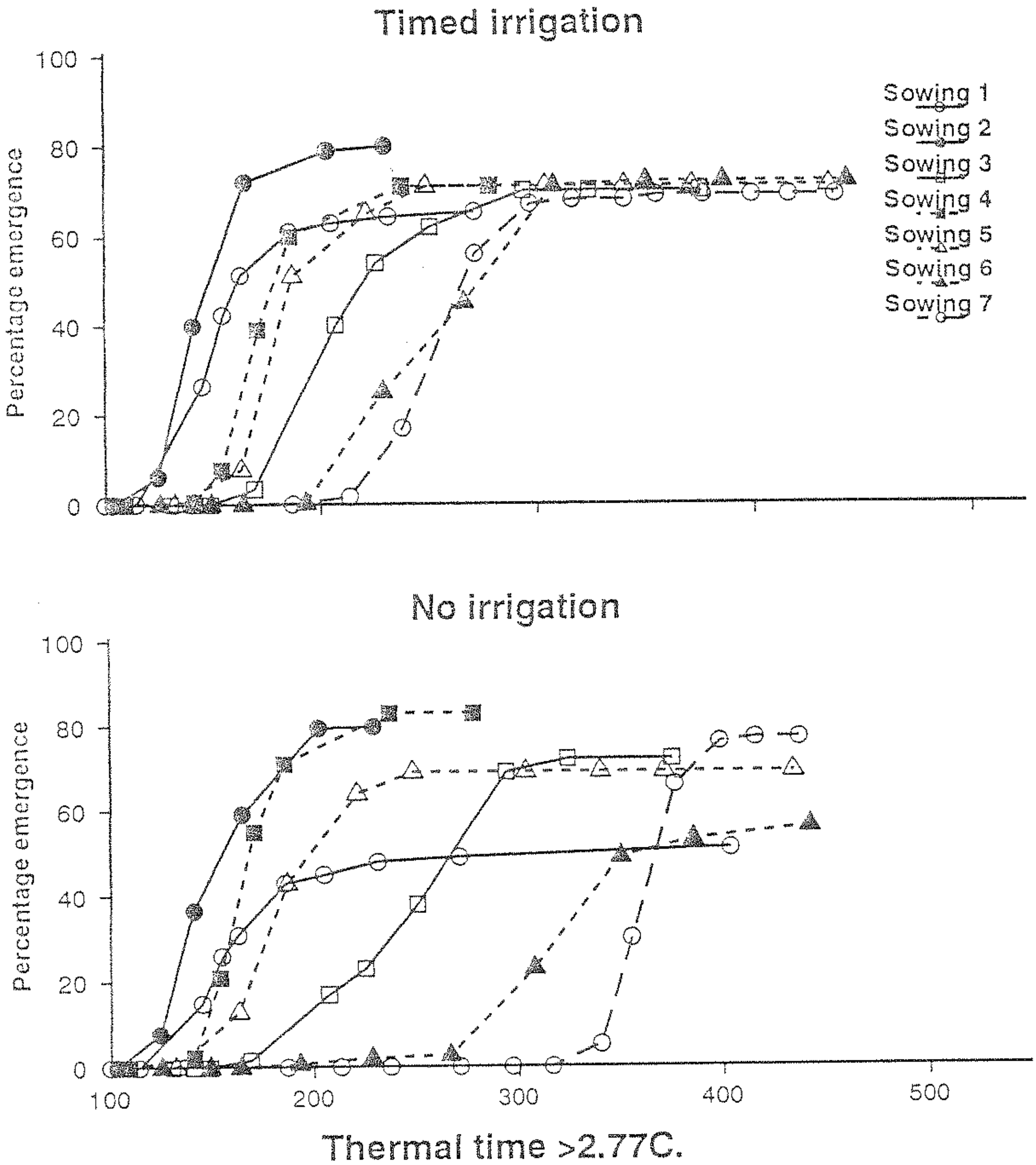


Figure 4a. The patterns of onion seedling emergence on plots with timed irrigation and on unirrigated plots. Data is presented on a thermal time scale to remove the effects of temperature between sowings. When plotted in this way, if seed-bed conditions were not limiting all seedling emergence curves would fall on the same line. Therefore, the greater similarity between emergence curves from timed irrigation plots compared to that from unirrigated plots illustrates more predictable seedling emergence.

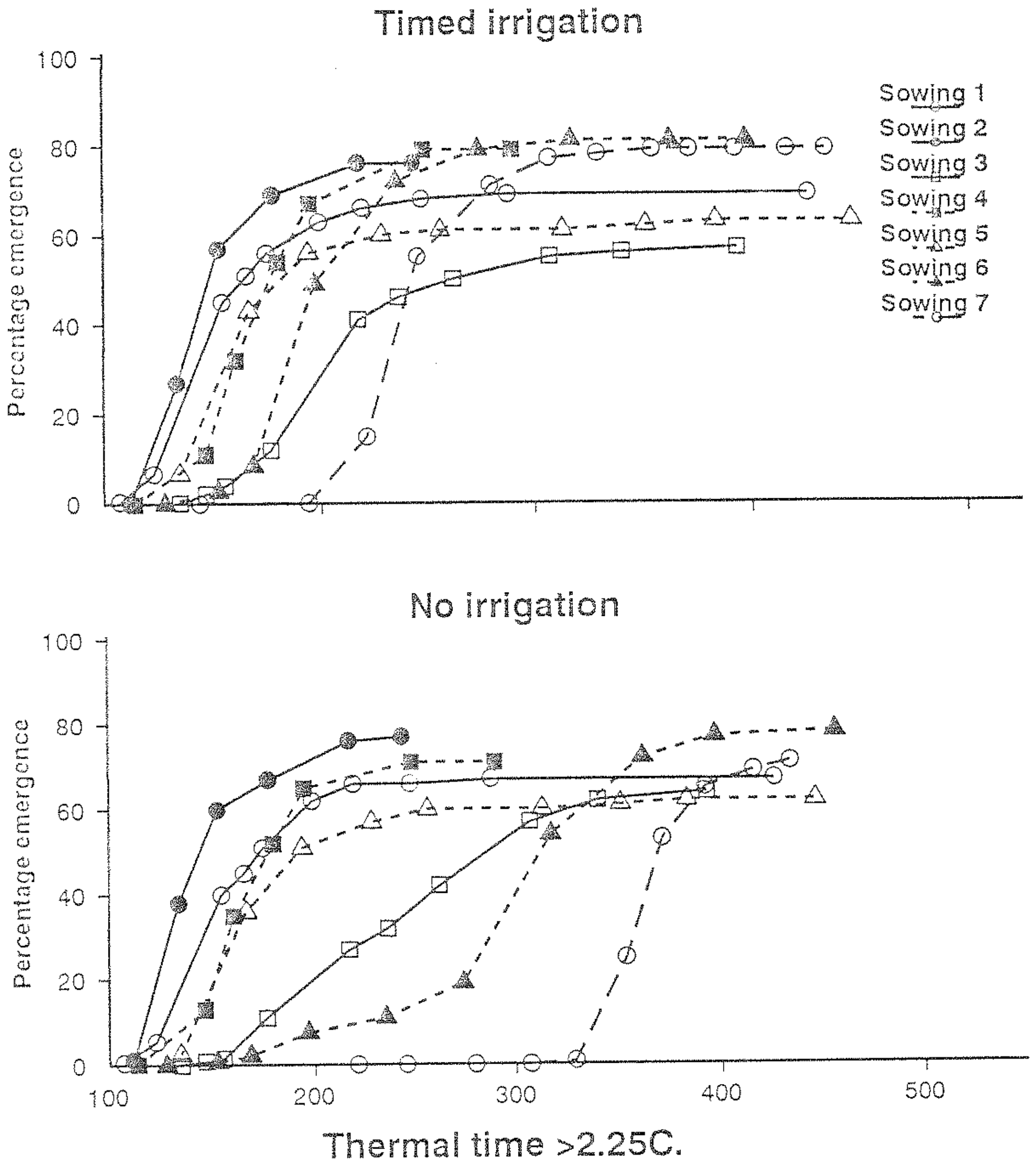


Figure 4b. The patterns of carrot seedling emergence on plots with timed irrigation and on unirrigated plots. Data is presented on a thermal time scale to remove the effects of temperature between sowings. When plotted in this way, if seed-bed conditions were not limiting all seedling emergence curves would fall on the same line. Therefore, the greater similarity between emergence curves from timed irrigation plots compared to that from unirrigated plots illustrates more predictable seedling emergence.

(1992 Expt.4)

Experiment 4	
Species	Onion c.v. Hysam Leek c.v. King Richard
Site	Wellesbourne (mobile covers)
Treatments	
1.Drill	SRI Dibber Drill and Coulter Drill (Stanhay S766)
2.Soil application	+/- Alcosorb (dibber drill only) +/- Soiltex @ 125l ha^{-1} in >1000l water(coulter drills only)
3.Irrigation	1. Timed - 15mm. water @ 90°Cd >1°C. 2. Heavy - 21 mm. water after drilling 3. Regular - 12.5mm. every 50°Cd >1°C.
Sowing date	Onion - 4 March Leek - 6 June
Experimental design	There were separate experiments for each species. Each experiment had a criss-cross latin square design with 4 replicates. There were 48 plots each a 6m. row containing 120 seeds. Plots were sown with a tractor-mounted Stanhay S766 or SRI dibber drill.Seeds 50mm. apart
Pest and disease control	1.Pre-emergence herbicide - Albrass @ 9l ha^{-1} + Dacthal @ 6 kg ha^{-1} in 500l.water (both crops)
Records taken	1.Seedling emergence 2.Soil compaction 4.Soil temperatures @ seed depth 5.Soil moisture contents 6.Seed germination in laboratory Onion 1° - 35°C. , Leek 5° - 35°C. (@ 5° intervals)

Results (1992 Expt. 4)

Onions

In general a greater number of seedlings emerged more uniformly on plots sown with the dibber drill than on plots sown with the Stanhay drill (table 2 and 3). There was little difference in seedling emergence between plots given a single timed irrigation (12.5 mm) and plots kept moist throughout the seedling emergence period by regular irrigations. However, there was a significantly greater spread of seedling emergence on plots given a single heavier irrigation (21 mm). There was no clear benefit from using either alcosorb with the dibber drill or soil conditioner (Soiltex L1) with the stanhay drill.

Leek

At this late drilling (6 June) the conditions were very dry and few seedling would have emerged without irrigation. Under these conditions seedling emergence was significantly higher and more uniform on plots kept moist throughout the seedling emergence period than in the other treatments with a single irrigation only (table 4 and 5). Seedling emergence tended to be higher on dibber-drilled plots suggesting that water to imbibe the seeds following sowing was limiting. Thus when seed are sown into a very dry seed bed a single 12.5 mm irrigation may be inadequate. Under these circumstances it is likely that pre sowing irrigation may be required also to ensure adequate initial seed imbibition.

(1992 Expt.4)

Table 2. The percentage onion seedling emergence in experiment 4.

Irrigation	Dibber Drill		Stanhay Drill		
	+Alcosorb	- Alcosorb	+ Soiltex	- Soiltex	Mean
Timed	77 (62)	81 (65)	76 (61)	70 (57)	76 (61)
Heavy	75 (60)	77 (62)	72 (59)	69 (56)	74 (59)
Regular	84 (67)	82 (65)	67 (55)	67 (55)	75 (61)
Mean	78 (63)	80 (64)	72 (58)	69 (56)	

Angular transformations in brackets for LSD comparisons:

LSD 14.2 for comparison between individual treatments ;

LSD 7.1, 8.2 for comparison between irrigation and drill means respectively

Table 3. The spread (days) of onion seedling emergence in experiment 4.

Irrigation	Dibber Drill		Stanhay Drill		
	+Alcosorb	- Alcosorb	+ Soiltex	- Soiltex	Mean
Timed	10.6	10.6	13.6	13.9	12.2
Heavy	17.3	17.8	14.5	17.2	16.7
Regular	10.7	9.7	11.5	11.1	10.8
Mean	12.9	12.7	13.2	14.1	

LSD 2.9 for comparison between individual treatments;

LSD 1.4 , 1.6 for comparison between irrigation and drill means respectively

(1992 Expt.4)

Table 4. The percentage leek seedling emergence in experiment 4.

Irrigation	Dibber Drill		Stanhay Drill		
	+Alcosorb	- Alcosorb	+ Soiltex	- Soiltex	Mean
Timed	43 (41)	39 (39)	42 (40)	44 (41)	42 (40)
Heavy	56 (48)	55 (48)	35 (36)	37 (37)	47 (42)
Regular	67 (55)	72 (58)	66 (55)	66 (54)	68 (56)
Mean	55 (48)	55 (48)	48 (44)	49 (44)	

Angular transformations in brackets for LSD comparisons:

LSD 7.8 for comparison between individual treatments ;

LSD 1.4, 1.6 for comparison between irrigation and drill means respectively

Table 5. The spread (days) of leek seedling emergence in experiment 4.

Irrigation	Dibber Drill		Stanhay Drill		
	+Alcosorb	- Alcosorb	+ Soiltex	- Soiltex	Mean
Timed	20.1	16.9	17.0	20.8	18.7
Heavy	13.7	14.6	20.3	18.0	16.7
Regular	5.9	5.8	8.5	8.6	10.8
Mean	13.2	12.4	15.3	15.8	

LSD 4.0 for comparison between individual treatments;

LSD 2.0 , 2.3 for comparison between irrigation and drill means respectively

(1992 Expts.5-7)

Experiment 5

Site	Wellesbourne - Polytunnel
Treatments	
Soil moisture (at drilling)	1.Dry (-0.36MPa) 2.Wet (-0.004MPa)
Irrigation	1. 12.5mm. water applied @ 20°Cd >1°C. 2. " " " 40 " " 3. " " " 80 " " 4. " " " 120 " " 5. " " " 160 " " 6. Regular - 6mm. water applied every Monday,Wednesday and Friday 7. None
Species	(Fast germinators) 1. Cabbage c.v. Offenham Compacta 2. Calabrese c.v. Corvet F1 3. Lettuce c.v. Saladin 4. Radish c.v. French Breakfast Lanquette
Experimental design	The experiment had a split-split plot design with soil moisture as main plots ; irrigation as sub-plots and species as sub-sub plots. There were 3 replicates to give 168 plots each a 1m. row sown by hand with 100 seeds.
Soil conditioner	Soiltex L1@ 125l ha^{-1} in >1000l water
Sowing date	7 April
Records taken	1.Seedling emergence 2.Soil moisture content 3.Soil temperatures at seed depth 4.Seed germination Cabbage & Lettuce 1 - 35°C. Calabrese & Radish 5 - 35°C. (@ 5°C. intervals)

(1992 Expts. 5-7)

Experiment 6	
Site	Wellesbourne - Polytunnel
Treatments	
Soil moisture (at drilling)	1.Dry (-0.60MPa) 2.Wet (-0.005MPa)
Irrigation	as Experiment 5/92
Species	(Medium germinators) Leek c.v. King Richard Onion c.v. Hysam
Seed	Untreated or primed
Experimental design	as Experiment 5/92
Soil conditioner	Soiltex L1 @ 125l ha^{-1} in >1000l water
Sowing date	2 June
Records taken	1.Seedling emergence 2.Soil moisture contents from soil samples and prototype Wallingford moisture probe 3.Soil temperatures at seed depth 4.Seed germination Onion 1 - 35°C. ; Leek 5 - 35°C. (@ 5°C. intervals)

(1992 Expts. 5-7)

Experiment 7

Treatments

Soil moisture (at drilling)	1.Dry (-0.61MPa) 2.Wet (>-1.5MPa)
Irrigation	1. 12.5mm. water applied @ 50°Cd >1°C. 2. " " " 100 " " 3. " " " 175 " " 4. " " " 250 " " 5. " " " 350 " " 6. Regular - 6mm. water applied every Monday,Wednesday and Friday 7. None
Species	Slow germinator Parsnip c.v. White Spear
Seed	Untreated or primed
Experimental design	as Experiment 5/92 with seed treatments as sub-sub plots (84 plots)
Soil conditioner	Soiltex L1 @ 125l ha^{-1} in >1000l water
Sowing date	28 July
Records taken	1.Seedling emergence 2.Soil moisture contents from soil samples 3.Soil temperatures at seed depth 4.Seed germination 5 - 35°C. (@ 5°C. intervals)

Results (1992 Expts. 5-7)

During the experiments carried out in 1992, seeds were sown into a moist seed bed produced by limited irrigation before sowing. The very rapidly-germinating primed leek seeds were able to establish a uniform crop using the moisture in the seed bed at sowing only. Consequently there was no significant difference between the unirrigated control and the irrigated treatments (Figure 5a). However, the moisture in the seed bed at sowing was not adequate to produce timely and uniform stands of seedlings from untreated seeds of any species (unirrigated controls in Figure 5b-d).

In all crops sown with untreated seeds there was a clear relationship between the thermal time requirement for germination, above the appropriate base temperature, and the pattern of seedling emergence in irrigation treatments. This pattern is illustrated in Figure 5b for calabrese, a species with rapid and uniform germination. When irrigation was applied close to the thermal time when germination would have occurred in a seed test, seedling emergence was not significantly different from that in soil kept moist throughout the seedling emergence period. As irrigation was progressively delayed there was a delay in seedling emergence, it became progressively less uniform and percentage seedling emergence declined. A similar pattern of results was shown with lettuce and radish.

Figures 5c and d illustrate the pattern observed in crops with seed that germinated more slowly and over a greater spread in thermal time. As irrigation time was delayed to the point where approximately 75% of seeds would germinate in a seed test the resulting percentage emergence increased to that on control plots kept moist throughout the seedling emergence period (Figures 5c and d). Further delay in time to irrigation reduced percentage emergence and increased the spread of seedling emergence times. Similar patterns of emergence were shown in untreated seeds of onion and leek. Thus, there was an optimum time to irrigate approximating to the thermal time when between 50 and 75% of seed germinated in a seed test. However, as in the case of cabbage (Figure 5d), to obtain the highest levels of uniform emergence irrigation needs to be delayed until *c.* 90°Cd after sowing which can result in a limited delay in seedling emergence time. Further data is presented for other species in Appendix 4.

In these experiments seeds were sown into moist seed beds as in good commercial practice. In very dry seed beds, where initial imbibition is severely limited, results can be more variable. However, the results presented for experiments in 1991 show that percentage onion seedling emergence was more predictable over a range of seed-bed conditions when given a single timed irrigation than when given either pre-sowing irrigation or no irrigation (Figure 3).

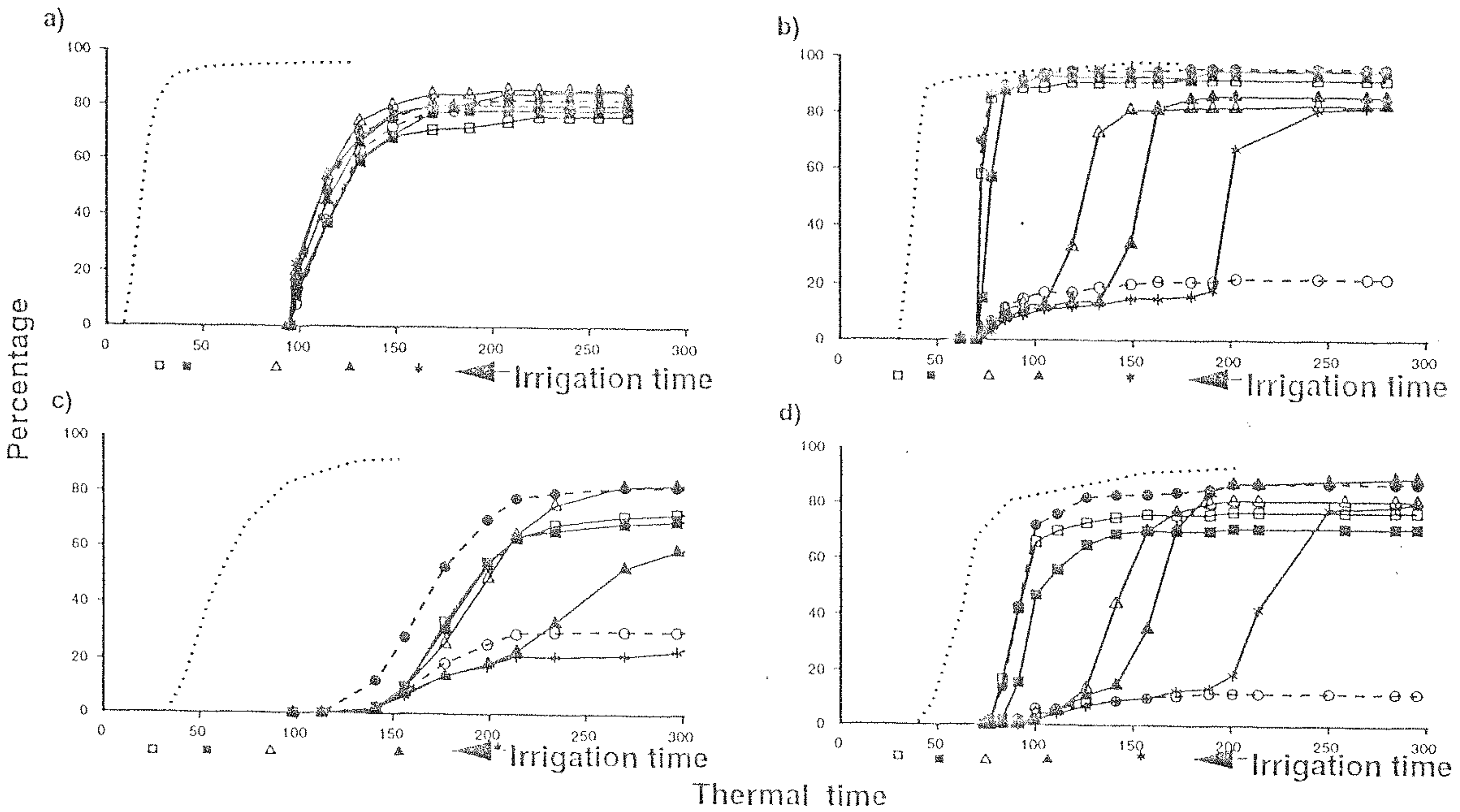


Figure 5 The patterns of primed leek (a) and untreated calabrese (b), carrot (c) and cabbage (d) germination in seed tests (....) and seedling emergence in the field following irrigation at different times. The thermal times to irrigation are indicated by symbols below the x axis. These same symbols are used on the corresponding seedling emergence distributions. Also shown are seedling emergence distributions from a seed bed kept moist (-●-) and from one having no irrigation (-○-).

Conclusions from 1992 experiments

The results presented show that there is an optimum time to irrigate following sowing to obtain improved crop establishment in a wide range of vegetable crops in the UK. This irrigation time is related to the progress of seed germination in the soil and will therefore differ between species, cultivars and even seed lots which inherently germinate at different rates. The thermal time to germination is therefore different for each species, but results suggest that it may be possible to generalise to produce three categories; fast germinators with thermal times to 50% germination (T_{50}) less than 40°Cd i.e. lettuce, radish, calabrese; medium rate germinators with T_{50} greater than 40 and less than 80°Cd, i.e. cabbage, onions, carrots and leek; and slow germinators with T_{50} greater than 80°Cd, i.e. parsnips. A single thermal time recommendation for each of the first two categories may be adequate as a guide to the timing of irrigation i.e. fast, 30-40 °Cd, and medium 80-90 °Cd. In species such as cabbage (medium), thermal time to germination can differ greatly between seed lots so that many may fit better into the fast germinator category. Limited experience has suggested that timing irrigation for species in the slow germinating category is less predictable. Irrigation timing for these species will depend on the seed lot and if germination is very spread in time a second irrigation may be required.

Discussion

In the following discussion basic principles of seed behaviour are used to explain the patterns of seedling emergence generated in these experiments and how the optimum timing of irrigation during seedling establishment can be predicted for different crops.

In the absence of water stress seed germination and seedling emergence patterns are predictable in thermal time above a base temperature (Garcia-Huidobro, Monteith and Squire, 1982). Whereas, in the variable soil moisture of the seed bed it has been argued, assuming adequate imbibition, that germination will progress predictably in thermal time providing soil water potential (ψ) remains above the minimum ψ (ψ_b) that allows germination of the seed (Finch-Savage and Phelps, 1993). When soil ψ falls below the seed ψ_b the progress of germination will cease just before radicle emergence. When water subsequently becomes available again, by rain or irrigation, germination and seedling emergence will progress to completion in thermal time. This approach can be used to explain the results presented here. For a detailed description and justification of this approach see Finch-Savage (1990a,b) and Finch-Savage and Phelps (1993).

In Figure 6 seed germination distributions in thermal time, determined under unstressed conditions in a seed test, have been used to indicate the progress of germination of each species in real time following a sowing on 7 April 1992. The figure also shows the changing pattern of soil water potential at sowing depth determined from ambient conditions with a computer model (Walker and Barnes, 1981). In this rapid drying situation it can be seen that soil ψ falls to below -1.5 MPa within two days of sowing. This ψ is likely to be below the ψ_b of most seeds. Therefore for seeds to germinate and emerge without irrigation, germination must have occurred before this time. Only in primed leek seed would a significant proportion of the seed population have germinated within two days under the temperature conditions experienced at this sowing. For all other crops, seeds would have imbibed initially, but then soil ψ fell below -1.5 MPa before they were able to start to germinate (Figure 6).

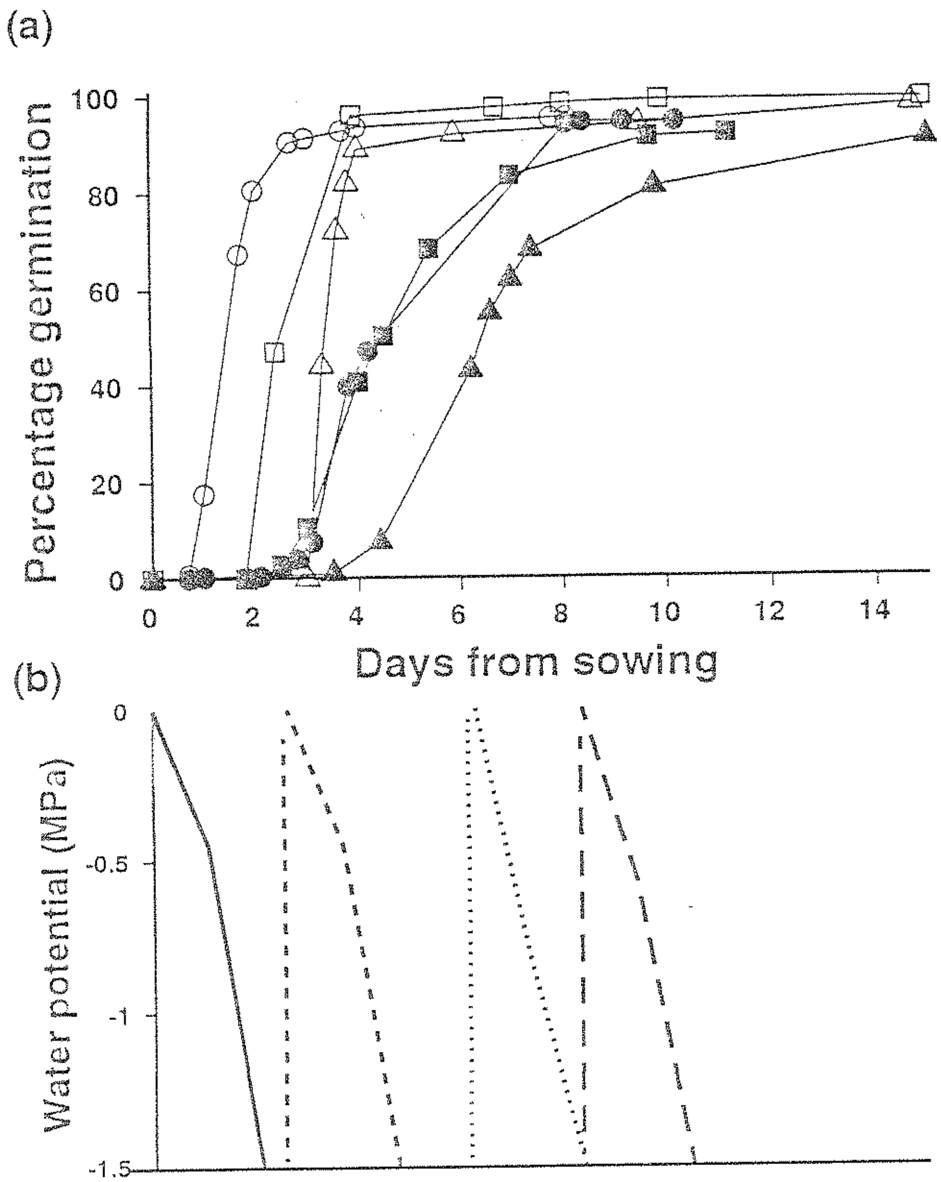


Figure 6. Simulated seed germination distributions (a) for primed leek ○, lettuce □, calabrese △, onion ●, carrot ■, and cabbage ▲, and soil water potential (b) following sowing in the field on 7 April 1992 The effect of a 12.5mm irrigation at 30 (- - -), 75 (·····), and 90 (- —) day degrees on soil water potential are shown.

If the seed bed was irrigated at 30 °Cd (*c.* 2.5 days) soil ψ increased and then remained above -1.5 MPa during the main germination period for lettuce, radish and calabrese the species in the fast germination category. However, soil ψ fell below -1.5 MPa again before germination would have begun in the remaining species. In the same way, irrigation at 75 °Cd (*c.* 6 days) would allow early germinating seeds, but not late germinating seeds of the medium rate germinators (onion, carrot, leek and cabbage) to progress to emergence, whereas, a later irrigation at 90 °Cd (*c.* 9 days), as recommended for these species, would have also allowed the late germinators to proceed. Seeds that would have been ready to germinate before irrigation in this situation would have remained in a state just before radicle emergence and would then germinate rapidly when water became available. However, ψ will vary throughout the seed bed and some seeds will find moisture to proceed to germination when others do not. Therefore if irrigation is delayed further, seeds in moisture are likely to produce a flush of emergence followed then by another flush resulting from later irrigation. In this way the patterns of seedling emergence which resulted from the different irrigation timings, seen in Figure 5, can be explained.

References

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Garcia-Huidobro, J., Monteith, J.L. and Squire, G.R., 1982. Time, temperature and germination of pearl millet (*Pennisetum typhoides* S and H). *Journal of Experimental Botany* 33:288-296.

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1993 Expt. 8

Introduction

At least ten sowings were made in each of three species, cabbage, leek and parsnip which were categorised for the purpose of timing irrigation as fast, medium and slow germinators respectively. The sowings were made on twelve possible occasions spread between March 26 and August 31 in an attempt to expose the treatments to a wide range of seed-bed conditions. Rainfall was well dispersed throughout the season and above the 25 year average for the site in each month except August. Figure 7 shows the pattern of soil water potential at sowing depth estimated by a computer model from measured rainfall and soil temperatures. It can be seen that there were significant dry periods after sowings 3 and 7 (S3 and S7 respectively) only. The opportunities to show benefits from timed irrigation were therefore limited by comparison with previous years. In normal practice, rainfall close to the time for irrigation would mean that irrigation was not required, and in an experiment it is a lost opportunity to show irrigation treatment effects. As a consequence of this pattern of rainfall the following results section shows little benefit of timed irrigation. We therefore constructed a model that would predict the number of occasions within a year when irrigation would have shown a benefit. A brief description of the model and estimates from the model of the potential benefits of timed irrigation over the past 21 sowing seasons is presented after the results section.

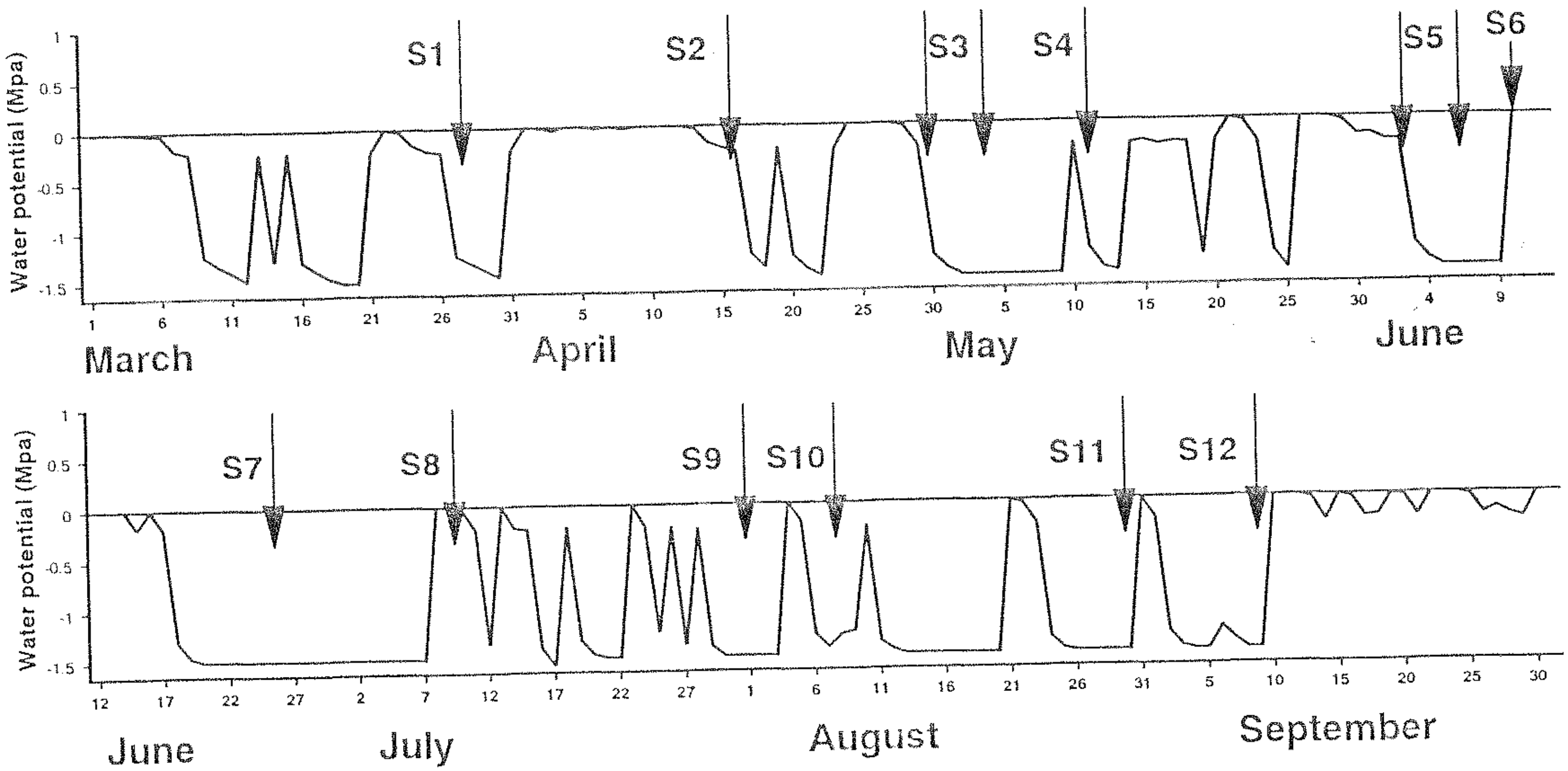


Figure 7. The pattern of soil water potential at sowing depth during the experimental period in 1993

(1993 Expt.8)

Site	Wellesbourne (field)
Treatments Species	1.Fast germinator - (C) Cabbage c.v. Myatts Offenham Compacta 2.Medium germinator -(L) Leek c.v. Toledo 3.Slow germinator - (P) Parsnip c.v . New White Skin
Irrigation	1. Timed (C) @ 28°Cd >1°C. (L) @ 90 " " (P) @ 200 " " 2. None
Drill	1. Coulter with no presswheel 2. Coulter with presswheel 3. " " " + 2.5kg weight 4. " " " + 5.0kg weight
Sowing dates	1. 26 March 2. 15 April 3. 29 April (L) & (P) ; 4 May (C) 4. 11 May 5. 3 June (L) & (P) ; 7 June (C) 6. 10 June (L) & (P) 7. 23 Jun 8. 6 July 9. 27 July 10. 3 August 11. 24 August (C) 12. 31 August (C)
Experimental design	Sowings were randomised over the experimental area. Each species and sowing was sown with a split plot design. Irrigation treatments were main plots and drill treatments were sub-plots. There were 2 replicates to give 16 sub-plots each of which was a 8m. long row . Seeds were sown (C) & (L) 17mm / (P) 34mm. apart with a tractor-mounted Stanhay Singulaire 785 drill
Pest and disease control	1.Pre-emergence herbicide (C) & (L) Albrass @ 9l ha^{-1} + Dacthal @ 6kg ha^{-1} in 500l water (P) Afalon @ 1.5l ha^{-1} in 200-400l water 2.Insecticide - sowings 3,4,7,9 against Bean seed fly Hostathion@ 2.5l ha^{-1} in >1000l water 3.Soil conditioner - sowings 5-12 - Soiltex L1@ 125l ha^{-1} in >1000l water
Records taken	1.Seedling emergence 2.Soil moisture contents 3.Soil temperatures at seed depth 4.Soil compaction 5.Sowing depth (L) 6.Germinations in laboratory 5-35°C. all species (@ 5°C. intervals)

Results (1993 Expt.8)

Cabbage

In crops sown without a seed press wheel, there was a significant (P<0.01) overall reduction in the spread of seedling emergence times and percentage emergence tended to be greater when timed irrigation was applied (Table 6). However, there was some evidence that the seed press wheel damaged cabbage seeds, although this showed on the timed irrigation plots only. Percentage emergence was lower on irrigated plots sown with the standard press wheel compared to those sown with no press wheel. Percentage emergence was progressively less as seed press-wheel weight increased.

Seedling emergence characters at individual sowings are shown in figure 8 and 9.

Leek

With leeks there was no overall effect of irrigation or press wheel (Table 7) on percentage emergence or spread of emergence, but T50 was significantly reduced across sowings by irrigation (irrigated, 14.1, unirrigated 15.3 days; P< 0.001). However there was a significant (P< 0.05) interaction between sowings and irrigation where irrigation significantly (P< 0.001) increased percentage emergence during the dry period following sowing 7 (Figure 10) only. Spread of seedling emergence was also large at this sowing. Low percentage emergence in all treatments at sowings 3 and 4 resulted from severe bean seed fly infections. Figure 11 further illustrates the lack of seed press-wheel effect at individual sowings.

The clear junction between root and shoot in the leek seedling makes it possible to get a good estimate of sowing depth by harvesting seedlings. The junction is formed at the position of the seed in the seed bed. We used this method to determine if increasing the weight of the seed press wheel increased sowing depth. If true, increased sowing depth from the additional weight of the press wheel may account for the lack of press wheel effect in this experiment. However, there was little effect of seed press-wheel weight up to 2.5 Kg on sowing depth. At 5 Kg sowing depth tended to be increased (Table 8).

To further investigate the lack of seed-bed effect, soil compaction readings (force required to penetrate the soil) were measured below sowing depth. There was no consistent effect of the press wheel on soil compaction (Figure 12). However, at all sowings of leek and cabbage recorded, the passage of the drill significantly increased soil compaction and this was much greater than the effect of the seed press wheel. It is therefore possible that the passage of the rear wheel of the coulter chassis causes greater compaction than the seed press wheel and therefore obscures its effect. Further work would be required to confirm this.

Parsnip

Timed irrigation significantly reduced mean emergence time (irrigated 17.9, unirrigated 19.2 days; P< 0.001) and increased percentage emergence (irrigated 86.1, unirrigated 82.5% (angular transformation); P< 0.05) although the effect varied across sowings (Figure 13). However, there was no consistent effect of the seed press wheel on seedling emergence (Table 9, Figure 14). Low seedling emergence at sowings 3 and 4 in all treatments resulted from a bean seed fly infection.

Table 6

Cabbage

Spread (days) - Meaned across sowings

	No presswheel	Presswheel 0 kg	+2.5 kg	+5 kg
Irrigation				
Timed	5.7	6.4	6.1	6.3
None	7.9	8.5	7.9	7.5
LSD	0.9			

Percentage germination (angular transformations)

Timed	75 (63)	68 (57)	66 (55)	63 (53)
None	73 (60)	71 (59)	73 (60)	70 (59)
LSD	- (3.9)			

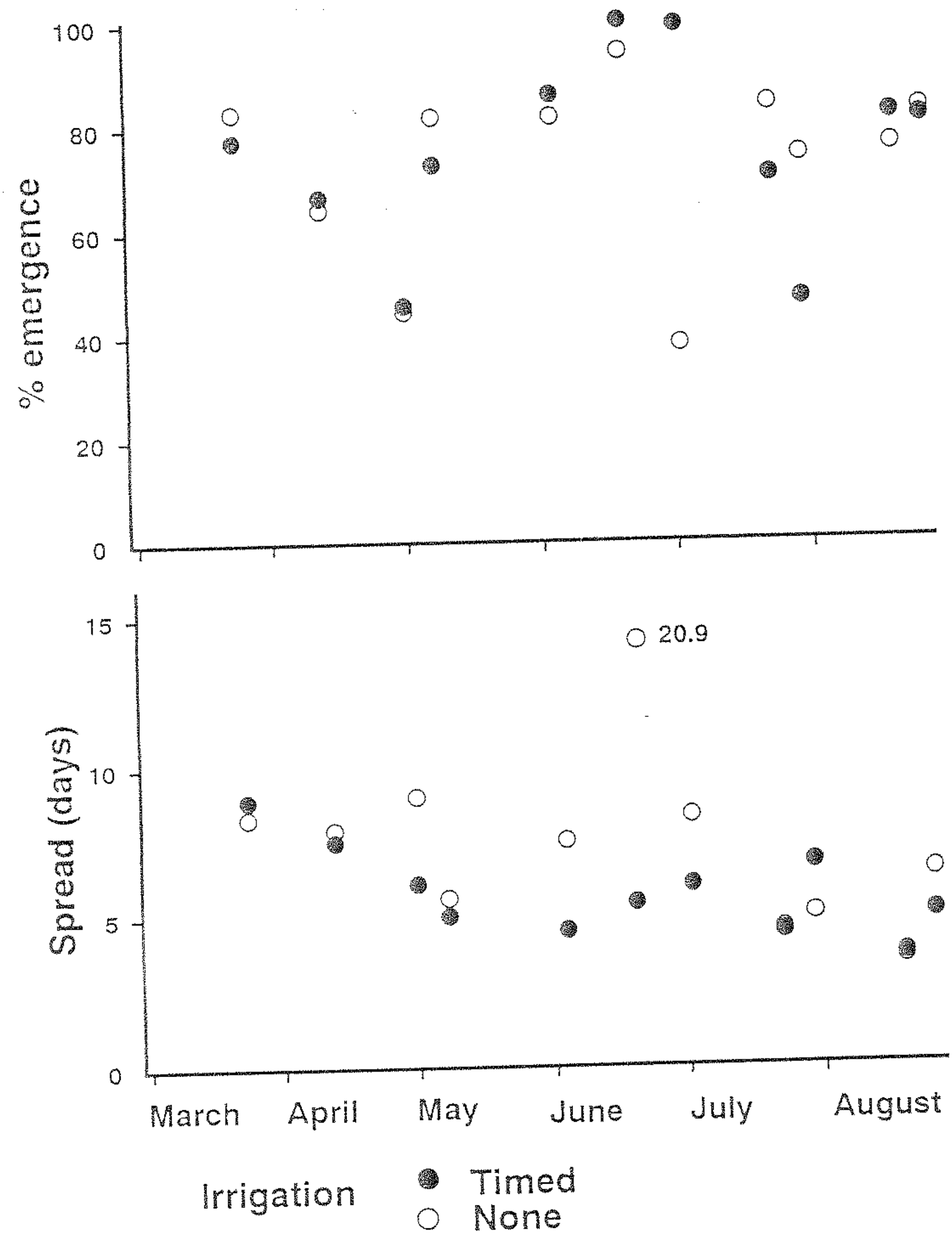


Figure 8. Percentage cabbage seedling emergence and spread of seedling emergence times for irrigation treatments on plots sown without a presswheel in experiment 8.

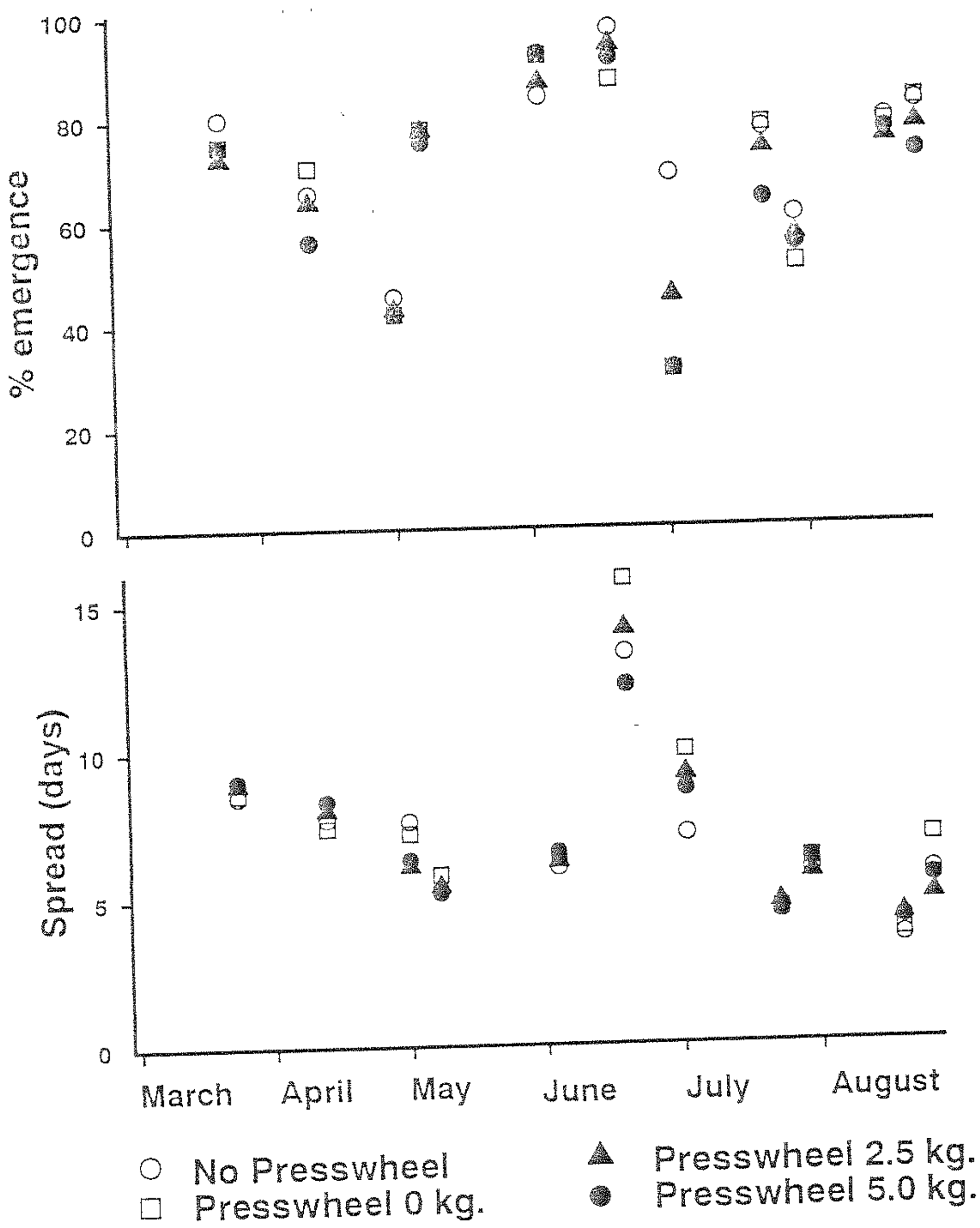


Figure 9. Percentage cabbage seedling emergence and spread of seedling emergence times for drill press-wheel treatments meaned across irrigation treatments in experiment 8.

Table 7

Leek

Spread (days) - Meaned across sowings

	No presswheel	Presswheel 0 kg	+2.5 kg	+5 kg
Irrigation				
Timed	7.3	7.0	7.1	7.0
None	6.2	6.8	6.6	7.2
LSD	0.8			

Percentage germination (angular transformations)

Timed	71 (61)	71 (60)	70 (59)	74 (64)
None	74 (63)	72 (61)	71 (61)	69 (58)
LSD	- (5.8)			

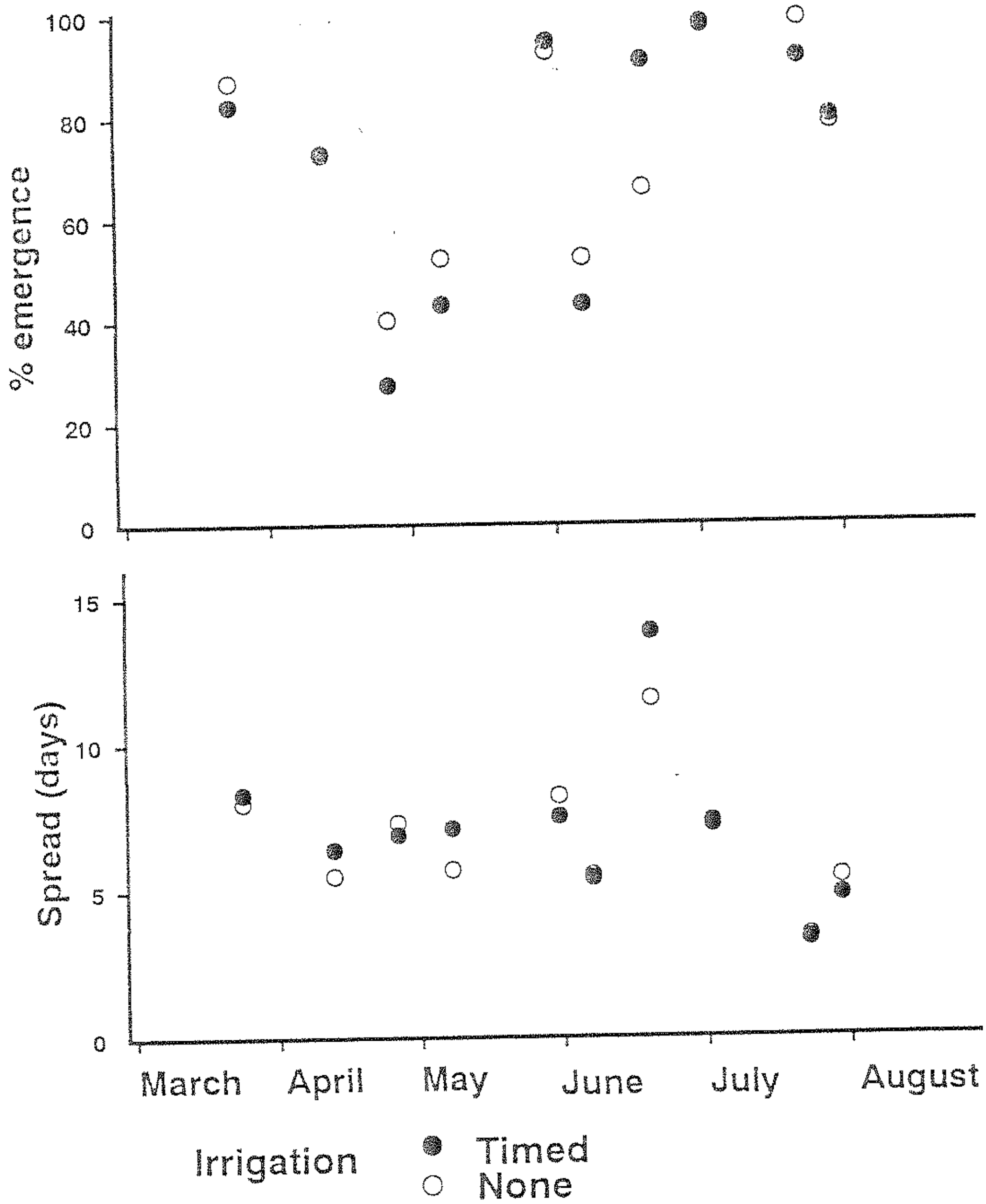


Figure 10. Percentage leek seedling emergence and spread of seedling emergence times for irrigation treatments meaned across drill press-wheel treatments in experiment 8.

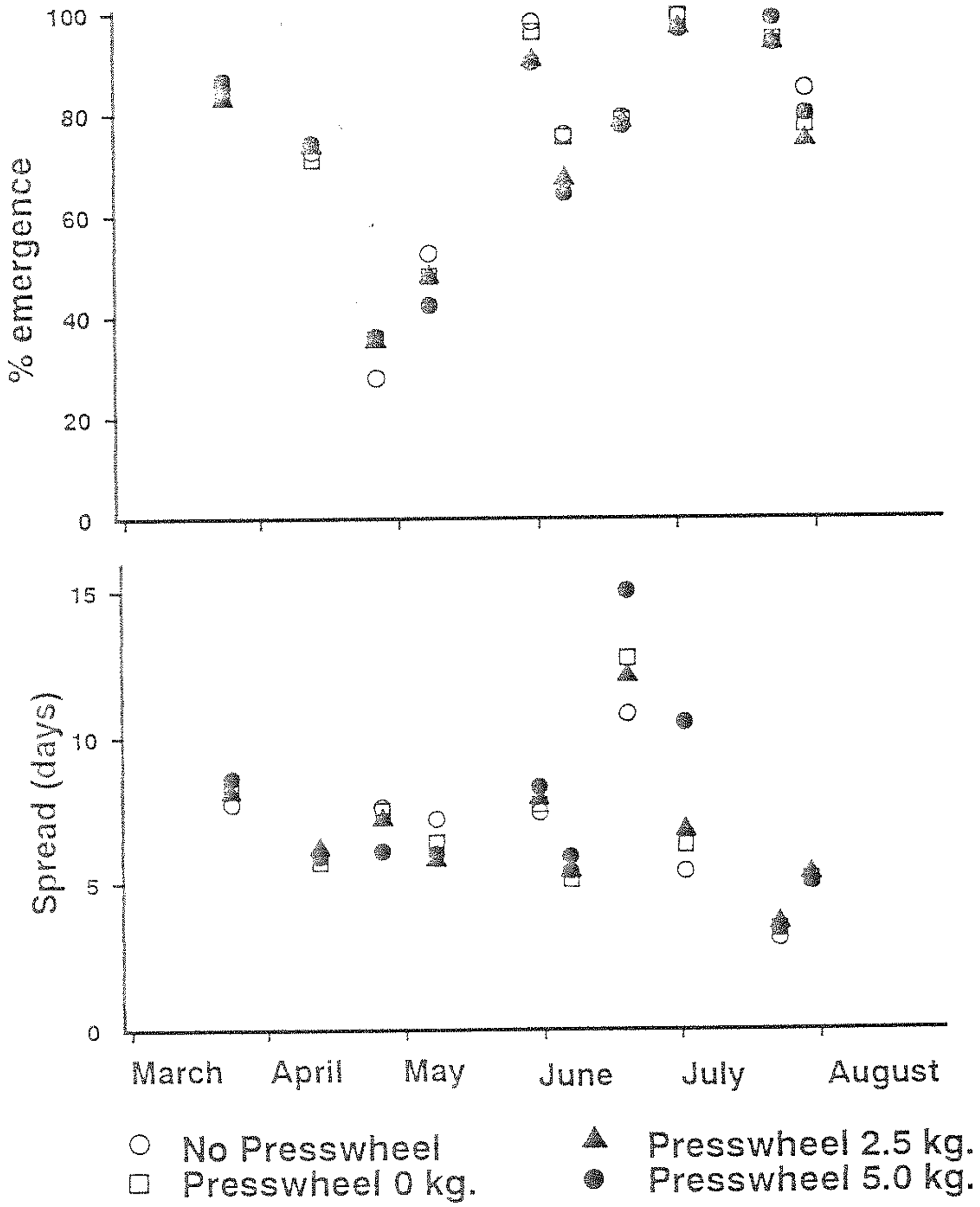


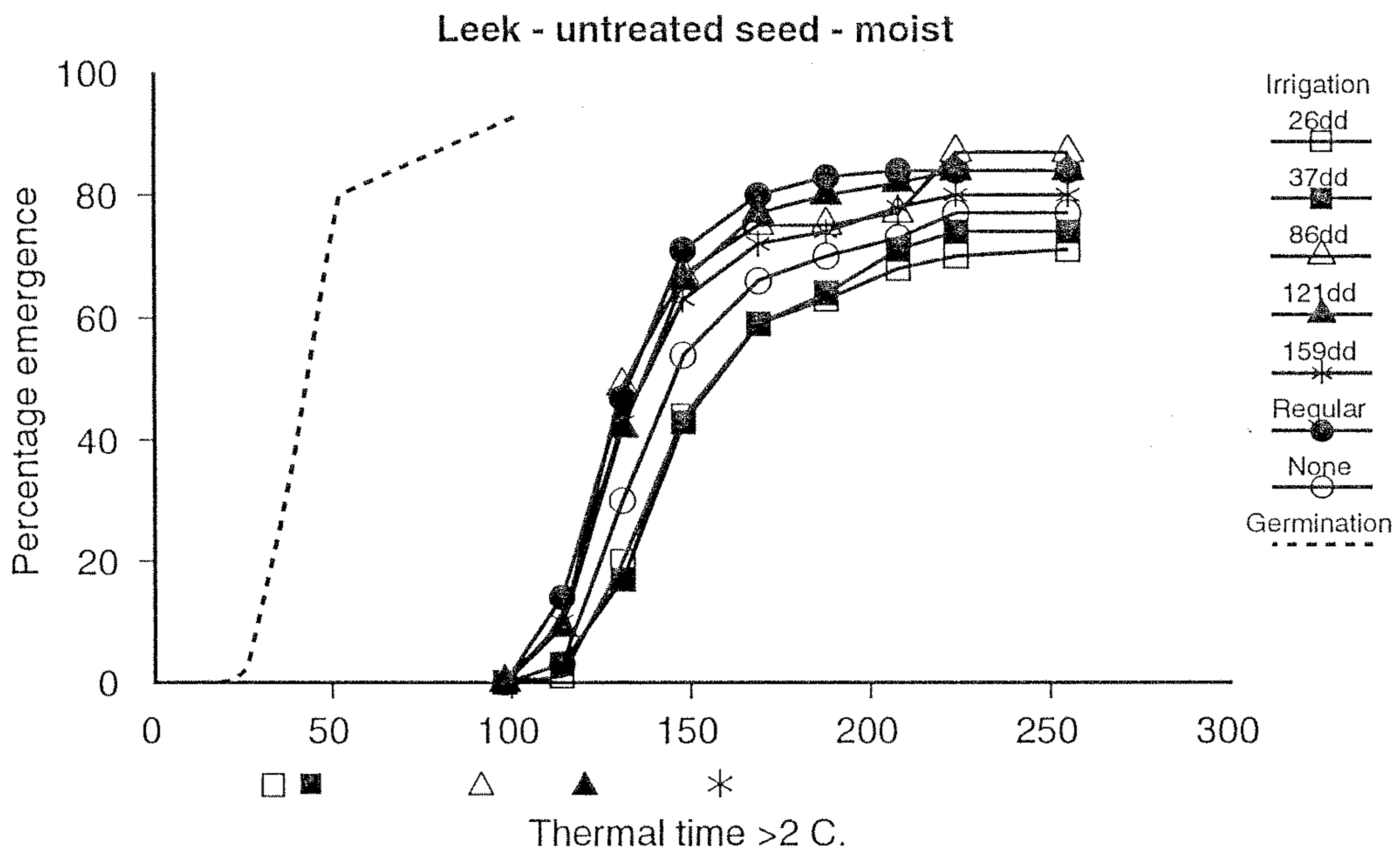
Figure 11. Percentage leek seedling emergence and spread of seedling emergence times for drill press-wheel treatments meaned across irrigation treatments in experiment 8.

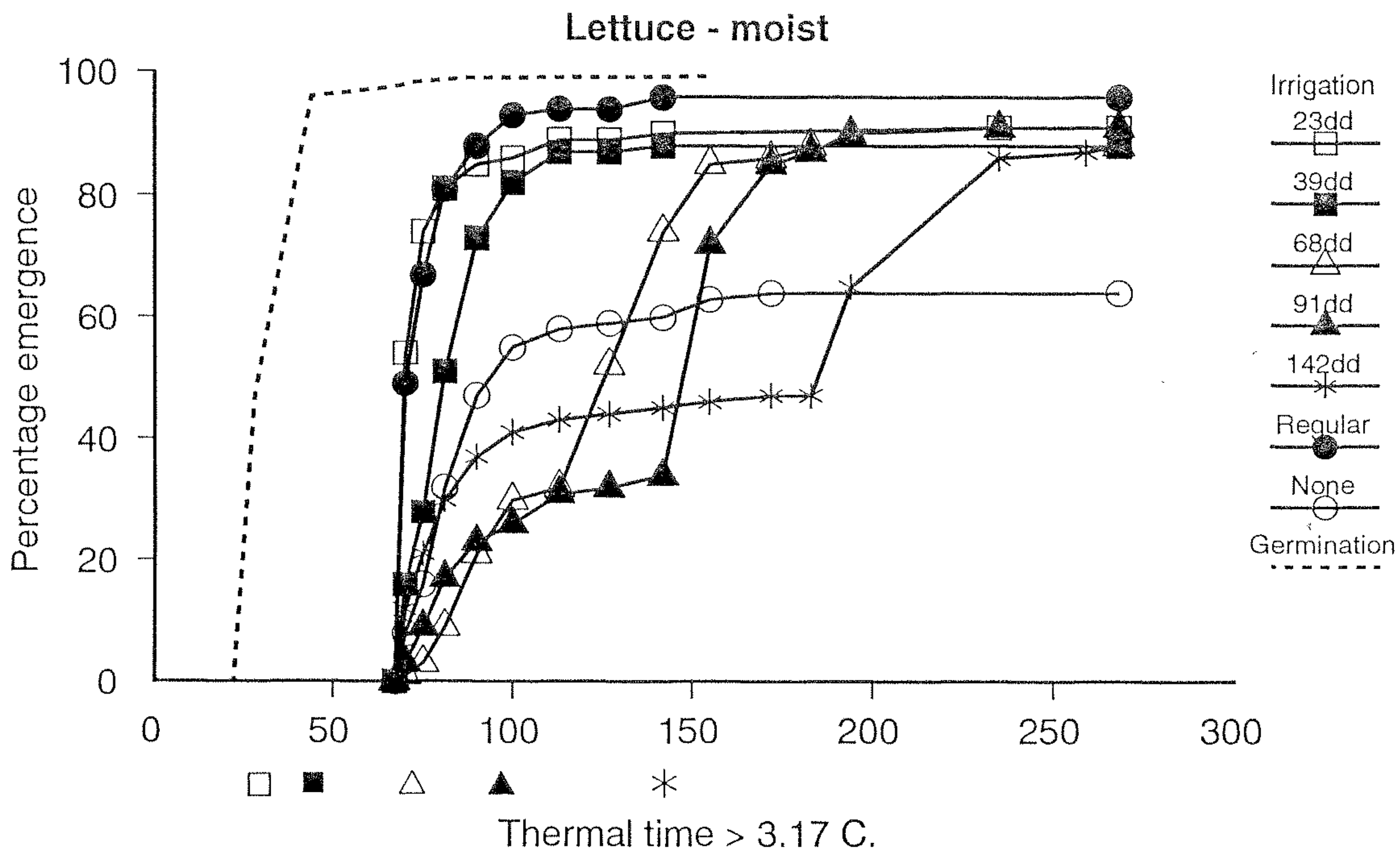
Table 8

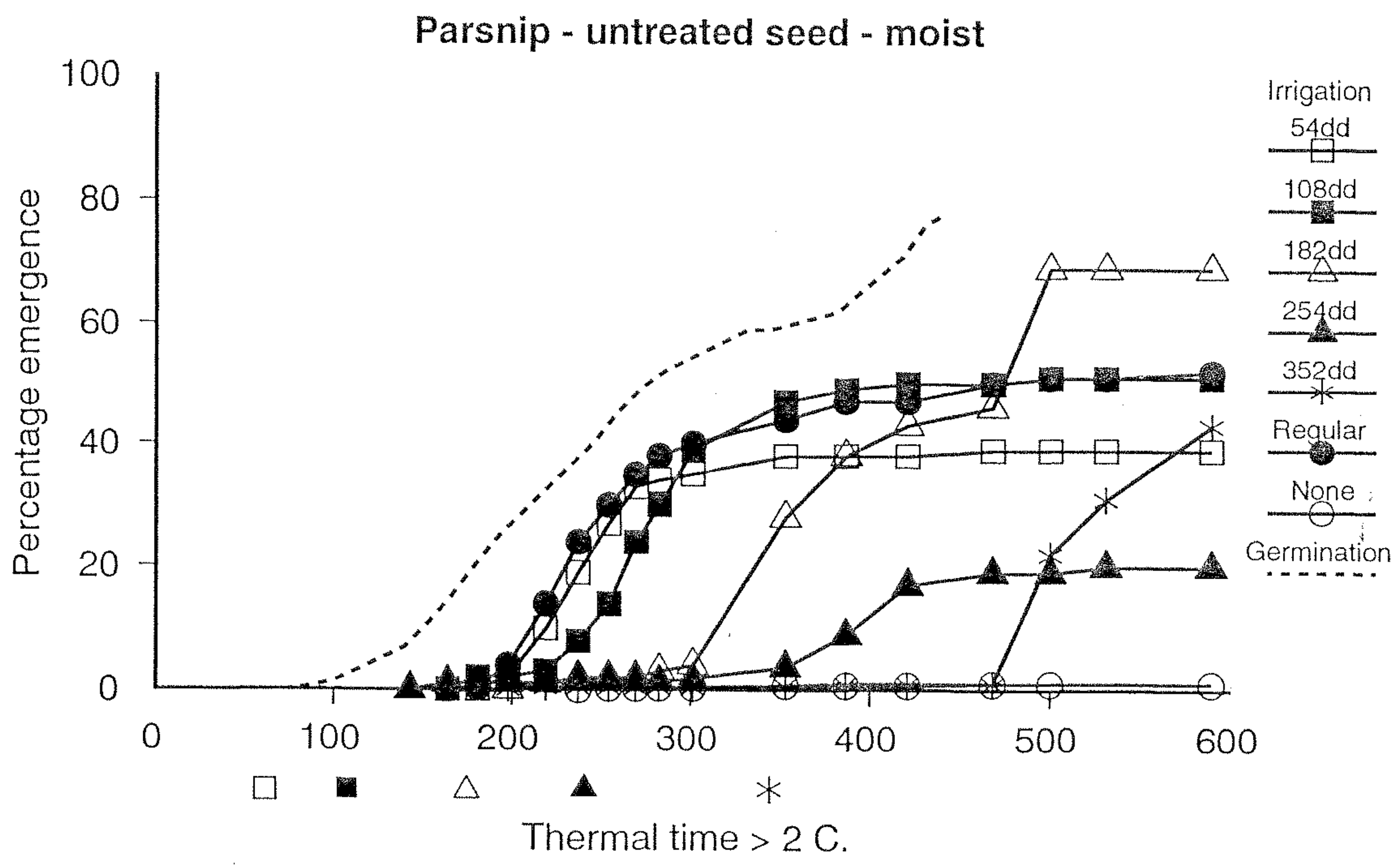
Leek - sowing depth

	Sowing 1 Mean depth (mm)	% coefficient of variation	Sowing 2 Mean depth (mm)	% coefficient of variation
No presswheel	24.4	22.4	28.9	14.4
0 kg	24.5	23.7	29.3	14.9
2.5 kg	25.2	23.6	29.5	16.6
5.0 kg	29.0	19.8	27.1	17.0
Mean	25.8	22.4	28.7	15.7
LSD	2.2	4.4	3.0	4.7

	Sowing 5 Mean depth (mm)	% coefficient of variation	Sowing 6 Mean depth (mm)	% coefficient of variation
No presswheel	27.4	17.0	31.3	16.4
0 kg	29.3	16.3	32.7	17.1
2.5 kg	31.2	17.3	31.8	17.2
5.0 kg	31.9	15.8	34.5	15.7
Mean	30.0	16.6	32.6	16.6
LSD	4.6	4.5	5.0	4.1

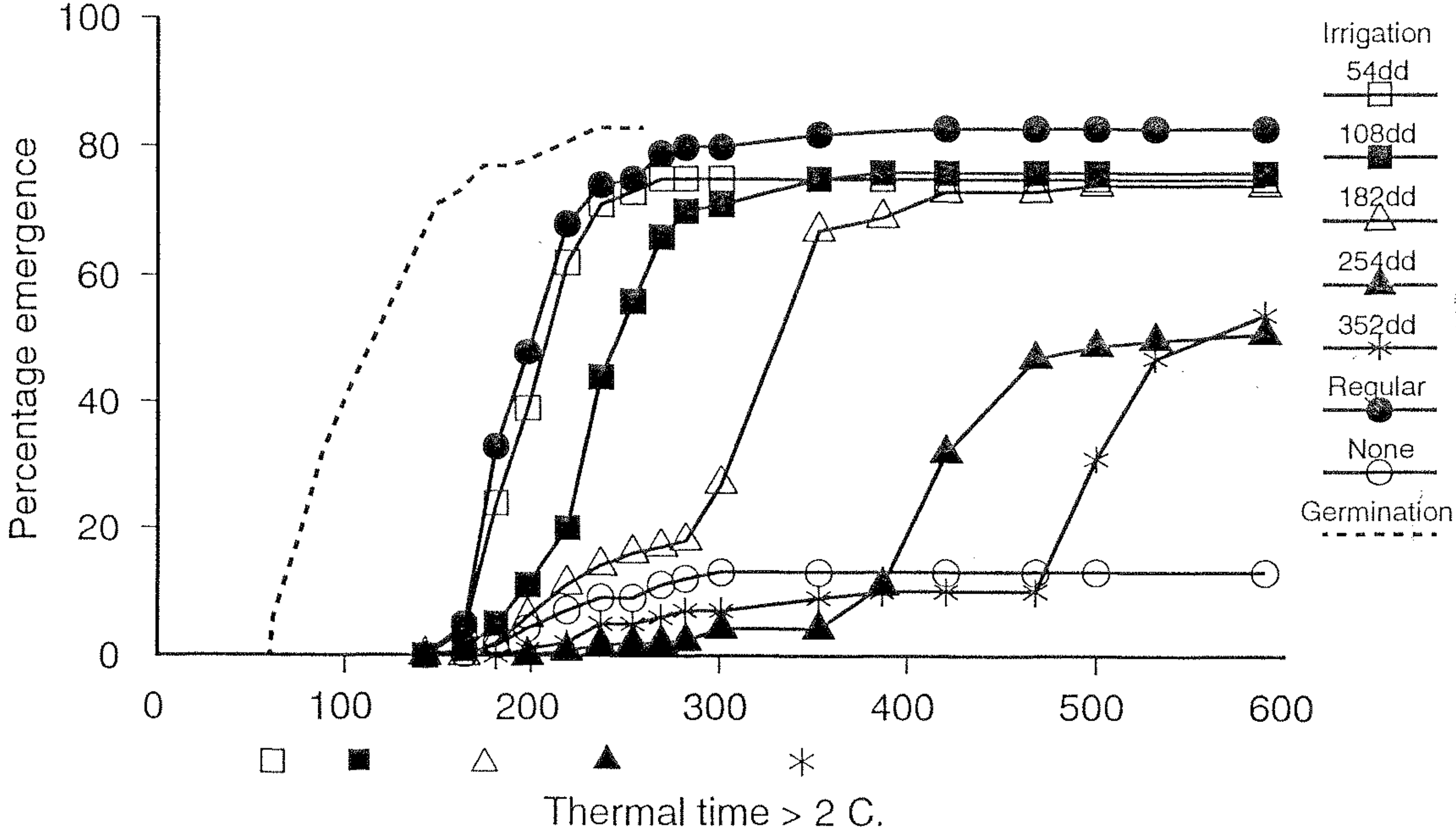

Leek - untreated seed - moist
Percentage emergence
0
20
40
60
80
100
0
50
100
150
200
250
300
Thermal time >2 C.
Irrigation
26dd
37dd
86dd
121dd
159dd
Regular
None
Germination

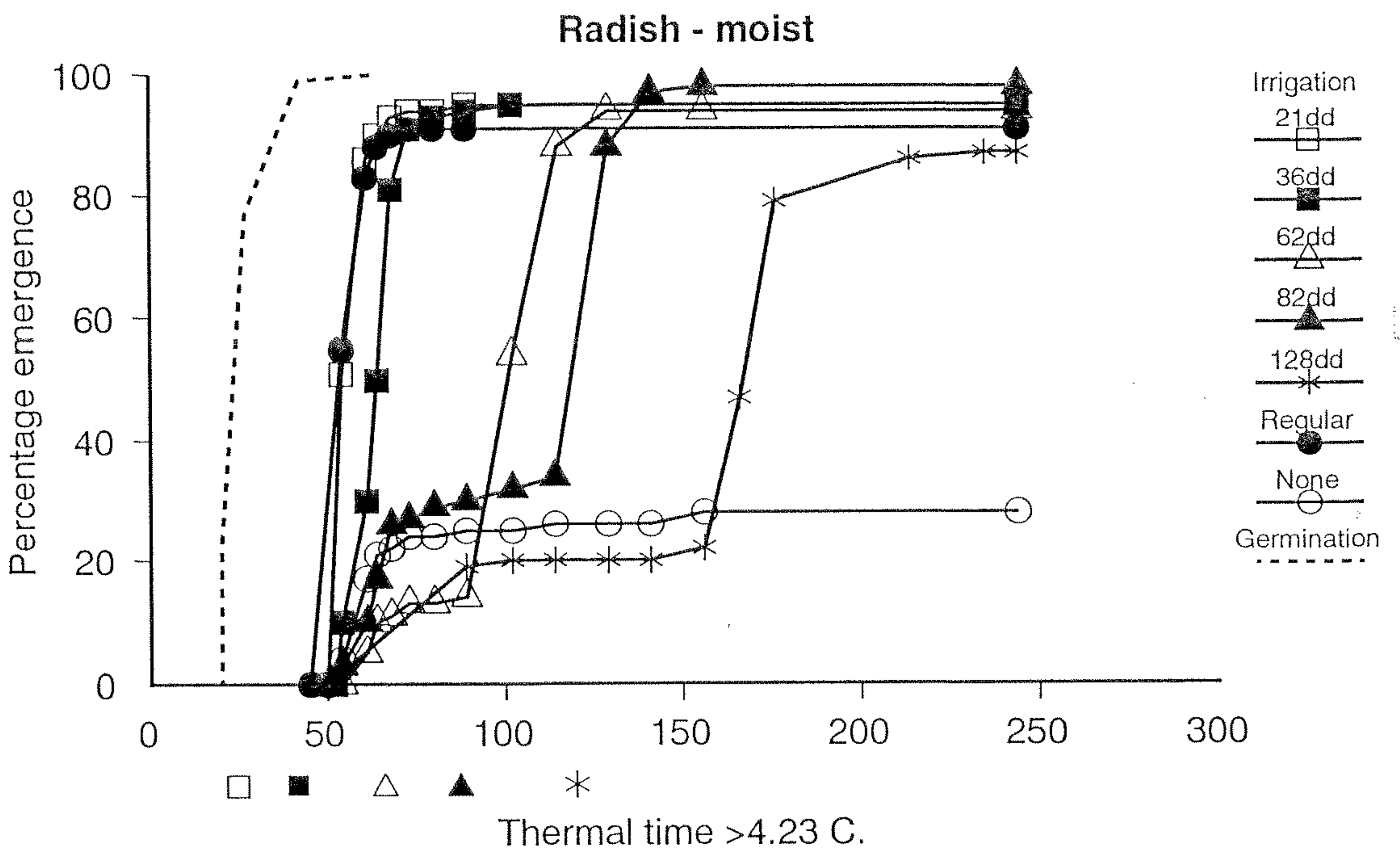

Lettuce - moist
Percentage emergence
0
20
40
60
80
100
0
50
100
150
200
250
300
Thermal time > 3.17 C.
Irrigation
23dd
39dd
68dd
91dd
142dd
Regular
None
Germination



Parsnip - untreated seed - moist
Percentage emergence
0
20
40
60
80
100
0
100
200
300
400
500
600
Thermal time > 2 C.
Irrigation
54dd
108dd
182dd
254dd
352dd
Regular
None
Germination

Parsnip - primed seed - moist




Radish - moist
Percentage emergence
0
20
40
60
80
100
0
50
100
150
200
250
300
Thermal time >4.23 C.
Irrigation
21dd
36dd
62dd
82dd
128dd
Regular
None
Germination

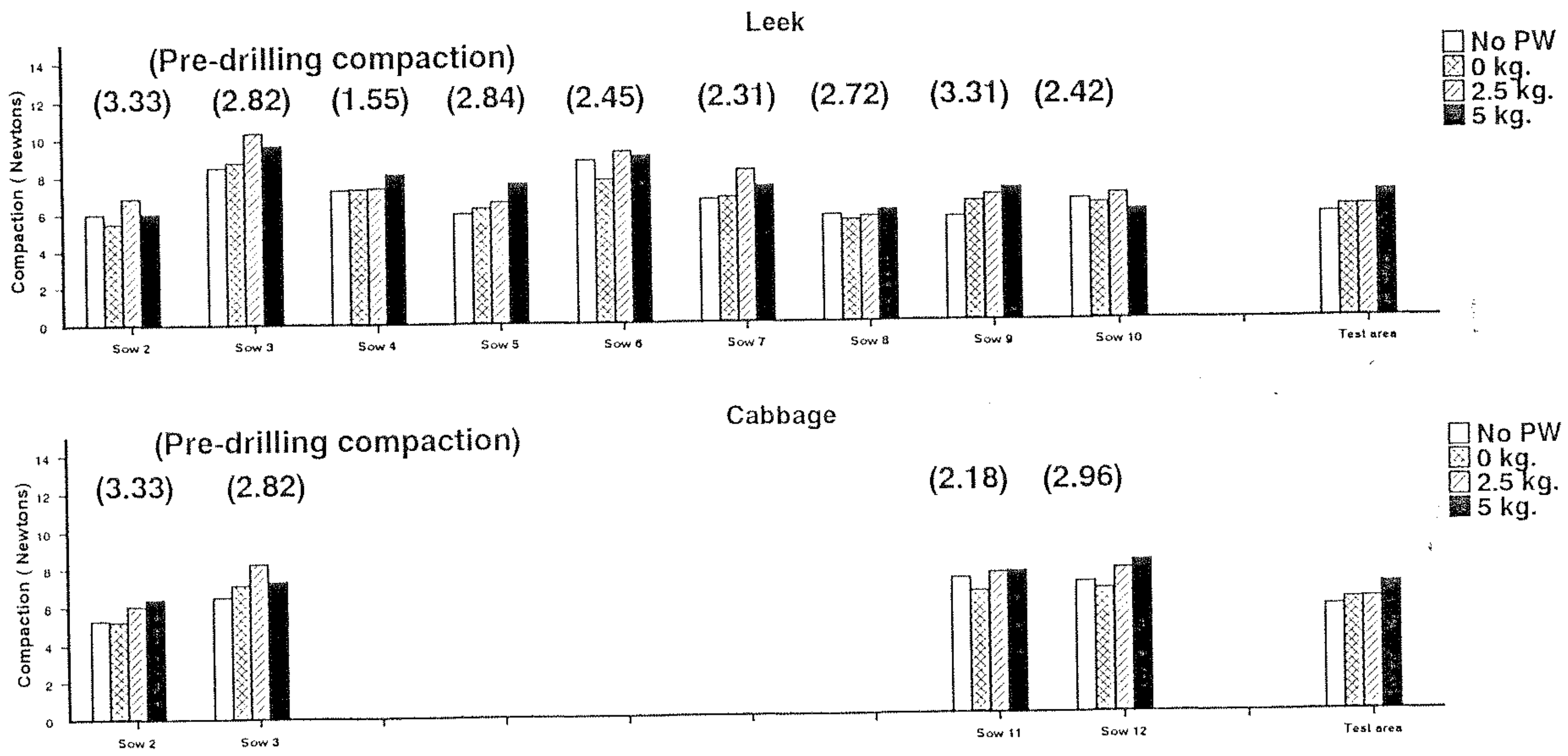


Figure 12. Measurements of soil compaction below the seed, before (in parenthesis) and after drilling, without and with seed presswheels of different weights

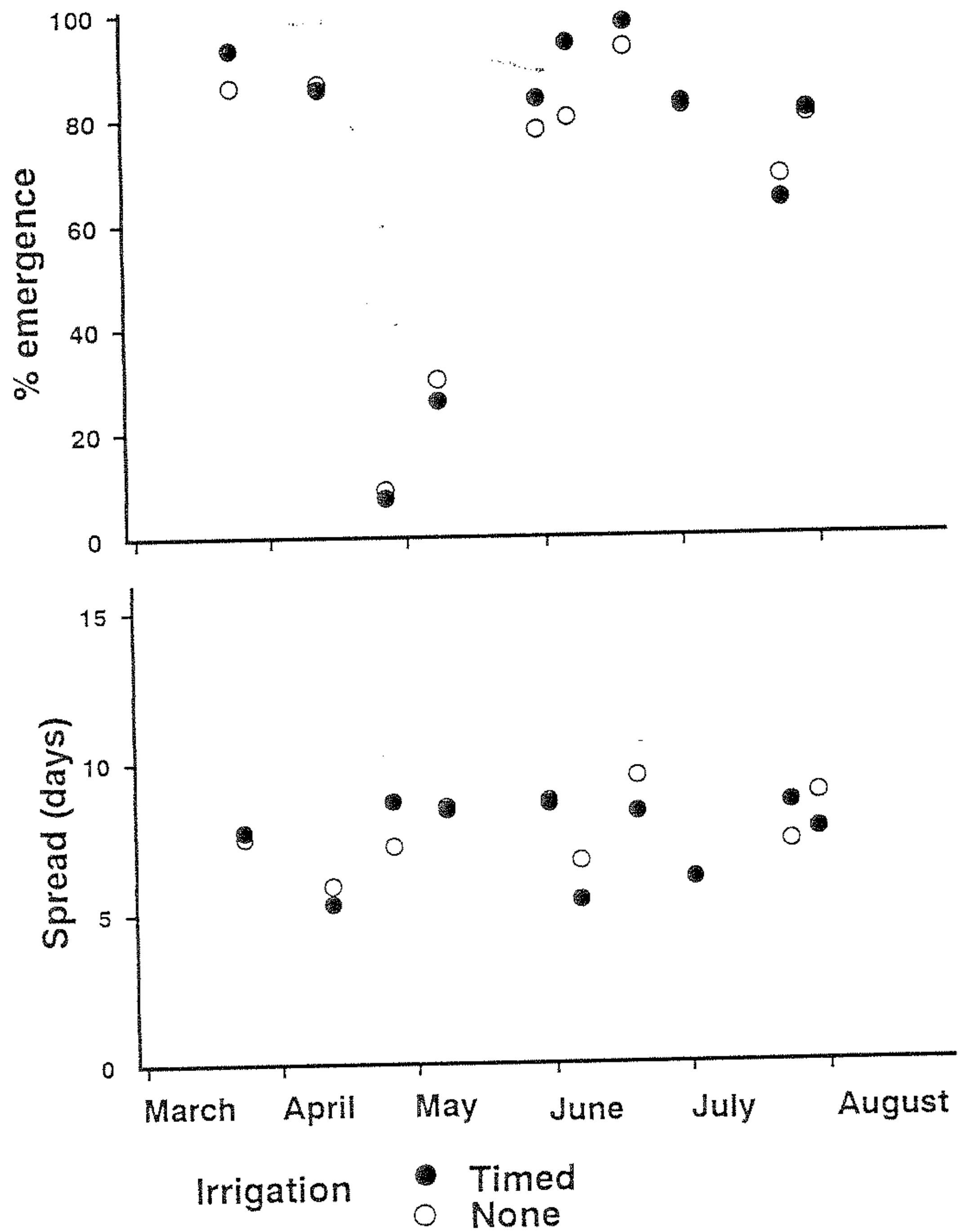


Figure 13. Percentage parsnip seedling emergence and spread of seedling emergence times for irrigation treatments meaned across drill press-wheel treatments in experiment 8.

Table 9

Parsnip

Spread (days) - Meaned across sowings

	No presswheel	Presswheel 0 kg	+2.5 kg	+5 kg
Irrigation				
Timed	7.5	7.7	6.9	6.6
None	7.6	7.4	7.3	8.3
LSD	1.0			

Percentage germination (angular transformations)

Timed	87 (73)	86 (72)	84 (69)	87 (74)
None	83 (69)	85 (69)	80 (65)	82 (67)
LSD	- (5.8)			

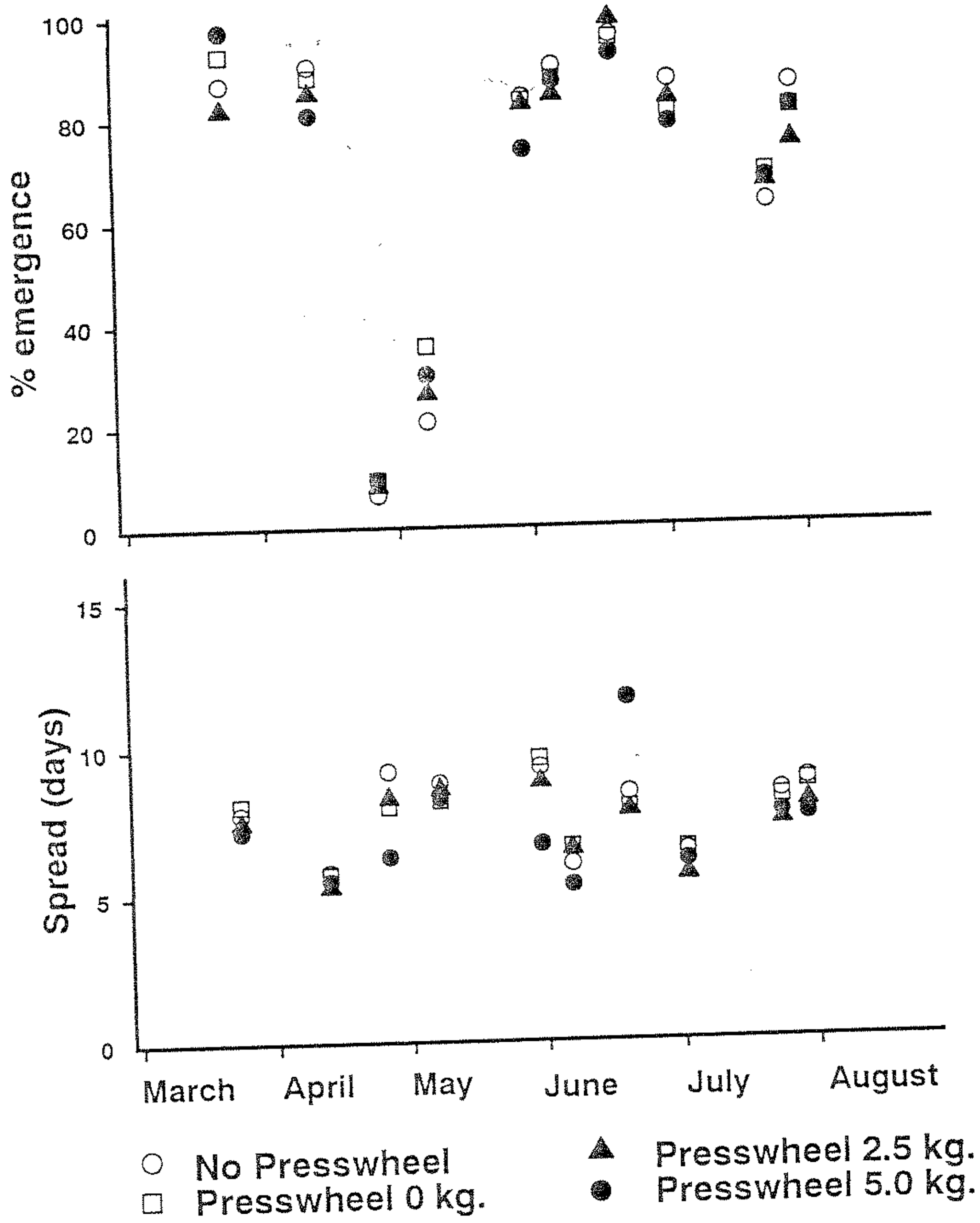


Figure 14. Percentage parsnip seedling emergence and spread of seedling emergence times for drill press-wheel treatments meaned across irrigation treatments in experiment 8.

Conclusions

There was no consistent effect of the press wheel on seedling emergence from leek or parsnip seeds. This was not due to an adverse effect of the press wheel on sowing depth. Limited evidence suggests that the passage of the rear coulter chassis over the drill line sufficiently compressed the seed bed to remove any effect of the seed press wheel. There was some evidence of press wheel damage with cabbage seeds although this appeared on irrigated plots only. This damage would need to be confirmed in further experiments.

Excessive and well dispersed rainfall throughout the season provided little opportunity to show the benefits of timed irrigation. However, during dry periods there was a benefit from timed irrigation in each of the three crops. These results were in agreement with the theoretical basis of the treatment. Because of the problems of frequent rainfall during the experimental season a model was constructed to estimate the percentage of sowing occasions on which there would be a measurable benefit of timed irrigation on seedling emergence. The model and its predictions are discussed below.

Irrigation response model

Rainfall and temperature data collected at the HRI Wellesbourne meterological station and soil pressure volume curves constructed for the experimental site were used to estimate soil water potential and temperature at sowing depth for each day in the season over the past 21 years. This was achieved using an existing HRI Wellesbourne model (Walker and Barnes, 1981). A detailed knowledge of the germination and seedling emergence behaviour of onions gained on this project and in previous work (Finch-Savage and Phelps, 1993) enabled us to construct a stochastic model to predict the response of onion crops to irrigation. The model was run for every day of the season between the end of February and the end of August in each of the last 21 years. The model determined if sowing was possible on that day; if irrigation was required when radicle growth was initiated in seeds; and if irrigation was not applied would the seed bed remain dry long enough to result in an adverse affect on seedling emergence. In this way the model predicted the number of potential sowing occasions in the season and the percentage of those occasions on which irrigation would reduce the spread of onion seedling emergence, and when it would also result in an increase in percentage emergence. The predicted outcome was compared against actual sowing occasions made in 1991 (reported above, Expts. 1-3). The model accurately predicted the sowings at which a benefit was recorded

Table 10 provides these estimates for the last 21 years. Out of a mean of 123 possible sowing occasions per year the model estimated that there would be a benefit from timed irrigation on an average of 38% of those occasions and up to 64% in one year. Of course on many occasions when the model predicts no effect there would be no need to irrigate because rainfall would have provided moisture in the seed bed. Table 11, gives a further breakdown of these predictions on a monthly basis.

Finch-Savage, W.E. and Phelps, K., 1993. Onion (*Allium cepa* L.) seedling emergence patterns can be explained by the influence of soil temperature and water potential on seed germination. *Journal of Experimental Botany* 44:407-414.

Walker, A. and Barnes, A., 1981. Simulation of herbicide persistence in soil; a revised computer model. *Pesticide Science* 12:123-132.

Table 10

Onions : Benefit of irrigation

1st April -------> 31st August (153 days)

Year	Drilling occasions water potential <-0.02 MPa	% of drilling occasions showing benefit from irrigation	
		Reduced spread of emergence	Reduced spread and increased % emergence
1993	125	26	22
1992	115	29	26
1991	126	31	28
1990	136	51	46
1989	120	47	38
1988	122	27	16
1987	114	35	29
1986	114	30	19
1985	113	24	17
1984	135	64	59
1983	113	47	40
1982	129	44	35
1981	129	36	28
1980	125	32	24
1979	123	37	30
1978	124	29	21
1977	121	47	41
1976	139	60	49
1975	115	27	26
1974	136	36	23
1973	120	37	32
Mean	123	38	31
Range	113-139	24-64	16-59

Table 11

Onions : Benefit of irrigation
21 year means

Month		Drilling occasions water potential <-0.02 MPa	% of drilling occasions showing benefit from irrigation: Reduced spread of emergence	Reduced spread and increased % emergence
March				
	mean	15	1	1
	range	2 ---> 26	0 ---> 13	0 ---> 13
April				
	mean	21	17	12
	range	10 ---> 30	0 ---> 63	0 ---> 13
May				
	mean	25	29	21
	range	19 ---> 31	0 ---> 93	0 ---> 90
June				
	mean	25	38	32
	range	18 ---> 28	0 ---> 75	0 ---> 71
July				
	mean	27	51	43
	range	21 ---> 31	9 ---> 90	0 ---> 87
August				
	mean	27	45	37
	range	23 ---> 30	13 ---> 93	4 ---> 89

APPENDIX 1..

HDC Contracts

1. TITLE OF PROJECT

Timing of water supply during crop establishment - FV39

2. BACKGROUND AND COMMERCIAL OBJECTIVE:

There is an increasing need to establish the correct number of uniformly-sized plants for efficient and profitable vegetable production. Independent surveys and experience indicate that on average only 50% of viable seeds establish plants in the field and in dry conditions double flushes of seedlings cause crop management problems and give crops with reduced yields. Recent work at HRI has indicated that a timely supply of water can considerably improve the predictability of crop establishment. At present there are no guidelines for the timing of water supply during this period and the objective of the work would be to develop techniques for providing these.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY:

Many factors contribute to poor establishment though the literature indicates that adequate water supply is one of the most important. It is estimated that up to £25m of vegetable seed is purchased annually in the UK. For field crops the poor levels of establishment not only reflect heavy losses in direct costs of seeds but there are also costs incurred in weed control management in variably-emerging crops. If a crop is not established at its full potential there are losses also in efficiency of application of fertilisers, pesticides and in efficiency of harvesting.

Most vegetable producers have access to and use irrigation for establishment. Its more effective use at a critical stage in development would justify the extra management input that will be needed.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK:

Preliminary results at HRI, Wellesbourne suggest that applied water (if needed) should coincide with the progress of seed germination and onset and rate of loss of desiccation tolerance. The objective would be to develop mathematical modelling approaches and produce a robust model for predicting the optimum timing of water supply. The model will then be tested in the field at several sites.

5. CLOSELY RELATED WORK COMPLETED OR IN PROGRESS:

There is a substantial body of knowledge collected by HRI and others on the environmental conditions influencing establishment but the linking of the timing of availability of water with the onset of germination of seed in the soil, loss of desiccation tolerance and the development of predictive models for germination progress is new. The work will be underpinned by strategic studies on seed germination in PU 2 at HRI, Wellesbourne.

6. DESCRIPTION OF THE WORK:

At HRI Wellesbourne

Several approaches will be adopted initially. In year 1, simple predictive models will be developed using existing germination and field establishment data. Alongside this work preliminary germination studies will be carried out on carrot and salad onion seed lots. These experiments will provide necessary parameters in models to calculate the progress of seed germination in the soil which will be used to predict timing of water supply.

During the following season (1991) the efficacy of these models will be tested in a serial sowing experiment with both carrots and salad onions. These experiments will provide a range of ambient environmental conditions during crop establishment. As weather conditions are variable, it is difficult to select sowing times that will expose seeds to the conditions of low soil moisture following sowing that often occur in mid to late spring. To overcome this problem and make efficient use of manpower, Dutch light frames having removable covers and containing field soil will be used to create these conditions.

For logistical reasons it is necessary to limit the number of crops in the initial investigation. All plots will be sprayed with soil conditioner to avoid confounding the results of timed water supply with soil capping, the effects of which would be site specific. This interaction could be studied in later experiments if required.

In year 2, if necessary, further development of the model will take place followed by detailed field experiments at several sites to include sites within HRI. It is envisaged that the work will also be expanded to other crops ie leeks and spring cabbage.

In year 3, it will be necessary to test the efficacy of the predictive models on a range of field sites. To do this it may be necessary to consider incorporating Arthur Rickwood in this plan as a subcontract from HRI. During this year if the methods of predicting the timing of water supply are successful, it will be appropriate to integrate this work with other techniques being developed in the HDC programme on crop establishment.

7. COMMENCEMENT DATE AND DURATION:

April 1991. 3 years.

8. STAFF RESPONSIBILITIES:

Project leader would be Dr W E Finch-Savage with research responsibility at Wellesbourne, an HSO would be responsible for data collection at Wellesbourne and analyses and interpreation from all sites. Responsibility for any field experiment at Stockbridge would be with Mr Antill and at Kirton with Dr Hiron with Dr Finch-Savage co-ordinating their roles. Dr Rowse at Wellesbourne would be involved with the modelling work.

9. LOCATION:

Wellesbourne will be the site for modelling work and initial experiments in year 1. Additional HRI sites will participate in field experiments in year 2 and 3.

FV39: Experiments 1992 (Year two)

1. In a series of experiments, optimum irrigation timings will be determined for a maximum of five further vegetable species and for primed seeds of two of those species. The species selected will have a wide range of thermal time requirements for germination. It is hoped that the thermal time requirement for germination can be related to the optimum timing for irrigation during crop establishment. In this way, a general recommendation for the timing of irrigation following sowing can be developed that will cover all vegetable species and treated seeds.

2. The germination characteristics of all primed and unprimed seeds to be used in experiments will be established at a range of five temperatures between 5 and 25°C. From this, the thermal time requirement and base temperatures for germination required for the predictive model can be determined.

3. In a further set of experiments, the potential benefit of timing irrigation following sowing with the dibber drill will be investigated in two crops, onion and leek.

4. Computer models exist that can simulate the pattern of changing soil moisture and temperature at seed depth following sowing under different environmental conditions. An investigation will be carried out to determine if these models can be employed to determine useful estimates of the quantity of irrigation water required to aid crop establishment. This estimate will be based on the thermal time required for emergence of the species concerned and soil moisture at the time of irrigation. A series of soil moisture determinations will be required in the field to test the accuracy of the models used in the study.

Additional expenditure

1. £1600, for expert advice and the rental of a prototype soil moisture probe from the Institute of Hydrology. The probe should be able to measure soil moisture at seed depth.

2. £150, for soil moisture release curves on three samples.

3. Share of Sandwich Student with FV40 for recording.

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for research/development project.

PROPOSAL

1. TITLE OF PROJECT

Contract No: FV/39a
Contract date: 29.3.93

THE INFLUENCE OF PRESS WHEEL-COMPACTION AND IRRIGATION TIMING ON CROP ESTABLISHMENT

2. BACKGROUND AND COMMERCIAL OBJECTIVE

Irrigation is commonly applied to establish seedlings in vegetable crops but there are currently no accepted recommendations for its timing during establishment and in practice this event may precede or occur at different times after sowing. Recent work at HRI has shown that although there is often sufficient water in the seed bed for seed to imbibe and begin the process of germination, the seed bed can dry out rapidly and to such an extent that moisture is not available to complete germination (radicle emergence) and support the continued growth of the seedling to the soil surface. It has also indicated that a timely supply of water during the post-sowing/pre-emergence phase can considerably improve the uniformity and predictability of establishment. The effects compared with no or untimely irrigation are large enough to indicate that the timing of availability of water supply to the developing seed before emergence takes place is one of the most significant factors influencing establishment of drilled vegetable crops.

A model has been developed that can describe the patterns of onion seedling emergence in the field by taking account of the influence of soil moisture and temperature. Initial experiments indicated that a simplified version of the model could be used to predict the progress of germination in soil, the stage of seed germination (ie emergence of radicle through the seed coat) when the seeds became sensitive to shortage of water, and, therefore, the optimum time to make water available to the developing seedling.

Using covered seedbeds we developed and tested these ideas for timing on two crops, carrot and onion, in 1991 (FV/39). The technique was shown to be effective and in 1992 we extended this work to six species representative of the full range of types of vegetable crop in the UK and their germination behaviour (FV/39 annex). We also examined how the predictions would need to be modified when primed seed and different types of drill were used. The results show that under the controlled conditions of these experiments a <u>single</u> application of water correctly timed can reduce the spread of germination, increase seedling emergence and also improve the predictability of emergence across sowings. It is now necessary to test this model system under a wide range of seed bed conditions in the open field so that robust guidelines for practical use can be developed.

Recent work with the dibber drill (FV 40) has shown the benefits of pressing the seed into the soil during drilling to ensure good seed/soil contact and therefore rapid uptake of water to promote germination. Some modern seed drills provide the opportunity to include a seed press wheel and preliminary results suggest that it may act in a similar manner to the dibber mechanism in ensuring good seed/soil contact. It is uncertain however, how much seed wheel pressure should be used in seed beds of differing moisture content to achieve optimum seed/soil contact and therefore seed germination. In addition, the use of a press-wheel may be important in promoting the initial stages of imbibition of water so helping to ensure that the model accurately predicts the timing of irrigation. In some fast germinating species the use of the press wheel to secure rapid water uptake and rapid germination and therefore effective use of the soil moisture reserves may obviate the need for irrigation to ensure reliable establishment.

The current proposal combines FV 39 with parts of FV 40 as was proposed in initial discussions with the HDC and project co-ordinators in 1992.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

Many factors contribute to poor establishment though the literature indicates that adequate water supply is one of the most important. It is estimated that up to £25m of vegetable seed is purchased annually in the UK. For field crops the poor levels of establishment not only reflect heavy losses in direct costs of seeds but there are also costs incurred in weed control management in variably-emerging crops. Significant reductions in graded yields at a single, destructive harvest also result from variable seedling emergence. If a crop is not established at its full potential there are losses also in efficiency of application of fertilisers, pesticides and in efficiency of harvesting.

More effective use of irrigation at a critical stage in development would justify the extra management input that will be needed.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

Results so far from work funded by MAFF initially and then by HDC in 1991 and 1992 show clearly that under protected seedbeds the application of a <u>single</u>, correctly timed irrigation can reduce the spread of seedling emergence times, increases percentage emergence and improve the <u>predictability</u> of seedling emergence across sowing occasions. Further testing of the model to predict the timing of irrigation under normal field conditions is now required to provide the basis for robust recommendations. A further need is to identify effective ways of putting this into practice. The predictions of timing will be most effective in instances where the seed rapidly takes up water after sowing and a further need is to examine if the use of a seed press wheel to ensure good seed/soil contact improves the reliability of the timing predictions for different sowing occasions and crops.. Its use may obviate the need for any irrigation with rapidly germinating species or for rapidly germinating primed seeds.

5. CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS

The proposed programme of work is underpinned by strategic work funded by MAFF on 'Factors influencing post-germination, pre-emergence seedling growth' in HH0401SFV. No other work of a similar nature is currently in progress in the UK or EC on field vegetables.

6. DESCRIPTION OF THE WORK

Between eight and ten sowings will be made, in the field using un-primed seed of three species having different germination rates. These rates will cover the normal range exhibited by the majority of the vegetable species grown in the UK and therefore the data obtained can be extended to other vegetable species exhibiting similar behaviour. Species of vegetable are to be chosen from radish, lettuce (fast), cabbage, leek, carrot (medium); and parsnips, red beet (slow).

These species will be sown with a coulter drill without seed press wheel and when the wheel is weighted to produce different levels of 'compaction' of the soil around the seed. Based on model predictions the seed beds will be given a single irrigation at the optimum time in comparison with an unirrigated, unprotected seed bed. The field experiment will be fully randomised and replicated giving 720 plots covering all treatments and species. Soil moisture content, water potential, soil compaction beneath the seed and temperature and rainfall will be recorded. Emerged seedlings will be counted daily and patterns of emergence related to environmental parameters and treatments.

7. COMMENCEMENT DATE AND DURATION

Start date 1.4.93 for 1 year

8. STAFF RESPONSIBILITIES

The project leader will be DR W E FINCH-SAVAGE (HRI). DR D GRAY (HRI) will provide advice on aspects of the work and MRS J R A STECKEL (HRI) will be responsible for the day-to-day running of experiments and computation of results. Dr Finch-Savage will have primary responsibility for interpretation of the data and in compiling the reports.

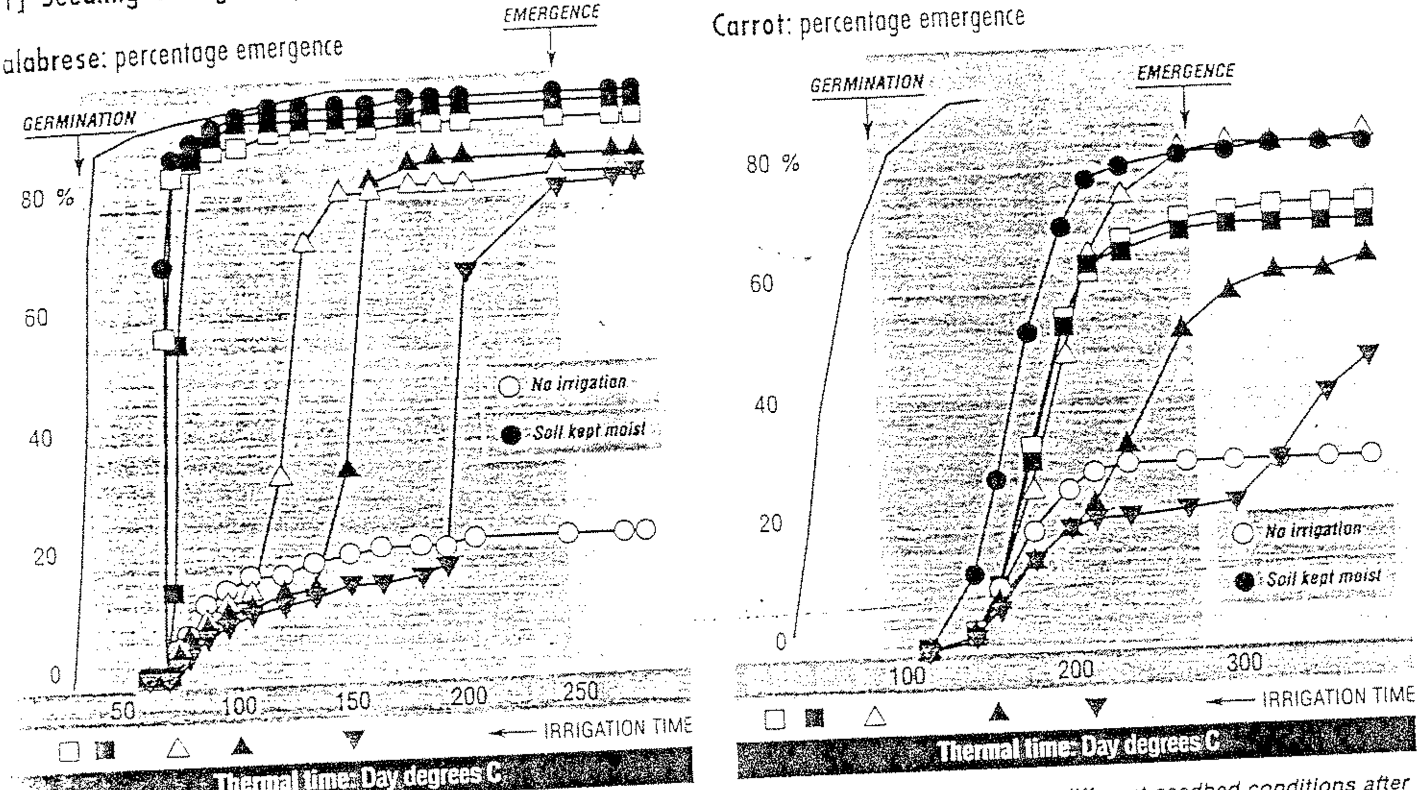
9. LOCATION

HRI, Wellesbourne

APPENDIX 2.

Grower article

.1] Seedling emergence patterns



..e patterns of a fast germinator — calabrese — and of a medium rate germinator — carrot — from different seedbed conditions after :.wing into a moist seed bed. Five irrigation times show different emergence patterns. When irrigation coincided with the thermal time :. give approximately 75% germination in a standard seed test seedling emergence was very similar to that in a seed bed kept moist ..roughtout. Sowing into moisture without further irrigation was inadequate and delaying irrigation beyond the optimum time progres-.ively increased the spread of emergence times.

HDC PROGRESS REPORT UPDATE

THE TIMING OF WATER SUPPLY

..rigation is commonly used .. establish seedlings in ve-..table crops but the UK has .. accepted recommenda-..ns for its timing in crop ..tablishment.

Pre-sowing irrigation of ..eedbeds has been recom-..ended in the past but is not ..voured by growers in our ..ariable climate. It rarely pro-..uces timely and uniform ..ands of seedlings.

Incorrectly timed irrigation ..fter sowing can cause serious problems. Even if a sufficient stand is achieved the resulting seedling emergence and size of plants at harvest can vary greatly. So when do you irrigate after sowing?

At HRI Wellesbourne we have tried to solve this problem by understanding the underlying causes of undesirable variation in seedling emergence times and plant size. The project is sponsored by HDC and based on more fundamental work supported by MAFF.

Research shows that the influence of soil moisture and temperature on germination can determine different patterns of seedling emergence in the field. These relationships have been quantified and a model has been developed to describe the patterns of onion seedling emergence in the field.

Further work has shown optimum times to irrigate crops after sowing relate to the progress of germination in the soil. A simplified model, using thermal time, can indicate the progress of germination in the soil, providing a way to predict the optimum time for irrigation after sowing.

The HDC initially funded tests for timing irrigation in carrots and onions. The range was extended to cover examples of the full range of vegetable crops in the UK.

We studied germination characteristics of untreated lettuce, cabbage, calabrese, radish, leek and parsnip seed at five temperatures between 5C and 25C. Primed seeds of leek and parsnip were also tested. These tests identified the required thermal time and base temperatures for germination. These germination characteristics were then linked to optimum timings of irrigation after sowing in detailed field experiments under mobile covers.

Timing of water supply during crop establishment

Location: HRI Wellesbourne

For more information contact: Dr Bill Finch-Savage, project leader quoting project no: FV39

"This work has already confirmed that irrigation is more complex than many of us acknowledge and more particularly that seedbed irrigation can be very important. Given the demands of customers for uniformity, consistency and quality, growers have to move towards a more managed system for irrigating their crops — not to mention the need to have control of irrigation costs."
Michael Holmes, project co-ordinator

Results

In all six species sown, pre-sowing irrigation of seedbeds alone could not consistently produce timely and uniform stands of seedlings from untreated seeds. It established a uniform crop in only one situation with rapidly germinating primed leek seeds.

Seed tests showed there was a clear relationship between the thermal time requirement for germination (above the appropriate base temperature) and the optimum time (in thermal time) to irrigate after sowing. In general, a single irrigation applied at the thermal time that between 50% to 70% of the seeds germinated in a seed test gave good results. Repre-

HDC PROGRESS REPORT UPDATE

sentative experimental results with calabrese and carrots are illustrated [1].

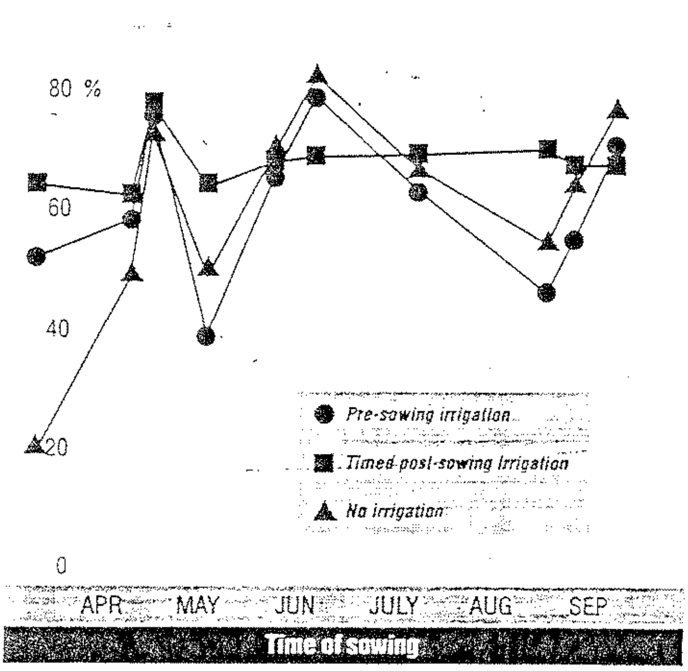
Each species has different thermal time requirements but it may be possible to streamline these to three categories.

They are:

- fast germinators with thermal times to 50% germination (T_{50}) less than 40 day degees — lettuce, radish, calabrese;
- medium-rate germinators with T_{50} greater than 40 and less than 80C — cabbage, onions, carrots and leek; and
- slow germinators with T_{50} greater than 80 day degrees — parsnips.

[2] Increased predictability across sowings with timed irrigation

Onion: percentage emergence



A single thermal time recommendation for each of the first two categories such as fast: 30 to 40 day degrees, and medium: 80 to 90 day degrees may be an adequate guide to irrigation timing.

The slow category timing will depend on the seed lot.

Seeds were sown into moisture in these experiments. Results would vary in very dry seedbeds where initial imbition is severely limited.

What next?

Results show a single correctly timed irrigation can potentially reduce the spread of seedling emergence times, increase percentage seedling emergence and improve predictability across sowings [2].

But the techniques need testing with a wider range of crops under variable field conditions to confirm them as the basis of reliable recommendations for irrigation timing in vegetable crop establishment. Identifying effective ways to commercialise this method and make it "grower friendly" is another important aim in this last year of the project.

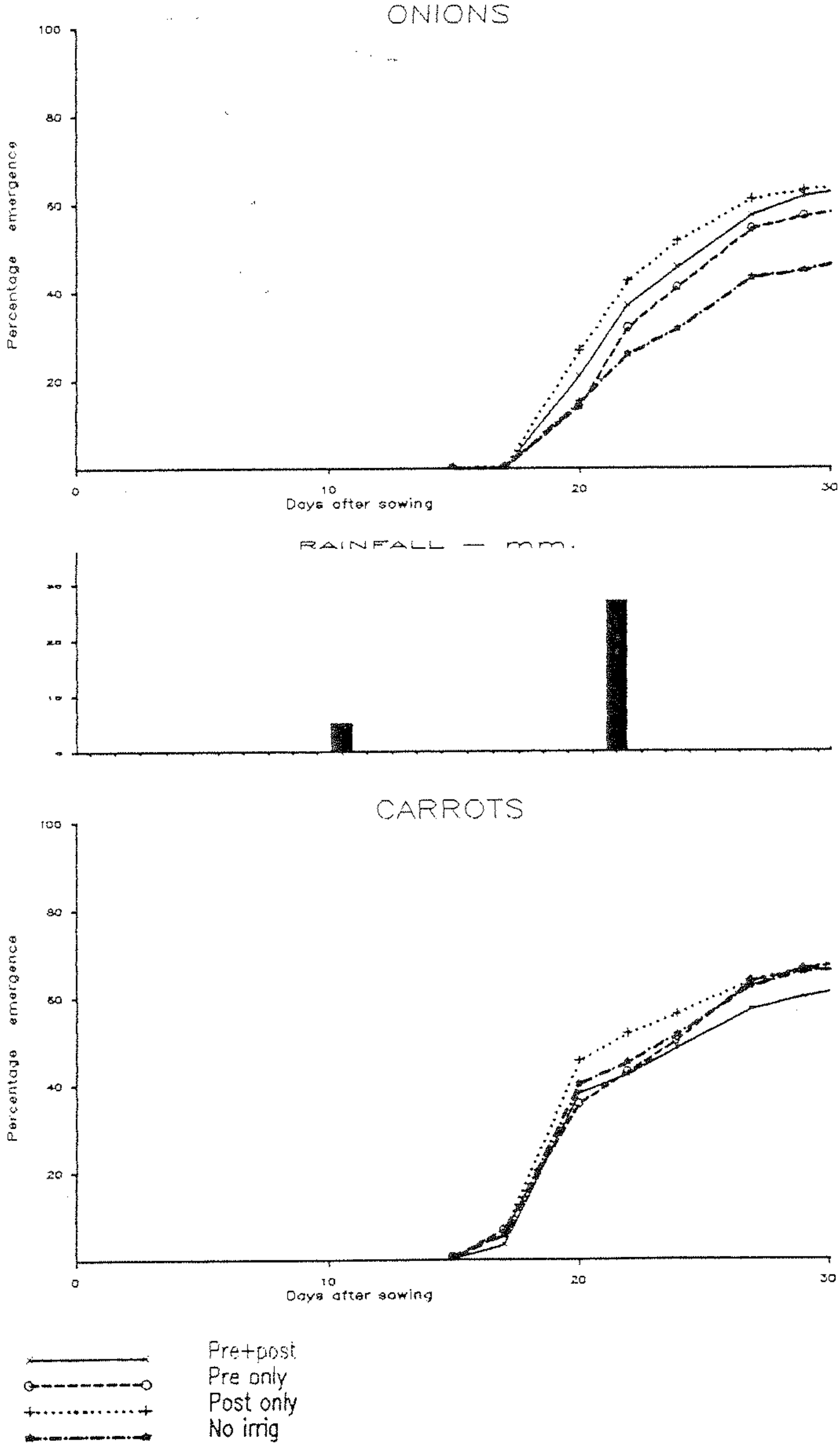
Dr Bill Finch-Savage
Department of annual plants
HRI Wellesbourne

APPENDIX 3.

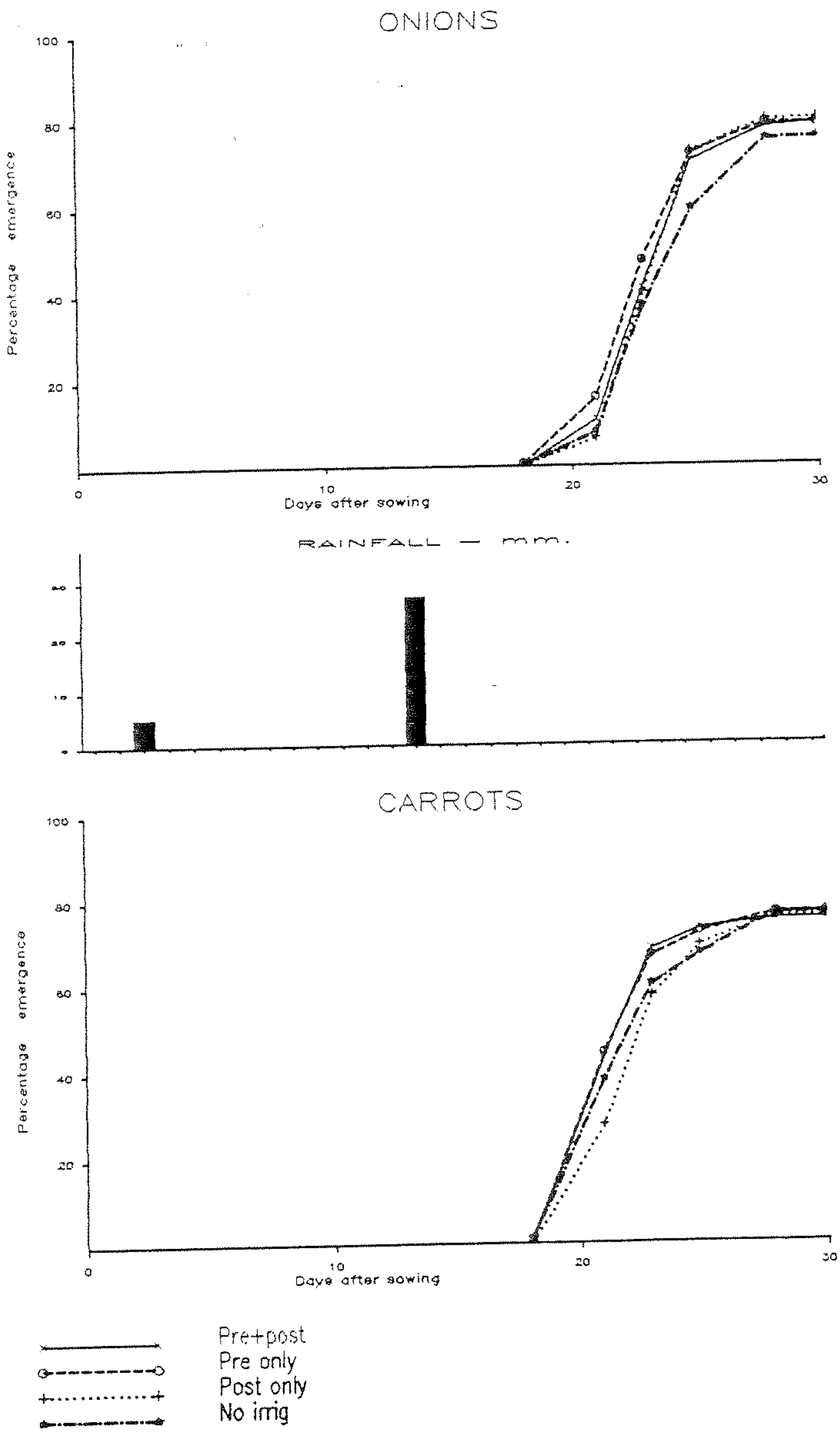
Expts 1 - 3

Figures showing percentage emergence of onion and carrot and rainfall for each sowing occassion

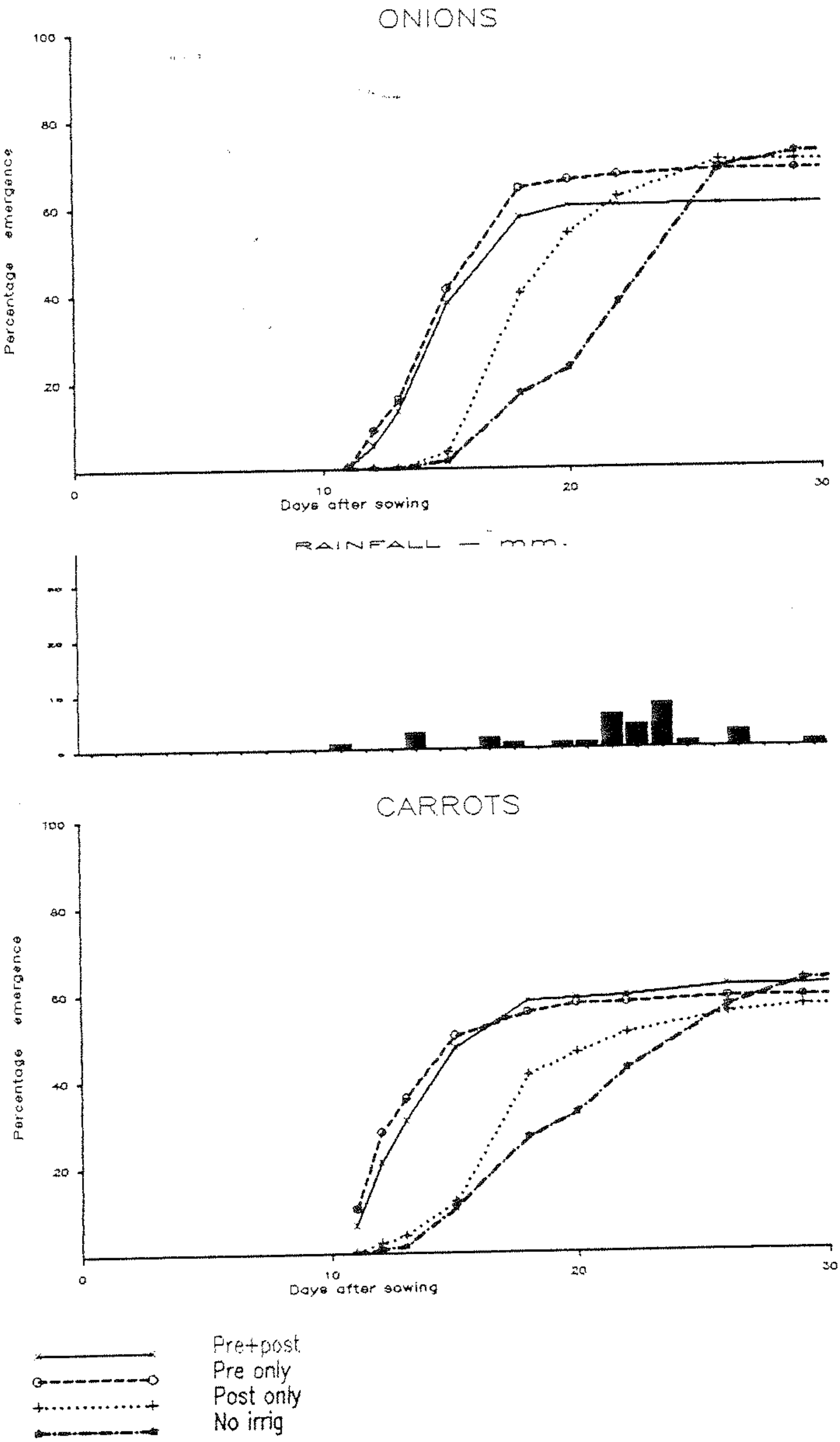
Expt 1. sown 9 April 1991



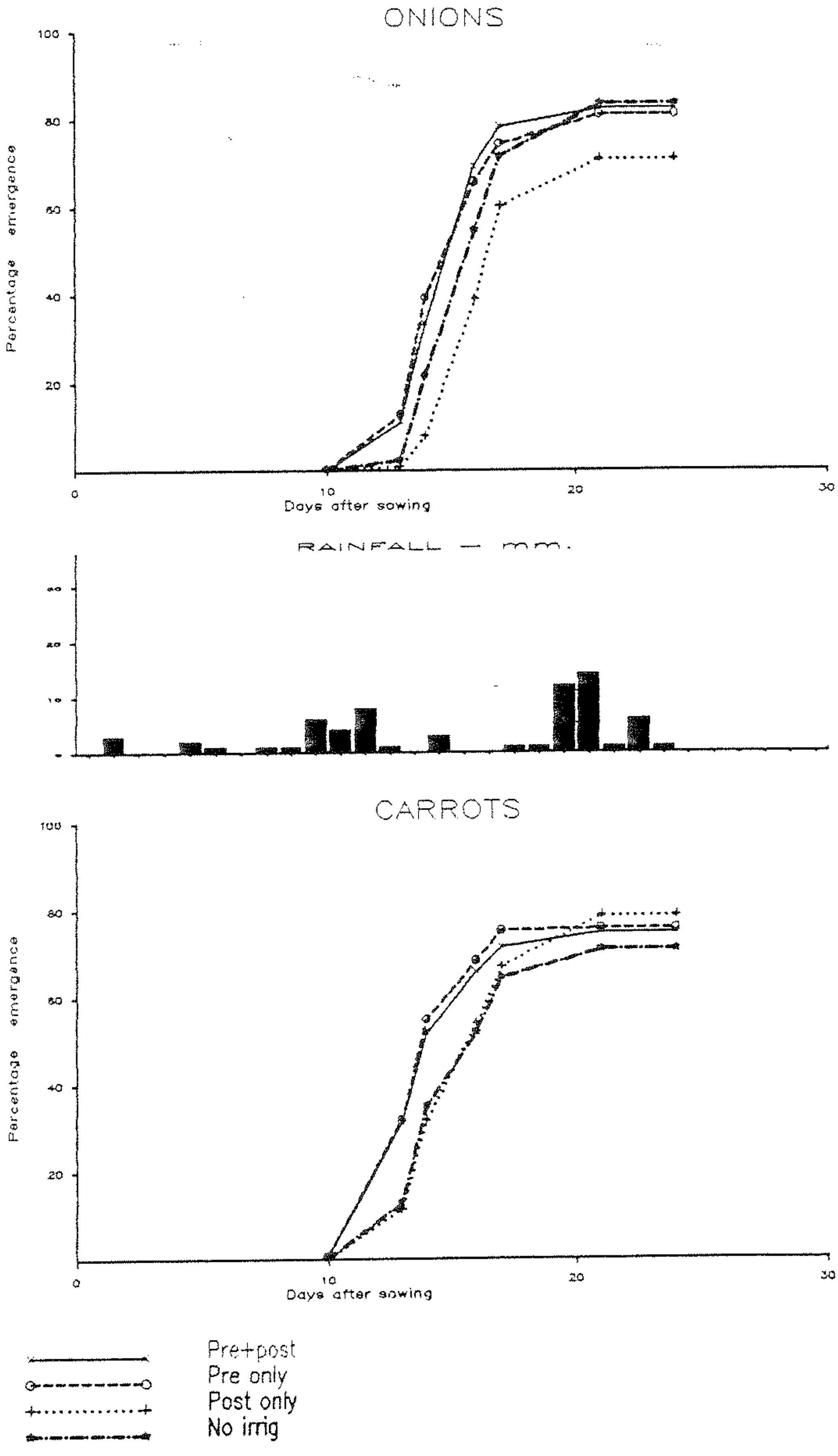
Expt 1. sown 15 April 1991



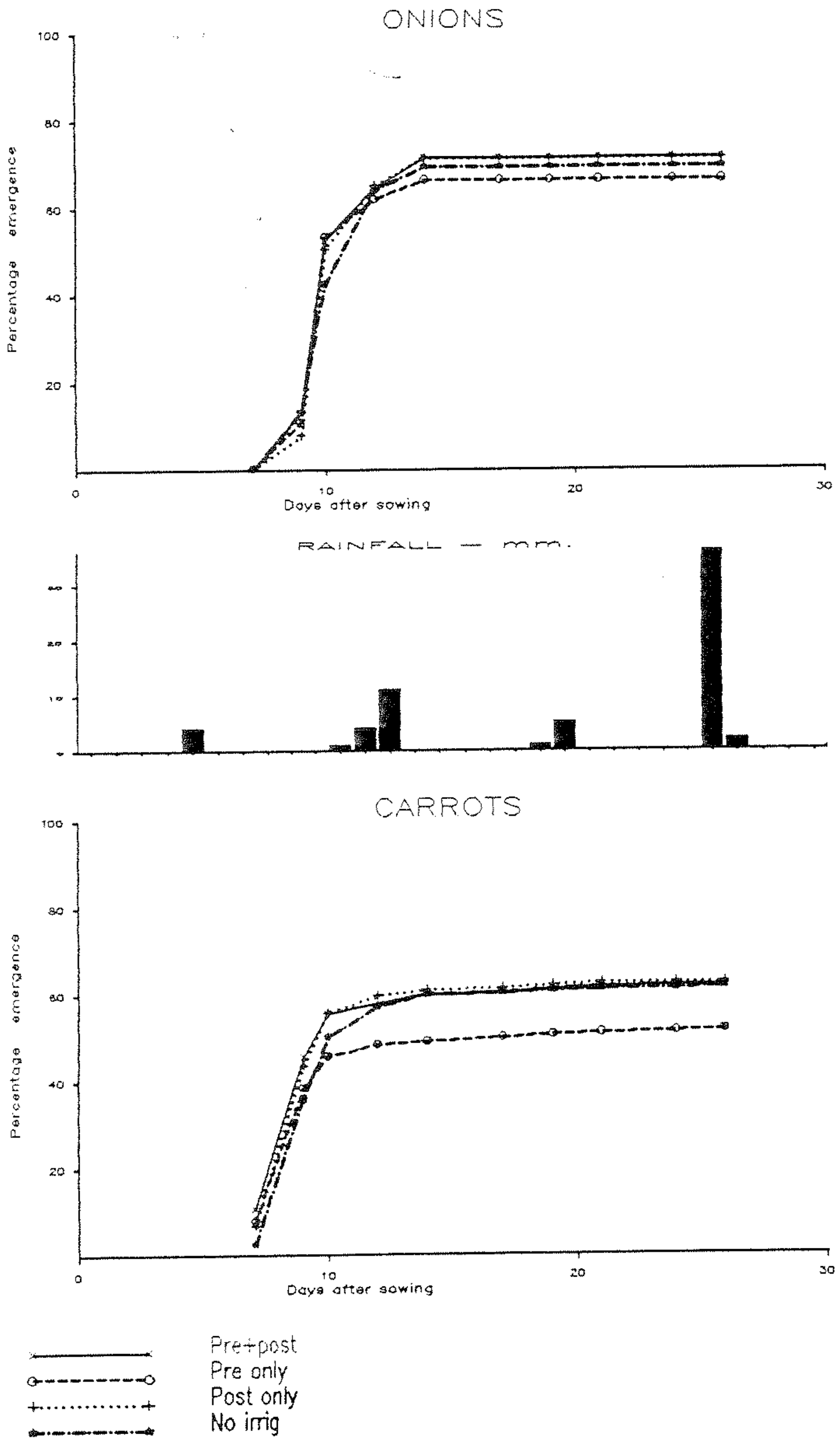
Expt 1. sown 23 May 1991



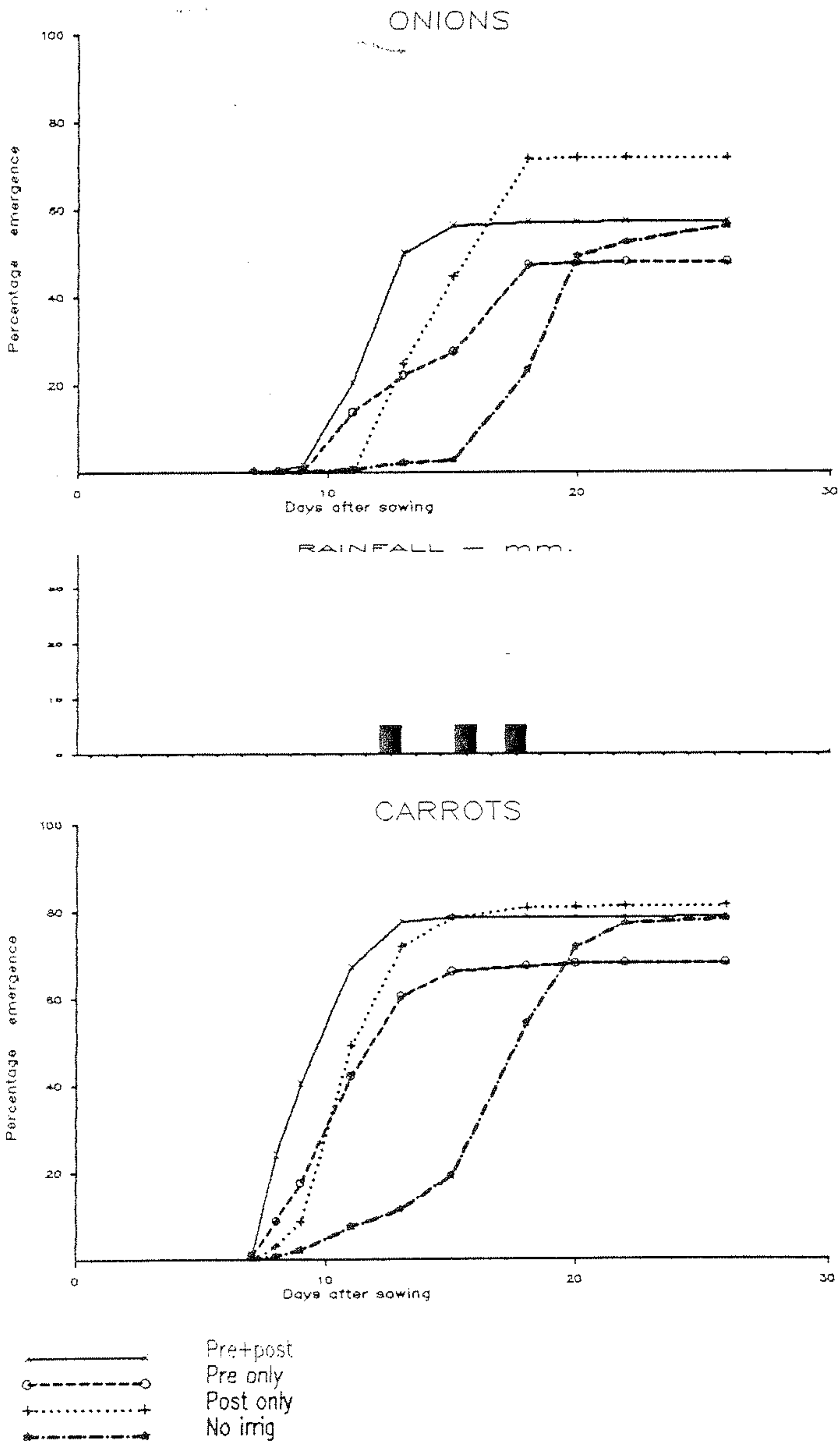
Expt 1. sown 4 June 1991



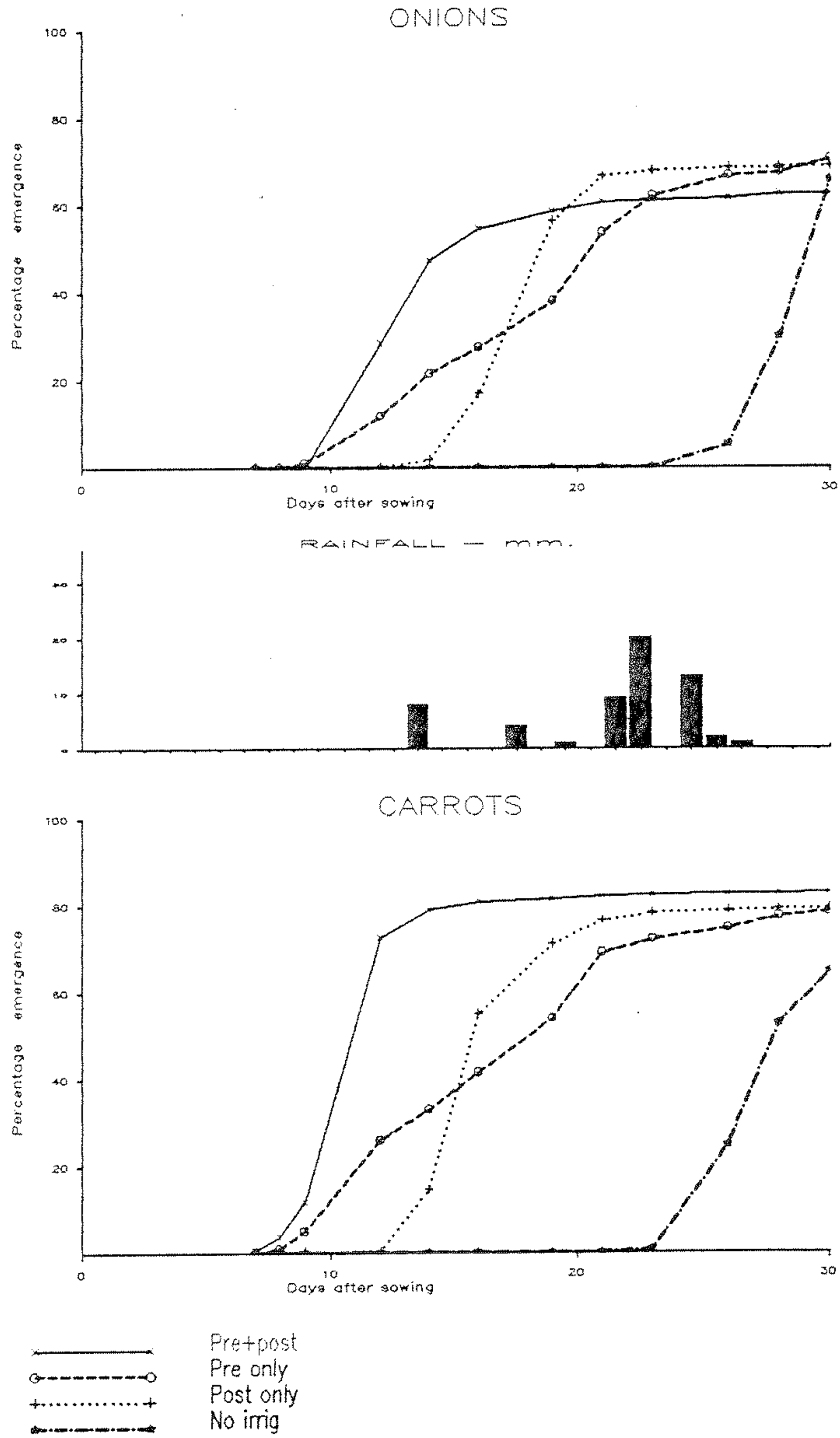
Expt 1. sown 5 July 1991



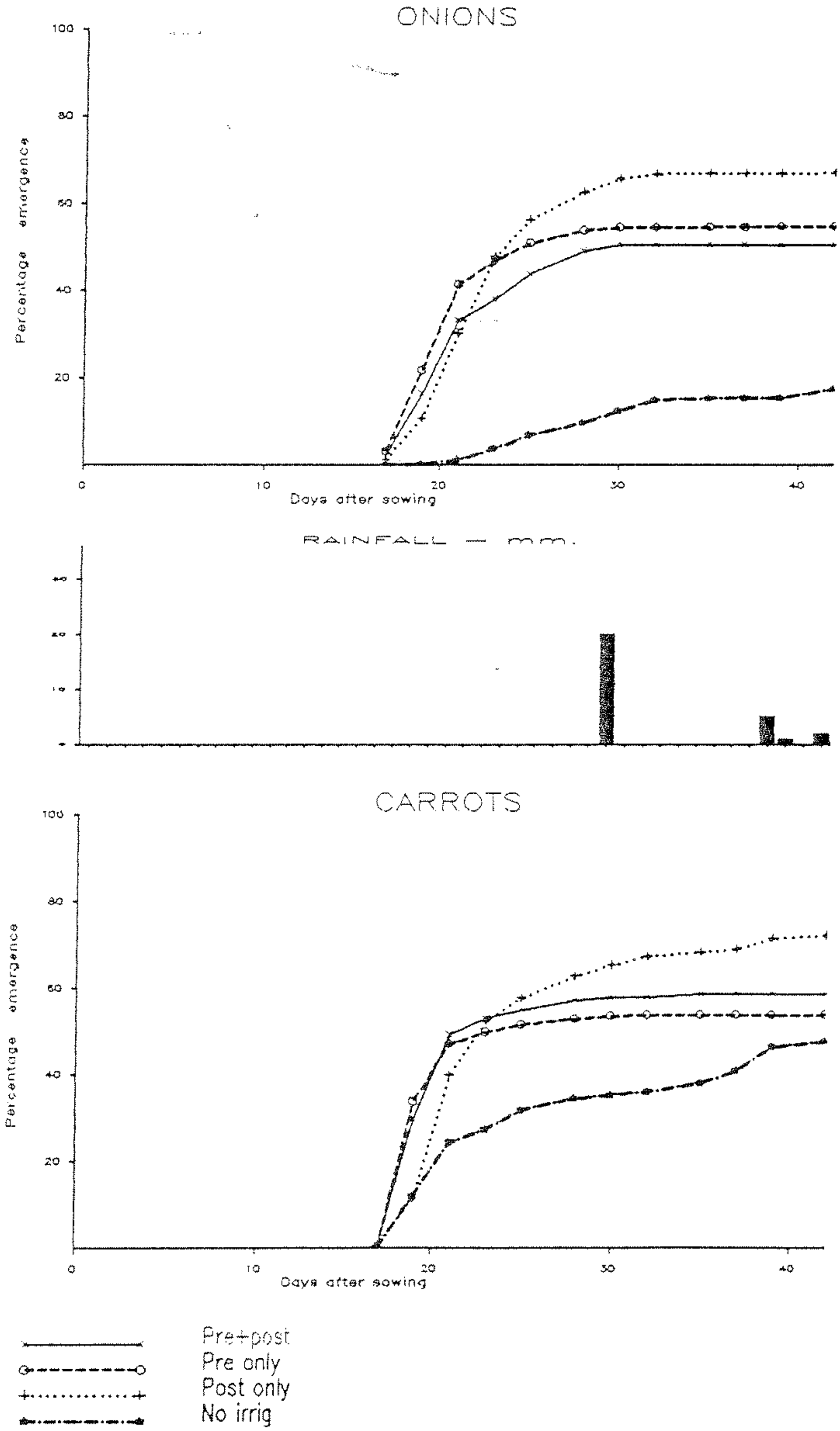
Expt 1. sown 14 August 1991



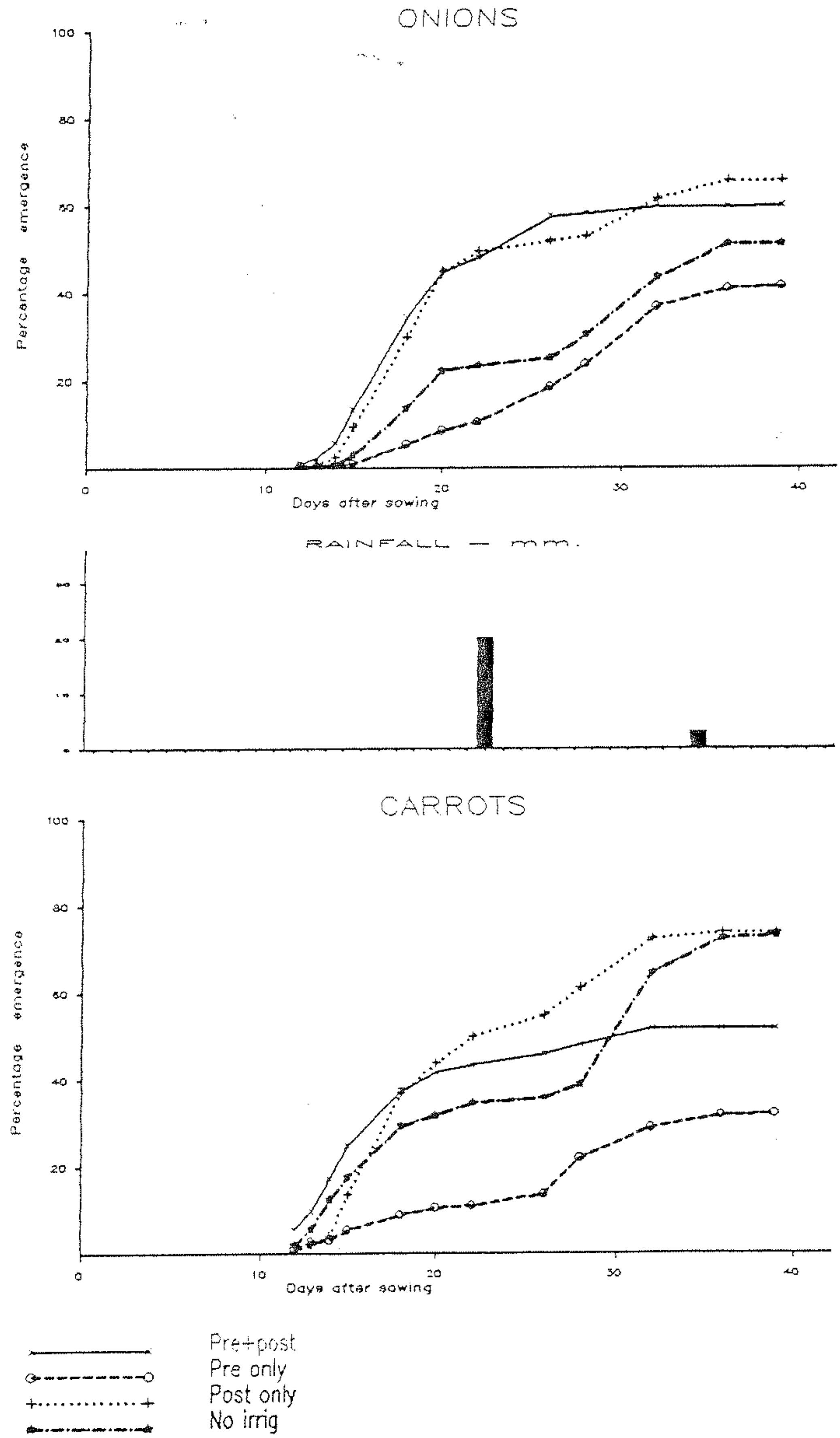
Expt 1. sown 4 September 1991



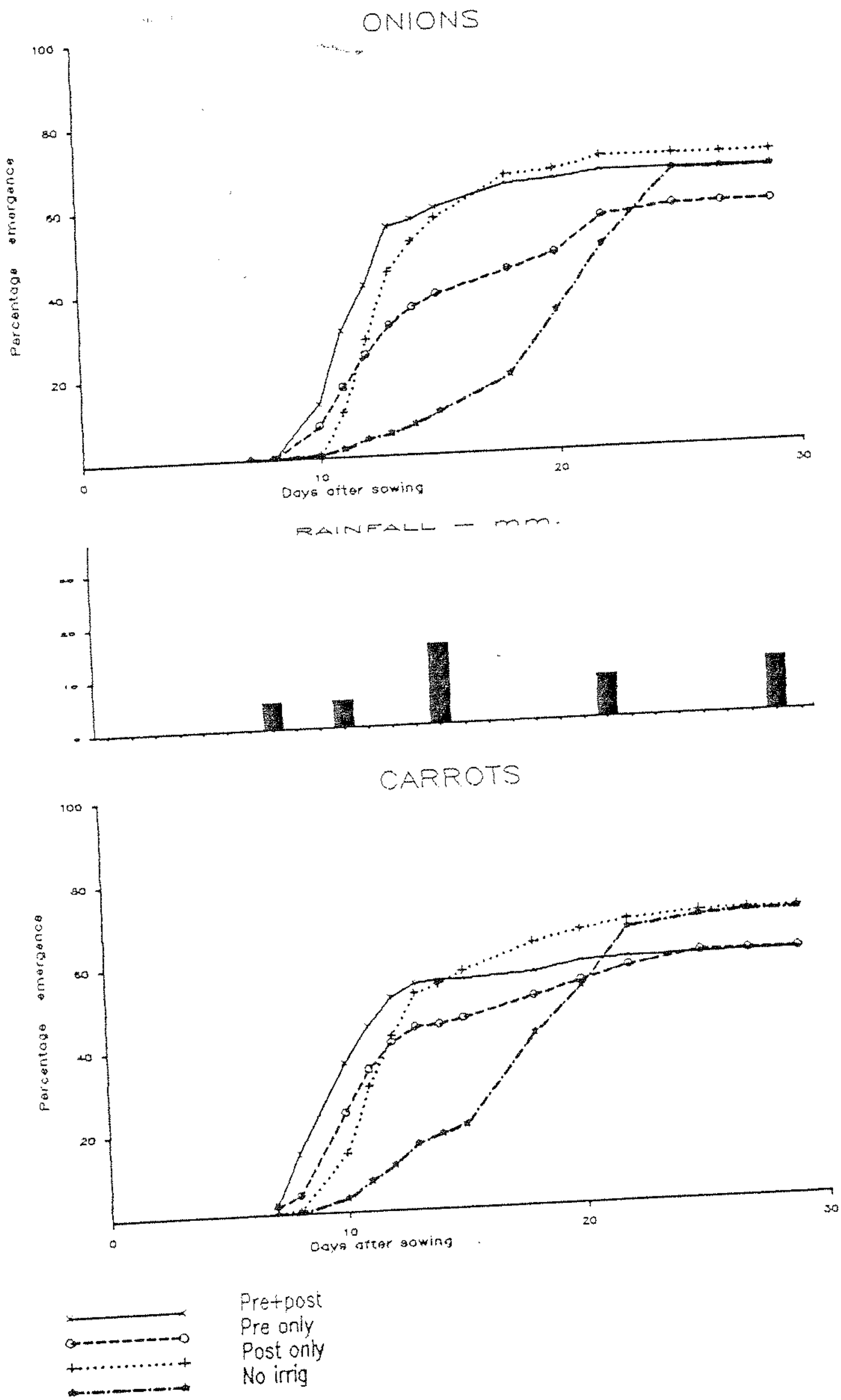
Expt 2. sown 11 March



Expt 2. sown 2 May



Expt 3. sown 22 August



	Base temperature (deg. C.)	Thermal time to 50% germination
Radish	4.23	24
Lettuce	3.17	29
Calabrese	2.65	39
Leek - primed	2.00	19
- untreated	2.00	43
Onion - primed	2.55	32
- untreated	2.55	55
Carrot	1.30	61
Cabbage	2.00	64
Parsnip - primed	2.00	115
- untreated	2.00	270