A Root Tube - Pegging Pan Apparatus: Preliminary Observations and Effects of Soil Water in the Pegging Zone[1]

J. M. Bennett*, P. J. Sexton, and K. J. Boote[2]

ABSTRACT

Soil conditions, especially water deficits in either the pegging or rooting zone or both, affect pod initiation and seed development of peanut (*Arachis hypogaea* L.). The objectives of this study were to 1) construct a root tube - pegging pan apparatus which would allow for physical separation of the rooting and pegging zones, 2) determine growth and development of peanut when grown in the apparatus, and 3) examine the effects of soil water in the pegging zone on the initiation and development of peanut fruits. An experimental apparatus was constructed to provide a mechanism for separation of the rooting and pegging zones, allowing for independent control of soil water in both zones. Root tubes (1.6 m long and 15 cm in dia.) were constructed of polyvinyl chloride tubing. Watering access tubes were inserted at 0, 0.5 and 1.0 m from the top of the root tube. The top of the root tube was closed with a convex cap having a 5-cm central hole through which a peanut plant was allowed to grow. A pegging pan (50 cm long x 35 cm wide x 20 cm deep) was fitted around the upper portion of the root tube. Preliminary studies demonstrated satisfactory shoot growth and pod development of peanut plants grown in the apparatus provided over-watering was avoided. It also appeared that pods and seeds formed in air-dry pegging zone soil. To examine this in more detail, an experiment was conducted comparing the effects of air-dry vs. moist (7 to 12% water by weight) pegging zone soil on pod and seed formation. The air-dry pegging zone reduced the percentage of tagged pegs which developed into full pods (those having reached full expansion) from 61 to 48% and reduced the growth rate of developing seeds and pods by 18 and 29%, respectively. The root tube - pegging pan apparatus provided a useful technique to gain a better understanding of peanut pod formation as influenced by soil water environments in the pegging zone.

Key Words: *Arachis hypogaea,* pod growth, seed growth, soil water deficits, water stress.

Both physical and chemical conditions in the pegging and rooting zone may independently affect pod and seed development in peanut (*Arachis hypogaea* L.) The importance of considering the nutritional status in the rooting zone separately from that in the pegging zone has been recognized for many years. Research in the 1940's and early 1950's clearly demonstrated that calcium must be available in the pegging zone for formation of peanut pods and seeds (1, 2, 5, 6, 7, 8, 10, 11). The importance of providing calcium in the pegging zone illustrates that the pegging and rooting zones may require separate management strategies and has led to the common practice of gypsum application near the time of pegging.

The experimental isolation of the pegging zone from the rooting zone provides a mechanism for imposing separate treatments in those two soil regions. Experimental techniques to separate the pegging and rooting zones were introduced many years ago. Such techniques have proven especially useful for demonstrating that nutrients such as calcium must be available in the pegging zone for direct uptake by the developing gynophores. Burkhart and Collins (7) were the first researchers to physically isolate the pegging and rooting zones of peanut. Later, Bledsoe *et al.* (1) used 15-L pots to contain soil for the rooting zone, while the shoot of the plant extended through a central hole in an "asphaltum-coated" metal pan into which the pegs formed. Skelton and Shear (13) grew peanut plants in 15-cm dia. clay pots and allowed the shoots of the plants to extend through an opening in a 30-cm "angel food" cake pan. Gynophores produced on the the main stem developed in soil contained separately in the cake pan. Variations of these techniques have been used by other investigators, primarily to study the effects of various nutrients in the rooting and pegging zones on pod and seed development (3, 8, 13, 14, 15).

Irrigation of sandy soils, typical of those in the peanut production regions, may provide adequate soil water in the deeper rooting zones for a week or so, while the surface soil and shallow pegging zones may dry rapidly in only a few days. The effects of dry pegging zone soil on peg penetration and development is not well understood. Recently, a few investigators have used techniques to separate the rooting and pegging zones in order to examine the effects of soil water in the two zones on seed and pod initiation, formation and development (12, 13, 16, 18). Underwood *et al.* (16) observed that pod growth and development were unaffected as soil water potential in the pegging zone declined to -1.5 MPa, but found very little pod development (less than 20% of the well-watered control) in air-dry soil. Pod development was also significantly delayed in the air-dry soil. Skelton and Shear (13) reported large increases in dead gynophores per plant and a 54% reduction in gynophores which showed fruit development in a dry pegging zone. Wright (18) observed seed yield reductions in two peanut cultivars (McCubbin and Gajah) when soil in the pegging zone was air-dry, but reported that the air-dry pegging zone had no effect on seed yield of a third cultivar (Robut 33-1).

Most attempts to isolate the rooting and pegging zones have utilized small pots or containers which resulted in limited rooting and pegging volumes. Although such designs have been quite useful for studying the effects of nutrient uptake by developing gynophores, they are not well-adapted for imposing gradual reductions in soil water availability in the rooting zone. Withholding of water from small pots with limited rooting volumes results in very rapid development of severe plant water deficits.

The objectives of this study were to 1) construct a root tube - pegging pan apparatus which would allow for physical separation of the rooting and pegging zones, 2) determine growth and development of peanut when grown in the apparatus, and 3) examine the effects of soil water in the pegging zone on the initiation and development of peanut fruits.

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[2]Associate professor, graduate research assistant, and professor, respectively.

*Corresponding author.

Materials and Methods

Construction of Root Tube - Pegging Pan Apparatus

Root tubes 1.6 m in length were cut from 15-cm dia. polyvinyl chloride (PVC) pipe (Fig. 1). At distances of 0.5 and 1.0 m from the top of each tube, 19-mm holes were drilled in the side of the root tubes to provide insertion points for water distribution tubes. Water distribution tubes (19-mm dia. PVC tubing), with small diameter holes on the bottom surface, were capped at one end, inserted horizontally across the diameter of the root tube, and a fine mesh screen was wrapped around each to prevent plugging with soil particles. A 45 degree elbow was attached to the water distribution tubes and 5 cm dia. watering access tubes secured. Strips of foam rubber were placed at the bottom of watering access tubes to slow the flow of water and reduce soil disturbance when water was added.

The bottom of each root tube was closed with an end cap into which four, 13-mm drainage holes had been drilled (Fig. 1.). Before filling the root tube with soil, a fine mesh screen was placed over the drainage holes on the inside of the end cap to prevent loss of soil from the bottom of the tube. A 25- to 75- mm layer of gravel was placed in the bottom of the tube to promote drainage of excess water.

A rubber pegging pan (50 cm long x 35 cm wide x 20 cm deep) was fitted around the upper portion of the root tube by cutting a hole the diameter of the root tube in the center of the bottom of the pan and slipping the pan over the top of the root tube (Fig. 1).

After the root tube was filled with soil, the top of the tube was closed with a convex PVC cap into which two, 5-cm holes were drilled (Fig. 1). The central hole in the cap was extended 2.5 cm above the convex cap using a PVC spacer which was glued into the hole. An upper watering access tube was secured into the other opening which was offset from the center of the convex cap. The space within the convex cap was then filled with soil and gently packed. After the convex cap was secured, the pegging pan was adjusted so that the upper lip of the pan was level with the top of the spacer in the cap. The pan was then filled to within 1 cm of the top with soil.

Preliminary Study

A preliminary study was conducted in the fall of 1988 to observe the growth and development of peanut when grown in the root tube - pegging pan apparatus. Root tubes were filled with a coarse builders' sand and the pegging pans contained a Kendrick fine sand (loamy, siliceous, hyperthermic

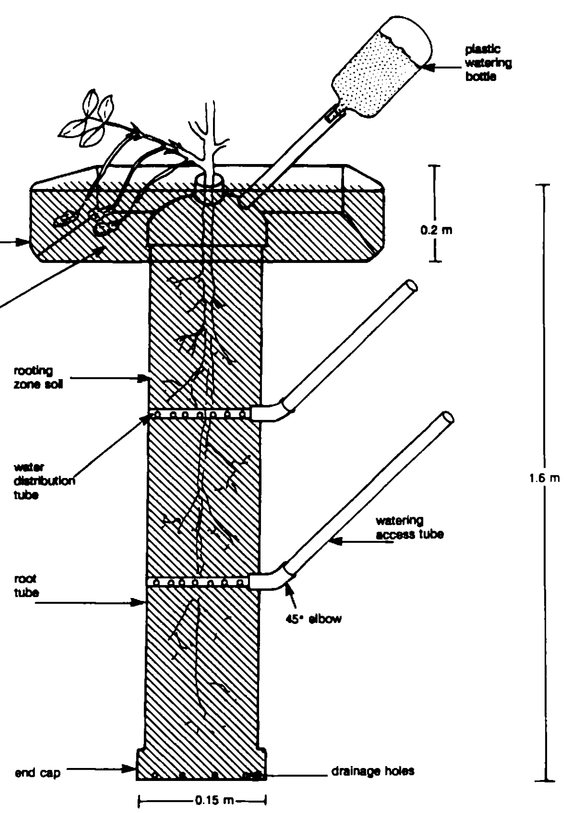

Fig. 1. Diagram of a root tube – pegging pan aparatus.

Arenic Paleudult) topsoil. Two germinated seeds of Florunner peanut were placed in each of 16 root tubes on 9 September and later thinned on 19 September to one plant per tube.

"Wet" and "dry" pegging zone treatments were imposed in the preliminary study. The wet pegging zone soil was kept moist by adding tap water when the soil surface appeared dry, whereas the dry pegging zone treatment consisted of air-dry soil with no water added. Water or nutrient solution (Ra-Pid-Gro Products, Chevron Chemical Co., San Francisco, CA) was alternately added daily to all 16 root tubes by filling either 1- or 2-L plastic bottles and inverting them into the openings of the upper watering access tubes (Fig. 1), allowing water to slowly drain from the plastic bottle into the root tubes. The rooting zone was maintained well-watered throughout the experiment. Inoculum of Bradyrhizobium was also added through the upper watering access tube to ensure nodulation. Plants were grown to maturity and observations of shoot growth and pod production were made. Due to some difficulties with over-watering, which are discussed later, data from detailed measurements made in this preliminary study are not reported.

Pegging Zone Soil Water Study

A second experiment was conducted in the spring of 1989 to more closely examine the effects of soil water deficits in the pegging zone on pod and seed growth. Sixteen root tubes and pegging pans were filled with air-dry Kendrick fine sand topsoil. Several additions of tap water through the upper watering access tubes ensured that the soil had settled completely before peanut seedlings were transplanted into the root tubes. It was necessary to add small amounts of soil to the top of the root tube until the soil volume had stabilized.

To reduce plant-to-plant variability, uniform seeds of a single component line of Florunner, F439-16-10-3, were planted on 10 Feb. 1989 into germination flats containing coarse sand. Two germinated seeds were transplanted into each root tube 4 d later when radicles were approximately 25 mm in length. After transplanting, the opening of the root tube was covered with aluminum foil to prevent evaporation of surface soil water and desiccation of seedlings. The aluminum foil was removed as the shoots began to emerge from the soil. Seedlings were thinned to one per root tube on 24 February and inoculum of Bradyrhizobium was added through the upper watering access tube to ensure nodulation. Plants reached the R1 stage of growth (4) on 3 March. To create more uniform pegging on longer lateral branches, flowers were removed each morning until 21 March, after which pegs were allowed to develop.

The soil in all 16 root tubes was watered frequently (every 2 to 3 d) through the upper watering access tubes with either 1 or 2 L of nutrient solution and maintained moist at all times throughout the study. Quantity and frequency of watering varied depending on environmental conditions and stage of plant development.

Treatments consisting of wet and dry pegging zones were imposed as pegs began to develop. Soil in one-half of the pegging pans remained air-dry (< 0.5% gravimetric soil water content) at all times, while the pegging zone soil in the remaining eight pegging pans was kept moist (gravimetric soil water content varied between 7 and 12%). Tap water was added to the wet pegging zones when the surface of the soil began to dry.

Beginning 24 March, pegs were tagged with color-coded, 18-mm wound clips as they entered the soil in the pegging pans. The clips were color-coded with respect to date so that at final harvest the age of the pods could be determined.

All plants in both pegging zone treatments were harvested during the week of 22 May and dry matter accumulation in pods, seeds, shoots, and roots was determined after oven-drying the samples. After harvesting shoots and pods, the bottom cap of the root tubes were removed. Soil and roots were flushed from the tube with a stream of water and roots were separated from soil by washing over a fine mesh screen. Pod and seed numbers per plant and rates of pod and seed dry matter accumulation were computed. All results were statistically analyzed using standard analysis of variance and linear regression procedures.

Maximum and minimum air temperatures within the greenhouse were monitored during the experiment and ranged between 25 to 32 C and 13 to 25 C, respectively. Maximum midday light intensities were near 1500 uE m^{-2} s^{-1}. Since soil temperatures have been shown to affect pod and seed growth (9), pegging zone temperatures (5-cm depth) were monitored with copper-constantan thermocouples in two wet and two dry pegging zones. Although the wet pegging zone soil was as much as 10 C cooler during the early phases of plant growth (before the plant canopies shaded the soil surface), mean maximum pegging zone temperatures during the period of rapid pod and seed growth were very similar (29.0 and 29.2 C for the wet and dry treatments, respectively, from 50 to 100 days after emergence).

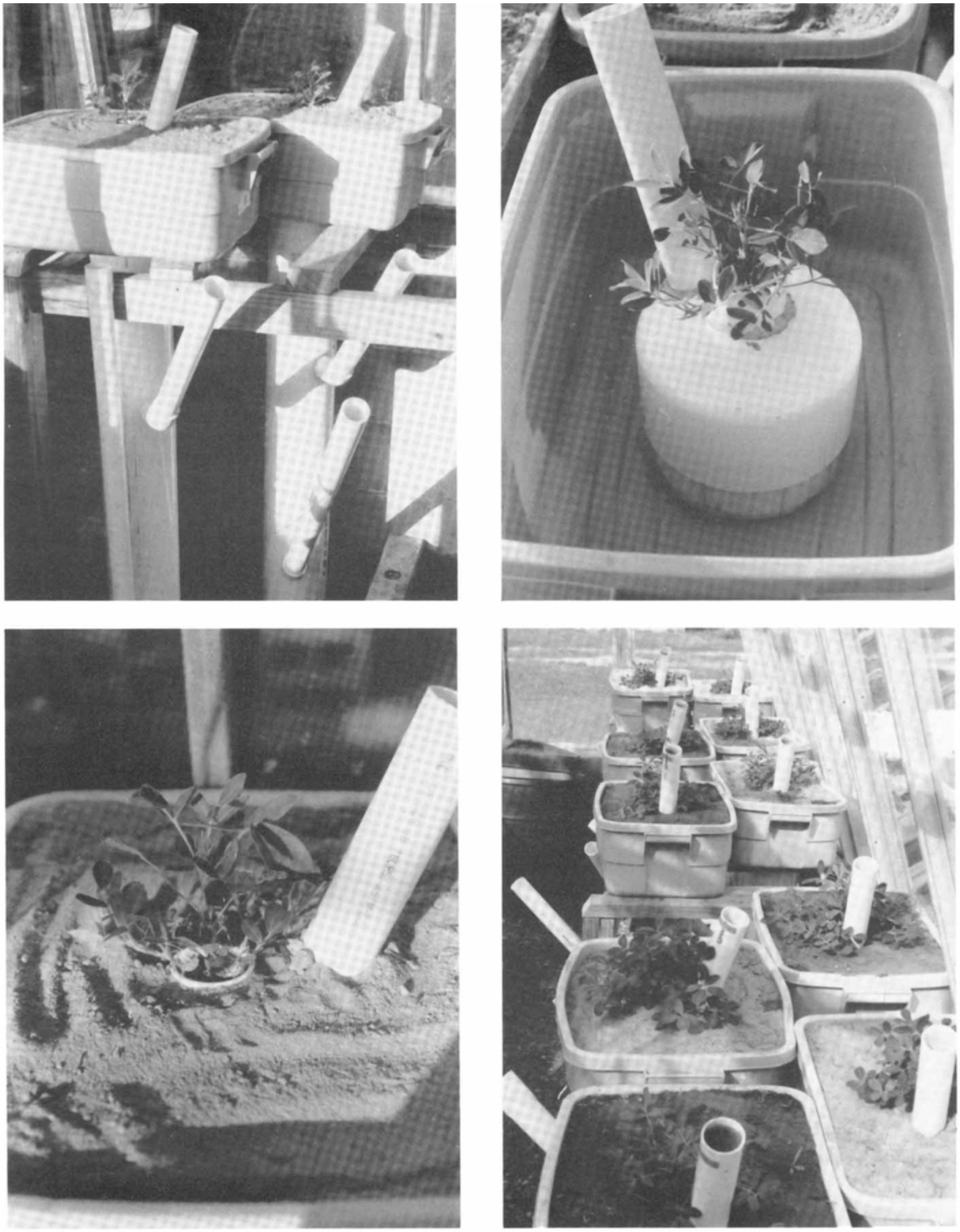

Fig. 2. Photographs of the root tube – pegging pan apparatus showing a) two root tube – pegging pans in place in a greenhouse, b) the top of a root tube with a small plant surrounded by an empty pegging pan, c) a plant and surrounding pegging pan filled with soil, and d) arrangement of tubes in a greenhouse. In d) note the contrast between the wet (darker) and dry (lighter) pegging zones.

Results and Discussion

Preliminary Study

Vegetative and fruit growth in the root tube - pegging pan apparatus was quite good and the technique successfully isolated the rooting and pegging zones. Photographs in Fig. 2 show two root tube - pegging pans in place in a greenhouse (Fig. 2a), the top of a root tube with a small plant surrounded by an empty pegging pan (Fig. 2b), a plant surrounded by a pegging pan filled with soil (Fig. 2c), and a typical arrangement of tubes in a greenhouse (Fig. 2d). In Figure 2d, wet and dry pegging zones appear as different shades of soil in the various pegging pans. Plants were grown to maturity in the tubes and, except for isolated problems with over-watering, normal shoot, root, pod, and seed growth was observed.

Several observations were made during this preliminary experiment. Even though drainage holes were provided in the bottom end cap and a layer of gravel added at the bottom of the root tube, occasional problems with excess water in the rooting zone were observed. Wilting of a few plants was occasionally observed even though 1 to 2 L of water were added at each watering which occurred as frequently as four to five times per week. When wilted plants were harvested, the lower portion of the soil profile appeared saturated with water. This potential problem was solved by more conservative watering and in recent studies has been completely eliminated by using a potting medium (Terra-Lite Metro Mix 500, W. R. Grace and Co., Cambridge, MA) which drains more readily. Because of the over-watering problems in a few tubes, data collected during this preliminary study are not reported. It was observed, however, that pods and seeds formed in the air-dry pegging zone treatments.

Effect of Pegging Zone Soil Water On Pod and Seed Development

Excellent and uniform plant growth was observed during this second experiment and over-watering problems were not encountered. Results from this experiment indicated that the soil water treatments imposed in the pegging zone did not affect the shoot growth of the plants. Total shoot weight, leaf weight and leaf area were similar for plants having wet or dry pegging zone treatments (data not shown), however, the dry pegging zone reduced the percentage of tagged pegs which developed into full pods (those having reached full expansion) from 61% to 48%. The dry pegging zone reduced total pod and seed weights per plant, growth rates of individual pods and seeds, and individual pod and seed weights (Table 1).

In contrast to expectations, it was surprising how well the pods and seeds developed in air-dry soil. Such results are also in contrast with those of Underwood *et al.* (16) who reported very little pod and seed growth in air-dry soil. Others (13,18), however, have shown only slight to moderate seed yield reductions in a dry pegging zone.

Seed development in the dry pegging zone is initially difficult to explain, considering the assumed requirement for direct uptake of calcium by developing pods. Direct uptake of calcium from air-dry soil would be unlikely. However, Underwood *et al.* (16) proposed that the water potential gradient might favor water movement from the stem through the peg and into the developing pod when the pegging zone was extremely dry. This direction of movement seems reasonable if the developing pod loses water to surrounding dry soil, but would not be likely if the pod was

Table 1. The effect of wet versus dry pegging zones on individual pod and seed weights, total pod and seed weights per plant and growth rates of individual pods and seeds.

Variable	Pegging Zone Treatment†	
	Wet	Dry
POD:		
Weight per Pod (g)	0.798	0.699 **
Growth Rate (g/pod/day)	0.049	0.035 **
Total Pod Weight (g/plant)	75.8	61.3 ‡
SEED:		
Weight Per Seed (g)	0.312	0.271 **
Growth Rate (g/seed/day)	0.022	0.018 **
Total Seed Weight (g/plant)	53.5	39.0 *

† Gravimetric soil water content varied between 7 and 12% in the "wet" pegging zone treatment and was less than 0.5% in the "dry" pegging zone treatment.

*,** Indicates a significant reduction due to the dry pegging zone soil at the 0.05 and 0.01 probability levels, respectively.

‡ Significantly different at 0.06 probability level.

in contact with moist soil or if air exchange with the soil was slow, preventing evaporation from the pod. Underwood *et al.* (16) further suggested that movement of water from the stem and into the pod might allow normal pod and seed development when the soil water in the pegging zone was as dry as -1.5 MPa. However, they did observe limited pod and seed development in drier (air-dry) soil. Skelton and Shear (13) demonstrated that when developing pods were removed from the soil and subjected to a drying environment, ^{45}Ca which was available only in the rooting medium was translocated to the developing fruit. Only traces of the radioactive calcium appeared in fruit which remained in moist soil. Weirsum (17) observed that dye would move from the root system of peanut plants to developing pods, but only if the pods were removed from the soil. Such evidence supports the hypothesis that gynophores enter a dry pegging zone and lose water by transpiration from the peg or developing pod, and that calcium will move in the transpiration stream to the developing fruit. Wright (18) observed lower calcium concentrations in pods which developed in air-dry soil (3% gravimetric soil water content) compared to those in pods developing in a moist pegging zone and suggested that pod and seed development in dry soil was genotype dependent.

Our experiences with the root tube - pegging pan apparatus suggest that the technique provides an excellent method for examining the effects of limited soil water in the pegging zone on peanut productivity. Use of the system revealed that pod and seed development of F439-16-10-3 peanut proceeded in air-dry pegging soil, although pod and seed yields were lower and rates of pod and seed growth were somewhat reduced.

More recent studies have also demonstrated that because of the larger volumes of soil contained in the rooting zone of this apparatus compared to previously described techniques, plant water deficits can be applied more gradually over a longer time period (7 to 10 d) following complete withholding of water. In addition, the apparatus is designed for adding water at three different depths of the rooting zone and can be used to impose treatments where only the lower one- or two-thirds of the rooting zone is watered. The more gradual progression of water deficits and the supply of water only at the lower depths of the soil profile impose conditions similar to those which may occur under dry field environments. As a result, we suggest that the root tube - pegging pan apparatus will also be useful for examining the effects of soil water deficits in the rooting zone of peanut.

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