P. coccineus had deep pink flowers unlike the bright red flowers of the male parent and were sufficiently fertile to produce pods with normal seeds after backcross, self, or inter-hybrid pollination. The reciprocal, P. coccineus × P. vulgaris, also produced some crippled types. Flower color was closer to the red of P. coccineus and, as reported by Ibrahim and Coyne (11), and fertility was higher. Self pollination of the interspecific F₁ produced an F₂ which segregated for flower color, producing some plants with deep scarlet to purple flowers of a size characteristic of P. coccineus. P. coccineus × P. acutifolius hybrids bore pink to red-pink flowers resembling those of the female parent. As in P. coccineus, the stigmatic beard prevented automatic self pollination. Cuttings of these hybrids planted in the field produced pods following bee activity. However, embryos excised from the pods were lost after transplanting into pots. Embryos produced by the cross F₁ (P. vulgaris × P. coccineus) × P. acutifolius were larger than those from 2-species crosses when excised and grew more rapidly in embryo culture. However, the fertility of the 3-species hybrids was low and the anthers did not dehisce (Table 1).

The number of interspecific hybrids recovered using embryo culture far exceeded our expectation and the degree of success previously reported (3, 8, 12). Removal of cotyledons and embryo culture in the dark may have been responsible. Additional work toward improving survival after transplanting from culture and increasing fertility in the resulting hybrid lines is warranted. Since P. coccineus × P. vulgaris and P. coccineus × P. acutifolius hybrids seem fertile enough to produce advanced generations, the use of P. coccineus as a bridge between P. vulgaris and P. acutifolius may result in 3-species hybrids with useful fertility.

Literature Cited


Root Morphological Characteristics of Kidney Beans as Influenced by Within-row Spacing

P.J. Stoffella
IFAS, University of Florida, Agricultural Research Center, P.O. Box 248, Fort Pierce, FL 33454
R.F. Sandsted, R.W. Zobel, and W.L. Hymes
Cornell University, Ithaca, NY 14853

Additional index words. Phaseolus vulgaris, uprooting, resistance, adventitious roots, basal roots, taproot

Abstract. Root morphological characteristics of 'Redkote' and 'Redkloud' kidney bean plants (Phaseolus vulgaris L.) were measured during 2 growth stages at 5, 10, 15, and 20 cm within-row spacings under field conditions. Significantly higher total root weight, shoot weight, basal root weight, and stem and hypocotyl diameters of individual plants occurred as within-row spacing increased. Uprooting resistance, taproot weight, and taproot diameter increased as within-row spacing increased up to 15 cm followed by a nonsignificant increase at 20 cm. No differences in adventitious root weight or shoot:root ratios occurred among within-row spacing treatments. 'Redkote' root parameters were significantly higher than those of 'Redkloud', with the exception of adventitious root weight and uprooting resistance. Seed yields were highest for 15 cm spacing although not significantly more than at 5 cm spacing. All parameters with the exception of basal root number were significantly lower during anthesis when compared with full plant fill growth stage.

Tanaka (8) has classified legume crops into alfalfa, vetch, and intermediate (soybean) root developmental types. Root growth of 26 legume crops differed in bean root developmental types. Root growth of 26 legume crops differed in their ability to elongate, branch, and thicken (9). Increasing root size of many field crops has been reported to improve water and nutrient uptake, lodging resistance, and ultimately yields.

Stoffella et al. (6) reported that plants of 4 black bean lines having a large root size were more upright and yielded higher than 2 cultivars ('Black Turtle Soup' and 'Strain 39'). The 4 lines had significantly greater basal root (roots arising from the basal section of the hypocotyl) weights and diameters and required more uprooting force than the 2 cultivars, suggesting that basal roots were responsible for lodging resistance.

Hidalgo (2) observed that a large sized main central root and a large number of secondary roots were able to extract greater amounts of water than smaller roots in dry beans. Johnson (3) reported that 'Redkloud', with a double grafted root system had a lower shoot and root water potential than a single root system under water stress. However root water potential was higher for the double root system under control conditions, suggesting that a larger root system may be advantageous where water stress is lacking.

Information on root morphological characteristics of kidney beans is limited. The purpose of this investigation was to measure several root morphological characteristics of kidney beans as influenced by within-row spacings.

Two red kidney bean cultivars ('Redkote' and 'Redkloud') were grown under field conditions during summer 1978, at
the Cornell Agronomy Research Farm, Aurora, New York. A fertilizer application of 280 kg/ha of 7N-9.2P-11.6K with the insecticide phorate (15G) (8 kg/ha) was banded just prior to planting. Cultivars were planted in 4 row plots with the middle 2 used for data collection. Each plot was 6.3 m in length with 81 cm between rows. Seeds were hand planted at 5.1 cm and after emergence thinned to 5.5, 10, 15 and 20 cm between plants. Each plot was divided into a 2.1 m section for root biomass evaluations, a 2.1 m section for uprooting resistance, and a 2.1 m section for yield data.

Root measurements were made 38 and 70 days after planting for 'Redkloud' and 38 and 78 days for 'Redkote'. Growth stages were characterized as anthesis (all plants with one or more blossoms) and full pod fill (majority of pods with fully developed seeds).

The experimental design was a randomized complete block with 4 replications and a split-split plot with cultivars as main effects, growth stages as sub-plots, and within-row spacings as sub-sub-plots.

Root measurements were made from 2 plants chosen at random and carefully excavated with a spade at a 20 cm radius around the plant. Roots were soaked in water and washed to remove any remaining soil. Total root biomass was partitioned as described by Stoffella et al. (7), into (a) adventitious roots — those arising from the upper part of the hypocotyl segments just below the soil surface; (b) basal roots — those arising from the basal hypocotyl segment just above the taproot; and (c) taproot — including any lateral roots arising from the taproot. Root biomass components and shoots were oven dried separately at 70°C for 4 days and weights determined.

Diameters of the stem (below the cotyledonary node), basal region (basal hypocotyl segment from which basal roots arise), and beginning of the taproot were measured after drying with a dial caliper. Diameter of the stem (below the cotyledonary node), basal region (basal hypocotyl segment from which basal roots arise), and beginning of the taproot were measured at the point of divergence from the basal hypocotyl segment and summed for individual plants.

Uprooting resistance was measured on 4 random plants per experimental unit. Each plant was cut off at the first node and its base attached to one end of a cable puller with the other end attached to a milk scale. The scale was attached to a lever based on a fulcrum, which enabled a relatively even application of hand pressure to the lever. The maximum pressure reading obtained to uproot the plant, as read from the scale, was recorded.

Plants from 2 adjacent 1.5 m rows were combined to determine seed yield and biological yield (roots + stems + pods + seeds). Samples were air dried with seed yield adjusted to 18% moisture. Harvest index (HI) was calculated as the seed yield x 100/biological yield.

Analysis of variance was performed on all data collected with mean separation only on main effects.

‘Redkote’ had a significantly greater root weight and smaller shoot/root ratio than ‘Redkloud’, although no differences in shoot weight were measured (Table 1). This suggests that the larger root weight of ‘Redkote’ accounted for the smaller shoot/root ratio, since shoot weight differences was not significant. Both shoot and root weight increased as within-row spacing increased. No significant differences in shoot/root ratios between spacings occurred. Adventitious root weight and shoot weight increased proportionally with wider within-row spacings thereby resulting in no shoot/root ratio differences. As would be expected, root weight, shoot weight, and shoot/root ratios were higher during full pod fill than at the anthesis growth stage. All root morphological characteristics of ‘Redkote’ were significantly greater than for ‘Redkloud’ with the exception of hypocotyl diameter and adventitious root weight (Table 2). As within-row spacings increased, all root morphological characteristics of individual plants generally increased with the exception of adventitious root weight. This increase was evident between growth stages with the exception of basal root number. Similarly, Hammes and Bartz (1) reported a more rapid root development rate between blossom and harvest stages as compared with emergence to blossom growth stage of snap beans.

Basal root weight accounted for the largest portion of the total root biomass in all 3 main effects. Stoffella et al. (6) reported that basal roots in black beans accounted for the differences in uprooting resistance. In this study there was a significant correlation between uprooting resistance and total root weight (r = .66) and to basal root weight (r = .63).

Hypocotyl diameter was significantly

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Root wt (mg)</th>
<th>Shoot wt (g)</th>
<th>Shoot:Root Uprooting ratio (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redkloud</td>
<td>633</td>
<td>37.3</td>
<td>54.2</td>
</tr>
<tr>
<td>Redkote</td>
<td>963</td>
<td>45.1</td>
<td>43.1</td>
</tr>
<tr>
<td></td>
<td>* ns</td>
<td>* ns</td>
<td>* ns</td>
</tr>
</tbody>
</table>

Table 1. Mean root weight, shoot weight, shoot:root ratio, and uprooting resistance as influenced by cultivar, within-row spacing, and growth stages in kidney beans grown under field conditions.

Hypocotyl diameter was significantly

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Seed yield (MT/ha)</th>
<th>Biological yield (MT/ha)</th>
<th>Harvest index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redkloud</td>
<td>3.53</td>
<td>5.44</td>
<td>65.2</td>
</tr>
<tr>
<td>Redkote</td>
<td>3.48</td>
<td>6.13</td>
<td>55.1</td>
</tr>
<tr>
<td></td>
<td>ns</td>
<td>**</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Mean seed and biological yields, and harvest index as influenced by cultivar and within-row spacing in kidney beans grown under field conditions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Adventitious root wt (mg)</th>
<th>Basal root wt (mg)</th>
<th>Taproot wt (mg)</th>
<th>Stem diam (mm)</th>
<th>Hypocotyl diam (mm)</th>
<th>Taproot diam (mm)</th>
<th>No basal root (mm)</th>
<th>Basal root diam (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redkloud</td>
<td>27</td>
<td>440</td>
<td>211</td>
<td>5.5</td>
<td>5.5</td>
<td>3.0</td>
<td>6.1</td>
<td>11.3</td>
</tr>
<tr>
<td>Redkote</td>
<td>84</td>
<td>656</td>
<td>348</td>
<td>6.5</td>
<td>6.0</td>
<td>3.6</td>
<td>7.9</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>ns</td>
<td>**</td>
<td>**</td>
<td>ns</td>
<td>ns</td>
<td>**</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

Table 2. Root morphological characteristics as influenced by cultivar, within-row spacing, and growth stages in kidney beans grown under field conditions.

W ithin-row spacing (cm)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Anthesis</th>
<th>Full pod fill</th>
<th>Seed weight (g)</th>
<th>Shoot weight (g)</th>
<th>Shoot:root ratio</th>
<th>Uprooting resistance (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>4.7d</td>
<td>4.3d</td>
<td>2.8e</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>904b</td>
<td>46.8a</td>
<td>13.08a</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>351a</td>
<td>5.3b</td>
<td>5.6a</td>
<td>4.7b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>33az</td>
<td>5.3d</td>
<td>5.6a</td>
<td>4.7b</td>
<td></td>
</tr>
</tbody>
</table>

ns, **Nonsignificant (ns) or significant at 5% (*) or 1% (**) level.

Mean separation within columns by Duncan’s multiple range test, 5% level.
correlated with basal root weight \( r = .88 \), basal root diameter \( r = .85 \), and with basal root number \( r = .67 \). Plants with larger hypocotyl diameter at the basal region, in wider within-row spacings, resulted in a larger diameter, a higher number, and a higher dry weight accumulation of basal roots. Stoffella et al. (7) concluded that basal roots in black beans are of importance to reducing lodging. No differences in seed yield occurred between cultivars although a higher biological yield and lower HI for 'Redkote' were noted (Table 3). Seed yield from 15 cm within-row spacing was significantly greater than from 10 or 20 cm, however, not significantly different from 5 cm. Kueneman (4) reported nonsignificant dry bean yield differences between 5 and 10 cm within-row spacing regardless of plant type. No differences in biological yield or HI were measured among within-row spacings.

A significant cultivar \( \times \) spacing interaction occurred for only total root weight. 'Redkote' had a larger increase in total root weight between 15 and 20 cm within-row spacings than 'Redcloud', thereby resulting in a significant cultivar \( \times \) spacing interaction. Uprooting resistance did not dramatically increase between 15 and 20 cm spacings for 'Redkote'. This resulted in a nonsignificant response for uprooting resistance between the 15 and 20 cm spacings. Since uprooting resistance responded similarly for the 2 cultivars at the other within-row spacings, the main effect for uprooting resistance due to cultivar differences was nonsignificant. Other first and second order interactions were significant for most root morphological characteristics.

Salih (5) reported that root weight in soybeans increased as within-row spacing increased. Similarly we found that root weight and other root morphological characteristics increased as within-row spacings increased. A larger root biomass production of individual plants could contribute to increases in water and nutrient uptake and lodging resistance in dry beans. Further investigations are needed to determine if these results exist at narrower row widths, where seed yields are generally higher, particularly during environmental stress conditions.

### Literature Cited


---

1. Received for publication February 5, 1981. Published as Paper No. 6204, Journal Series, Nebraska Agricultural Experiment Station. Research was conducted under Projects No. 20-36 and No. 20-40.

2. Graduate student, Professor, Department of Horticulture, and Director of Panhandle Station, Scottsbluff, respectively. The current address of the senior author is Department of Horticulture, University of Illinois, Urbana, IL 61801.

3. The authors appreciate grants received from the Anna Elliott Foundation and the Rocky Mountain Bean Dealers Association to support the research and also seed of several cultivars to plant in trials from the Kelley Bean Co., Chester Brown Co., Nebraska.

---


**Rate of Water Uptake and Sites of Water Entry in Seeds of Different Cultivars of Dry Bean**

Safi S. Korban, Dermot P. Coyne, and John L. Weihing

University of Nebraska, Lincoln, NE 68583

Additional index words. imbibition, micropyle, raphe, hilum, seed coat. *Phaseolus vulgaris*

**Abstract.** Variations occurred in the rate of water uptake of seeds of different dry bean cultivars (*Phaseolus vulgaris* L.). 'Pinto UI 111' had a higher water uptake by 24 hours than the other 6 cultivars. The micropyle was the main site for water entry in white-seeded 'Great Northern' and it is inferred that the raphe and or hilum areas were mainly involved in water uptake in 'Pinto UI 111'. No water uptake through the seed coat of seeds of 7 cultivars occurred by 2, 4, or 8 hours and only a small amount by 24 hours, except 'GN Star' where no water uptake was noted indicating that it had an impermeable seed coat during that period.

Seed hardness causes reduced or delayed germination of bean seeds and it degrades the texture of processed bean products. This is due to reduced or complete lack of imbibition of water by the hard seeds. Genetic variations for this trait were first reported by Lebedeff (4, 5). The barrier to water intake is a critical regulating element and research has been conducted to determine the relative importance of various areas of the seed in their hindrance to water uptake by the bean seeds (3, 8, 9, 11) and on the relation of water uptake and transverse cotyledon cracking (1, 6, 7). Watson (10) dismissed the role of structural differences in the testa in relation to water permeability. Kyle and Randall (3) reported that the micropyle was the primary area of water entry in Great Northern (GN) beans while the raphe and hilum areas were important sites of water entry in a Red Mexican dry bean cultivar.

Since there are conflicts in the literature on the nature of seed hardness in beans and only one seed stock of GN dry beans was used earlier by Kyle and Randall (3), the objective of this study was to determine the rate of water uptake in various GN cultivars with 'Bulgarian White' and 'Pinto UI 111'. The relative importance of the micropyle and seed coat in water uptake in relation to seed hardness in these cultivars was also investigated.

The dry bean cultivars used in the investigations were 'GN Emerson', 'GN UI 59', 'Bulgarian White', 'GN Star', 'Pinto UI 111', 'GN 1140' and 'GN D-88'. The cultivars were planted in single row plots, 30 seeds per 5 m row length, rows spaced 55 cm apart, in a randomized complete block design with 3 replications, in the field at Scottsbluff, Nebraska, on June 6, 1979.

Single plants were harvested in September at physiological maturity (most pods brown and some yellow), allowed to dry in paper bags and then threshed by hand. Twenty seeds per cultivar from each replicate were weighed and soaked in distilled water (22°C) for 24 hr (method 1). Seeds were weighed after 1, 2, 4, 8 and 24 hr of soaking. The amount of water imbibed was calculated by subtracting the original weight from the latter weights. The initial seed moisture content, \( x \approx 11.5\% \), was determined by drying sub-samples at 68°C for 48 hr.

Sites of water entry into the bean seeds were also investigated. In one treatment,