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Orientation of Root and Cotyledon in Pepper Seedlings and Its Use in Field Production

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Abstract. **'TAMBel-2' bell pepper transplants (*Capsicum annuum* L.) were grown in a greenhouse for 39 days in north–south (N–S) oriented trays. About 69% of the plants had monodirectional (one plane pointing either N–S, E–W, NW–SE, or SW–NE) lateral root patterns, 23% had bidirectional (two planes), and 7% had omnidirectional (all around) root patterns relative to a N–S greenhouse tray orientation. Transplants were planted with cotyledons N–S (parallel to the N–S bed), with cotyledons E–W (perpendicular to the N–S bed), and at random, without regard to orientation. These plants subsequently were cultivated either deeply (9 cm) or shallowly (3 cm) 3, 5, and 7 weeks after transplanting. Transplants planted E–W by cotyledon orientation yielded significantly more early and overall marketable pods in contrast to those planted N–S by cotyledon orientation or at random. Deep cultivation decreased productivity in contrast to shallow cultivation and negated any benefit to E–W cotyledon orientation. Root and cotyledon orientations in field-seeded peppers were determined for 'Hidalgo', 'TAM-Mild Chile-2', 'TAMBel-2', and 'Grand Rio 66' peppers ≈2 months after field-seeding. At least 95% of the populations in all cultivars had monodirectional root orientations. Generally, orientations were divided equally among N–S, E–W, NW–SE, and NE–SW directions. Cotyledon orientation highly correlated with root orientation in all cultivars.**

Certain plant species exhibit unique lateral root orientation patterns. Sugar beets (*Beta vulgaris* L.) exhibited east–west (E–W) lateral root orientations (6). Winter wheat (*Triticum sativum vulgare* Lam.), flaxweed (*Descrviania sophia* L. Webb), and stink weed (*Thlapsi arvense* L.) consistently exhibited north–south (N–S) root orientations; however, spring wheat (*Triticum aestivium* L.), fall-sown rye (*Secale cereale* L.), spring rape (*Brassica napus* L.), and spring barley (*Hordeum vulgare* L.) exhibited roots that were omnidirectional or all around (4). Several theories, such as magnetotropism or geomagnetotropism (2, 4, 5), genetic inheritance (1, 10), hilum placement (1), physiological factors (8, 10), and cultural practices (3, 7) have been offered to explain these phenomena.

Peppers also exhibit various lateral root orientation patterns. In a study of root development, Weaver and Bruner (11) stated that lateral roots originated in rows on opposite sides of the primary root axis. Awoleye (1) found that the cultivar El Paso, an Anaheim-type pepper, had monodirectional lateral roots on two sides of the primary root axis (generally N–S or E–W). Seed hilum placement of 'El Paso' was correlated highly with cotyledon orientation and direction.

Deep cultivation of seedling peppers is used commercially in the Lower Rio Grande Valley of Texas to encourage deep rooting and thereby lessen the potential for water stress. Yields may be affected by cultivation practices and lateral root orientation. Pruning roots by mechanical cultivation may be a major consideration accounting for yield suppression. Deep cultivation prunes roots and tends to dry the soil, both of which may depress plant growth and pepper yield (10).

The goal of this study was to develop a cultural system using transplant orientation to increase bell pepper yield. The objectives of this study were to a) determine the degree and correlation of root and cotyledon orientation in peppers direct-seeded in the field and grown as greenhouse transplants and b) determine if transplanting pepper transplants by cotyledon orientation, and differentially cultivating, affect marketable yield.

Transplant cotyledon and root orientation. Bell peppers 'TAMBel-2' were seeded on 27 July 1985 into containers with a 30.5 cm^3 cell volume filled with a soilless medium. The trays were oriented lengthwise in a permanent N–S direction during transplant production in a greenhouse until 6 Sept. The plants were fertilized weekly to runoff with a solution of 200N–87P–166K ($mg \cdot liter^{-1}$) from 10 to 31 Aug.

On 4 Sept., the cotyledon and root orientations of 399 plants were determined in relation to their greenhouse N–S tray orientation. The roots of each plant were rinsed of medium, and cotyledon and root orientation were determined as in Table 1.

Cotyledon and root orientation of field-seeded peppers. To determine if root and cotyledon orientation is more pronounced in direct-seeded peppers, 'Hildago' (serrano type), 'Grande Rio-66' and 'TAMBel-2' (bell types), and 'TAM Mild Chile-2' (Anaheim type) peppers were field-seeded in N–S rows 3 Feb. 1986 into a Raymondville clay loam, a Vertic Calciustoll. *N*,*N*-diethyl-2-(1-naphthalenyloxy)-propionamide (napropamide) at 1.7 $kg \cdot ha^{-1}$ was preplant-incorporated. There was 1 m between rows. From 1 to 4 Apr., root and cotyledon orientations were determined as previously described from 302, 335, 420, and 391 seedlings, respectively, for the four cultivars by gently pulling seedlings from the recently irrigated field.

Effect of transplant orientation and cultivation practices on yield. To test the effect of cotyledon orientation on yield, transplants were selected and field-planted on 5 Sept. with a N–S cotyledon orientation, or with a E–W cotyledon orientation in a N–S-oriented bed. As a control, plants were transplanted randomly into plots without regard to their cotyledon orientation in a N–S bed. The test rows were guarded on the east and west by border rows. There was 1 m between each N–S row, and each plot was 4.6 m long. Plants were spaced 15 cm apart within the rows. Each plot contained 25 plants.

The experimental design was a randomized complete block with four replications. To determine the effect of cultivation practices in relation to plant orientation, field plots were cultivated either at a depth of 9 cm (deep) or 3 cm (shallow). Cultivations were made on 26 Sept. and 9 and 24 Oct. using a cultivator (Lilliston, Albany, Ga.) set 8 cm on each side of the plants.

α,α,α-trifluoro-2,6-dinitro-*N*,*N*,-dipropyl-p-toluidine (trifluralin) at 0.5 $kg \cdot ha^{-1}$ was preplant-incorporated on 20 Aug. Napropamide at 1.7 $kg \cdot ha^{-1}$ was postplant-directed on 10 Oct. Nitrogen at 55 $kg \cdot ha^{-1}$ was applied as banded sidedressings on 25 Sept., 23 Oct., and 25 Nov. The field was irrigated at 50% moisture depletion as indicated by tensiometers on 5, 10, and 27 Sept.; 11, 23, and 31 Oct.; and 14 Nov.

The plots were harvested four times at weekly intervals beginning 13 Nov. and ending 4 Dec. All fruit were stripped from the plants on the last harvest. The peppers were graded according to USDA standards (9).

Degree and correlation of root and cotyledon orientation in greenhouse transplants and field-seeded peppers. About 69% of the 'TAMBel-2' transplants had monodirec-

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Table 1. Percentage and correlations of 'TAMBel-2' pepper transplants exhibiting various root–cotyledon orientations.

Cotyledon orientation (N, W–E, S)	Root orientation (percent of total population[z]): Monodirectional				Bidirectional				Omnidirectional		
	|	—	\	/	⊥	⊤	⊣	⊢	*	Other	Total
|	19.3	2.5	0.8	0.8	0.2 **	1.2	3.5	3.5	1.7	0	33.5
	0.44**[y]	−0.23**	−0.13**	−0.22**	−0.11*	NS	0.11*	NS	NS	NS	
—	3.5	12.5	1.8	2.3	2.5	2.5	1.2	2.5	2.3	0.7	31.8
	−0.27**	0.32**	NS	−0.13	0.15**	0.11*	NS	NS	NS	NS	
\	4.3	2.3	4.0	1.5	0.3	0	1.3	1.3	1.0	0	16.0
	NS	NS	0.31**	NS	NS	NS	NS	NS	NS	NS	
/	2.0	3.3	0.5	8.0	0.8	0.8	0.5	0.3	2.3	0	18.5
	−0.19**	NS	NS	0.44**	NS	NS	NS	−0.11*	NS	NS	
Total	29.1	20.6	7.1	12.6	3.8	4.5	6.5	7.6	7.3	0.7	

[z]n = 399.
[y]Correlation coefficients (r).
*,**,NSSignificant at the 5% and 1% levels, or nonsignificant, respectively.

Table 2. Percentage and correlations of field-seeded peppers exhibiting various root/cotyledon orientations.

Cotyledon orientation (N, W–E, S)	Root orientation (percent of total population[z]): Monodirectional					
	|	—	\	/	Other	Total
	Hidalgo Chile (n = 302)					
|	20.9	0.3	0.3	0.3	1.7	23.5
	0.88[z]	−0.31	−0.27	−0.31	NS	
—	1.3	24.2	0.3	0	2.0	27.8
	−0.26	0.88	−0.31	−0.36	NS	
\	0	0	20.9	0	1.3	22.2
	−0.28	−0.31	0.94	−0.32	NS	
/	0	1.0	0	25.5	0	26.5
	−0.32	−0.30	−0.31	0.97	NS	
Total	22.2	25.5	21.5	25.8	4.9	
	TAMBel-2 (n = 420)					
|	32.1	0	0	0	0.3	32.4
	0.99	−0.38	−0.37	−0.36	NS	
—	0	23.6	0	0	0	23.6
	−0.38	1.00	−0.30	−0.27	NS	
\	0	0	22.6	0	0	22.6
	−0.37	−0.30	1.00	−0.28	NS	
/	0	0	0	21.4	0	21.4
	−0.36	−0.27	−0.28	1.00		
Total	32.1	23.6	22.6	21.4	0.3	
	TAM-Mild Chile-2 (n = 391)					
|	17.4	0	0.2	0.6	1.0	19.2
	0.90	−0.27	−0.31	−0.24	NS	
—	0.8	22.9	0	0.2	0.7	24.6
	−0.24	0.92	−0.38	−0.30	NS	
\	0.9	0	30.0	0	0	30.9
	−0.29	−0.38	0.96	−0.37	NS	
/	0.2	1.3	0.5	23.0	0.2	25.2
	−0.26	−0.26	−0.36	0.92	NS	
Total	19.3	24.2	30.7	23.8	1.9	
	Grande Rio-66 (n = 335)					
|	26.6	0	0	0	0	26.6
	1.00	−0.37	−0.34	−0.32	NS	
—	0	27.2	0	0	0	27.2
	−0.37	0.99	−0.34	−0.33	NS	
\	0	0	23.9	0	0	23.9
	0.31	−0.34	1.00	−0.30	NS	
/	0	0.3	0	22.0	0	22.3
	−0.32	−0.31	−0.30	0.99	NS	
Total	26.6	27.5	23.9	22.0	0	

[z]Correlation coefficients (r) are significant at the 1% level except where noted nonsignificant (NS).

tional (one plane pointing either N–S, E–W, NW–SE, or SW–NE) lateral root patterns, 22% were bidirectional, and 7% were omnidirectional (Table 1). Of the 40 actual cotyledon–root relationships observed, there were five relationships that were the most common, comprising almost 50% of the population. These relationships, with their respective percentages of the population, were: N–S cotyledons and N–S roots (19%); E–W cotyledons and E–W roots (13%); NE–SW cotyledons and NE–SW roots (8%); NW–SE cotyledons and N–S roots (4%); and NW–SE cotyledons and NW–SE roots (4%). Correlation coefficients between root and cotyledon orientations did not exceed 0.44, which does not indicate strong relationships.

The relationships between root and cotyledon orientations of field-seeded peppers varied considerably from that reported with transplanted peppers. In all direct-seeded cultivars, monodirectional root orientation predominated and bidirectional and omnidirectional root orientations were rare (Table 2). Apparently, bidirectional and omnidirectional rooting patterns in transplanted peppers are encouraged by pruning of the tap root during greenhouse transplant production. In the field, however, the undisturbed root development of the tap root favors monodirectional root orientations. Generally, root and cotyledon orientations were distributed evenly among N–S, E–W, NE–SW, and NW–SE directions in 'Hidalgo' and 'Grande Rio-66'. With 'TAM-Mild Chile-2', ≈30% of the cotyledons and roots were oriented NW–SE, with lesser amounts of variation distributed among the other directions. With 'TAMBel-2', 32% of the roots and cotyledons were oriented N–S, with the remainder of the variation distributed among the other directions. The majority of roots in 'TAMBel-2' transplants also were oriented N–S (Table 1). There were negligible differences in these relationships among the serrano or hot-type peppers and the milder Anaheim and bell pepper types.

With all cultivars, correlation coefficients were high in those relationships where root and cotyledon orientations were in the same direction but were low in mixed direction relationships (Table 2). Unlike transplanted peppers, cotyledon orientation highly correlated with root orientation in field-seeded peppers. Therefore, if a particular root orientation is desired in direct-seeded peppers, plants with the undesired cotyledon orientation can be thinned.

Table 3. Cumulative marketable yields of deep- and shallow-cultivated 'TAMBel-2' bell peppers transplanted by cotyledon orientation or at random.

Cultivation method	Orientation	Yield ($t \cdot ha^{-1}$) 13 Nov.	20 Nov.	27 Nov.	4 Dec.
Deep	N–S	2.6	6.1	10.3	14.5
	E–W	4.6	7.9	12.5	16.9
	Random	4.0	7.9	12.2	17.5
Shallow	N–S	2.6	6.0	13.0	15.0
	E–W	6.2	13.3	19.4	25.8
	Random	2.9	6.5	11.0	17.6
Significance					
N–S vs. random		NS	NS	NS	**
E–W vs. random		*	**	**	**
Deep vs. shallow		NS	*	**	**
E–W vs. N–S		**	**	**	**

*,**,NS Significant at the 5% and 1% levels, or nonsignificant, respectively.

Influence of transplant orientation and cultivation practices on yield. Of the cultural systems evaluated, the method combining E–W cotyledon orientation and shallow cultivation increased early and overall marketable yields (Table 3). These increased yields were due to a significant increase in the number of pods produced and not to an increase in individual pod weight (data not shown). The deeply cultivated E–W cotyledon system yielded less No. 1 pods in all four harvests as compared to the E–W shallow-cultivated system.

The orientation of the cotyledons affected yield in contrast to random transplanting, which was considered the commercial standard. Orthogonal contrasts indicated that orienting transplants N–S by cotyledons significantly limited overall yields in contrast to the randomly transplanted control. Conversely, orienting transplants E–W significantly increased early and overall yields in contrast to random transplanting (Table 3). Because the rows in the field were established in a N–S orientation, we assumed that the plants with E–W cotyledon orientation had roots growing predominantly perpendicular to the row for the growing season. All sidedressings were applied as a band in the N–S direction and furrow irrigation flowed N–S. Also, roots that were perpendicular to the bed were distant from the center of the bed, where salts accumulated and concentrated as a result of evaporation and soil wetting and drying patterns. This observation may explain yield suppressions that occurred with N–S orientations.

Orthogonal contrasts indicated that deep cultivation limited overall yields but did not affect production on first harvest (Table 3). Although the system combining E–W orientation and shallow cultivation increased yields in contrast to N–S orientation with shallow cultivation, deep cultivation in E–W plots negated any benefit to orientation.

The strong correlations between root and cotyledon orientation in direct-seeded peppers suggests a greater use of "orienting" seedlings to increase yields. Direct-seeded peppers could be oriented by thinning all seedlings except those in an E–W cotyledon direction in N–S rows, but this practice may be laborious and cost-prohibitive commercially. Further work is needed to document yield potential of oriented direct-seeded peppers. Also, it is important to document whether root patterns persist through plant maturity. Deep cultivation, independent of seedling orientation, was detrimental to yields.

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Inoculation of Sweet Potato with *Azospirillum*

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***Abstract.* The response of sweet potato (*Ipomoea batatas* Lam.) to inoculation with *Azospirillum* with and without fertilizer N was evaluated in a greenhouse and field study. In the greenhouse study, storage root N concentration of 'Centennial' and 'Jewel' were higher with 34 mg N/pot + inoculant (Cd strain) than with 34 mg N/pot without inoculant. In the field study, the marketable and total root yields and root N contents of 'Centennial' for the 0 kg N/ha + Cd inoculant and 0 kg N/ha + TI-sp-(7+11) inoculant treatments were higher than for the 0 kg N/ha control and were not different from or higher than the 67 kg N/ha treatments with or without the inoculants.**

The N_2-fixing bacteria *Azospirillum* has been isolated from a range of grass, grain, cereal, and orchard crop rhizospheres in tropical and temperate regions (1, 11, 13–16). A survey of rhizosphere soil of 14 crops in Brazil indicated that *Azospirillum*-like bacteria were associated with a number of crops, including sweet potato (5). Iswaran et al. (10) reported the isolation of N_2-fixing bacteria from several tubers and roots of nonleguminous plants, including sweet potato. Hill et al. (7–9) isolated and characterized strains of *A. brasilense* and *A. lipoferum* associated with the roots of six sweet potato cultivars. Inoculation of forage grass, grain, and cereal crops with *Azospirillum* has produced increases in plant growth, dry weight, total N content, and yield, although responses have not always been consistent (2–4, 12). The objective of this study was to determine if *Azospirillum* inoculation influenced storage root and foliage production and nitrogen content of sweet potato.

Experiment 1. Slips of three sweet potato cultivars ('Centennial', 'Jewel', and 'Rojo

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