J. Amer. Soc. Hort. Sci. 111(5):660–665. 1986.

Field Emergence of Tomato, Carrot, and Onion Seeds Primed in an Aerated Salt Solution

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Additional index words. *Lycopersicon esculentum, Daucus carota, Allium cepa,* osmoconditioning, germination

Abstract. **Conditions for priming tomato (*Lycopersicon esculentum* Mill.), carrot (*Daucus carota* L.), and onion (*Allium cepa* L.) seeds in solutions of K_3PO_4 + KNO_3 and K_2HPO_4 + KNO_3 were optimized in a series of laboratory and field experiments. When primed in K_3PO_4 + KNO_3 (−1.6 MPa) for 7, 14, or 21 days at 15°, 20°, or 25°C, the percentage of emergence was unchanged in tomato, increased in carrot, and decreased in onion. Although there were some species differences, all priming treatments reduced time-spread and increased median rate of emergence. For this solution, priming at 15° for 14 days was optimal for all 3 species. Detailed experiments using optimized priming solutions in an aerated column for tomato (K_2HPO_4 + KNO_3, −1.0 MPa) and for carrots (K_3PO_4 + KNO_3, −1.5 MPa) demonstrated that 18 days was necessary to prime tomato seeds maximally by reducing the time-spread of germination from 73 to 12 hr. With carrots, the maximal response was obtained after 16 days of priming. For both species, continued gains in germination could be obtained from prolonged priming, although only at the expense of a reduced percentage of germination. Air-drying and storing of tomato and carrot seeds for up to 28 days had no effect on subsequent emergence in the field. Conversely, air-drying of onion seeds reduced the percentage of emergence and increased time-spread and rate of emergence. In contrast, salt-primed tomato seeds exhibited an increase in percentage and rate of emergence, and a decrease in time-spread of field emergence. Primed carrot seeds exhibited a faster rate of field emergence than those not primed.**

With the increasing mechanization of horticulture, strong demands have arisen for sure, rapid, and uniform establishment of crops. To meet these stringent requirements, advances in the biology and technology of seedling establishment are required. Perhaps the most promising method of increasing the rate and uniformity of seedling establishment is seed priming or osmoconditioning. Priming involves the hydration of seeds in an osmotic solution that permits the preliminary processes of germination but not the final phase of radicle emergence (1, 8–10).

In laboratory studies, a range of osmotica has been used for priming seeds, including mannitol, glycerol, sucrose, and inorganic salts of K, Na, and Mg (8), but most work has been conducted with the high-M_r organic compound polyethylene glycol (PEG), acclaimed by Heydecker (7). Although only a few field trials of primed seeds have been undertaken, they show that early emergence [parsley (8); carrot (13); carrot, onion, and celery (1); and beet (9)] may occur in the field and perhaps lead to improved yield. A number of difficulties exist in developing a large-scale treatment of seeds using PEG because of its viscosity and low oxygen-diffusivity (11) and the toxicity of contaminants and breakdown products (6).

However, salt solutions, particularly a combination of nitrate and phosphate salts of K, can be as effective as PEG in seed priming (2, 3, 14) and have the added advantage of low viscosity and potential for reuse. For these reasons the salt solutions have the potential to be incorporated in a commercial-scale priming operation. Finally, the applicability of the priming process may be aided greatly if the primed seed can be dried, without a loss of effectiveness, and sown in conventional seeding equipment.

Received for publication 20 Sept. 1985. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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In this paper we report a study designed to evaluate the potential usefulness of solutions of potassium nitrate and potassium phosphate for large-scale priming of tomato, carrot, and onion seeds. In previous studies we found high salt solution priming to be comparable to PEG priming (unpublished data).

Materials and Methods

Temperature and duration of priming (Expt. 1). Seeds of tomato 'UC 82B', carrot 'Yates Baby 242', and onion 'Creamgold' were placed in petri dishes containing the priming solution 0.105 M K_3PO_4 + 0.209 M KNO_3 (−1.6 MPa). This solution was chosen as representative of those reported in the literature to give favorable results for priming. The petri dishes were kept at constant temperatures of 15°, 20°, or 25°C for 7, 14, or 21 days. Following treatment, 4 replicates (50 seeds per replicate) of each species from each temperature were sown in emergence trays at 15°. Untreated seeds of each species were sown also. The emergence trays used were clear plastic containers (125 × 90 × 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 to 2 mm). The trays were watered to excess, then allowed to drain while equilibrating to temperature during the 24 hr preceding use. In each tray, 50 seeds were sown in 5 rows of 10, with the seeds equidistant from one another. Sowing depths were 9 mm for tomato seeds and 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 12-hr intervals until complete or until no further plumules had emerged over 4 days.

Priming in aerated columns of solution (Expt. 2). Two columns, one of small diameter (28-mm, glass) and one of large diameter (50-mm, acrylic) were three-quarters filled with priming solution (0.105 M K_3PO_4 + 0.209 M KNO_3, −1.6 MPa). Each column contained an aerator placed beneath a piece of nylon gauze and fed from an aquarium pump. More than 1500 carrot seeds were placed in each column. In addition to supply-

ing oxygen, the pumped air kept the solution and seeds agitated and well-distributed in the column. For comparison, 8 replicates were primed in petri dishes as for Expt. 1. 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 (i.e., after 2 and 8 days). After priming, 8 replicates from each treatment were sown in emergence trays at 15° as described for Expt. 1. Emergence was recorded at 12-hr intervals until complete.

Optimum duration of priming at 15°C (Expt. 3). Tomato and carrot seeds were placed in columns containing aerated priming solutions. Two solutions were used—0.090 M K_2PO_4 + 0.118 M KNO_3 (−1.0 MPa) for tomato seeds and 0.102 M K_3PO_4 + 0.204 M KNO_3 (−1.5 MPa) for carrot seeds. These solutions were chosen from the results of experiments conducted to determine optimal priming solutions from a range of solutions (unpublished data). The solutions were maintained at the same level by addition of water to replace evaporative losses. Solutions were replaced after 2, 8, and 15 days. Four replicates were removed from each column and placed in petri dishes on water-moistened filter papers at 2-day intervals after commencement until 22 days. Germination was recorded at 2-hr intervals for the first 16 hr, then at 12-hr intervals until complete.

Drying of primed seeds (Expt. 4). Seeds were primed in aerated columns of solution for 14 days at 15°C. Following priming, the seeds were dried at 15° for 1, 7, 14, or 28 days and sown in the field as described below.

Field emergence of primed seeds (Expt. 5). Seeds of tomato, carrot, and onion were primed for 14 days at 15°C in bulk in acrylic columns containing an aerated solution of 0.105 M K_3PO_4 + 0.209 M KNO_3 (−1.6 MPa). In order to obtain a range of soil temperatures, the seeds were planted in early spring at the Agricultural Research Center, Yanco, NSW, Australia, with 5 sowing times for tomato, 4 for carrot, and 3 for onion.

The seeds were sown in 1.5-m beds prepared by rotary-hoe cultivation of a sandy clay loam. 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 5 m of bed, into which 2 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 2.5 m of bed. The seeds were hand-sown in 2 "scatter" bands 200 mm wide and 20 mm deep. The approximate density was one seed per 500 mm^2, resulting in 2000 seeds per replicate.

Onion. A replicate consisted of 2.5 m of bed into which were 4 rows of seeds. The seeds were hand-sown in individual holes 25 mm deep at 25 mm intervals within a row, resulting in 400 seeds per replicate.

There were 4 replicates of each treatment allocated at random within separate blocks for each species. Records were made of emergence of a sample within each plot—1 m length of bed for tomato and onion and 0.25 m length of bed for carrot seeds. Observations were made twice daily.

Analysis of results. A Gompertz function (5) was fitted to each set of germination and emergence data by the method of least squares. The median rate of germination/emergence (reciprocal of the time to germination/emergence of the median seed to germinate/emerge) and the time-spread of germination/emergence (the time between 5% and 80% of the maximum germination/emergence) were calculated from the Gompertz functions. Statistical analysis included determination of least significant differences, analysis of variance, and regression analysis.

Results

Temperature and duration of priming. Priming duration and temperature did not affect the maximum percentage of emergence of tomato seeds (Fig. 1A) but increased the maximum percentage of emergence of carrot seeds (Fig. 1B) and reduced the maximum percentage of emergence of onion seeds (Fig. 1C). Carrot and onion seeds showed reductions in maximum percentage with increased duration of priming. Some onion seeds germinated in the priming solution. Within 7 days at 25°C, 4.5% germinated. After 21 days, this percentage increased to 22.5% at 25°, 26% at 20°, and 36.5% at 15°.

All priming treatments produced median rates of emergence that were about twice those of untreated seeds at 15°C. Seeds primed at 15° showed a continuing improvement in median rate with increased duration in all species, whereas treatment at high temperatures generally did not (Fig. 1 D–F).

Priming of tomato seeds halved the time-spread of emergence at 15°C with little effect of duration evident (Fig. 1G). The time-spread of emergence of primed carrot seeds was reduced below that of untreated seeds; however, there was lengthening of time-spreads after 21 days priming over those from 14 days priming (Fig. 1H). Priming of onion seeds reduced the time-spread of emergence to about two-thirds that of untreated seeds at 15°, except for seeds treated at 25° for 21 days (Fig. 1I).

While almost any priming temperature and duration would be suitable for priming tomato seeds, only 4 combinations gave satisfactory results for carrot seeds (15°C for 14 days, 20° for 7 or 14 days, and 25° for 7 days). Although priming of onion seeds for 7 days produced improved emergence without significant loss of percentage, only priming at 15° produced further improvement without loss of percentage.

In order to produce primed seeds for field studies, it was necessary to increase the size of the priming apparatus from the petri dish method used above and to select a common temperature for priming all 3 species. Consequently, a temperature of 15°C was chosen for all further work and an aerated column, similar to that of Darby and Salter (4), was tested for priming efficiency.

Priming in a column of aerated solution. Priming of carrot seeds in a column of aerated solution resulted in emergences that were not different from those of seeds primed in petri dishes (data not shown). These results were similar to those obtained in Expt. 1, although the time-spreads of emergence of the seeds from all 3 priming treatments used in Expt. 2 were longer than those of seeds similarly primed in Expt. 1.

Tomato. Increasing the duration of priming of tomato seeds caused a small reduction in the maximum percentage of germination at 15°C with durations longer than 8 days (Fig. 2A). The overall linear regression with duration was statistically significant, although this reduction was from 96.6% at 0 days to 91.5% at 22 days. There was virtually no effect of priming for <2.2 days on the median rate of emergence, but the median rate increased linearly thereafter to a value some 15 times that of unprimed seeds after 18 days priming, after which it stabilized (Fig. 2B). The time-spread of germination of primed seeds improved with increasing duration of priming, from 73 hr for untreated seeds to 12 hr for seeds primed for 20 days (Fig. 2C). The maximal response to priming of tomato seeds was achieved

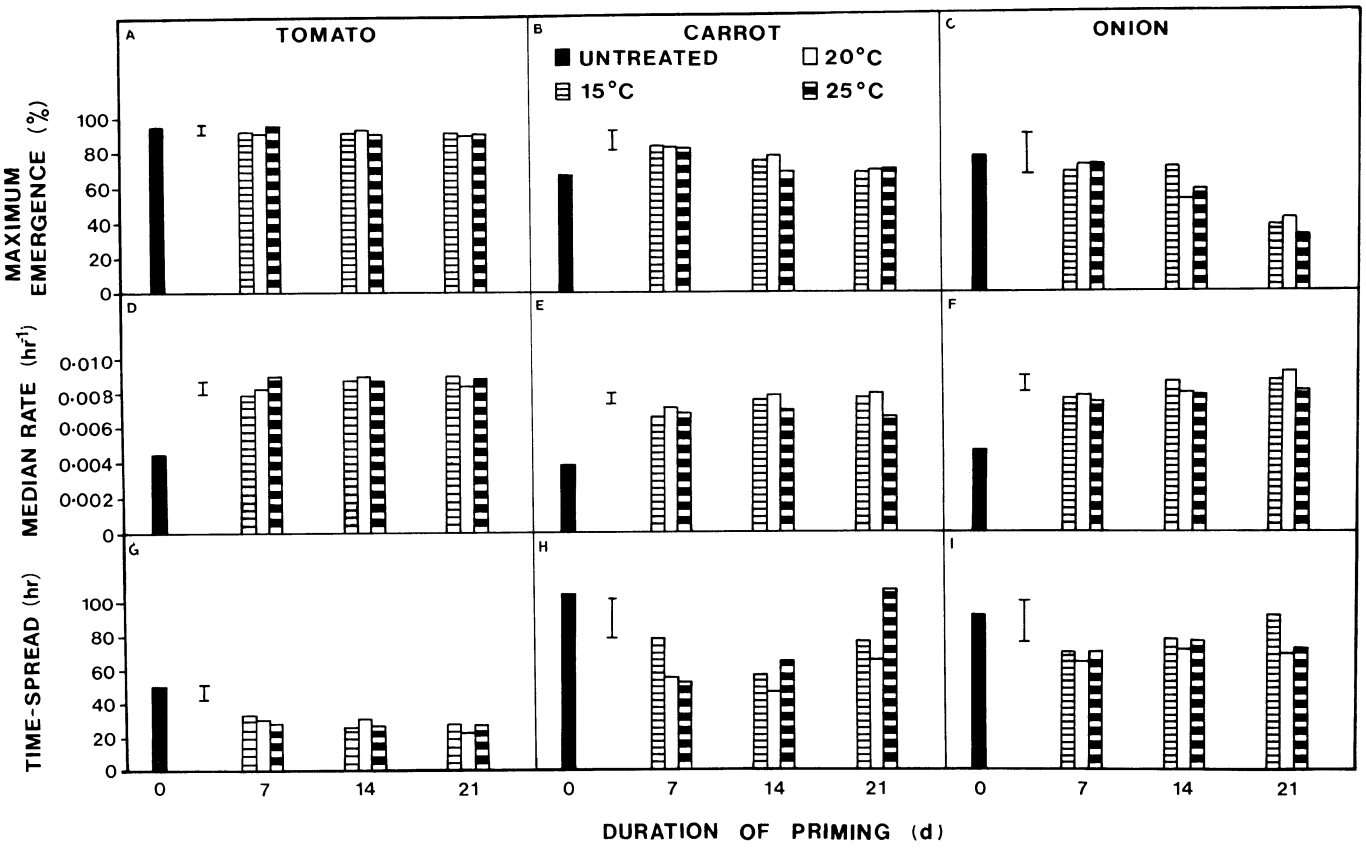

Fig. 1. The effect of temperature and duration (d, days) of priming in 0.105 M K_3PO_4 + 0.209 M KNO_3 on the emergence of tomato, carrot, and onion seeds at 15°C. **A, B, C.** Maximum percentage of emergence. **D, E, F.** Median rate of emergence, the reciprocal of the time to the emergence of the median seed. **G, H, I.** Time-spread of emergence, the time from 5% emergence to 80% of the maximum emergence. Least significant differences (0.05) are shown.

through priming for 18 days, although differences after about 12 days were small, especially in time-spread.

Carrot. Increasing the duration of priming of carrot seeds in 0.102 M K_3PO_4 + 0.204 M KNO_3 (−1.5 MPa) caused a small but significant reduction in the maximum percentage of germination, from 74.7% for unprimed seeds to 66.0% after 22 days treatment (Fig. 2A). The median rate of germination increased linearly with duration of priming to reach 0.0402 hr^{-1} after 22 days (Fig. 2B). Priming carrot seeds also reduced the time-spread of germination linearly to 37 hr after 22 days priming, which was about one-third of that of untreated seeds (Fig. 2C). The maximal response was obtained from seeds primed for 16 days, although priming for periods longer than 8 to 10 days reduced the percentage of seeds that germinated.

For both species, it was apparent that although continued gains in emergence could be obtained by longer priming, these gains were at the expense of germination percentage.

Drying of primed seeds. Drying of tomato and carrot seeds for up to 8 days in the laboratory following priming caused no adverse effects to their germination at 15°C (data not shown). In order to determine whether drying and the length of dry storage of primed seeds had any influence on their emergence performance in the field, a 2nd experiment was conducted in which the storage was extended to 28 days for all 3 species.

Air-drying of tomato seeds for up to 28 days prior to sowing had no effect on the priming response of the seeds. Similarly air-drying of primed carrot seeds caused no change to the maximum percentage of field emergence, the median rate of field emergence, or to the time-spread of emergence. Although air-drying of primed onion seeds for one day reduced the maximum percentage of field emergence below that of untreated seeds, there were no effects of further drying (data not shown).

Field emergence of primed seeds—tomato. The priming of tomato seeds resulted in a slightly increased maximum percentage of field emergence at all sowing dates (Fig. 3B). There was a trend towards reduced maximum percentages from the early to the late sowings. This trend was more marked in the untreated than treated seeds. This reduction in maximum percentage with sowing date may have resulted from soil crusting that became more pronounced as the season developed. The median rate of field emergence of primed seeds was faster than that of untreated seeds at all sowing dates, with a tendency for the difference to diminish as the soil temperature increased (Fig. 3C). The time-spread of field emergence of primed seeds was less than that of untreated seeds for all sowings, except the last, when soil temperatures were highest. The mean time-spreads of primed seeds were 36% shorter than that of untreated seeds, but improvements at individual sowings were as high as 67% (Fig. 3D).

Carrots. Overall, there was no difference between the maximum percentage of field emergence of primed carrot seeds and that of untreated seeds; however, the untreated seeds had a higher maximum percentage at the first sowing (89%) relative to that of the primed seeds (69%), while the primed seeds had a higher maximum percentage (67%) at the 2nd sowing relative to that of untreated seeds (40%) (Fig. 4B). As with tomato seeds, there

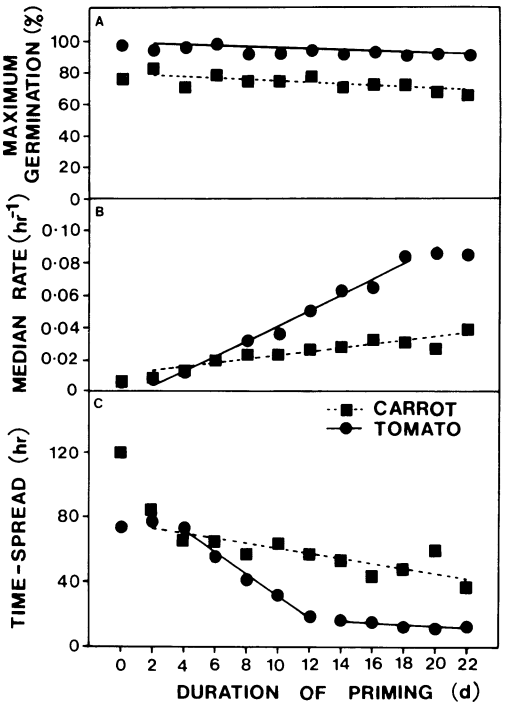

Fig. 2. The effect of duration (d, days) of priming of tomato seeds in 0.090 M K_2HPO_4 + 0.118 M KNO_3 and of carrot seeds in 0.102 M K_3PO_4 + 0.204 M KNO_3 on their germination at 15°C. **A.** Maximum percentage of germination. **B**. Median rate of germination. **C**. Time-spread of germination. Regression equations were:

(**A**) tomato, y = 95.8 − 0.20d (r^2 = 31.3%),
carrot, y = 79.4 − 0.52d (r^2 = 48.4%),

(**B**) tomato (2 to 18 days), y = −0.0071 + 0.0049d (r^2 = 97.9%),
carrot, y = 0.0108 + 0.0012d (r^2 = 83.2%),

(**C**) tomato (4 to 12 days), y = 95.2 − 9.31d (r^2 = 96.8%),
(14 to 22 days), y = 22.4 − 0.44d (r^2 = 40.6%),
carrot, y = 76.2 − 1.56d (r^2 = 65.3%).

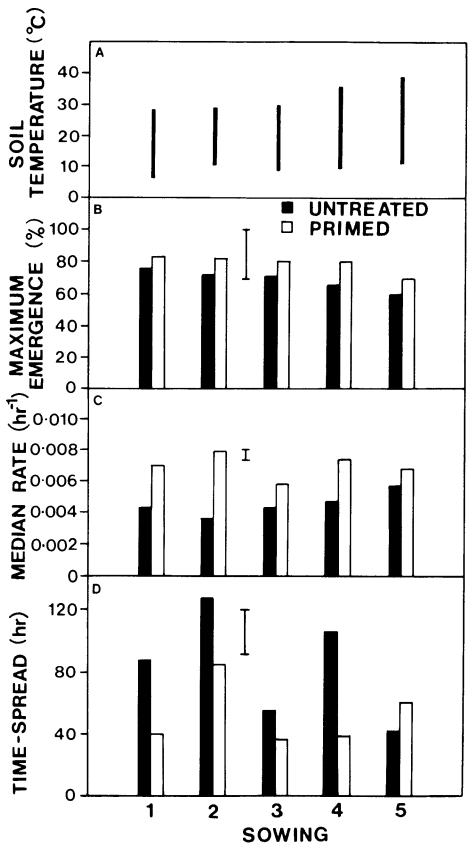

Fig. 3. The effect of priming in 0.105 M K_3PO_4 + 0.209 M KNO_3 at 15°C for 14 days on the emergence of tomato seeds in the field at 5 sowing dates in early spring. **A**. Soil temperature range based on the mean maximum and minimum soil temperatures over 7 days from the sowing date. **B**. Maximum percentage of field emergence. **C**. Median rate of field emergence. **D**. Time-spread of field emergence. Least significant differences (0.05) are shown.

was a declining trend in maximum percentages from early to late sowings. The median rate of field emergence of primed seeds was faster at all sowings than that of untreated seeds (Fig. 4C). The time-spread of field emergence of primed seeds was not different from that of untreated seeds, except at the 2nd sowing (Fig. 4D).

Onions. The priming of onion seeds resulted in maximum percentage of field emergence that was about half that of untreated seeds, with mean maximum percentages of 32% for primed seeds and 60% for untreated seeds (Fig. 5B). However, the median rates of field emergence of primed seeds were significantly faster than those of untreated seeds (Fig. 5C), and there was no difference in time-spread between primed and untreated seeds (Fig. 5D).

Discussion

The effects of priming temperature and duration were interrelated (Fig. 1). There was greater benefit from priming at a low temperature (15°C) for a long time than at high temperatures, whereas priming for too long at too high a temperature reduced the percentage of germination. However, this aspect of priming has not been explored in any detail, and it is quite possible that temperatures <15° could be more suitable. Different species have different minimum temperatures for germination, so low temperature 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.

The need for compatibility of treatment temperature for all species resulted in the selection of 15°C as best, with a duration of about 10 to 14 days. However, higher temperatures with shorter durations would be equally beneficial for priming of tomato or carrot seeds, but not onion seeds. Although prolonged periods of priming resulted in continued improvements in germination of tomato and carrot seeds, these improvements were somewhat offset by reductions in viability (Fig. 2). It should be noted that part of the advancement of primed seeds in laboratory tests may be due to the imbibition time for the control seeds. However, the maintenance of the germination benefits after drying following priming of tomato and carrot seeds suggests the likelihood of a commercial-scale priming treatment to produce seeds compatible with existing sowing equipment.

The priming of onion seeds markedly decreased field emergence (Fig. 5). This decline was in contrast to the results from Expt. 1, in which the same priming treatment (in petri dishes) produced seeds with maximum percentages of germination equal to that of the untreated seeds (Fig. 1C). This difference may have resulted from the 24-hr drying treatment given to all primed seeds sown in the field, whereas in laboratory tests the seeds were sown moist. Onion seeds have been shown to have low viability when dried after storage at high relative water contents (12). As this priming solution did not prevent all seeds from

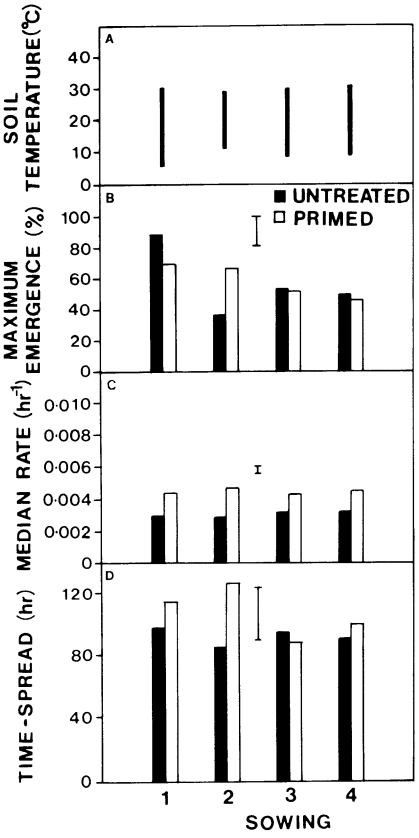

Fig. 4. The effect of priming in 0.105 M K_3PO_4 + 0.209 M KNO_3 at 15°C for 14 days on the emergence of carrot seeds in the field at 4 sowing dates in early spring. **A**. Soil temperature range based on the mean maximum and minimum soil temperature over 7 days from the sowing date. **B**. Maximum percentage of field emergence. **C**. Median rate of field emergence. **D**. Time-spread of field emergence. Least significant differences (0.05) are shown.

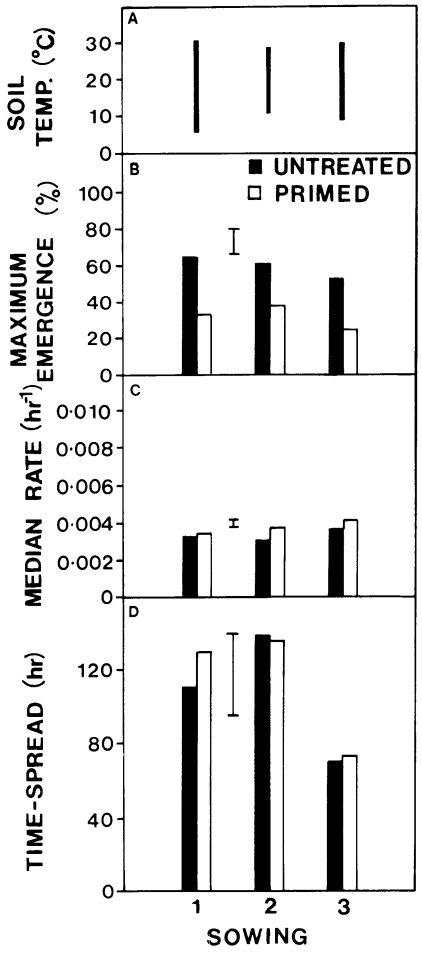

Fig. 5. The effect of priming in 0.105 M K_3PO_4 + 0.209 M KNO_3 at 15°C for 14 days on the emergence of onion seeds in the field at three sowing dates in early spring. **A**. Soil temperature range based on the mean maximum and minimum soil temperatures over 7 days from the sowing date. **B**. Maximum percentage of field emergence. **C.** Median rate of field emergence. **D.** Time-spread of field emergence. Least significant differences (0.05) are shown.

germinating during treatment, a large proportion may have reached a stage of development that was no longer tolerant of desiccation.

The results from the 2nd experiment demonstrated that it was possible to prime large numbers of seeds in salt solutions using an apparatus based upon the design of Darby and Salter (4), and to obtain results comparable to priming in petri dishes. Szafirowska et al. (13) showed that PEG-primed carrot seeds produced crops with yields increased by up to 93%, in small field plots sown in cold soil from a priming treatment of small (1.6-g) lots of seeds. Our results from the limited investigations in the field showed that effective means for priming large quantities of tomato seeds in salt solutions could be devised. Moreover, the primed tomato seeds had an increased percentage of emergence in the field as well as improved uniformity of emergence over those of untreated seeds. Although less satisfactory, carrot seeds could be primed in bulk in salt solutions to produce early emerging seedlings in the field.

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J. Amer. Soc. Hort. Sci. 111(5):665–669. 1986.

Improved Performance of Bearing 'Delicious' Apple Trees with Nitrogen and Phosphate Fertilization in a Low-phosphorus Soil

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Additional index words. *Malus domestica*, nutrition, mineral composition of leaves, growth and development, yield

Abstract. **Bearing 15-year-old 'Oregon Spur', 'Redspur', and 'Wellspur Delicious'/seedling apple (*Malus domestica* Borkh.) trees in a low-P (2 to 4 ppm) soil were treated over 3 years with different forms and rates of N and N + P fertilizers to overcome a severe condition of low vigor and low yields. Fruit size and leaf N were greater on trees receiving all forms of N fertilizer than on the untreated controls. Levels of leaf P were up to 2 times greater on $NH_4H_2PO_4$ [mono-ammonium phosphate (MAP)] treated trees than on the controls or N-only [$(NH_4)_2SO_4$, NH_4NO_3, $Ca(NO_3)_2$ or urea] treated trees. In most instances, the higher rates of MAP (applied in 1983 and 1984) resulted in greater shoot extension and leaf weight than the controls and most of the N-only treated trees. Yield (3-year mean) was greater on 'Oregon Spur' and 'Redspur' cultivars treated with the moderate rate of MAP than in the controls or in most of the N-only treated trees.**

For many decades, N fertilizer has been the primary nutrient element recommended for apple production in Washington (1). Although a response of apple trees to P is reported to be rare in commercial orchards (3, 4), recent investigations have shown a marked response to soil-applied P by young apple trees grown in low-P soils in the Pacific Northwest (7, 8) and in other areas (10–12). Koch et al. (5) reported a response of apple seedlings to incorporations of P into fumigated soil with or without inoculations of mycorrhizae.

Because an increasing number of apple orchards have declining vigor and reduced production, an investigation was initiated to determine possible means for correcting this condition. In many instances, soil tests revealed low available P (<10 ppm) in orchards where the trees were of low vigor and productivity, and in the more extreme cases the trees eventually died.

The objectives of this study were to compare different rates of MAP and equivalent rates of N-only fertilizers [$(NH_4)_2SO_4$, NH_4NO_3, $Ca(NO_3)_2$, and urea] with untreated control trees for increasing: a) leaf N and P; b) tree vigor; c) fruit number; and d) fruit size.

Materials and Methods

Stunted 15-year-old apple trees, in a 6 × 3 m planting, were tested for their response to N and N + P fertilization. All trees were in a condition of low vigor, and fruit size was small. Three strains ('Oregon Spur', 'Redspur', and 'Wellspur') of 'Delicious' apple trees on seedling rootstocks were used in the test and observed over a 3-year period.

The orchard was located in central Washington near Royal City on Frenchman Hills at an elevation of 435 m with a southern exposure. The soil chemical properties at a depth of 0 to 30 cm had the following ranges: pH = 8.1 to 8.4; organic matter = 0.9% to 1.5%; P = 2 to 4 ppm (bicarbonate method); K = 57 to 154 ppm; and Ca = 111 to 244 meq per 100 g. The above tests show a high level of Ca but a low level of P. A low-P soil is generally considered to be <10 ppm P.

Until 1984, the trees were irrigated once a week for 24 hr with permanent-set, under-tree sprinklers. However, in 1984 and 1985, the irrigation schedule was changed to an interval of every 5th day for a 12-hr set. The latter method of irrigation was well-suited to the soil type and resulted in an improved tree condition with less stress.

Eight treatments were randomly assigned to each of the 3 'Delicious' strains. There were 5 replications of each treatment–strain combination, each consisting of 4 trees. The 8 treatments consisted of an untreated control, 3 rates of MAP, and 4 sources of N-only fertilizers [$(NH_4)_2SO_4$, NH_4NO_3, $Ca(NO_3)_2$, and urea). All 4 N-only fertilizers were applied at a rate equivalent to the moderate rate of N per tree (0.3 kg) for the MAP fertilizer. In 1983 and 1984, the above treatments were broadcast on the surface under the drip line of each tree in late April, just prior to the first spring irrigation.

The strip-block design was considered appropriate in this experiment to account for a shallow soil condition across the upper part of the orchard. The experimental design also was modified

Received for publication 16 Dec. 1985. I express appreciation for the cooperation of the Royal Flush Orchard Enterprise (Lloyd Erlandson, manager) and Dwayne Visser, agricultural technician. Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not give its approval to the exclusion of other products that may be suitable. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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