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Rhizosphere pH Influences Early Root Morphology and Development of Bell Peppers

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Abstract. Bell peppers (*Capsicum annuum* L. 'Early California Wonder') were seeded in glass tubes on agar-based media adjusted to pH 4.1, 5.9, or 7.3 to evaluate germination, emergence, shoot growth, and root morphology for 16-day-old seedlings. Taproot lengths were measured daily from 1 to 10 days following radicle protrusion. Time from seeding to germination (radicle protrusion) differed by only one-half day among pH treatments. Peppers in a pH 5.9 medium emerged (fully expanded cotyledons) 1 day earlier than plants grown in media at pH 4.1 or 7.3. Plants grown in a pH 5.9 medium had higher shoot and root weights and longer stems than plants grown at pH 4.1 or 7.3. Shoot: root ratios were similar regardless of medium pH. However, taproot growth rate from 1 to 10 days after radicle protrusion was faster for plants grown in a pH 5.9 than in a pH 4.1 or 7.3 medium. On average, there was one basal and one lateral root per plant and they were minimally influenced by pH. The data suggest that acidic or alkaline media adversely affect early shoot and taproot development of bell peppers, but with minimal influence on time to germination or emergence, and on subsequent lateral and basal root initiation.

Shoemaker and Carlson (1990) reported that germination of eight bedding plant species was affected by pH, with the highest

percent germination occurring at pH 5.5 to 7.5 for most species. However, percent germination of tomato (*Lycopersicon esculentum* Mill.) and petunia (*Petunia hybrida* Vilm.) was not affected by acidity of irrigation water (Bailey and Hammer, 1986). Barker (1989) has cited many investigations measuring changes in root morphology in response to N source or concentration. Zobel (1989) has reviewed studies indicating edaphic environmental factors, such as moisture, temperature, mineral concentration, and gaseous atmosphere, affected root morphology.

We found no information on the influence

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Table 1. Germination, emergence, shoot, and root characteristics of bell peppers 16 days after seeding as influenced by pH.^a

Medium pH ^y		Germination ^x (days)	Emergence ^w (days)	Shoot wt (mg)	Root wt (mg)	Shoot : root ratio	Stem ht (mm)	Taproot length (mm)	Basal roots (no.)	Lateral roots (no.)
Initial	Final									
4.1	4.5 c	4.6 b	6.7 a	52.7 b	11.8 b	5.0	28.4 c	53.8 b	1.7 a	0.8 a
5.9	5.7 b	4.5 b	5.4 b	68.9 a	13.8 a	5.4	38.1 a	62.7 a	1.5 a	0.9 a
7.3	6.9 a	5.0 a	6.8 a	54.4 b	10.7 b	5.5	34.4 b	46.1 c	0.6 b	0.1 b

^aMean separation within columns by Duncan's multiple range test, $P = 0.05$.^ypH values of media were measured just before seeding and just after plant extraction, 16 days after seeding.^xDays from seeding to radicle protrusion.^wDays from radicle protrusion to fully expanded cotyledon.

Fig. 1. Taproot growth rate from 1 to 10 days after radicle protrusion for seeds placed in pH 7.3, 5.9, or 4.1 medium. Linear regression equations are: (pH = 7.3) $y = -0.006 + 5.11x$ ($r^2 = 0.82$); (pH = 5.9) $y = 2.65 + 6.67x$ ($r^2 = 0.87$); (pH = 4.1) $y = -3.03 + 5.88x$ ($r^2 = 0.87$); where y = taproot length (mm), x = days from radicle protrusion. Regression coefficients (slopes) were significantly different from each other according to t tests, $P = 0.05$.

of rhizosphere pH on bell pepper seedling root growth and development. Root morphological characteristics of young bell pepper plants have been described by Stoffella et al. (1988a). The purpose of this investigation was to measure the effects of pH on bell pepper germination, emergence, and subsequent seedling shoot growth and root morphology.

A gel medium containing organic salts according to Linsmaier and Skoog (1965) and Gelrite gellan gum at 2.0 g·liter⁻¹ (Merck & Co., Rahway, N.J.) were used for germination and seedling growth. Gel solution pH values (5.7) were adjusted to 3.5 with 1 N HCl, 5.9 with 0.2 N KOH, or 8.0 with 6 N KOH before autoclaving. Since pH can be altered by autoclaving (Skirvin et al., 1986), the initial pH values of the media were purposely adjusted to desired post-autoclaving pH. Each medium was dispensed in glass tubes (25 x 200 mm) at 40 ml/tube before being autoclave at 121°C and 1.1 kg·cm⁻² for 20 min. Gel pH values following the autoclaving were 4.1, 5.9, or 7.3. Pre-autoclave (liquid) and post-autoclave (solid) media pH was measured with a pH meter (Metrohm Herisau, Model E12, Switzerland) at 20°C.

Seeds of 'Early California Wonder' were surface-sterilized for 20 min in 2% NaOCl solution then rinsed three times in sterilized water. One seed was placed in each tube in the center of the surface of the gelled me-

dium. The tubes were placed in racks that were covered with black polyethylene film. The black plastic was used to reduce light to the root zone while allowing light to the developing shoots. Racks with glass tubes were placed in a growth room at a constant $25 \pm 1^\circ\text{C}$. The photoperiod was 16 hr using cool-white fluorescent tubes (Philips TLM 40W/33RS and Osram Hell Wiss, 2:1 ratio), with a photon flux rate (PAR) of $65 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. Roots were observed using the technique of Stoffella et al. (1988a). A single plant in a glass tube was considered an experimental unit. A randomized complete-block design was used with each pH treatment replicated 44 times.

Time (days) to germination (radicle protrusion) and emergence (fully expanded cotyledons) was observed daily. Taproot lengths were measured daily from 1 to 10 days after radicle protrusion, except on day 5. Plants were extracted from the gel with forceps 16 days after seeding. Root and shoot fresh weights, stem heights (basal hypocotyl end to stem tip), number of basal roots (roots originating from the taproot-hypocotyl transition zone) (Zobel, 1975), and number of lateral roots were determined. Shoot : root ratios were calculated for each seedling. Medium pH for each tube was measured immediately following root extraction.

Each variable was subjected to analysis of variance and pH treatment means were separated by a Duncan's multiple range test at $P = 0.05$. Linear regression analysis was performed for each pH treatment with taproot lengths as the dependent variable and days from radicle protrusion as the independent variable. t tests were used to detect differences between regression coefficients (slopes).

Days to germination was delayed by 0.5 day in pH 7.3 as compared with pH 4.1 or 5.9 (Table 1). Days to emergence (fully expanded cotyledons) was 1 day earlier at pH 5.9 than in a pH 4.1 or 7.3.

Plants grown at pH 5.9 had significantly higher shoot and root weights than plants grown at pH 4.1 or 7.3 (Table 1). However, shoot : root ratios were similar for all pH values (Table 1). This result suggests that plant root and shoot weights were affected similarly by the pH treatments. Plants grown at pH 5.9 had significantly longer stems than plants grown at pH 4.1 or 7.3 (Table 1).

Taproot lengths increased linearly from 1 to 10 days after radicle protrusion, regardless of pH (Fig. 1). Similar linear taproot growth rates were reported for raw, primed, or pre-

germinated bell pepper seeds grown at 15, 25, or 35°C from 1 to 7 days following radicle protrusion (Stoffella et al., 1988b). Taproots of plants grown at pH 5.9 grew faster between 1 and 10 days after radicle protrusion (Fig. 1) and had longer taproots 16 days after seeding (Table 1) than plants grown at pH of 4.1 or 7.3.

The number of mean basal and lateral roots averaged 1.2 and 0.5 per plant, respectively, when pooled over all pH media treatments (Table 1). Similar low values were reported for 10-day-old 'Early California Wonder' seedlings (Stoffella et al., 1988a). Plants grown in media with pH 4.1 or 5.9 averaged slightly more lateral and basal roots than plants grown in a pH 7.3 medium. Apparently, pH of the medium minimally affected the number of basal and lateral roots.

Media pH values 16 days after seeding were 4.5, 5.8, and 6.9 for initial pH treatments of 4.1, 5.9, and 7.3, respectively (Table 1). Plant roots have been reported to either increase (Liu, 1980; Marschner et al., 1986) or decrease rhizosphere pH (Grinstead et al., 1982; Shaller, 1987). Rhizosphere pH changes may be influenced by the soil buffering capacity (Schaller, 1987), mineral absorption capacity and efficiency of the plant species (Marschner and Romheld, 1983), and initial soil pH (Yousef and Chino, 1984). The increase in pH by 16 days in media with initial pH of 4.1 or 5.9 may be attributed to an increase in anion uptake, therefore resulting in a cation accumulation or lower pH. The decrease in pH by 16 days in medium initially at pH 7.3 may be attributed to increased cation uptake, therefore resulting in an anion accumulation or lower pH. Riley and Baker (1970) and Nye (1986) reported that pH changes are usually restricted to the rhizosphere. Changes in pH in this study may be attributed to the low buffering capacity of the gel media relative to the media used by Riley and Barker (1970) or Nye (1986). Yousef and Chino (1984) reported similar rhizosphere pH changes with barley (*Hordeum vulgare* L.) or soybeans (*Glycine max* Mer.) grown in acid and alkaline soils. Root exudates also may have altered pH of the media. *Cucumis callus* has been reported to significantly alter post-autoclave pH of media within 48 hr (Skirvin et al., 1986).

A pH of 5.9 was more favorable for bell pepper emergence, seedling shoot growth, and taproot growth rate than either pH 4.1 or 7.3. However, pH had minimal effects on the subsequent number of basal and lateral roots.

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