CHAPTER 5

TECHNIQUES OF PRIMING

In order to ascertain the most effective priming treatment, it is necessary to first determine the most appropriate solution and then the most effective temperature and duration of the priming treatment. Also before field evaluation of priming can be undertaken it is necessary to scale the treatment up for the priming of bulk quantities of seeds. Further, if existing drilling equipment is to be used then primed seeds must be dried after treatment. A series of experiments were conducted to explore these requirements.

5.1 THE INTERACTION OF TEMPERATURE AND DURATION OF PRIMING ON THE EMERGENCE OF TOMATO, CARROT AND ONION SEEDS. (EXPERIMENT 7).

5.1.1 Methods

Seeds of tomato, carrot and onion were placed in petri dishes containing the priming solution 0.105M K_3PO_4 + 0.209M KNO_3 (-1.6 MPa). This solution was chosen as representative of those reported in the literature to give favourable results for priming. The petri dishes were kept at constant temperatures of 15, 20, or 25 C for seven, fourteen or twenty-one days. Following treatment four replicates (fifty seeds per replicate) of each species from each temperature were sown in emergence trays at 15 C. Four replicates of untreated seeds of each species were sown in emergence trays for comparison. The emergence trays were clear plastic containers (125 x 90 x 75 mm) with drainage holes in their bases. The trays contained a layer of clean gravel and were filled with washed river sand (particle size 1 - 2 mm). The trays were watered to excess then allowed to drain whilst equilibrating to temperature during the twenty-four hours preceeding use. In each tray fifty seeds were sown in five rows of ten, the seeds were equidistant from one another. Sowing depths were 9 mm for tomato seeds, 7 mm for carrot and onion seeds. Emergence was taken as the appearance of the plumule above the surface of the sand. Emergence was recorded at twelve-hour intervals until complete or until no further had emerged over four consecutive days.

5.1.2 Results

5.1.2.1 Tomato

Maximum percentage emergence of primed tomato seeds was not significantly different from that of untreated seeds (Table 35, Appendix Table A1.11). Within the priming treatment combinations seeds treated at 15 C for 7 days, 20 C for 14 days or at 25 C for 7 days were significantly higher than those from the other treatment combinations. All priming treatments produced tomato seeds which had median rates of emergence which were about twice as fast as those of untreated seeds at 15 C (Table 36, Appendix Table A1.11). Seeds primed at 15 C showed further improvement in median rate with lengthening of duration of treatment from 0.0079 h^{-1} for 7 days treatment to 0.0090 h^{-1} for seeds treated for 21 days. Seeds treated at the higher temperatures did not show a continued improvement in median rate with the increase in duration of priming treatment.

The time to the beginning of emergence at 15 C was halved by priming (Table 37, Appendix Table A1.11). Seeds primed at 15 C showed a continuing decrease in time to the beginning of emergence with lengthening of treatment from 108 hours for seeds treated for 7 days to 95 hours for seeds treated for 21 days. Seeds primed at the higher temperatures did not show further improvement with lengthening of treatment. Seeds treated at 25 C showed an increase in time to the beginning of emergence, although not significantly different, with lengthening of treatment. The time-spread of emergence at 15 C was decreased by priming to almost half that of untreated seeds (Table 37, Appendix Table A1.11). The time-spread of emergence of seeds

Table 35. The effect of temperature and duration of priming of tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the maximum percentage emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Maximum percentage emergence (%) (Control: 95.3)		
15	92.4	91.0	91.4
20	90.7	93.1	89.1
25	95.0	89.7	90.4

Table 36. The effect of temperature and duration of priming of tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the median rate of emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Median rate of emergence (h^{-1}) (Control: 0.0044)		
15	0.0079	0.0087	0.0090
20	0.0083	0.0090	0.0084
25	0.0090	0.0087	0.0089

Table 37. The effect of temperature and duration of priming of tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the time to 5% emergence and the time-spread of emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Time to 5% emergence (h) (Control: 198)		
15	108	101	95
20	105	94	106
25	95	100	97
	Time-spread of emergence (h) (Control: 49)		
15	32.5	24.9	26.5
20	29.3	30.3	22.1
25	26.7	25.3	25.9

treated at 25 C remained unchanged with the increase in duration of the treatment. The time-spread of emergence of seeds treated at 20 C was not reduced below that of seeds treated for 7 days by a further 7 days treatment, but 21 days treatment at 20 C further shortened the time-spread. Seeds treated at 15 C for 7 days had the longest, 32.5 hours, time-spread of any of the primed tomato seeds. This was reduced to 24.9 hours after 14 days priming and remained unchanged after 21 days priming.

5.1.2.2 Carrot

Priming of carrot seeds increased the maximum percentage emergence at 15 C over that of untreated seeds (Table 38, Appendix Table A1.12). Seeds primed for 7 days at any temperature had the highest maximum percentage, 83%. The improvement in maximum percentage decreased with lengthening of the duration of treatment at all temperatures. Primed carrot seeds had median rates of emergence at 15 C which were about twice that of untreated seeds (Table 39, Appendix Table A1.12). At all temperatures carrot seeds treated for 14 days had the fastest median rates. Seeds primed at 15 or 20 C for 14 days had overall the fastest median rates (0.0076 h^{-1} and 0.0078 h^{-1}).

Priming of carrot seeds reduced the time to the beginning of emergence to approximately half that of untreated seeds at 15 C (Table 40, Appendix Table A1.12). Seeds treated for 21 days showed the largest reductions in time to the beginning of emergence reaching times of about 90 hours. At all temperatures there was a continuing reduction with increase in duration of treatment. Lowering of temperature of treatment had a similar effect. This resulted in those seeds treated at 15 C for 21 days

Table 38. The effect of temperature and duration of priming of carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the maximum percentage emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Maximum percentage emergence (%) (Control: 66.5)		
15	83.4	74.8	68.6
20	82.7	77.6	70.2
25	82.5	68.6	70.4

Table 39. The effect of temperature and duration of priming of carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the median rate of emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Median rate of emergence (h^{-1}) (Control: 0.0038)		
15	0.0066	0.0076	0.0077
20	0.0071	0.0078	0.0080
25	0.0068	0.0070	0.0066

Table 40. The effect of temperature and duration of priming of carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the time to 5% emergence and the time-spread of emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Time to 5% emergence (h) (Control: 209)		
15	108	100	87
20	111	103	88
25	119	108	92
	Time-spread of emergence (h) (Control: 103)		
15	77.5	55.6	74.9
20	53.8	46.2	64.5
25	50.8	64.0	106

having the shortest time to the beginning of emergence of any primed seeds, 87 hours. The time-spread of emergence of primed seeds was significantly reduced below that of untreated seeds at 15 C, except for that of seeds treated at 25 C for 21 days (Table 40, Appendix Table A1.12). At all treatment temperatures there was a significant increase in the time-spread of emergence for seeds treated for 21 days. Four treatment combinations (seeds treated at 15 C for 14 days, at 20 C for 7 or 14 days, and at 25 C for 7 days) had time-spreads of emergence which were of the order of fifty percent of that of untreated seeds.

5.1.2.3 Onion

Priming of onion seeds reduced the maximum percentage emergence at 15 C below that of untreated seeds (Table 41, Appendix Table A1.13). Seeds treated for 7 days were least affected, with seeds treated at 15 C for 14 days similarly affected. There were further reductions in maximum percentage with lengthening of the priming treatment. This effect was marked at higher temperature with maximum percentage emergence falling from 73% for seeds treated at 25 C for 7 days to 33% for seeds treated for 21 days. The median rate of emergence at 15 C was increased to almost twice that of untreated seeds (Table 42, Appendix Table A1.13). There were further improvements in median rate with increase of duration of treatment. Of the treatments which produced seeds with the least reduced maximum percentage emergence, those with fastest median rate were primed at 15 C for 14 days.

Priming of onion seeds reduced the time to the beginning of emergence to half that of untreated seeds at 15 C (Table 43, Appendix Table A1.13). There was continued reduction with lengthening of treatment. Similarly, lowering of treatment temperature resulted

Table 41. The effect of temperature and duration of priming of onion seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the maximum percentage emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Maximum percentage emergence (%) (Control: 77.8)		
15	69.0	72.3	38.9
20	72.4	52.9	43.2
25	72.8	59.0	32.6

Table 42. The effect of temperature and duration of priming of onion seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the median rate of emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Median rate of emergence (h^{-1}) (Control: 0.0046)		
15	0.0076	0.0086	0.0087
20	0.0078	0.0080	0.0093
25	0.0075	0.0079	0.0082

Table 43. The effect of temperature and duration of priming of onion seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on the time to 5% emergence and the time-spread of emergence at 15 C. Data for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Time to 5% emergence (h) (Control: 167)		
15	93.1	72.5	70.0
20	93.7	88.1	73.7
25	94.6	82.4	88.9
	Time-spread of emergence (h) (Control: 90.8)		
15	68.4	77.3	91.1
20	63.2	71.4	67.5
25	69.0	76.4	71.7

in reduced times. This resulted in those seeds treated at 15 C for 21 days having the shortest time. The seeds treated at 15 C for 14 days had the shortest time to the beginning of emergence of those seeds with least affected maximum percentage emergence. The time-spread of emergence of primed onion seeds was reduced by about one-third below that of untreated seeds at 15 C, except that of seeds treated at 15 C for 21 days (Table 43, Appendix Table A1.13). Seeds treated for 7 days at all temperatures had the shortest time-spreads of seeds treated at that temperature. Some seeds germinated in the priming solution. Within 7 days at 25 C 4.5% germinated, after 21 days this increased to 22.5% at 25 C, 26% at 20 C and 36.5% at 15 C.

5.2 THE PRIMING OF CARROT SEEDS USING A COLUMN OF AERATED SOLUTION. (EXPERIMENT 8).

As mentioned in Chapter 1, Darby and Salter (1976) described an apparatus with which it was possible to prime large quantities of small seeds. This apparatus consisted of a perspex column containing an aerator which was attached to a pump. It was filled with a solution of K_3PO_4 + KNO_3. Darby and Salter used this column to prime celery seeds. In this experiment the efficiency of the column method of seed priming was evaluated by comparison with the petri dish method.

5.2.1 Methods

Two columns, one of smaller (28 mm diameter [glass]) and one of larger diameter (50 mm [perspex]) were three-quarter filled with priming solution (0.105M K_3PO_4 + 0.209M KNO_3, -1.6 MPa) and placed in a 15 C constant temperature room. Each column contained an aerator placed beneath a piece of nylon gauze, which was fed from an aquarium pump. Over 1500 carrot seeds (determined by weight) were placed in each column. In addition to supplying oxygen the pumped air kept the solution and seeds agitated and, consequently, well distributed in the column. For comparison eight replicates were primed in petri dishes as for Experiment 7. Both petri dishes and columns were kept at 15 C for 14 days. The solutions in the columns were changed at the same time as the seeds were transferred to new dishes, viz. after two and eight days. After priming, eight replicates from each treatment were sown in emergence trays at 15 C as described for Experiment 7. Emergence was recorded at twelve-hour intervals until complete.

5.2.2 Results

Priming of carrot seeds in a column of aerated solution resulted in emergence responses which were not significantly different from those of seeds primed in petri dishes (Table 44, Appendix Table A1.14), except that the time-spread of emergence of the seeds primed in the smaller column was significantly shorter than that of the seeds primed in the petri dishes, but not of the seeds primed in the larger column. These results were similar to those obtained in Experiment 7, although the time-spreads of emergence of the seeds from all three priming treatments used in Experiment 8 were longer than those of seeds similarly primed in Experiment 7.

Table 44. The effect of priming carrot seeds at 15 C for 14 days in aerated columns of solution of 0.105M K_3PO_4 + 0.209M KNO_3 on their emergence at 15 C. Data for petri dish primed seeds also given.

Petri dish	Small col.	Large col.
	Maximum percentage emergence (%)	
79.8	76.6	75.1
	Median rate of emergence (h^{-1})	
0.0067	0.0070	0.0071
	Time to 5% emergence (h)	
103	106	100
	Time-spread of germination (h)	
80.3	68.5	74.8

5.3 THE EFFECT OF DURATION OF PRIMING IN OPTIMAL SOLUTIONS ON THE GERMINATION OF TOMATO AND CARROT SEEDS. (EXPERIMENT 9).

In order to determine the optimum duration of priming at 15 C an extended range of sampling times, over those used for Experiment 7, were chosen for tomato and carrot seeds in optimal priming solutions.

5.3.1 Methods

Tomato and carrot seeds were placed in columns containing aerated priming solutions. Two solutions, 0.090M K_2HPO_4 + 0.118M KNO_3 (-1.0 MPa) and 0.079M K_3PO_4 (-0.5 MPa) were used for tomato seeds and one solution for carrot seeds, 0.102M K_3PO_4 + 0.204M KNO_3 (-1.5 MPa). These solutions were chosen from the results obtained from Experiments 1 and 2. The solutions were maintained at the same level by addition of water to replace evaporative losses. Solutions were replaced after two, eight and fifteen days. Four replicates were removed from each column and placed in petri dishes on water-moistened U70 papers at two day intervals after commencement until the twenty-second day. Germination was recorded at two-hour intervals for the first sixteen hours, thence at twelve-hour intervals until complete.

5.3.2 Results

5.3.2.1 Tomato Seeds

Increasing the duration of priming of tomato seeds did not significantly affect the maximum percentage germination at 15 C; however, there was a trend towards a reduction in maximum percentages with durations longer than 8 days (Figure 3a, Appendix Table A1.15). The overall linear regressions with duration were statistically significant although these represented a decrease from 96.6% at 0 days to only 91.5% at 22 days. Priming tomato seeds in either solution for only 2 days significantly increased the median rate of germination over that of untreated seeds and this continued to increase linearly with increased duration (Figure 3b, Appendix Table A1.15). There was no significant difference between the two priming solutions in their effect on median rate of germination, M, the lines of best fit with time, t, being

$K_2HPO_4 + KNO_3$ - $M = -0.0041 + 0.0045t$ ($r^2 = 96.9$)

K_3PO_4 - $M = -0.0049 + 0.0047t$ ($r^2 = 93.6$)

That is, there was virtually no effect of priming for less than about 2.2 days, but the median rate increased linearly thereafter to a value some 17 times that of unprimed seeds after 22 days of treatment.

Priming of tomato seeds in either solution for a 2 day period produced seeds which began germination after 101 hours, well before the untreated seeds (134 hours). Increasing the duration of priming reduced the time to the beginning of germination to 3.9 hours for seeds primed in the $K_2HPO_4 + KNO_3$ solution for 22 days and to 2.1 hours for seeds primed in the K_3PO_4 solution for

Figure 3. The effect of duration of priming (t) of tomato seeds in 0.090M K_2HPO_4 + 0.118M KNO_3 (solid squares ■ and solid lines) or in 0.079M K_3PO_4 (open circles ○ and broken lines) at 15 C on:

(a) the maximum percentage germination (A) at 15 C

$K_2HPO_4 + KNO_3$ - $A = 95.8 - 0.200t$ ($r^2 = 31.3$)

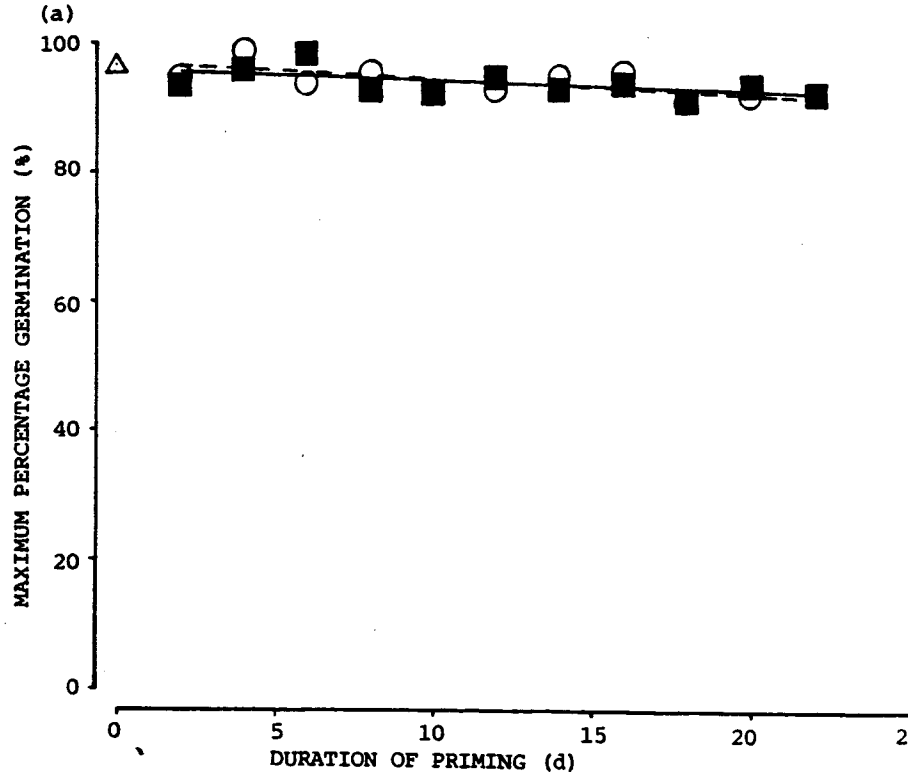
K_3PO_4 - $A = 96.6 - 0.242t$ ($r^2 = 40.1$)

(b) the median rate of germination (M) at 15 C

$K_2HPO_4 + KNO_3$ - $M = -0.0041 + 0.0045t$ ($r^2 = 96.9$)

K_3PO_4 - $M = -0.0049 + 0.0047t$ ($r^2 = 93.6$)

Data for untreated seeds also given (open triangles △).


(a)
MAXIMUM PERCENTAGE GERMINATION (%)
100
80
60
40
20
0
0
5
10
15
20
25
DURATION OF PRIMING (d)

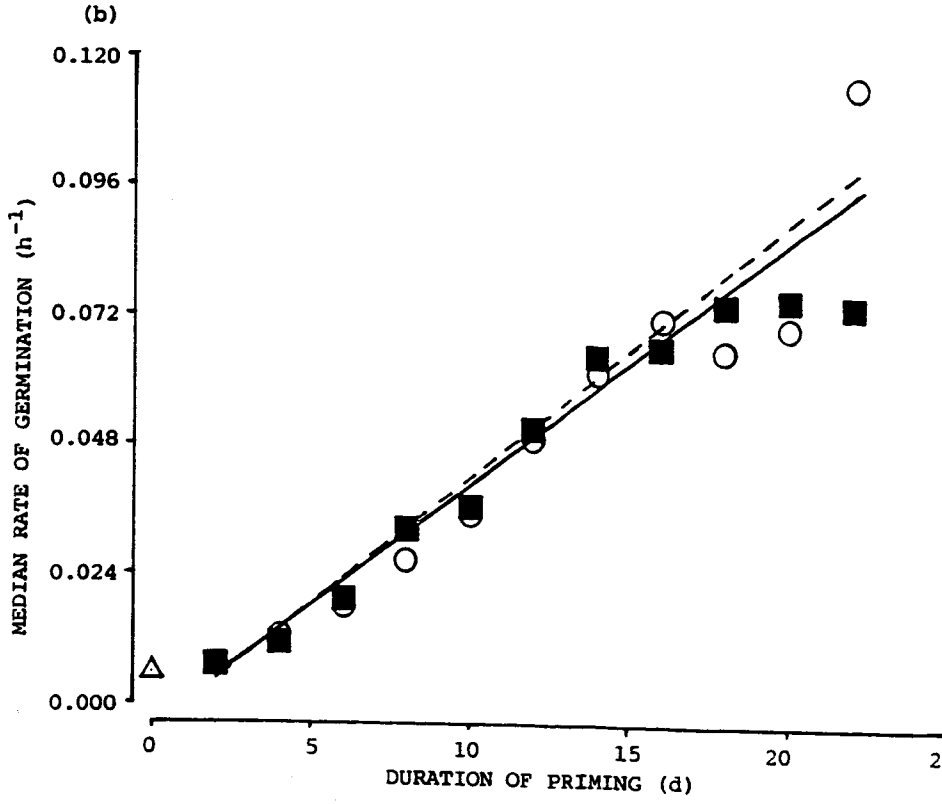

(b)
MEDIAN RATE OF GERMINATION (h^{-1})
0.120
0.096
0.072
0.048
0.024
0.000
0
5
10
15
20
25
DURATION OF PRIMING (d)

Figure 3. The effect of duration of priming (t) of tomato seeds in 0.090M K_2HPO_4 + 0.118M KNO_3 (solid squares ■ and solid lines) or in 0.079M K_3PO_4 (open circles ○ and broken lines) at 15 C on:

(c) the time to 5% germination (T) at 15 C

$K_2HPO_4 + KNO_3$ - $\ln T = 5.45 - 1.36 \ln t$ ($r^2 = 93.9$)

K_3PO_4 - $\ln T = 5.85 - 1.62 \ln t$ ($r^2 = 98.6$)

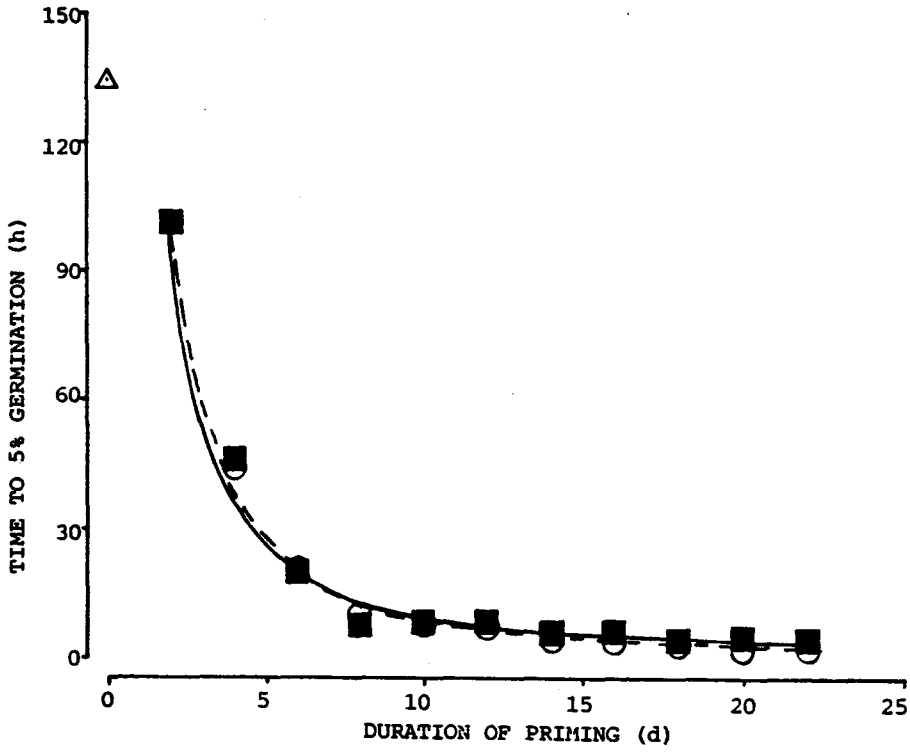
(d) the time-spread of germination (S) at 15 C

$K_2HPO_4 + KNO_3$ - $\ln S = 5.34 - 0.910 \ln t$ ($r^2 = 89.7$)

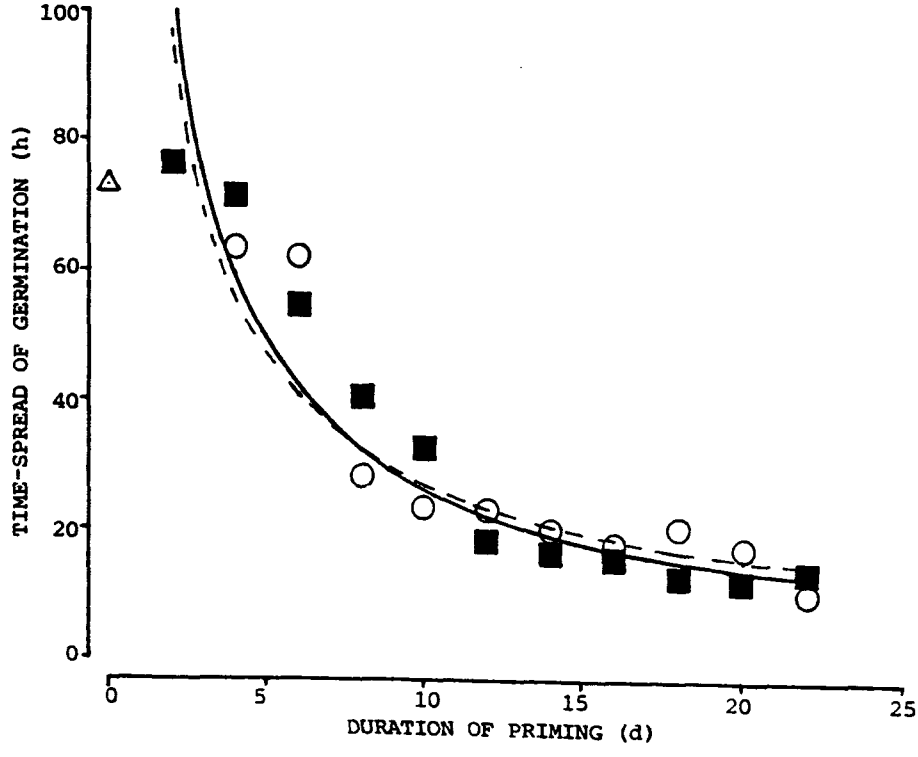
K_3PO_4 - $\ln S = 5.13 - 0.797 \ln t$ ($r^2 = 87.4$)

Data for untreated seeds also given (open triangles △).

(c)


150
120
90
60
30
0
TIME TO 5% GERMINATION (h)
0
5
10
15
20
25
DURATION OF PRIMING (d)

(d)


100
80
60
40
20
0
TIME-SPREAD OF GERMINATION (h)
0
5
10
15
20
25
DURATION OF PRIMING (d)

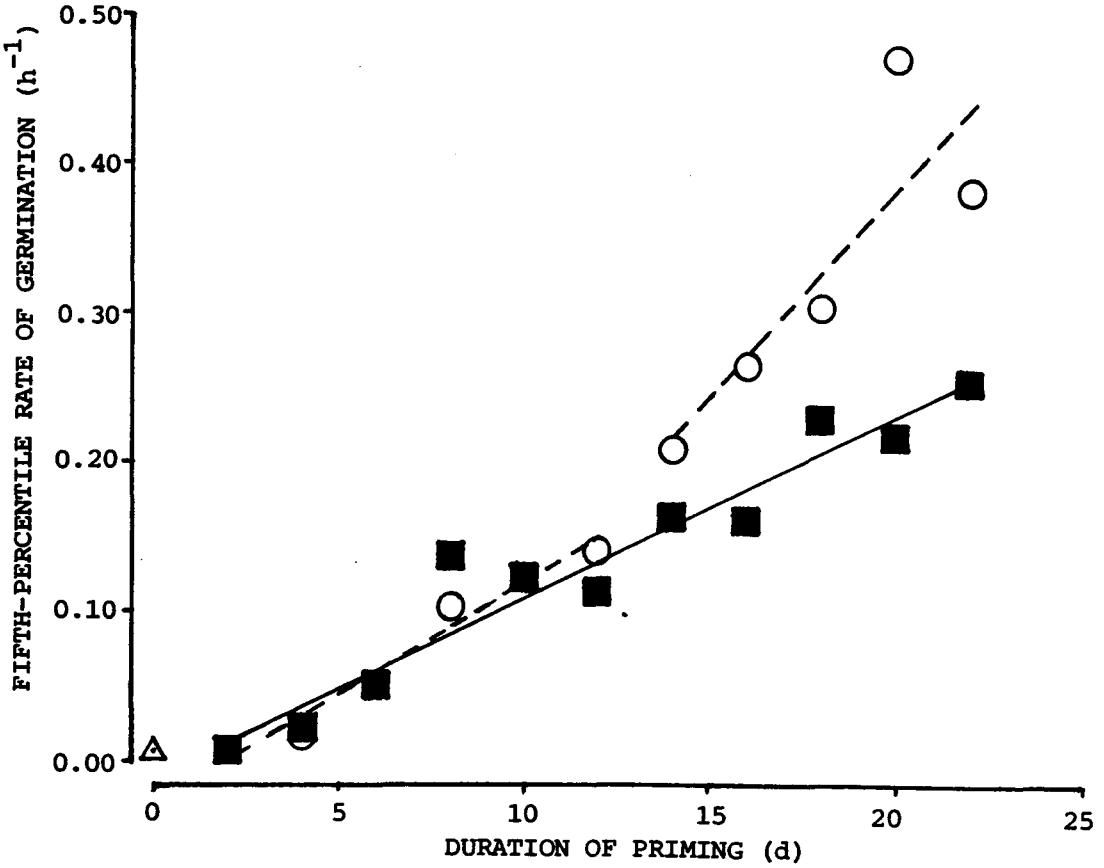
20 days. There was no significant difference between the two solutions on the time to the beginning of germination (Figure 3c, Appendix Table A1.15) or the rate of germination (i.e. the reciprocal of time), which was linear and similar for both solutions until about 12 days. Thereafter, the seeds treated in the K_3PO_4 solution showed an increase in the rate with time, departing from the continuing line which held for the K_2HPO_4 + KNO_3 treated seeds (Figure 4).

Similarly, the time-spread of gemination of primed seeds improved with lengthening of the duration of priming, from 73 hours for untreated seeds to 12.1 hours for seeds primed in the K_2HPO_4 + KNO_3 solution for 20 days and to 10.4 hours for seeds primed in the K_3PO_4 solution for 22 days (Figure 3d, Appendix Table A1.15). Although there was no significant difference between the time-spreads of the seeds from the two solutions, those primed in the K_2HPO_4 + KNO_3 solution had smaller time-spreads than seeds primed in the K_3PO_4 solution, from 12 to 20 days of treatment, this compensating for the somewhat earlier beginning of germination of the seeds from the K_3PO_4 solution. It will be appreciated from Figure 3b that this effect had disappeared by the time the median seed had germinated. The maximal response to priming of tomato seeds was achieved through priming in 0.090M K_2HPO_4 + 0.118M KNO_3 for 18 days, although differences in either solution after about 12 to 14 days were small.

Figure 4. The effect of duration of priming (t) of tomato seeds in 0.090M K_2HPO_4 + 0.118M KNO_3 (solid squares ■ and solid lines) or in 0.079M K_3PO_4 (open circles ○ and broken lines) at 15 C on the rate of germination of the fifth-percentile seed to germinate (R):

$K_2HPO_4 + KNO_3$	-	$R = -0.0085 + 0.0119t$	($r^2 = 92.3$)
K_3PO_4 (2 - 12 days)	-	$R = -0.0256 + 0.0143t$	($r^2 = 95.8$)
K_3PO_4 (14 - 22 days)	-	$R = -0.1729 + 0.0277t$	($r^2 = 63.7$)

Data for untreated seeds also given (open triangles △).


FIFTH-PERCENTILE RATE OF GERMINATION (h^{-1})
0.50
0.40
0.30
0.20
0.10
0.00
0
5
10
15
20
25
DURATION OF PRIMING (d)

5.3.2.2 Carrot Seeds

Increasing the duration of priming of carrot seeds in 0.102M K_3PO_4 + 0.204M KNO_3 (-1.5 MPa) caused a small but significant reduction in the maximum percentage germination, A, which decreased with duration of priming, t:

$$A = 79.4 - 0.52t \qquad (r^2 = 48.4)$$

However, the effect was small, from 74.7% for unprimed seeds to 66.0% after 22 days treatment (Figure 5a). The median rate of germination of primed carrot seeds was significantly faster after 2 days priming, 0.0091 h^{-1} than that of untreated seeds, 0.0067 h^{-1}. The median rate of germination continued to increase with lengthening of the priming treatment, linearly for the first 8 days and curvilinearly thereafter, to reach 0.0402 h^{-1} for seeds primed for 22 days (Figure 5b).

Priming of carrot seeds for a period of 4 days produced seeds with significantly reduced times to the beginning of germination below that of untreated seeds (36.7 hours). Lengthening the duration of priming caused further reductions to 3.3 hours after 20 days of priming (Figure 5c). There were no significant reductions in time to the beginning of germination for seeds primed for periods longer than 12 days. Priming carrot seeds for 2 days significantly reduced the time-spread of germination to 83.8 hours, shorter than that of untreated seeds (119 hours). This process of reduction of time-spread continued with lengthening the duration of priming to produce seeds with a time-spread of germination of 36.6 hours after 22 days priming (Figure 5d). Although only seeds primed for 22 days had a time-spread of germination significantly shorter than that of 4-day-primed seeds (64.7 hours) there was a trend to shorter time-spreads with

Figure 5. The effect of duration of priming (t) of carrot seeds in 0.102M K_3PO_4 + 0.204M KNO_3 at 15 C on:

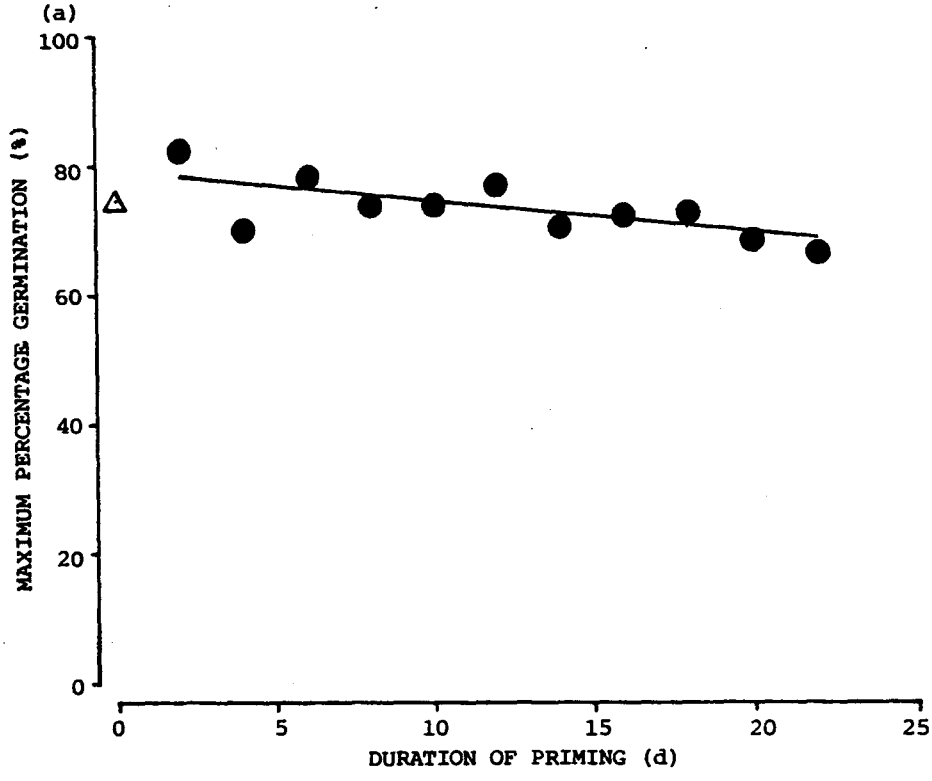
(a) the maximum percentage germination (A) at 15 C

$$A = 79.4 - 0.521t \quad (r^2 = 48.4)$$

(b) the median rate of germination (M) at 15 C

$$M = 0.0108 + 0.0012t \quad (r^2 = 83.2)$$

Data for untreated seeds also given (open triangles △).


(a)
MAXIMUM PERCENTAGE GERMINATION (%)
100
80
60
40
20
0
0
5
10
15
20
25
DURATION OF PRIMING (d)

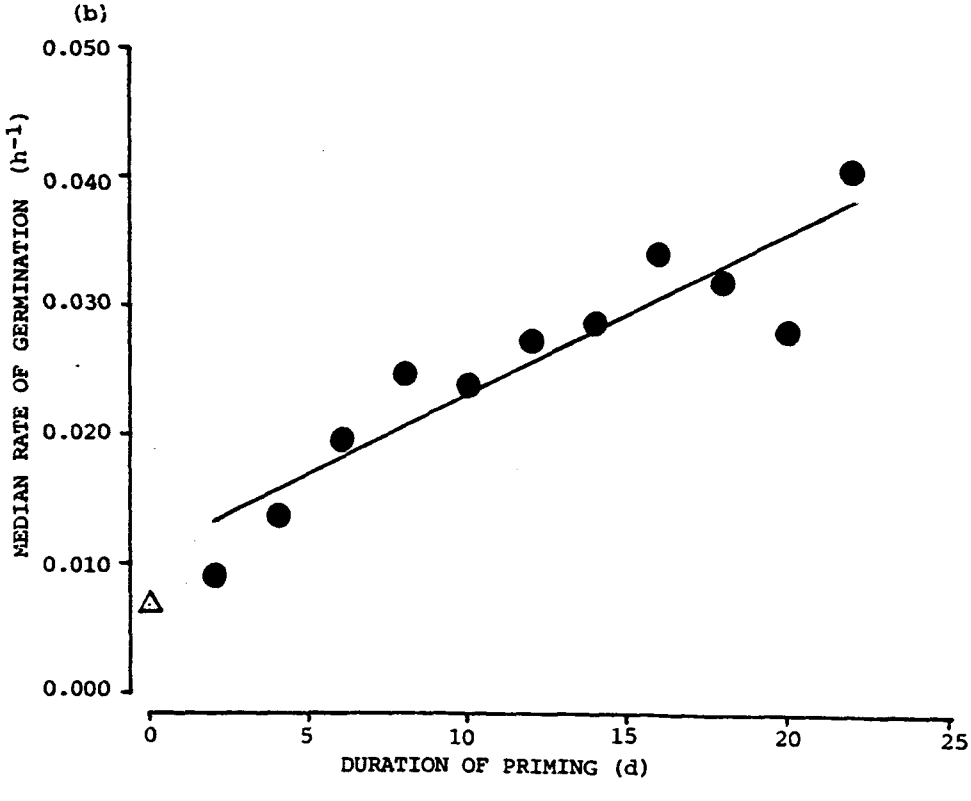

(b)
MEDIAN RATE OF GERMINATION (h-1)
0.050
0.040
0.030
0.020
0.010
0.000
0
5
10
15
20
25
DURATION OF PRIMING (d)

Figure 5. The effect of duration of priming (t) of carrot seeds in 0.102M K_3PO_4 + 0.204M KNO_3 at 15 C on:

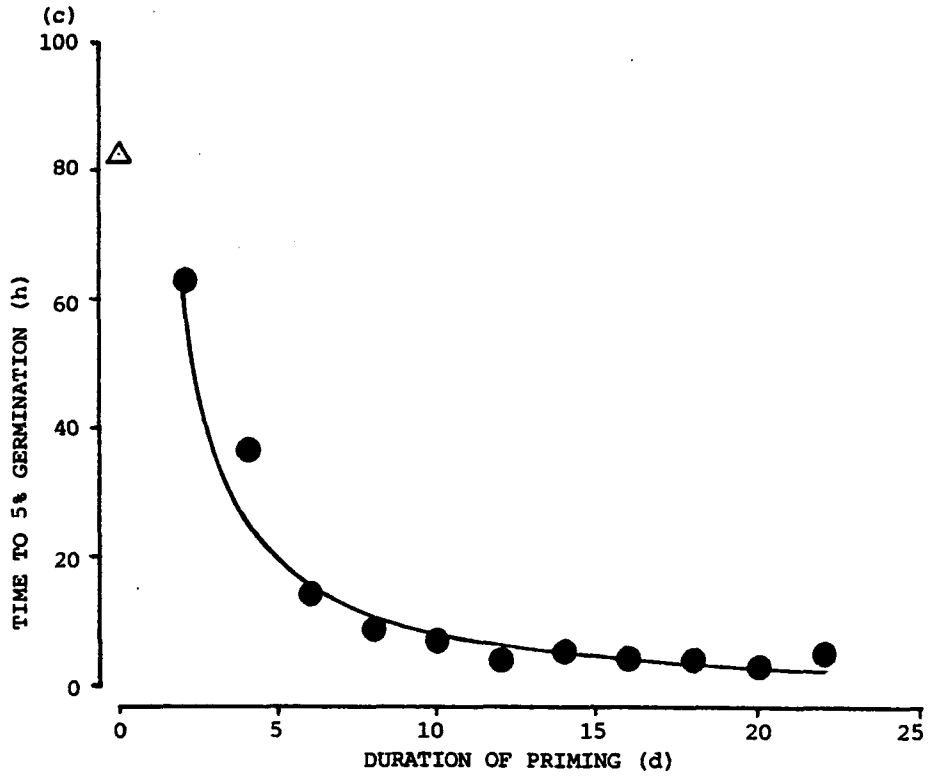
(c) the time to 5% germination (T) at 15 C

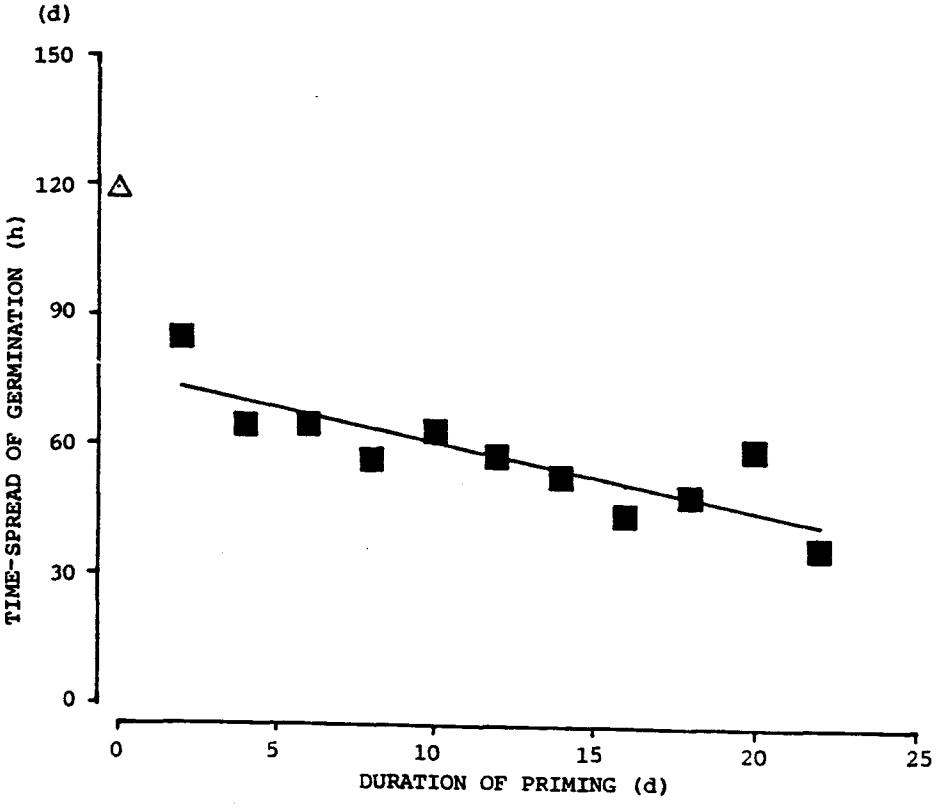
$$\ln T = 4.98 - 1.25 \ln t \quad (r^2 = 92.5)$$

(d) the time-spread of germination (S) at 15 C

$$S = 76.2 - 1.56t \quad (r^2 = 65.3)$$

Data for untreated seeds also given (open triangles △).


(c)
100
80
60
40
20
0
TIME TO 5% GERMINATION (h)
0
5
10
15
20
25
DURATION OF PRIMING (d)


(d)
150
120
90
60
30
0
TIME-SPREAD OF GERMINATION (h)
0
5
10
15
20
25
DURATION OF PRIMING (d)

longer durations of priming. The maximal response was obtained from seeds primed for 16 days, although priming for periods longer than 8 to 10 days caused reductions in the percentage of seeds to germinate.

5.4 THE EFFECTS OF DRYING PRIMED SEEDS. (EXPERIMENT 10).

If primed seeds are to be sown with conventional drilling equipment the seeds must be dried after priming. In order to determine the effects of this drying treatment a series of experiments were undertaken.

5.4.1 Methods

Tomato seeds were primed in 0.105M K_3PO_4 + 0.209M KNO_3 (-1.5 MPa) at 15 C for 14 days in petri dishes, as described for Experiment 7. After priming, four replicates of fifty seeds each were immediately sown in emergence trays at 15 C as described for Experiment 7. The remaining seeds were surface dried then placed on tissue paper and allowed to dry at 15 C. After 1, 2, 4 and 8 days four replicates were sown in emergence trays at 15 C. Emergence was recorded at twelve-hour intervals until complete.

5.4.22 Results

5.4.2.1 Tomato

The drying of primed tomato seeds did not affect the maximum percentage emergence (Table 45, Appendix Table A1.16). Although the median rate of emergence of primed seeds was half that of untreated seeds there was no significant difference between the median rates of primed seeds which had been dried for up to 8 days before sowing (Table 46, Appendix Table A1.16). Similarly, the time to the beginning of emergence of primed seeds was reduced to 116 hours, about half that of untreated seeds, but was

Table 45. The effect of drying following priming, in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days, on the maximum percentage emergence at 15 C of tomato seeds. Data for untreated seeds also given.

Duration of drying (d)				
0	1	2	4	8
Maximum percentage emergence (%) (Control: 95.3)				
90.0	92.3	93.6	87.5	95.6

Table 46. The effect of drying following priming, in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days, on the median rate of emergence at 15 C of tomato seeds. Data for untreated seeds also given.

Duration of drying (d)				
0	1	2	4	8
Median rate of emergence (h^{-1}) (Control: 0.0044)				
0.0077	0.0075	0.0076	0.0076	0.0076

Table 47. The effect of drying following priming, in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days, on the time to the 5% emergence and the time-spread of emergence at 15 C of tomato seeds. Data for untreated seeds also given.

Duration of drying (d)				
0	1	2	4	8
Time to 5% emergence (h) (Control: 198)				
117	119	112	118	115
Time-spread of emergence (h) (Control: 49)				
23.1	23.8	33.2	25.4	30.8

not affected by drying for up to 8 days (Table 47, Appendix Table A1.16). However, the time-spread of emergence of primed seeds was affected by drying, with duration of drying increasing the time-spread from 23 hours for undried primed seeds to 31 hours for 8 day-dried primed seeds. The time-spreads of the 2 and 8 day-dried primed seeds were significantly longer than those of the other primed seeds (Table 47, Appendix Table A1.16).

5.4.2.2 Carrot

Carrot seeds were primed in petri dishes as described for Experiment 7. Following priming, four replicates of fifty seeds each were immediately sown in emergence trays at 15 C as described for Experiment 7. The remaining seeds were surface dried then divided into two groups and kept at 15 C. One half of the seeds were placed in front of a fan in order to hasten the rate of drying while the other half were dried as were tomato seeds. After 1, 2, 4 and 8 days four replicates from each group were sown in emergence trays at 15 C. Emergence was recorded at twelve-hour intervals until complete.

The drying of primed carrot seeds did not significantly affect the maximum percentage emergence (Table 48, Appendix Table A1.17). There was a trend to lower maximum percentages with lengthening of the drying period for non-fan-assisted dried seeds. The median rate of emergence of primed carrot seeds was twice that of untreated seeds. Drying of the primed seeds did not significantly affect the median rate of emergence, but there was a trend towards slower median rates with longer drying times, particularly for the fan-assisted dried seeds (Table 49, Appendix

Table 48. The effect of drying with or without fan assistance following priming, in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days, on the maximum percentage emergence at 15 C of carrot seeds. Data for untreated seeds also given.

	Duration of drying (d)				
	0	1	2	4	8
	Maximum percentage emergence (%) (Control: 66.5)				
fan -	79.1	76.5	75.3	72.4	68.6
fan +	-	76.6	79.1	79.4	71.5

Table 49. The effect of drying with or without fan assistance following priming, in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days, on the median rate of emergence at 15 C of carrot seeds. Data for untreated seeds also given.

	Duration of drying (d)				
	0	1	2	4	8
	Median rate of emergence (h^{-1}) (Control: 0.0038)				
fan -	0.0070	0.0068	0.0072	0.0071	0.0067
fan +		0.0070	0.0071	0.0066	0.0063

Table 50. The effect of drying with or without fan assistance following priming, in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days, on the time to the 5% emergence and the time-spread of emergence at 15 C of carrot seeds. Data for untreated seeds also given.

	Duration of drying (d)				
	0	1	2	4	8
	Time to 5% emergence (h) (Control: 209)				
fan -	99	109	107	101	97
fan +	-	105	101	112	104
	Time-spread of emergence (h) (Control: 103)				
fan -	80.7	68.0	59.2	72.2	94.7
fan +	-	68.6	70.0	70.5	98.9

Table A1.17). Primed carrot seeds had times to the beginning of emergence which were about half that of untreated seeds. There was no effect of length of drying treatment on the time to the beginning of emergence of primed seeds (Table 50, Appendix Table A1.17). Similarly, the time-spread of emergence of primed carrot seeds was not affected by drying, but there was a trend to longer time-spreads for longer periods of drying. These longer time-spreads (97 hours) were similar to that of untreated seeds (103 hours).

5.5 CONCLUSIONS

The results from the foregoing experiments clearly showed that it was possible to prime bulk quantities of seeds and obtain similar results to those of seeds primed in petri dishes. Therefore it should be possible to scale up the treatment for commercial operation. The seeds primed in these experiments showed similar improvements in emergence to those obtained for the germination experiments reported in Chapter 3.

The effects of the temperature and duration of priming were interrelated. All three species showed adverse effects from priming for a long period at 25 C, with longer time-spreads and reduced maximum percentages of emergence by comparison with those seeds primed at lower temperatures for the same period. Tomato seeds were the most robust in their response to temperature and duration, showing comparatively small effects. The results from Experiment 7 indicated that a priming treatment for 14 days at 15 C would give good results for all three species; however, the onion seeds showed a tendency to germinate in the priming solution used here. This was consistent with the results from Experiment 3, where a lower osmotic potential solution of K_3PO_4 + KNO_3 also failed to prevent germination.

The maximum percentage emergence of the primed carrot seeds in Experiment 7 was much higher (80%) than that of those primed seeds in Experiment 2 (60%). Conversely, the maximum percentage emergence of the untreated carrot seeds used in Experiment 7 (66%) was much lower than that of the untreated seeds in Experiment 2 (81%). Consequently, priming of carrot seeds in a -1.5 MPa K_3PO_4 + KNO_3 solution should be judged to not

greatly affect the percentage germination. The results from Experiment 9 showed this. Priming of carrot seeds in Experiment 2 was for a period of 28 days, whereas Experiment 9 revealed that the optimum duration was about 8 to 10 days, longer periods caused a decrease in the number of seeds germinating. In contrast, there was no significant reduction in the maximum percentage germination or emergence for any duration of priming of tomato seeds, although Experiment 9 showed a trend towards lower percentages with longer periods of priming.

The results from Experiment 9 showed that lengthening the duration of priming caused continued improvements in the median rate, the time to the beginning and the time-spread of germination. With tomato seeds the improvements were small after 12 to 14 days; however, carrot seeds showed significant improvements obtained from priming for about 8 to 10 days, but thereafter the decrease in time-spread and slightly increased of germination were offset by the decrease in the number of seeds germinating.

The drying of primed tomato and carrot seeds for up to 8 days did not affect the maximum percentage emergence. Similarly, the median rate of emergence and the time to the beginning of emergence were unaffected; however, the time-spread of emergence was unaffected by 1 or 4 days drying, but 2 and 8 days drying lengthened the time-spread of emergence.

Generally, provided the temperature and duration used were appropriate it was possible to prime large quantities of seeds and obtain effects similar to those of petri-dish priming of smaller quantities. The lack of any significant effect from

drying of the seeds following priming indicated further possibilities for large scale operation using conventional drilling equipment.

CHAPTER 6

FIELD EMERGENCE OF PRIMED SEEDS

(EXPERIMENT 11)

Before priming can be judged to be a successful seed treatment it must be evaluated in the field. A small scale field trial of primed seeds was undertaken to determine the effects of priming on crop establishment, it not being possible to follow the plants through to maturity.

6.1 METHODS

Seeds of tomato, carrot and onion were primed for 14 days at 15 C in bulk in separate perspex columns containing an aerated solution of 0.105M K_3PO_4 + 0.209M KNO_3 (-1.6 MPa). In order to obtain a range of soil temperatures the seeds were planted in the spring of 1981 from early September through to mid-October at the Agricultural Research Centre, Yanco, there being five sowing times. A comparison of post-priming air-drying times ranging from one, through seven and fourteen days to twenty-eight days drying prior to sowing was also included.

The seeds were sown in 1.5 metre wide beds prepared by rotary-hoe cultivation of a sandy clay loam soil. The trial plot was watered by sprinkler irrigation on a daily basis or as required to maintain field capacity. The sowing arrangements for each species were as follows:

Tomato - a replicate consisted of a five metre length of bed, one and one half metres wide, into which two rows of seeds were sown 300 mm apart. The seeds were hand sown in individual holes 25 mm deep and 50 mm apart. Each replicate contained 200 seeds.

Carrot - a replicate consisted of a two and one half metre length of bed. The seeds were hand sown in two "scatter" bands 200 mm wide and 20 mm deep. The density aimed for was one seed per 500 mm^2, resulting in 2000 seeds per replicate.

Onion - a replicate consisted of a two and one half metre length of bed into which were sown four rows of seeds. The seeds were placed individually into 25 mm deep holes at 25 mm intervals within a row. This resulted in 400 seeds per replicate.

There were four replicates of each treatment allocated at random within seperate beds for each species. Records were made of emergence of a sample within each plot - 1 metre length of bed for tomato and onion, 0.25 metre length for carrot seeds. Similar observations were made of the time of appearance of the first true leaves within the carrot and tomato plots. Observations were made twice daily.

6.2 RESULTS

6.2.1 Tomato

The priming of tomato seeds resulted in a higher maximum percentage field emergence at all sowing dates. On average the maximum percentage field emergence of primed seeds was 9% higher than unprimed seeds. Although the difference was not significant

Table 51. The effect of priming tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the maximum percentage field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
		Maximum percentage field emergence (%)		
6.9.81	5.9	27.8	75.6	82.9
17.9.81	10.9	28.9	71.9	81.8
1.10.81	8.7	30.3	71.1	79.4
7.10.81	8.9	35.7	65.9	79.6
22.10.81	11.1	39.0	60.1	69.8
Mean			69.1	78.9

Table 52. The effect of priming tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the median rate of field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
		Median rate of field emergence (h^{-1})		
6.9.81	5.9	27.8	0.0043	0.0070
17.9.81	10.9	28.9	0.0036	0.0079
1.10.81	8.7	30.3	0.0043	0.0058
7.10.81	8.9	35.7	0.0047	0.0074
22.10.81	11.1	39.0	0.0057	0.0068
Mean			0.0045	0.0069

at every sowing the mean of all sowing dates were significantly different (Table 51, Appendix Table A1.18) as was a t-test of differences between treatments at each sowing date. There was a trend towards lower maximum percentages from the early to the late sowings. This trend was more marked in untreated tomato seeds. This reduction in maximum percentage with sowing date may have resulted from the crusting nature of the soil which became more pronounced as the season developed. The median rate of field emergence of primed seeds was significantly faster than that of untreated at all sowing dates, with mean median rates of 0.0069 h^{-1} for primed seeds and 0.0045 h^{-1} for untreated seeds (Table 52, Appendix Table A1.18).

Priming significantly reduced the time to the beginning of field emergence of tomato seeds at all sowing dates from 6/9/81 to 22/10/81. On average the time to the beginning of field emergence was reduced by 37% (179 hours to 113 hours) (Table 53, Appendix Table A1.18). The time-spread of field emergence of primed seeds was less than that of untreated seeds for all sowings, except October 22. The mean time-spreads of primed seeds were 36% shorter than that of untreated seeds (72 vs 49 hours), but improvements at individual sowings were as high as 67% (7/10/81) (Table 53, Appendix Table A1.18). The longest time-spread for both primed and untreated seeds was for the September 17 sowing. This was despite the fact that at this sowing the primed seeds had the shortest time to the beginning of field emergence and the fastest median rate of all sowings. It probably resulted from slow emergence of the late emerging seeds caused by the low soil temperatures after the first seeds had emerged at higher soil temperatures.

Table 53. The effect of priming tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the time to 5% field emergence and the time-spread of field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
		Time to 5% field emergence (h)		
6.9.81	5.9	27.8	185	119
17.9.81	10.9	28.9	209	81
1.10.81	8.7	30.3	201	153
7.10.81	8.9	35.7	155	112
22.10.81	11.1	39.0	154	114
Mean			179	113
		Time-spread of field emergence (h)		
6.9.81	5.9	27.8	88.1	39.1
17.9.81	10.9	28.9	127	84.6
1.10.81	8.7	30.3	54.7	36.4
7.10.81	8.9	35.7	106	38.6
22.10.81	11.1	39.0	42.1	61.1
Mean			77.1	49.1

Table 54. The effect of post-priming air-drying of tomato seeds on their field emergence. Data for untreated seeds also given. Seeds were sown in conjunction with October 22 sowing.

Duration of drying (d) 1	7	14	28
Maximum percentage field emergence (%) (Control: 60.1)			
69.8	75.9	67.7	62.6
Median rate of field emergence (h^{-1}) (Control: 0.0057)			
0.0068	0.0070	0.0067	0.0070
Time to 5% field emergence (h) (Control: 154)			
114	114	114	117
Time-spread of field emergence (h) (Control: 42.1)			
61.1	52.4	65.7	49.3

Air-drying seeds for up to 28 days prior to sowing had no significant effect on the priming response of tomato seeds (Table 54, Appendix Table A1.19).

The percentage of emerged seedlings reaching the first true leaf stage was not different between the primed and unprimed treatments (91.3%, Table 55, Appendix Table A1.20). However, seedlings from the priming treatment reached the first true leaf stage significantly faster than those of untreated seedlings at all sowings except October 22, with mean median rates of 0.0027 h^{-1} for primed seedlings and 0.0022 h^{-1} for untreated seedlings (Table 56, Appendix Table A1.20). Similarly, the time to the beginning of attainment of first true leaves was significantly faster for primed seedlings at all sowings except October 22. There was a reduction in time to the beginning of attainment of first true leaf stage from early to late sowings, with the September 17 sowing having the longest time, 411 hours (primed seedlings), reflecting lower temperatures and the October 22 sowing the shortest, 263 hours (primed) (Table 57, Appendix Table A1.20). The time-spread of attainment of first true leaves was shorter for primed seedlings, mean time-spread of 82 hours, than that of untreated seedlings, mean of 120 hours (Table 57, Appendix Table A1.20).

Table 55. The effect of priming tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the maximum percentage of seedlings to attain first true leaves.

Sowing date	Control	Primed
	Maximum percentage of attainment of first true leaves (%)	
6.9.81	90.6	93.5
17.9.81	88.2	98.4
1.10.81	87.6	94.2
7.10.81	96.4	82.8
22.10.81	92.4	81.5
Mean	91.3	91.3

Table 56. The effect of priming tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the median rate of attainment of first true leaves.

Sowing date	Control	Primed
	Median rate of attainment of first true leaves (h^{-1})	
6.9.81	0.0019	0.0025
17.9.81	0.0019	0.0022
1.10.81	0.0023	0.0028
7.10.81	0.0024	0.0031
22.10.81	0.0028	0.0029
Mean	0.0022	0.0027

Table 57. The effect of priming tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the time to 5% attainment of first true leaves and the time-spread of attainment of first true leaves.

Sowing date	Control	Primed
Time to 5% attainment of first true leaves (h)		
6.9.81	429	364
17.9.81	481	411
1.10.81	373	316
7.10.81	368	284
22.10.81	270	263
Mean	377	323
Time-spread of attainment of first true leaves (h)		
6.9.81	165	56.2
17.9.81	98.7	72.4
1.10.81	103	84.3
7.10.81	101	74.2
22.10.81	147	147
Mean	120	82.2

6.2.2 Carrots

There was no significant difference between the maximum percentage field emegence of primed carrot seeds and that of untreated seeds; however, the untreated seeds had a higher maximum percentage at the September 5 sowing (89%) to that of the primed seeds (68.8) while the primed seeds had a higher maximum percentage (66.7) at the September 17 sowing to that of untreated seeds (36.9%) (Table 58, Appendix Table A1.21). With primed seeds there was a trend to lower maximum percentages from early to late sowings, with the untreated seeds this trend was disturbed by the low maximum percentage for the September 17 sowing. The median rate of field emergence of primed seeds was significantly faster at all sowings than that of untreated seeds, with mean median rates of 0.0045 h^{-1} for primed seeds and 0.0031 h^{-1} for untreated seeds (Table 59, Appendix Table A1.21).

Priming reduced the time to the beginning of emergence at all sowings by an average of 39 percent (167 hours vs 276 hours). priming had the greatest effect on the time to the beginning of emergence at the first sowing when the soil temperature was lowest (143 hours vs 303 hours) (Table 60, Appendix Table A1.21). The mean time-spread of field emergence of primed seeds, 107 hours, was significantly longer than that of untreated seeds, 92.4 hours; however, except at the September 17 sowing the differences between primed and untreated seeds were not significant (Table 60, Appendix Table A1.21).

Table 58. The effect of priming carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the maximum percentage field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
			Maximum percentage field emergence (%)	
5.9.81	5.6	30.6	89.1	68.8
17.9.81	10.9	28.9	36.9	66.7
30.9.81	8.6	29.8	53.6	52.1
7.10.81	8.9	35.7	49.5	45.8
Mean			59.8	58.8

Table 59. The effect of priming carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the median rate of field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
			Median rate of field emergence (h^{-1})	
5.9.81	5.6	30.6	0.0030	0.0044
17.9.81	10.9	28.9	0.0029	0.0047
30.9.81	8.6	29.8	0.0032	0.0043
7.10.81	8.9	35.7	0.0032	0.0045
Mean			0.0031	0.0045

Table 60. The effect of priming carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the time to 5% field emergence and the time-spread of field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
		Time to 5% field emergence (h)		
5.9.81	5.6	30.6	274	166
17.9.81	10.9	28.9	303	143
30.9.81	8.6	29.8	261	191
7.10.81	8.9	35.7	270	173
Mean			276	167
		Time-spread of field emergence (h)		
5.9.81	5.6	30.6	98.0	115
17.9.81	10.9	28.9	85.2	127
30.9.81	8.6	29.8	95.8	88.6
7.10.81	8.9	30.7	91.0	99.9
Mean			92.4	107

Table 61. The effect of post-priming air-drying of carrot seeds on their field emergence. Data for untreated seeds also given. Seeds were sown in conjunction with September 5 sowing.

Duration of drying (d) 1	7	14	28
Maximum percentage field emergence (%) (Control: 89.1)			
68.7	84.4	73.6	69.5
Median rate of field emergence (h^{-1}) (Control: 0.0030)			
0.0044	0.0047	0.0046	0.0048
Time to 5% field emergence (h) (Control: 274)			
166	150	164	161
Time-spread of field emergence (h) (Control: 98)			
115	112	97	86

Air-drying of primed carrot seeds for 1 and 28 days resulted in lower maximum percentage field emergence than that of untreated seeds. There was no significant difference between drying periods in their effects on maximum percentage field emergence, median rate of field emergence nor on time to the beginning of field emergence; however, air-drying for 28 days caused a significant reduction of the time-spread from that of seeds dried for 1 or 7 days, but these time-spreads were not significantly different from that of the untreated seeds (Table 61, Appendix Table A1.22).

The priming of carrot seeds did not affect the maximum percentage of seedlings to attain the fist true leaf stage of development, with mean maximum percentages of 80% for primed seedlings and 75.5% for untreated seedlings (Table 62, Appendix Table A1.23). The primed seedlings attained their first true leaves at median rates which were faster than those of untreated seeds, mean median rates of 0.0022 h^{-1} for primed seedlings and 0.0018 h^{-1} for untreated seedlings (Table 63, Appendix Table A1.23). The time to the beginning of attainment of first true leaves of primed seedlings was shorter than that of untreated seedlings at all sowings, mean times were 379 hours (primed) and 489 hours (untreated) (Table 64, Appendix Table A1.23). However, there was no difference in the time-spread of attainment between primed seedlings, mean time-spread of 131 hours, and untreated seedlings, mean of 114 hours, although the time-spread of primed seedlings at the September 5 sowing was significantly longer (185 hours) than that of untreated seedlings (116 hours) (Table 64, Appendix Table A1.23).

Table 62. The effect of priming carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the maximum percentage of seedlings to attain first true leaves.

Sowing date	Control	Primed
	Maximumpercentage of attainment of first true leaves (%)	
5.9.81	87.0	91.0
17.9.81	60.2	73.2
30.9.81	96.1	96.9
7.10.81	41.8	40.9
Mean	75.5	79.9

Table 63. The effect of priming carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the median rate of attainment of first true leaves.

Sowing date	Control	Primed
	Median rate of attainment of first true leaves (h^{-1})	
6.9.81	0.0016	0.0020
17.9.81	0.0017	0.0021
30.9.81	0.0020	0.0024
7.10.81	0.0020	0.0024
Mean	0.0018	0.0022

Table 64. The effect of priming carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the time to 5% attainment of first true leaves and the time-spread of attainment of first true leaves.

Sowing date	Control	Primed
Time to 5% attainment of first true leaves (h)		
5.9.81	564	384
17.9.81	517	423
30.9.81	435	348
7.10.81	451	365
Mean	489	379
Time-spread of attainment of first true leaves (h)		
5.9.81	116	185
17.9.81	111	110
30.9.81	117	133
7.10.81	110	108
Mean	114	131

6.2.3 Onions

The priming of onion seeds resulted in maximum percentage field emergence that was about half that of untreated seeds, with mean maximum percentages of 32.4% for primed seeds and 60.2% for untreated seeds (Table 65, Appendix Table A1.24). However, the mean median rate of field emergence of primed seeds was significantly faster than that of untreated seeds, probably due to the lower maximum percentages (Table 66, Appendix Table A1.24). The time to the beginning of field emergence of primed seeds was shorter for the September 17 sowing (190 hours) than that of untreated seeds (240 hours). At other sowings there was no difference (Table 67, Appendix Table A1.24). There was no difference in time-spread between primed and untreated seeds, with mean time-spreads of 109 hours (primed) and 102 hours (untreated) (Table 67, Appendix Table A1.24).

The air-drying of primed onion seeds for 14 days caused a reduction in the maximum percentage field emergence below that of primed seeds dried for 1 or 28 days. There was no effect of air-drying treatment on the median rate of field emergence, the time to the beginning of field emergence nor on the time-spread of field emergence. The low time-spread value (98 hours) for the 14 day-dried primed seeds resulted from the low maximum percentage emergence of these seeds (21%) (Table 68, Appendix Table A1.25).

Table 65. The effect of priming onion seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the maximum percentage field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
			Maximum percentage field emergence (%)	
5.9.81	5.6	30.6	65.3	33.3
17.9.81	10.9	28.9	61.2	38.3
30.9.81	8.6	29.8	53.9	25.4
Mean			60.2	32.4

Table 66. The effect of priming onion seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the median rate of field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
			Median rate of field emergence (h^{-1})	
5.9.81	5.6	30.6	0.0034	0.0035
17.9.81	10.9	28.9	0.0032	0.0038
30.9.81	8.6	29.8	0.0038	0.0042
Mean			0.0035	0.0038

Table 67. The effect of priming onion seeds in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on the time to 5% field emergence and the time-spread of field emergence. Seven day mean maximum and minimum soil temperatures at 5mm also given.

Sowing date	Soil temp. (C) Min.	Max.	Control	Primed
		Time to 5% field emergence (h)		
5.9.81	5.6	30.6	231	221
17.9.81	10.9	28.9	240	190
30.9.81	8.6	29.8	229	208
Mean			233	206
		Time-spread of field emergence (h)		
5.9.81	5.6	30.6	110	130
17.9.81	10.9	28.9	139	136
30.9.81	8.6	29.8	70.0	73.2
Mean			102	109

Table 68. The effect of post-priming air-drying of onion seeds on their field emergence. Data for untreated seeds also given. Seeds were sown in conjunction with September 5 sowing.

Duration of drying (d) 1	7	14	28
Maximum percentage field emergence (%) (Control: 65.3)			
33.2	28.9	21.0	39.8
Median rate of field emergence (h^{-1}) (Control: 0.0034)			
0.0035	0.0035	0.0036	0.0035
Time to 5% field emergence (h) (Control: 231)			
221	232	238	223
Time-spread of field emergence (h) (Control: 110)			
130	117	98.2	127

6.3 CONCLUSIONS

The priming of tomato seeds resulted in a higher percentage field emergence at all sowing dates. Drying following priming did not affect the maximum percentage field emergence. The primed tomato seeds showed improvements in the median rate of field emergence, the time to the beginning of emergence and in the time-spread of field emergence. The results for the attainment of first true leaves showed similar trends to those seen in the field emergence data.

The priming of carrot seeds did not affect the percentages of plants emerging and reaching the first true leaf stage, it improved the median rate of field emergence, and reduced the time to the beginning of field emergence by up to 50%; however, the time-spread of field emergence of primed seeds was longer than that of untreated seeds. The air-drying of primed carrot seeds did not affect their response.

The priming of onion seeds resulted in a markedly decreased emergence response. This is in contrast to the results from Experiment 7, where the same priming treatment (except that it was there performed in petri dishes) produced seeds with maximum percentages of germination equal to that of the untreated seeds (Table 41). This difference may have resulted from the drying treatments given to all primed seeds in Experiment 11.

Thus, in this experiment, priming of tomato seeds indicated likely benefits that were maintained over the period of observation. However, it was not possible to follow the plants through to maturity to see if uniformity of fruit yield was

achieved. Carrots behaved less satisfactorily although the treatment could be useful where earlier emergence is desired and uniformity is less essential. The treatment was deemed to have failed with onions. These aspects will be explored further in the next section.

CHAPTER 7

DISCUSSION

7.1 PRIMEABLE SEEDS

The effects of priming on the germination responses of four species were explored in this thesis; these were ones in which it is believed that improved uniformity of establishment and/or earlier emergence in cold soils would be advantageous. The results of the series of exploratory empirical experiments that were made indicated that tomato seeds were readily primed in any of a series of salt solutions or in PEG solution. The next most tractable species was carrot for which any of the solutions tried was adequate, but in which prolonged treatment led to impaired germination of a proportion of seeds; for this species it would seem that 8 to 10 days priming is adequate whereas tomato showed improved performance after priming for 16 to 18 days. It appeared that onion could be primed in either K_2HPO_4, K_3PO_4 or PEG solutions. All salt solutions were toxic to sorghum or failed to prevent germination, although the results of Experiment 4 suggested that PEG at -2 to -2.25 MPa may be effective. These results agree with Roberts' (1948) finding that different salts of a given element do not give similar results with different species when used for seed soaking. As Roberts suggested it is necessary to determine both the most suitable salt(s) and concentration to maximise the effects.

No attempt has been made to explore the reasons for these differences between species. They possibly reflect differences

in seed composition and form. Embryo growth occurred in carrot seeds during priming and has been claimed to be the most important factor leading to enhanced germination (Wiebe and Tiessen, 1979). The increase in embryo size of carrot seeds during hardening and presumably during priming, is due mainly to cell division (Austin et al, 1969); however, Coolbear and Grierson (1979) reported unchanged levels of DNA after priming of tomato seeds, indicating little likelihood of nuclear and, therefore, cell division during the priming of tomato seeds. Moreover, improvements in uniformity of germination and emergence of primed carrot seeds were found to be much smaller than those of primed tomato seeds as evidenced by the results from Experiment 10. This difference may have been attributable to differences in embryo growth during priming, although no measurements were made of such growth. In this sense then, priming may be seen as an extension of the maturation process of seed development.

7.2 EFFECTS OF SALTS

Seeds have been shown to take up salts when placed in salt solutions (Roberts, 1948; Daster and Mone, 1958; Majury, 1981) and the presence of salts in soaking solutions enhances germination (Roberts, 1948; Hegarty, 1970). Dastur and Mone (1958) were able to demonstrate that the salts were preferentially distributed within the seed. Cotton seeds soaked in a solutions of KNO_3 for 6 hours showed a very small (0.2%) increase in nitrogen content of the embryo and a much larger increase in the testa. Seeds soaked in KH_2PO_4 solutions showed increases in potassium and phosphate content only in the testa. Majury (1981) showed that sorghum seeds took up higher levels (on

a dry weight basis) of phosphate from a K_3PO_4 + KNO_3 solution than did tomato seeds, although tomato also took up measurable amounts. No attempt has been made to take this observation further; for example, it is possible that PO_4^{3-}, K^+ and NO_3^- may be held in the seed coats of tomato, but are readily accessible to the embryo of sorghum. Priming of tomato seeds in a solution containing manganese reportedly supplied the manganese requirements of tomato plants grown in manganese-deficient nutrient solutions for approximately 40 days (Traverse and Riekels, 1973). However, it remains unclear whether seeds derive any significant nutritional benefit from the salts taken up during priming using salts of the major plant nutrients, although Roberts' (1948) remarkable yield improvements for barley and oat seeds soaked in nutrient solutions and grown in nutrient-deficient soils indicate that the possibility may exist.

The results from Chapter 3 showed that tomato and carrot seeds primed in solutions which contained KNO_3 showed shorter time-spreads of germination than those from solutions which did not. Similarly, Hegarty (1970) demonstrated that a KNO_3 solution used for pre-sowing drought-hardening of carrot seeds was more beneficial than water alone. The presence of nitrate during imbibition may provide additional substrate for amino acid synthesis. As indicated by Khan et al (1981) protein synthesis may be integral to the enhancement of germination caused by priming. Thus, the presence of nitrate in the priming solution may permit further protein synthesis which improves the germination response of the primed seed population. However, seeds have differing capacities to reduce nitrate and this may cause the observed differences in response. These issues can only be explored by detailed biochemical studies.

Most of the experiments reported here were made with K_3PO_4 + KNO_3 as the osmoticum. This procedure was adopted following previous experience (Table 2) and because PEG is such a difficult substance to use, especially with large quantities of seeds (Peterson, 1976) - due to its tendency to breakdown to toxic products (Greenway et al, 1968) and to retard the diffusion of oxygen (Mexal, Fisher, Osteryoung and Reid, 1975). However, the results from Chapter 3 indicated that, with adequate precautions, PEG was overall the safest material to use, although lower osmotic potentials were needed to retard germination than with salt solutions. This in itself was puzzling as all the evidence indicated that salts were absorbed, even if they did not reach the embryo. Comparable effects were obtained from priming tomato and carrot seeds in appropriate salt solutions as from priming in PEG solutions. This agrees with the results of Bussell and Gray (1976); Gray and Steckel (1977); Rumpel and Szudyga (1970); Wiebe and Tiessen (1979). Similar to Bussell and Gray (1976) tomato seeds were found to prime best in a salt solution; however, the solution found best (K_2HPO_4 + KNO_3) was not the one used by Bussell and Gray (1976) (K_3PO_4 + KNO_3). In contrast, Sachs (1977) obtained the best results from priming watermelon seeds with KNO_3 solutions.

7.3 EFFECTS OF TEMPERATURE

The effects of the temperature and duration of priming were interrelated (Experiment 7). Priming for too long a period caused a reduction in the percentage of seeds germinating. There was greater benefit to the population of seeds from priming at a lower temperature (15 C) for a longer time than at higher temperatures. However, this aspect of priming has not been

explored in any detail and it is quite possible that temperatures lower than 15 C could be suitable. Different species have different minimum temperatures for germination, of course, so low temperature itself could prevent germination for a certain period. Nevertheless, it is believed that the benefits of priming arise from metabolic reactions proceeding during treatment, so too low a temperature may prove counter-productive. There is need to explore more fully the effect of priming temperatures on a range of species and to relate this to detailed studies of the metabolic reactions proceeding.

7.4 LARGE SCALE PRIMING

The results from Experiment 8 clearly demonstrate that it is possible to prime large numbers of seeds in salt solutions using an apparatus based upon the design of Darby and Salter (1976), and obtain comparable results to priming in petri dishes. Moreover, the maintenance of the germination benefits after drying following priming of tomato and carrot seeds in salt solutions (Experiments 10 and 11) point to the likelihood of a commercial-scale priming treatment. This is in contrast to the lack of a large scale treatment using PEG as pointed out by Adegbuyi *et al* (1981). However, it is not yet clear that difficulties associated with an aerated PEG solution will prove insurmountable on a large scale.

7.5 PRIMED SEEDS IN THE FIELD

The results from the limited investigations of Experiment 11 showed that effective means for priming large quantities of tomato seeds could be devised which produced benefits at

emergence that were maintained at least to the first true leaf stage. Moreover, the primed tomato seeds had a higher percentage emergence as well as improved times to emergence and uniformity of emergence over those of untreated seeds in the field. Although less satisfactory, carrot seeds could be similarly primed in bulk, and produced earlier emerging seedlings in the field. While these results may be favourable there is a long period from emergence to maturity which needs investigation. It is essential to extend these experiments to ascertain whether the advantages are maintained throughout development and growth. Szafirowska et al (1981) have shown that PEG-primed carrot seeds produced crops with yields increased by up to 93%, in small field plots sown in cold soil.

7.6 CONCLUSIONS

The general principles that emerge from this study are: (i) that it seems possible to prime any seed provided that a non-toxic solution which prevents germination can be found; (ii) that this solution should have the highest osmotic potential needed to prevent germination at the temperature and for the period of priming; (iii) that priming should not be of too long a duration although this varies with species; and (iv) the temperature should be relatively low.

Satisfying these requirements in a priming treatment will enable the production of seeds which are capable of more rapid and uniform germination, particularly at suboptimal soil temperatures, which may lead to increases in crop uniformity and yield at maturity.

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APPENDIX 1

Table A1.1. The effect of osmoticum and osmotic potential on the germination of tomato seeds. Transformed values together with standard errors of the means given in brackets. Values of seeds germinated in water also given.

Osmotic potential	Osmoticum					
	K_2HPO_4	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3	K_3PO_4	PEG
(MPa)	Maximum percentage germination (rad) (H_2O: 1.36[0.226])					
	(0.063)	(0.067)	(0.062)	(0.092)	(0.169)	(0.086)
-0.25	1.30	1.35	1.42	1.38	1.06	1.33
-0.50	0.722	1.27	1.19	1.13	0.0	1.29
-0.75	0.0	0.878	1.05	0.845	0.0	0.736
-1.00	0.0	0.0	1.09	0.217	0.0	0.0
-1.25	0.0	0.0	0.0	0.0	0.0	0.0
-1.50	0.0	0.0	0.0	0.0	0.0	0.0
-1.75	0.0	0.0	0.0	0.0	0.0	0.0
	Median rate of germination (ln) (H_2O: -4.89[0.067])					
	(0.063)	(0.043)	(0.059)	(0.030)	(0.045)	(0.046)
-0.25	-5.48	-5.36	-5.21	-5.64	-6.08	-5.51
-0.50	-6.40	-5.94	-5.92	-6.26	-	-5.77
-0.75	-	-6.35	-6.18	-6.76	-	-6.28
-1.00	-	-	-6.56	-6.75	-	-
	Time to 5% germination (ln) (H_2O: 4.63[0.089])					
	(0.076)	(0.055)	(0.081)	(0.037)	(0.067)	(0.063)
-0.25	5.16	5.02	4.92	5.34	5.78	5.27
-0.50	6.07	5.58	5.51	5.90	-	5.48
-0.75	-	5.92	5.80	6.34	-	5.92
-1.00	-	-	6.02	6.56	-	-
	Time-spread of germination (ln) (H_2O: 3.98[0.331])					
	(0.110)	(0.149)	(0.068)	(0.081)	(0.067)	(0.069)
-0.25	4.75	4.64	4.41	4.89	5.29	4.54
-0.50	5.72	5.30	5.43	5.63	-	4.95
-0.75	-	5.84	5.62	6.29	-	5.71
-1.00	-	-	6.26	5.94	-	-

APPENDIX 1

Table A1.2. The effect of osmoticum and osmotic potential of treatment solution on the subsequent germination of tomato seeds. Transformed values together with standard errors of the means given in brackets. Values of untreated seeds germinated in water also given.

Osmotic potential	Treatment solution					
	K_2HPO_4	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3	K_3PO_4	PEG
(MPa)	Maximum percentage germination (rad) (H_2O: 1.36[0.226])					
	(0.084)	(0.069)	(0.040)	(0.050)	(0.052)	(0.068)
-0.50	-	-	-	-	1.16	-
-0.75	1.28	-	-	-	1.21	-
-1.00	1.28	1.28	-	-	1.18	1.19
-1.25	1.32	1.32	1.28	1.16	1.22	1.31
-1.50	1.33	1.19	1.13	1.12	1.35	1.29
-1.75	1.27	1.17	1.13	1.14	1.27	1.36
	Median rate of germination (ln) (H_2O: -4.89[0.067])					
	(0.054)	(0.039)	(0.034)	(0.035)	(0.057)	(0.065)
-0.50	-	-	-	-	-1.95	-
-0.75	-2.24	-	-	-	-2.53	-
-1.00	-2.94	-2.04	-	-	-2.89	-2.63
-1.25	-3.28	-2.45	-2.47	-2.71	-3.88	-3.13
-1.50	-3.63	-2.73	-2.84	-2.87	-3.97	-3.45
-1.75	-3.92	-3.03	-3.27	-3.09	-4.46	-3.66
	Time to 5% germination (ln) (H_2O: 4.63[0.089])					
	(0.414)	(0.124)	(0.253)	(0.076)	(0.057)	(0.188)
-0.50	-	-	-	-	-0.154	-
-0.75	0.093	-	-	-	1.18	-
-1.00	1.78	1.03	-	-	1.69	1.36
-1.25	1.77	1.50	0.864	1.88	2.46	2.11
-1.50	2.14	2.07	2.07	2.21	3.07	2.31
-1.75	2.75	2.35	2.62	2.52	3.59	2.24
	Time-spread of germination (ln) (H_2O: 3.98[0.331])					
	(0.098)	(0.101)	(0.116)	(0.086)	(0.090)	(0.114)
-0.50	-	-	-	-	2.38	-
-0.75	2.56	-	-	-	2.79	-
-1.00	3.12	2.14	-	-	3.10	2.82
-1.25	3.57	2.49	2.71	2.72	4.09	3.25
-1.50	3.87	2.57	2.81	2.69	4.00	3.62
-1.75	4.10	2.88	3.09	2.84	4.49	3.94

APPENDIX 1

Table A1.3. The effect of osmoticum and osmotic potential on the germination of carrot seeds. Transformed values together with standard errors of the means given in brackets. Values of seeds germinated in water also given.

Osmotic Potential	Osmoticum					
	K_2HPO_4	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3	K_3PO_4	PEG
(MPa)	Maximum percentage germination (rad) (H_2O: 0.948[0.130])					
	(0.046)	(0.039)	(0.039)	(0.057)	(0.053)	(0.071)
-0.25	0.953	0.999	0.955	0.940	0.805	0.972
-0.50	0.750	1.02	0.880	0.895	0.738	1.02
-0.75	0.735	0.896	0.808	0.817	0.439	0.905
-1.00	0.457	0.736	0.658	0.475	0.161	0.757
-1.25	0.120	0.414	0.456	0.0	0.0	0.361
-1.50	0.0	0.258	0.197	0.0	0.0	0.0
-1.75	0.0	0.0	0.0	0.0	0.0	0.0
	Median rate of germination (ln) (H_2O: -5.03[0.081])					
	(0.020)	(0.024)	(0.030)	(0.021)	(0.023)	(0.052)
-0.25	-5.18	-5.14	-5.20	-5.20	-5.18	-5.06
-0.50	-5.53	-5.40	-5.43	-5.42	-5.51	-5.07
-0.75	-5.77	-5.70	-5.71	-5.79	-5.97	-5.34
-1.00	-6.02	-5.93	-5.93	-6.06	-6.21	-5.62
-1.25	-6.16	-6.14	-6.14	-	-	-5.98
-1.50	-	-6.24	-6.28	-	-	-
	Time to 5% germination (ln) (H_2O: 4.65[0.084])					
	(0.045)	(0.033)	(0.019)	(0.038)	(0.036)	(0.080)
-0.25	4.76	4.76	4.73	4.82	4.84	4.67
-0.50	5.17	5.03	5.06	5.02	5.14	4.71
-0.75	5.24	5.28	5.33	5.36	5.72	4.98
-1.00	5.76	5.55	5.59	5.91	6.19	5.10
-1.25	6.12	5.91	5.91	-	-	5.73
-1.50	-	6.14	6.23	-	-	-
	Time-spread of germination (ln) (H_2O: 4.46[0.390])					
	(0.076)	(0.087)	(0.097)	(0.098)	(0.087)	(0.067)
-0.25	4.69	4.57	4.82	4.62	4.54	4.53
-0.50	4.94	4.83	4.84	4.91	4.93	4.48
-0.75	5.49	5.22	5.14	5.34	5.14	4.73
-1.00	5.22	5.37	5.31	4.76	3.53	5.34
-1.25	4.62	5.27	5.23	-	-	5.22
-1.50	-	4.75	4.39	-	-	-

APPENDIX 1

Table A1.4. The effect of osmoticum and osmotic potential of treatment solution on the subsequent germination of carrot seeds. Transformed values together with standard errors of the means given in brackets. Values of untreated seeds germinated in water also given.

Osmotic potential	Treatment solution					
	K_2HPO_4	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3	K_3PO_4	PEG
(MPa)	Maximum percentage germination (rad) (H_2O: 0.948[0.130])					
	(0.051)	(0.058)	(0.056)	(0.046)	(0.036)	(0.112)
-0.75	-	-	-	-	0.161	-
-1.00	0.440	-	-	0.217	0.390	-
-1.25	0.421	0.649	0.449	0.456	0.633	0.617
-1.50	0.621	0.625	0.422	0.671	0.677	0.850
-1.75	0.583	0.603	0.385	0.762	0.664	0.800
	Median rate of germination (ln) (H_2O: -5.03[0.081])					
	(0.173)	(0.231)	(0.191)	(0.089)	(0.097)	(0.104)
-0.75	-	-	-	-	-2.20	-
-1.00	-2.59	-	-	-2.03	-2.45	-
-1.25	-2.73	-2.84	-2.20	-2.31	-4.19	-3.60
-1.50	-3.93	-2.45	-2.47	-2.75	-4.36	-3.46
-1.75	-4.40	-2.75	-2.76	-4.14	-4.43	-3.51
	Time to 5% germination (ln) (H_2O: 4.65[0.084])					
	(0.298)	(0.468)	(0.286)	(0.328)	(0.192)	(0.414)
-0.75	-	-	-	-	1.22	-
-1.00	1.19	-	-	0.600	0.779	-
-1.25	1.42	-0.547	0.479	0.701	3.04	1.87
-1.50	2.12	0.427	0.566	1.64	3.71	0.576
-1.75	3.37	0.710	1.24	2.24	3.83	0.318
	Time-spread of germination (ln) (H_2O: 4.46[0.390])					
	(0.196)	(0.255)	(0.223)	(0.155)	(0.124)	(0.081)
-0.75	-	-	-	-	2.96	-
-1.00	2.98	-	-	2.51	2.92	-
-1.25	3.10	3.41	2.69	2.72	4.42	4.02
-1.50	4.38	2.91	2.99	2.98	4.25	3.99
-1.75	4.51	3.22	3.15	4.57	4.25	4.07

APPENDIX 1

Table A1.5. The effect of osmoticum and osmotic potential on the germination of onion seeds. Transformed values together with standard errors of the means given in brackets. Values of seeds germinated in water also given.

Osmotic potential	Osmoticum					
	K_2HPO_4	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3	K_3PO_4	PEG
(MPa)	Maximum percentage germination (rad) (H_2O: 1.38[0.213])					
	(0.050)	(0.067)	(0.047)	(0.057)	(0.040)	(0.062)
-0.25	1.35	1.41	1.45	1.29	1.26	1.24
-0.50	1.25	1.36	1.30	1.34	1.20	1.29
-0.75	1.24	1.35	1.27	1.24	1.15	1.26
-1.00	1.19	1.17	1.33	1.27	0.864	1.22
-1.25	0.914	1.20	1.28	1.02	0.227	1.22
-1.50	0.463	1.15	1.06	0.933	0.0	0.0
-1.75	0.0	0.843	0.873	0.543	0.0	0.202
	Median rate of germination (ln) (H_2O: -4.70[0.111])					
	(0.027)	(0.034)	(0.037)	(0.029)	(0.028)	(0.047)
-0.25	-4.82	-4.83	-4.83	-4.80	-4.88	-4.84
-0.50	-5.03	-4.96	-5.02	-5.02	-5.14	-5.01
-0.75	-5.31	-5.21	-5.21	-5.23	-5.48	-5.25
-1.00	-5.59	-5.42	-5.47	-5.55	-6.08	-5.55
-1.25	-6.05	-5.78	-5.75	-6.09	-6.30	-5.95
-1.50	-6.31	-6.00	-6.02	-6.28	-	-
-1.75	-	-6.44	-6.26	-6.70	-	-6.01
	Time to 5% germination (ln) (H_2O: 4.35[0.084])					
	(0.039)	(0.051)	(0.040)	(0.035)	(0.049)	(0.059)
-0.25	4.45	4.45	4.44	4.49	4.49	4.54
-0.50	4.65	4.51	4.57	4.63	4.72	4.68
-0.75	4.89	4.68	4.72	4.84	5.07	4.84
-1.00	5.16	4.95	4.96	5.07	5.36	4.95
-1.25	5.45	5.28	5.30	5.40	6.11	5.37
-1.50	5.84	5.44	5.49	5.80	-	-
-1.75	-	5.90	5.76	6.42	-	5.92
	Time-spread of germination (ln) (H_2O: 4.01[0.555])					
	(0.103)	(0.136)	(0.088)	(0.080)	(0.120)	(0.136)
-0.25	4.18	4.20	4.23	4.06	4.30	4.04
-0.50	4.42	4.42	4.57	4.45	4.61	4.29
-0.75	4.80	4.89	4.83	4.68	4.98	4.72
-1.00	5.10	5.02	5.13	5.15	6.01	5.30
-1.25	5.85	5.41	5.33	5.98	5.40	5.70
-1.50	5.99	5.73	5.72	5.90	-	-
-1.75	-	6.17	5.93	5.93	-	4.69

APPENDIX 1

Table A1.6. The effect of osmoticum and osmotic potential of treatment solution on the subsequent germination of onion seeds. Transformed values together with standard errors of the means given in brackets. Values of untreated seeds germinated in water also given.

Osmotic potential	Treatment solution					
	K_2HPO_4	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3	K_3PO_4	PEG
(MPa)	Maximum percentage germination (rad) (H_2O: 1.38[0.213])					
	(0.118)				(0.034)	(0.087)
-1.50	-	-	-	-	1.12	1.28
-1.75	1.16	-	-	-	1.08	1.28
	Median rate of germination (rad) (H_2O: -4.70[0.111])					
	(0.105)				(0.031)	(0.141)
-1.50	-	-	-	-	-2.71	-2.04
-1.75	-2.57	-	-	-	-3.26	-1.89
	Time to 5% germination (ln) (H_2O: 4.35[0.084])					
	(0.275)				(0.031)	(0.214)
-1.50	-	-	-	-	1.79	0.859
-1.75	1.67	-	-	-	2.47	0.796
	Time-spread of germination (ln) (H_2O: 4.01[0.555])					
	(0.029)				(0.054)	(0.193)
-1.50	-	-	-	-	2.78	2.20
-1.75	2.63	-	-	-	3.24	2.02

APPENDIX 1

Table A1.7. The effect of osmoticum and osmotic potential on the germination of sorghum E 57 seeds. Transformed values together with standard errors of the means given in brackets. Values of seeds germinated in water also given.

Osmotic potential	Osmoticum					
	K_2HPO_4	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3	K_3PO_4	PEG
(MPa)	Maximum percentage germination (rad) (H_2O: 1.15[0.100])					
	(0.0323)	(0.0543)	(0.0500)	(0.0382)	(0.0424)	(0.0527)
-0.25	1.12	1.19	1.22	1.21	1.05	1.07
-0.50	1.06	0.916	1.08	0.889	0.904	1.12
-0.75	0.790	0.785	0.883	0.602	0.633	0.859
-1.00	0.736	0.638	0.784	0.502	0.319	0.408
-1.25	0.391	0.545	0.626	0.187	0.0	0.130
-1.50	0.191	0.310	0.294	0.0	0.0	0.0
-1.75	0.0	0.0	0.0	0.0	0.0	0.0
	Median rate of germination (ln) (H_2O: -3.92[0.040])					
	(0.0403)	(0.0264)	(0.0194)	(0.0368)	(0.0305)	(0.0388)
-0.25	-4.05	-4.08	-4.01	-3.97	-4.04	-4.58
-0.50	-4.13	-4.12	-4.13	-4.14	-4.07	-4.68
-0.75	-4.31	-4.26	-4.25	-4.27	-4.25	-4.80
-1.00	-4.45	-4.40	-4.42	-4.42	-4.46	-5.00
-1.25	-4.71	-4.62	-4.63	-4.57	-	-
-1.50	-4.86	-4.75	-4.88	-	-	-
	Time to 5% germination (ln) (H_2O: 3.57[0.148])					
	(0.0449)	(0.0299)	(0.0389)	(0.0346)	(0.0448)	(0.0414)
-0.25	3.73	3.71	3.69	3.68	3.72	4.27
-0.50	3.78	3.83	3.82	3.77	3.78	4.30
-0.75	3.94	3.98	3.86	3.92	3.93	4.46
-1.00	4.21	4.09	4.10	4.09	4.21	4.62
-1.25	4.41	4.30	4.30	4.42	-	-
-1.50	4.67	4.50	4.51	-	-	-
	Time-spread of germination (ln) (H_2O: 3.26[0.329])					
	(0.131)	(0.0912)	(0.107)	(0.153)	(0.0676)	(0.192)
-0.25	3.35	3.48	3.29	3.18	3.30	3.80
-0.50	3.49	3.36	3.36	3.54	3.28	4.11
-0.75	3.70	3.48	3.70	3.68	3.58	4.14
-1.00	3.54	3.71	3.74	3.78	3.71	4.55
-1.25	4.02	3.93	3.97	3.68	-	-
-1.50	4.11	4.02	4.48	-	-	-

APPENDIX 1

Table A1.8. The effect of osmoticum and osmotic potential of treatment solution on the subsequent germination of sorghum E 57 seeds. Transformed values together with standard errors of the means given in brackets. Values of untreated seeds germinated in water also given.

Osmotic potential	Treatment solution					
	K_2HPO_4	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3	K_3PO_4	PEG
(MPa)	Maximum percentage germination (rad) (H_2O: 1.15[0.100])					
	(0.037)	(0.122)				(0.045)
-1.00	-	-	-	-	-	0.974
-1.25	-	-	-	-	-	1.19
-1.50	0.458	-	-	-	-	1.04
-1.75	0.572	0.298	-	-	-	1.17
	Median rate of germination (rad) (H_2O: -3.92[0.040])					
	(0.033)	(0.140)				(0.045)
-1.00	-	-	-	-	-	-3.37
-1.25	-	-	-	-	-	-3.37
-1.50	-3.21	-	-	-	-	-3.32
-1.75	-3.41	-3.44	-	-	-	-3.22
	Time to 5% germination (ln) (H_2O: 3.57[0.148])					
	(0.157)	(0.140)				(0.181)
-1.00	-	-	-	-	-	2.70
-1.25	-	-	-	-	-	2.55
-1.50	2.79	-	-	-	-	2.49
-1.75	3.03	3.17	-	-	-	2.42
	Time-spread of germination (ln) (H_2O: 3.26[0.329])					
	(0.180)	(0.485)				(0.111)
-1.00	-	-	-	-	-	3.22
-1.25	-	-	-	-	-	3.36
-1.50	2.68	-	-	-	-	3.14
-1.75	2.91	2.77	-	-	-	3.20

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Table A1.9. The effect of osmoticum and osmotic potential on the germination of sorghum E 55e seeds. Transformed values together with standard errors of the means given in brackets. Values of seeds germinated in water also given.

Osmotic potential	Osmoticum		
	K_2HPO_4 + KNO_3	KNO_3	K_3PO_4 + KNO_3
(MPa)	Maximum percentage germination (rad) (H_2O: 1.13[0.070])		
	(0.0369)	(0.0512)	(0.0202)
-0.50	0.964	1.01	0.998
-1.00	0.827	0.857	0.676
-1.50	0.555	0.583	0.186
	Median rate of germination (ln) (H_2O: -3.93[0.0334])		
	(0.0270)	(0.0185)	(0.0435)
-0.50	-4.12	-4.07	-4.16
-1.00	-4.43	-4.38	-4.50
-1.50	-4.80	-4.95	-5.00
	Time to 5% germination (ln) (H_2O: 3.52[0.197])		
	(0.0394)	(0.0459)	(0.0491)
-0.50	3.82	3.78	3.85
-1.00	4.03	3.98	4.17
-1.50	4.43	4.43	4.87
	Time-spread of germination (ln) (H_2O: 3.40[0.350])		
	(0.0676)	(0.0822)	(0.107)
-0.50	3.36	3.27	3.41
-1.00	3.91	3.82	3.85
-1.50	4.26	4.68	3.92

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Table A1.10. The effect of hydration of sorghum E 57 seeds in atmospheres of high humidity on their emergence at 20 C. Transformed values together with standard errors of the means given in brackets. Values for untreated seeds also given.

Relative humidity	Duration (d) 5	10	16
(%)	Maximum percentage emergence (rad) (Control: 1.27[0.326])		
	(S.E. body of table: 0.0401)		
81	1.06	1.03	1.08
93	1.09	0.837	0.750
98	1.09	0.736	0.613
	Median rate of emergence (ln) (Control: -4.65[0.0173])		
	(S.E. body of table: 0.0134)		
81	-4.68	-4.72	-4.67
93	-4.67	-4.71	-4.66
98	-4.68	-4.64	-4.59
	Time to 5% emergence (ln) (Control: 4.49[0.0192])		
	(S.E. body of table: 0.0385)		
81	4.52	4.58	4.54
93	4.48	4.58	4.49
98	4.50	4.52	4.39
	Time-spread of emergence (ln) (Control: 3.29[0.0684])		
	(S.E. body of table: 0.164)		
81	3.32	3.22	3.13
93	3.42	3.21	3.33
98	3.45	3.04	3.41

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Table A1.11. The effect of temperature and duration of priming of tomato seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on emergence at 15 C. Transformed values together with standard errors of the means given in brackets. Values for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Maximum percentage emergence (rad) (Control: 1.26[0.138])		
	(S.E. body of table: 0.0489)		
15	1.18	1.14	1.15
20	1.14	1.20	1.10
25	1.25	1.11	1.13
	Median rate of emergence (ln) (Control: -5.42[0.0437])		
	(S.E. body of table: 0.0136)		
15	-4.84	-4.74	-4.71
20	-4.78	-4.71	-4.77
25	-4.71	-4.74	-4.72
	Time to 5% emergence (ln) (Control: 5.29[0.0213])		
	(S.E. body of table: 0.0251)		
15	4.69	4.61	4.56
20	4.65	4.54	4.66
25	4.56	4.61	4.57
	Time-spread of emergence (ln) (Control: 3.89[0.274])		
	(S.E. body of table: 0.116)		
15	3.48	3.22	3.28
20	3.38	3.41	3.10
25	3.29	3.23	3.26

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Table A1.12. The effect of temperature and duration of priming of carrot seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on emergence at 15 C. Transformed values together with standard errors of the means given in brackets. Values for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C) Maximum percentage emergence (rad) (Control: 0.728[0.0413])			
	(S.E. body of table: 0.0577)		
15	0.987	0.845	0.756
20	0.974	0.889	0.778
25	0.971	0.756	0.781
Median rate of emergence (ln) (Control: -5.58[0.0394])			
	(S.E. body of table: 0.0206)		
15	-5.02	-4.89	-4.86
20	-4.95	-4.86	-4.83
25	-4.99	-4.96	-5.01
Time to 5% emergence (ln) (Control: 5.34[0.0270])			
	(S.E. body of table: 0.0507)		
15	4.68	4.61	4.47
20	4.71	4.64	4.47
25	4.78	4.68	4.52
Time-spread of emergence (ln) (Control: 4.64[0.274])			
	(S.E. body of table: 0.115)		
15	4.35	4.05	4.32
20	3.99	3.83	4.17
25	3.93	4.16	4.67

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Table A1.13. The effect of temperature and duration of priming of onion seeds in 0.105M K_3PO_4 + 0.209M KNO_3 on emergence at 15 C. Transformed values together with standard errors of the means given in brackets. Values for untreated seeds also given.

Temperature	Duration (d) 7	14	21
(C)	Maximum percentage emergence (rad) (Control: 0.892[0.172])		
	(S.E. body of table: 0.0548)		
15	0.762	0.808	0.400
20	0.810	0.557	0.447
25	0.816	0.631	0.332
	Median rate of emergence (ln) (Control: -5.38[0.0242])		
	(S.E. body of table: 0.0393)		
15	-4.88	-4.75	-4.75
20	-4.86	-4.83	-4.68
25	-4.89	-4.84	-4.80
	Time to 5% emergence (ln) (Control: 5.12[0.105])		
	(S.E. body of table: 0.0684)		
15	4.53	4.28	4.25
20	4.54	4.48	4.30
25	4.55	4.41	4.49
	Time-spread of emergence (ln) (Control: 4.51[0.235])		
	(S.E. body of table: 0.128)		
15	4.23	4.35	4.51
20	4.15	4.27	4.21
25	4.23	4.34	4.27

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Table A1.14. The effect of priming carrot seeds in a column of aerated solution of 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days on their emergence at 15 C. Transformed values together with standard errors of the means given in brackets. Values for petri dish primed seeds also given.

Petri dish	Small col.	Large col.
	Maximum percentage emergence (rad)	
	(S.E.: 0.0250)	
0.923	0.873	0.850
	Median rate of emergence (ln)	
	(S.E.: 0.0150)	
-5.00	-4.97	-4.95
	Time to 5% emergence (ln)	
	(S.E.: 0.0219)	
4.64	4.66	4.60
	Time-spread of emergence (ln)	
	(S.E.: 0.0510)	
4.39	4.23	4.32

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Table A1.15. The effect of duration of priming of tomato seeds in 0.090M K_2HPO_4 + 0.118M KNO_3 or in 0.079M K_3PO_4 at 15 C on their germination at 15 C. Transformed values together with standard errors of the means given in brackets, t-statistics given as well, (ns) not significant at p=0.05, (sign) significant at p=0.05. Values for untreated seeds also given.

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Duration	K_3PO_4	K_2HPO_4 + KNO_3	
Maximum percentage germination (rad) (Control: 1.31[0.277])			
	(S.E.: 0.0568)		
2	1.21	1.25	(n=4, t=-0.433, ns)
4	1.29	1.43	(n=4, t=-1.406, ns)
6	1.38	1.21	(n=4, t=2.303, ns)
8	1.18	1.27	(n=4, t=-1.260, ns)
10	1.17	1.18	(n=4, t=-0.150, ns)
12	1.23	1.19	(n=4, t=0.546, ns)
14	1.18	1.23	(n=4, t=-0.432, ns)
16	1.20	1.26	(n=4, t=-0.769, ns)
18	1.14	1.14	(n=4, t=0.015, ns)
20	1.18	1.15	(n=4, t=0.385, ns)
22	1.15	1.16	(n=4, t=-0.087, ns)
Median rate of germination (ln) (Control: -5.17[0.0684])			
	(S.E.: 0.0768)		
2	-4.97	-4.94	(n=4, t=-1.175, ns)
4	-4.46	-4.39	(n=4, t=-2.273, ns)
6	-3.95	-4.02	(n=4, t=0.474, ns)
8	-3.43	-3.26	(n=4, t=-2.290, ns)
10	-3.32	-3.05	(n=4, t=-1.728, ns)
12	-2.97	-3.00	(n=4, t=0.427, ns)
14	-2.74	-2.79	(n=4, t=0.433, ns)
16	-2.73	-2.64	(n=4, t=-0.854, ns)
18	-2.46	-2.73	(n=4, t=5.079, sign)
20	-2.45	-2.50	(n=4, t=0.305, ns)
22	-2.46	-2.17	(n=4, t=-2.581, sign)
Time to 5% germination (ln) (Control: 4.90[0.0461])			
	(S.E.: 0.140)		
2	4.61	4.62	(n=4, t=-0.173, ns)
4	3.82	3.78	(n=4, t=0.283, ns)
6	3.00	3.00	(n=4, t=-0.010, ns)
8	2.00	2.28	(n=4, t=-1.375, ns)
10	2.09	2.09	(n=4, t=0.032, ns)
12	2.18	1.97	(n=4, t=2.154, ns)
14	1.81	1.57	(n=4, t=2.623, sign)
16	1.82	1.33	(n=4, t=2.509, sign)
18	1.48	1.20	(n=4, t=0.846, ns)
20	1.54	0.754	(n=4, t=4.548, sign)
22	1.37	0.963	(n=4, t=1.745, ns)

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Table A1.15. The effect of duration of priming of tomato seeds in 0.090M K_2HPO_4 + 0.118M KNO_3 or in 0.079M K_3PO_4 at 15 C on their germination at 15 C. Transformed values together with standard errors of the means given in brackets, t-statistics given as well, (ns) not significant at p=0.05, (sign) significant at p=0.05. Values for untreated seeds also given.

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Duration	K_3PO_4	K_2HPO_4 + KNO_3	
	Time-spread of germination (ln) (Control: 4.29[0.210])		
	(S.E.: 0.129)		
2	4.21	4.34	(n=4, t=1.208, ns)
4	4.15	4.27	(n=4, t=0.947, ns)
6	4.13	4.00	(n=4, t=-1.199, ns)
8	3.33	3.71	(n=4, t=2.395, ns)
10	3.15	3.48	(n=4, t=1.123, ns)
12	3.14	2.92	(n=4, t=-1.431, ns)
14	3.02	2.81	(n=4, t=-1.316, ns)
16	2.89	2.75	(n=4, t=-0.739, ns)
18	3.02	2.57	(n=4, t=-4.043, sign)
20	2.86	2.50	(n=4, t=-1.397, ns)
22	2.34	2.60	(n=4, t=1.116, ns)

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Table A1.16. The effect of drying following priming, in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days, of tomato seeds on their emergence at 15 C. Transformed values together with standard errors of the means given in brackets. Values for untreated seeds also given.

Duration (d)				
0	1	2	4	8
Maximum percentage emergence (rad) (Control: 1.26[0.138])				
		(S.E.: 0.0908)		
1.12	1.18	1.21	1.07	1.27
Median rate of emergence (ln) (Control: -5.42[0.0437])				
		(S.E.: 0.0131)		
-4.87	-4.89	-4.88	-4.88	-4.89
Time to 5% emergence (ln) (Control: 5.29[0.0213])				
		(S.E.: 0.0239)		
4.76	4.78	4.72	4.77	4.74
Time-spread of emergence (ln) (Control: 3.89[0.274])				
		(S.E.: 0.109)		
3.14	3.17	3.50	3.23	3.43

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Table A1.17. The effect of drying with or without fan assistance following priming, in 0.105M K_3PO_4 + 0.209M KNO_3 at 15 C for 14 days, of carrot seeds on their emergence at 15 C. Transformed values together with standard errors of the means given in brackets. Values for untreated seeds also given.

	Duration (d)				
	0	1	2	4	8
Maximum percentage emergence (rad) (Control: 0.728[0.0413])					
	(0.108)	(S.E. body of table: 0.0579)			
fan -	0.913	0.871	0.853	0.809	0.756
fan +	-	0.873	0.912	0.918	0.797
Median rate of emergence (ln) (Control: -5.58[0.0394])					
	(0.096)	(S.E. body of table: 0.0196)			
fan -	-4.96	-4.99	-4.94	-4.95	-5.00
fan +	-	-4.96	-4.95	-5.02	-5.06
Time to 5% emergence (ln) (Control: 5.34[0.0270])					
	(0.132)	(S.E. body of table: 0.0363)			
fan -	4.59	4.69	4.67	4.61	4.57
fan +	-	4.66	4.62	4.72	4.64
Time-spread of emergence (ln) (Control: 4.64[0.274])					
	(0.105)	(S.E. body of table: 0.0921)			
fan -	4.39	4.22	4.08	4.28	4.55
fan +	-	4.23	4.25	4.26	4.59

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Table A1.18. The effect of priming tomato seeds in 0.105M K_3PO_4 + KNO_3 at 15 C for 14 days on their field emergence. Transformed values together with standard errors given in brackets, t-statistics given as well, (ns) not significant at p=0.05, (sign) significant at p=0.05. Values for untreated seeds also given.

Sowing date	Control	Primed	
	Maximum percentage field emergence (rad)		
(S.E. body of table: 0.0815)			
6.9.81	0.857	0.977	(n=4, t=-1.303, ns)
17.9.81	0.803	0.957	(n=4, t=-1.227, ns)
1.10.81	0.791	0.917	(n=4, t=-1.037, ns)
7.10.81	0.720	0.920	(n=4, t=-3.050, sign)
22.10.81	0.645	0.773	(n=4, t=-0.841, ns)
Mean	0.763	0.909	(n=20, t=-2.825, sign)
(S.E.: 0.0577)			
	Median rate of field emergence (ln)		
(S.E. body of table: 0.0368)			
6.9.81	-5.46	-4.96	(n=4, t=-17.565, sign)
17.9.81	-5.63	-4.85	(n=4, t=-9.084, sign)
1.10.81	-5.44	-5.16	(n=4, t=-11.483, sign)
7.10.81	-5.36	-4.90	(n=4, t=-12.850, sign)
22.10.81	-5.17	-4.99	(n=4, t=-3.039, sign)
Mean	-5.41	-4.97	(n=20, t=-9.420, sign)
(S.E.: 0.0260)			
	Time to 5% field emergence (ln)		
(S.E. body of table: 0.0339)			
6.9.81	5.22	4.78	(n=4, t=13.425, sign)
17.9.81	5.34	4.39	(n=4, t=11.962, sign)
1.10.81	5.30	5.03	(n=4, t=14.448, sign)
7.10.81	5.04	4.72	(n=4, t=7.524, sign)
22.10.81	5.03	4.73	(n=4, t=6.946, sign)
Mean	5.19	4.73	(n=20, t=7.818, sign)
(S.E.: 0.0240)			
	Time-spread of field emergence (ln)		
(S.E. body of table: 0.136)			
6.9.81	4.48	3.67	(n=4, t=2.942, sign)
17.9.81	4.85	4.44	(n=4, t=2.995, sign)
1.10.81	4.00	3.60	(n=4, t=2.726, sign)
7.10.81	4.66	3.65	(n=4, t=5.532, sign)
22.10.81	3.74	4.11	(n=4, t=-1.976, sign)
Mean	4.35	3.89	(n=20, t=3.158, sign)
(S.E.: 0.0964)			

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Table A1.19. The effect of post-priming air-drying of tomato seeds on their field emergence. Transformed values together with standard errors given in brackets. Values for untreated seeds also given.

Control	Duration of drying (d) 1	7	14	28
	Maximum percentage field emergence (rad)			
		(S.E.: 0.0976)		
0.645	0.773	0.862	0.743	0.677
	Median rate of field emergence (ln)			
		(S.E.: 0.0377)		
-5.17	-4.99	-4.97	-5.00	-4.97
	Time to 5% field emergence (ln)			
		(S.E.: 0.0357)		
5.03	4.73	4.74	4.73	4.77
	Time-spread of field emergence (ln)			
		(S.E.: 0.107)		
3.74	4.11	3.96	4.19	3.90

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Table A1.20. The effect of priming tomato seeds in 0.105M K_3PO_4 + KNO_3 at 15 C for 14 days on the attainment of first true leaves. Transformed values together with standard errors given in brackets, t-statistics given as well, (ns) not significant at p=0.05, (sign) significant at p=0.05. Values for untreated seeds also given.

Sowing date	Control	Primed	
Maximum percentage attainment of first true leaves (rad)			
(S.E. body of table: 0.115)			
6.9.81	1.13	1.21	(n=4, t=-0.731, ns)
17.9.81	1.08	1.39	(n=4, t=-1.704, ns)
1.10.81	1.07	1.23	(n=4, t=-1.319, ns)
7.10.81	1.30	0.975	(n=4, t=1.583, ns)
22.10.81	1.18	0.952	(n=4, t=1.280, ns)
Mean	1.15	1.15	(n=20, t=0.003, ns)
(S.E.: 0.0813)			
Median rate of attainment of first true leaves (ln)			
(S.E. body of table: 0.0336)			
6.9.81	-6.26	-5.98	(n=4, t=-13.273, sign)
17.9.81	-6.29	-6.12	(n=4, t=-7.101, sign)
1.10.81	-6.07	-5.90	(n=4, t=-7.202, sign)
7.10.81	-6.05	-5.80	(n=4, t=-5.942, sign)
22.10.81	-5.87	-5.85	(n-4, t=-0.187, ns)
Mean	-6.11	-5.93	(n=4, t=-3.818, sign)
(S.E.: 0.0238)			
Time to 5% attainment of first true leaves (ln)			
(S.E. body of table: 0.0210)			
6.9.81	6.06	5.90	(n=4, t=9.086, sign)
17.9.81	6.18	6.02	(n=4, t=7.185, sign)
1.10.81	5.92	5.76	(n=4, t=5.790, sign)
7.10.81	5.91	5.65	(n=4, t=11.804, sign)
22.10.81	5.60	5.57	(n=4, t=0.578, ns)
Mean	5.93	5.78	(n=20, t=2.622, sign)
(S.E.: 0.0149)			
Time-spread of attainment of first true leaves (ln)			
(S.E. body of table: 0.154)			
6.9.81	5.11	4.03	(n=4, t=10.822, sign)
17.9.81	4.59	4.28	(n=4, t=1.785, ns)
1.10.81	4.63	4.43	(n=4, t=0.774, ns)
7.10.81	4.62	4.31	(n=4, t=1.353, ns)
22.10.81	4.99	4.99	(n=4, t=-0.013, ns)
Mean	4.79	4.99	(n=20, t=3.058, sign)
(S.E.: 0.109)			

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Table A1.21. The effect of priming carrot seeds in 0.105M K_3PO_4 + KNO_3 at 15 C for 14 days on their field emergence. Transformed values together with standard errors given in brackets, t-statistics given as well, (ns) not significant at p=0.05, (sign) significant at p=0.05. Values for untreated seeds also given.

Sowing date	Control	Primed	
	Maximum percentage field emergence (rad)		
(S.E. body of table: 0.0903)			
5.9.81	1.10	0.758	(n=4, t=2.039, ns)
17.9.81	0.378	0.730	(n=4, t=-3.480, sign)
30.9.81	0.566	0.548	(n=4, t=0.151, ns)
7.10.81	0.518	0.476	(n=4, t=0.373, ns)
Mean	0.518	0.628	(n=4, t=0.132, ns)
(S.E.: 0.0638)			
	Median rate of field emergence (ln)		
(S.E. body of table: 0.0261)			
5.9.81	-5.80	-5.43	(n=4, t=-10.774, sign)
17.9.81	-5.84	-5.35	(n=4, t=-10.186, sign)
30.9.81	-5.74	-5.46	(n-4, t=-7.685, sign)
7.10.81	-5.76	-5.42	(n=4, t=-13.429, sign)
Mean	-5.79	-5.42	(n=20, t=-17.113, sign)
(S.E.: 0.0184)			
	Time to 5% field emergence (ln)		
(S.E. body of table: 0.0378)			
5.9.81	5.61	5.11	(n=4, t=18.881, sign)
17.9.81	5.71	4.96	(n=4, t=9.666, sign)
30.9.81	5.57	5.25	(n=4, t=8.333, sign)
7.10.81	5.60	5.15	(n=4, t=7.757, sign)
Mean	5.62	5.12	(n=20, t=12.960, sign)
(S.E.: 0.0268)			
	Time-spread of field emergence (ln)		
(S.E. body of table: 0.103)			
5.9.81	4.59	4.75	(n=4, t=-0.815, ns)
17.9.81	4.45	4.84	(n=4, t=-7.847, sign)
30.9.81	4.56	4.48	(n=4, t=0.848, ns)
7.10.81	4.51	4.60	(n=4, t=-0.496, ns)
Mean	4.51	4.67	(n=20, t=-1.905, ns)
(S.E.: 0.0730)			

APPENDIX 1

Table A1.22. The effect of post-priming air-drying of carrot seeds on their field emergence. Transformed values together with standard errors given in brackets. Values for untreated seeds also given.

Control	Duration of drying (d) 1	7	14	28
		Maximum percentage field emergence (rad)		
		(S.E.: 0.128)		
1.10	0.758	1.004	0.827	0.768
		Median rate of field emergence (ln)		
		(S.E.: 0.0371)		
-5.80	-5.43	-5.37	-5.38	-5.34
		Time to 5% field emergence (ln)		
		(S.E.: 0.0577)		
5.61	5.11	5.01	5.10	5.08
		Time-spread of field emergence (ln)		
		(S.E.: 0.121)		
4.59	4.75	4.72	4.58	4.56

APPENDIX 1

Table A1.23. The effect of priming carrot seeds in 0.105M K_3PO_4 + KNO_3 at 15 C for 14 days on the attainment of first true leaves. Transformed values together with standard errors given in brackets, t-statistics given as well, (ns) not significant at p=0.05, (sign) significant at p=0.05. Values for untreated seeds also given.

Sowing date	Control	Primed	
Maximum percentage attainment of first true leaves (rad)			
(S.E. body of table: 0.0808)			
5.9.81	1.06	1.14	(n=4, t=-0.829, ns)
17.9.81	0.646	0.821	(n=4, t=-2.142, ns)
30.9.81	1.29	1.32	(n=4, t=-0.213, ns)
7.10.81	0.431	0.421	(n=4, t=0.085, ns)
Mean	0.856	0.926	(n=20, t=-0.526, ns)
(S.E.: 0.0571)			
Median rate of attainment of first true leaves (ln)			
(S.E. body of table: 0.0150)			
5.9.81	-6.44	-6.19	(n=4, t=-16.528, sign)
17.9.81	-6.36	-6.18	(n=4, t=-10.638, sign)
30.9.81	-6.22	-6.05	(n=4, t=-8.011, sign)
7.10.81	-6.22	-6.05	(n=4, t=-6.195, sign)
Mean	-6.31	-6.12	(n=20, t=-6.022, sign)
(S.E.: 0.0106)			
Time to 5% attainment of first true leaves (ln)			
(S.E. body of table: 0.0175)			
5.9.81	6.34	5.95	(n=4, t=12.138, sign)
17.9.81	6.25	6.05	(n=4, t=13.898, sign)
30.9.81	6.08	5.85	(n=4, t=16.995, sign)
7.10.81	6.11	5.90	(n=4, t=6.470, sign)
Mean	6.19	5.94	(n=20, t=7.330, sign)
(S.E.: 0.0123)			
Time-spread of attainment of first true leaves (ln)			
(S.E. body of table: 0.104)			
6.9.81	4.75	5.22	(n=4, t=-4.067, sign)
17.9.81	4.71	4.70	(n=4, t=0.113, ns)
1.10.81	4.77	4.89	(n=4, t=-0.974, ns)
7.10.81	4.70	4.68	(n=4, t=0.080, ns)
Mean	4.73	4.87	(n=20, t=-1.634, ns)
(S.E.: 0.0734)			

APPENDIX 1

Table A1.24. The effect of priming onion seeds in 0.105M K_3PO_4 + KNO_3 at 15 C for 14 days on their field emergence. Transformed values together with standard errors given in brackets, t-statistics given as well, (ns) not significant at p=0.05, (sign) significant at p=0.05. Values for untreated seeds also given.

Sowing date	Control	Primed	
	Maximum percentage field emergence (rad)		
(S.E. body of table: 0.0604)			
5.9.81	0.711	0.339	(n=4, t=4.354, sign)
17.9.81	0.658	0.393	(n=4, t=2.402, ns)
30.9.81	0.569	0.257	(n=4, t=6.256, sign)
Mean	0.646	0.330	(n=12, t=6.217, sign)
(S.E.: 0.0427)			
	Median rate of field emergence (ln)		
(S.E. body of table: 0.0224)			
5.9.81	-5.68	-5.64	(n=4, t=-0.825, ns)
17.9.81	-5.75	-5.56	(n=4, t=-7.184, sign)
30.9.81	-5.58	-5.49	(n=4, t=-3.491, sign)
Mean	-5.67	-5.56	(n=12, t=-3.217, sign)
(S.E.: 0.0159)			
	Time to 5% field emergence (ln)		
(S.E. body of table: 0.0524)			
5.9.81	5.44	5.40	(n=4, t=0.482, ns)
17.9.81	5.48	5.25	(n=4, t=2.871, sign)
30.9.81	5.44	5.34	(n=4, t=1.922, ns)
Mean	5.45	5.33	(n=12, t=2.857, sign)
(S.E.: 0.0371)			
	Time-spread of field emergence (ln)		
(S.E. body of table: 0.129)			
5.9.81	4.70	4.87	(n=4, t=-1.213, ns)
17.9.81	4.94	4.91	(n=4, t=0.142, ns)
30.9.81	4.25	4.29	(n=4, t=-0.219, ns)
Mean	4.63	4.69	(n=12, t=-0.402, ns)
(S.E.: 0.0910)			

APPENDIX 1

Table A1.25. The effect of post-priming air-drying of onion seeds on their field emergence. Transformed values together with standard errors given in brackets. Values for untreated seeds also given.

Control	Duration of drying (d) 1	7	14	28
		Maximum percentage field emergence (rad)		
		(S.E.: 0.0466)		
0.711	0.339	0.293	0.211	0.409
		Median rate of field emergence (ln)		
		(S.E.: 0.0313)		
-5.68	-5.65	-5.65	-5.63	-5.66
		Time to 5% field emergence (ln)		
		(S.E.: 0.0536)		
5.44	5.40	5.45	5.47	5.41
		Time-spread of field emergence (ln)		
		(S.E.: 0.105)		
4.70	4.87	4.76	4.59	4.85