FOLIAR FEEDING OF PHOSPHORUS
ON PEANUTS

By

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CHAPTER I

INTRODUCTION

Peanuts contribute significantly to the world food supply. The high protein and oil content suitable for human consumption is second to only soybeans in total contribution. Isolated peanut proteins has been found to be superior to soybean protein for food enrichment and new food product preparations because of its lower flavor and flatulent contributions but with equivalent, or better protein quality. An increased demand for peanut protein is predicted for such uses. Oil seed proteins are expected to play an even more important role in world nutrition, especially for increasing quality protein in diets.

Almost four billion pounds of peanuts are produced in the United States annually at a value of more than 500 million dollars. Most of this crop is used in peanut butter, confections, bakery items and roasted nut snacks (31). Approximately 123,000 acres of Spanish peanuts were grown in Oklahoma in 1978 with 115,000 acres of those harvested with an estimated value of 43.5 million dollars. Spanish peanut yield and quality is improved by the proper use of fertilizers and the crop is made more profitable for the farmers of the state.

Yields of Spanish peanuts in Oklahoma have responded to phosphate application to a greater extent than N and K fertilization, though in some areas responses to added phosphate is erratic or absent. A tropical lateritic soils are low in available phosphate, it being found in unavailable forms with Al, Fe or clay minerals. Availability of phosphate on these soils is often not improved measurably by application of phosphate fertilizer. If foliar application methods prove feasible, a savings in phosphate and increased yields would result in a large part of the world where peanuts are grown.

Experiments by Barel and Black (1) have shown that pyro- and polyphosphate with combinations of surfactants can be utilized by soybeans and corn. Likewise, phosphate might be applied to peanuts by foliar techniques with satisfactory effectiveness for improvement of peanut yields and quality.

The objective of this study was to determine the extent of phosphate utilization by Spanish peanuts by foliar application with an experimental "stickative" from Buckman Laboratories (BL-2142). Comparisons between root uptake and phosphorus utilization by foliar application at different rates and varying concentrations of stickative were made. Perhaps foliar treatments can only be used as a supplementary application method. Evaluation of the stickative for foliar application with phosphorus will also be made.

CHAPTER II

LITERATURE REVIEW

Phosphorus Fixation in Soils

Phosphorus (P) available to support plant growth may be low in soils due to fixation or reversion reactions when the soil pH is low or when the soil pH is high. Growth and productivity of crops is often limited when P availability is low even though total P may seem to be adequate.

Hemwall (20) stated that soils usually contain 0.10 to 0.25 percent P_2O_5 and rarely more than 0.50 percent. In general, inorganic forms of P are preponderant, although some soils tested have shown as much as 75 percent of the total P present to be in organic forms. Normally, inorganic P exists as salts of orthophosphoric acid, fluoro-, oxy-, and hydroxy phosphates of iron (Fe), aluminum (Al), calcium (Ca), titanium (Ti), magnesium (Mg), and Manganese (Mn).

Fe and Al oxides and hydroxides have been recognized by many workers as playing major roles in P fixation. As a result, a reduction of free Fe oxide content of soil colloids reduced the magnitude of P fixation.

Hemwall (20) further explained that P is fixed as Fe and Al compounds of very low solubilities and both are probably precipitated and absorbed under soil conditions. The formation of insoluble Fe and Al compounds is governed by solubility products, common ions, and salt effect principles. However, the mechanism of P fixation by clay minerals and by Fe and Al oxides or hydroxides are identical.

Hall and Baker (18) studied P fixation by montmorillonite and vermiculite clays as influenced by pH and soluble Al. They concluded the P retention increased with increasing Al levels in montmorillonite. It was considered that the interaction of pH and clays was more important because P absorbed by montmorillonite increased with increasing pH while for vermiculite, the amount of P absorbed tend to decrease with increasing pH.

Cole and Jackson (10) studied the solubility constants for $Al(OH)_2H_2PO_4$ (variscite) in relation to P fixation. Variscite is sufficiently soluble to furnish P for plant growth but the presence of relatively soluble Al source such as gibbsite and kaolinite, and to some extent montmorillonite, might decrease P in soil solution to a point that P became the limiting factor in plant growth.

Kamprath (22) conducted an experiment on soil acidity and liming and inferred that highly weathered Oxisols and Ultisols generally have a pH less than 5.0 and an exchangeable Al greater than 50 percent saturation. Neutralization of the exchangeable Al by liming increased plant uptake of P and yield response to applied P. However, P availability was decreased when the soil pH was raised above 6.7. Raising the pH of acid Andosols above 5.8 increased P fixation.

McCormick and Borden (28) investigated P fixation by Al in plant roots. Color photomicrograph of sectioned vs. unsectioned roots confirmed an Al and P at the root surface; in epidermal and cortical regions extending from the root tip to 1-5 mm back. The Al-P interaction appeared to be associated with the cell wall outside the cytoplasmic membrane. Al was capable of removing P from the root cells in addition to inhibiting P uptake.

Clarkson (9) studied Al-P interaction at root surface, also. He recognized that P fixation was important and reduced plant available P in acid soil. While the precise mechanisms of P fixation remain subjects of debate, there is general agreement on precipitation of Al- and Fe-P(S) and that absorption of P onto positively charged surface of Al and Fe(ferric) hydroxides were significant processes. Below pH 5.0, and frequently below pH 6.5, amorphous Al hydroxides surface are positively charged. Such surfaces absorb and precipitate P from solution forming $Al(OH)_2H_2PO_4$. Presumeably, cell surfaces with Al hydroxides present will allow the same reaction to occur and quite effectively reduce P available for plant uptake.

Engelstad and Russel (12) proposed methodology for increasing the effectiveness of P fertilization for tropical soils which usually have relatively high contents of Fe and/or Al oxides and hydroxides. However, they found a wide variation in P fixation among tropical soils. They suggested three alternatives to be considered for P fertilization of high P fixing soils: 1) application of sufficient soluble P initially to satisfy the fixation capacity, 2) band- or row- placement of soluble P at rates adequate for the immediate crop only, and 3) use lower soluble P fertilizers, either alone or with high solubility P fertilization.

Panda and Misra (32) summarized results of an experiment with lateritic high P fixing soil for which the application of water soluble P produced megre response. They recommended the use of inexpensive P sources like ground rock phosphate with 10 to 20 percent acidulated P sources. This treatment seemed to satisfy the soil fixing capacity and resulted in satisfactory levels of P to support plant production.

Clarkson (8) studied the effect of Al on the uptake and utilization of P by barley seedlings. Two interactions at the outer cell surfaces (nonmetabolic) and inside the cells, perhaps involving mitochondria, affecting phosphorylation of hexose sugars. The predominant Al - ion species at the pH (4.4) of their studies was $Al(OH)_2^+$. They postulated hydroxyl ions at root cell surfaces might result in precipitation of $Al(OH)_3$ and envisioned a possible continuous absorption-precipitation process effectively reducing P for uptake and transport by plants. When Al was found inside root cells it had an inhibitory effect on phosphorylation of hexose sugars.

Effect of Phosphorus Deficiency in Plants

Bieleski (3) conducted an experiment on the effect of P levels on the growth of duckweed (spirodela). Data from his experiment is given in Table I. Growth rate fell progressively as sufficient P plants were transferred to no P medium. Growth stopped after 15 days. Of the P forms in tissues (Pi, phosphate esters, Phospholipids, and RNA) reduction of P most marked measurable effect was on the Pi content. It fell from 30 μM/g fresh weight on day one to 8 μM/g on day four and 3 μM/g on day nine. After growth had ceased on day 19 the Pi content had dropped to 0.7 μM/g.

The phosphate ester content was not so markedly affected by falling in the same day sequence from 3.5 μM/g to 2.0 μM/g, and to 1.3 μM/g; after the day 19 the level of 0.6 μM/g decreased only slightly. RNA and phopholipid contents were even less affected, dropping in etc.

TABLE I

PHOSPHORUS COMPOUNDS IN THE PLANT

P Forms	Day (P in μM/g fresh weight) 0	4	9	19	Final as % of Initial Control
Pi	30	8	3	0.7	2.0
P-esters	3.5	2.0	1.3	0.6	13
P-lipids	7.5	7.0	4.0	2.0	24
RNA	3.5	3.0	2.0	1.2	32

Rossiter (34) summarized P deficiency and flowering in subterranean clover (T. subterraneum L.). He stated that unless P deficiency was acute, P had little affect on flower initiation, however, position of the first flower was affected where it occurred on a lateral branch for high P plants and always on the main axis for low P plants. The first flower node was lower on low P plants, but this was interpreted to be an effect of slower plant development.

Terry and Ulrich (38) recorded the effect of P on photosynthesis and respiration in leaves of sugar beets. P concentration (soluble and total) decreased rapidly during the first week when withheld from the nutrient solution, then more slowly for the next 23 days. Rate of CO_2 fixation diminished as soon as P leaf levels decreased, and within three days after cutoff.

Wright and Barton (41) studied transpiration and absorption and translocation of ^{32}P in plants. There was a positive relationship between transpiration rate and ^{32}P absorption and translocation of P regardless of method used to vary transpiration.

Hanway and Weber (19) studied accumulation of N, P, and K in soybeans (Glycine max (L.) Merrill) and reported that K had little or no effect on P accumulation and N resulted in small increase of P accumulation compared to the effect on yield and N accumulation.

Response of Plants to Foliar Application of Nutrient Elements

An experiment on the effect of foliar application of P on growth and mineral composition of peanuts (Arachis hypogeae L.) under salt stress conditions was reported by Malakondaiah and Rejeswararao (26). Foliar P applications increased the dry weight of all plant parts in control (non-salinized) and salinized plants. Foliar P increased Ca and K content in all plant parts as well. Foliar P application resulted in a partial amelioration of the depressing effect of salinity on K and Ca uptake. An increase in RNA and DNA in foliage and roots of the control salt treated plants was also noted.

Gorde and Kibe (17) investigated the effect of foliar and soil application of P fertilizer on Chinese Mung beans (Phaseolus aures). They concluded that N, P_2O_5 and K_2O content in P treated plants were significantly increased over those in control plants. Foliar application of 20 pounds P_2O_5/acre on 25 day old plants gave maximum grain yield followed by the same amount of P applied by three equally split doses on 25, 35, and 40 days.

Patra (33) studied the response of groundnut to foliar application of urea at pegging stage and found that differences in heights and the number of primary branches were significant while total plant growth was not. However, an increase in the concentration of urea enormously increased the yield.

The response of subterranean clover (Trifolium subterraneum L.) to foliar application of P studied by Bouma (4) revealed that foliar spray of P on plant tops without root P appreciably increased dry weight of the total plant compared with control plants. Increasing the uptake of ^{32}P sprayed on clover leaves was enhanced by the increase in the relative humidity of the surrounding air, probably, due to a low drying of the spray on the leaves or an increase in the water content of the absorbing cells.

Bouma (4) also indicated that dry weights of clover leaves and petioles with foliar P were increased at least twice as high as those of plants without foliar P even though spray damage was quite apparent at the highest P concentrations because of over tolerance limit for leaf injury. He concluded from his work that foliar feeding of P contributed a little benefit of hastening recovery from P deficiency in subterranean clovers, especially when the availability of P applied to root environment presents no problems.

Foliar application of a N, P, K, and S solution can significantly increase the yield of soybeans during the seed-filling period. An experiment of Garcia and Hanway (16) gave the results that foliar application is most effective when the ratio of N, P, K, and S in foliar sprays for soybeans is approximately 10:1:3:0.5 respectively. It was also indicated that the foliar spray with an N, P, K, and S solution during that period was able to increase seed yields as a result of maintaining a high level of photosynthesis without any nutrient depletion in the leaf.

Sita Ram and Abraham (35) studied the effect of foliar application of fertilizers on the fibre quality of "Laxmi" cotton. They summarized that foliar sprays of urea or orthophosphoric acid did not significantly affect the mean fiber length. But urea and orthophosphoric acid sprayed in combination significantly increased the bundle strength and maturity coefficient of the cotton.

Neumann (3) proposed the rapid evaluation of leaf damages by foliar application of N, P, K, and S on corn leaves. He stated that higher concentrations of the fertilizer produced greater damage. Urea phosphate could supply less P through corn leaves than other P sources before causing membrane damage. Laboratory evidence showed leaf damage by urea and urea phosphate at concentrations of 66 g/liter and 19 g/liter, respectively. Available leaf area and the concentration of fertilizer are the limitations of leaf damage.

Wittwer and Teubner (40) studied foliar absorption of mineral nutrients by bean plants. They reported that plants deficient in P absorbed foliar-applied ^{32}P more rapidly than those grown in P-rich media. The translocation of P from foliar application to the roots and fruits was depressed as a result of the high level of P and nutrient intensity in root media. In addition, high levels of P in the vascular system also retard foliar transport rather than influence absorption.

Process of Foliar Penetration and Absorption of Substances

When chemical compounds or nutrient elements are applied to the plant by foliar sprays, foliar penetration and absorption probably occur simultaneously. The rate of permeation through the leaf depends on the physiological structure of the plant leaf, the kind and nature of chemical compounds, and environmental factors.

Skoss (36) studied the structure and composition of the plant cuticle in relation to environmental factors and permeability. He reported that environmental factors slightly affected cuticle formation. Temperature differences caused two effects on cuticle formation: quantitatively affecting total deposition, and qualitatively affecting the proportion of cutin to wax on the leaf. Low day temerature associated with relatively low light intensity resulted in least production of cuticle. The wax content of cuticle produced under 10°C day temperature was lowest, giving a cuticle-to-wax ratio of 4.2:1. Normally, the 17°C day temperature favored high total production of wax.

Hull, Morton, and Wharrie (21) observed the environmental influences on cuticle development and resultant foliar penetration, and they stated that the trichomes or leaf hairs, where present, might also serve as portals of entry in addition to direct cuticular and stomatal penetration. Absorption via this route, although sometimes considered a type of cuticular absorption, was less well authenticated.

Franke (13) investigated mechanisms of foliar penetration of solutions and found that ectodesmata, fine structures in the outer walls of epidermal cells were directly related to foliar absorption and excretion whereas trichomes and hairs were often particularly active in absorption. The exchange of aqueous substances favorably occurred at guard cells, except gas exchange only through stomatal pores. He summarized his study of isolated cuticular membranes that they were permeable to both organic and inorganic ions including undissociated molecules. The penetration of ions was determined by the kind of charge, absorbability, and ion radius. The penetration of substances through cuticular and cellulose layers of the wax is analogous to the excretion of materials by the protoplast. However, more information on these processes is needed. Clearly, the mechanism of penetration through the wall must be diffusion, a physical process, but foliar absorption of ions through the plasma membrane is the energy-requiring process.

Bukovac and Wittwer (5) studied the absorption and mobility of foliar-applied nutrients where Na^{22}, P^{32}, S^{35}, Cl^{36}, K^{42}, Ca^{45}, Mn^{52-54}, Fe^{55-59}, Cu^{64}, Zn^{65}, Rb^{86}, SR^{89}, Mo^{99}, $BaLa^{140}$, were applied on the leaves of Blue Lake bean and their studies apparently showed that all elements were absorbed and translocated at unequal rates or not in a comparable pattern. Any mass-flow mechanism of transport was unlikely. While P, S, and possibly Zn were also highly mobile in the bean plant, either absorption or transport, or both, occurred at a slower rate than that for Na, K, Rb, and Cl.

Effect of Surfactant on Foliar Penetration and Absorption of Chemicals

Surfactants affect the application of foliar sprays since they can change the viscosity of liquids. The importance of surfactants has been recognized as to their beneficial characteristics since the turn of this century. Generally, the breakpoint or threshold for effective concentrations of surfactant was varied in the range from 0.01 to 0.1 percent (22).

Foliar penetration of chemicals was studied by Dybing and Currier (11) with applications of fluorescent dye, radioactive isotopes, and prussian blue to Zebrina pendula Schnizl., apple (Pyrus malus L.), and bean (Phaseolus vulgaris L.). The studies showed that cuticular penetration occurred, but ^{32}P phosphate entry via this route was relatively slow. However, the equeous solution penetrated rapidly through stomata if an efficient surfactant was used at a proper concentration. Surfactants varied in their ability to promote stomatal entry, and their effective concentrations also varied with the plant species. However, they concluded that the leaves of all tested plants were readily penetrated via the stomatal route by the solutions except the leaves of Phaseolus vulgaris L. which required a greater concentration of surfactants. Nevertheless, stomatal penetration by surfactant-free solutions has not been clearly demonstrated in these tests.

Cantliffe and Wilcox (6) indicated that surfactants reduced surface tension of solutions and maintained a greater liquid contact area. As a result, the surface tension can be reduced enough to overcome adverse effects of air pockets created by leaf hairs and wax, and to facilitate penetration into the stomatal apertures. The results of their study on the influence of fat-sugar surfactants on P absorption through leaf surfaces showed that the surfactants in the nutrient sprays at a 0.5 percent concentration were generally most effective except Polyoxyethylenated Tallow Sucroglyceride (PTS) which had the greatest effect at 1.0 percent concentration. P absorption was increased with a combination of

on agricultural sprays on the variation of phytotoxicity with the chemical structure of surface-active agents by using 61 surface-active agents and two varieties of apple and two of plum. The results showed that the 0.5 percent concentration of the surface-active agent caused 100 percent wetting in most of the materials, particularly on apple leaves.

Furmidge (15) suggested that phytotoxicity was very dependent upon the chemical constitution of a surface-active agent and the effects might have been related to ionic charges, size of ions or molecules which control the rate and magnitude of their penetration and leaf damage. The greater the molecular size of the surface-active agent the less the leaf damage. As the mechanism of the leaf cuticle has not been completely known, the prediction of chemical reactions is impossible. He also indicated that the non-ionic materials, unlike ionic materials, were much less active chemically and probably caused less leaf damage.

The effect of organosilicone surfactant in foliar nutrient sprays on increased absorption of P and Fe salts through stomatal infiltration was studied by Neumann and Prinz (29). They showed that the organosilicone surfactant L 77 promoted an eight percent increase in water content of leaves immersed in the solution for 15 minutes. The increase was higher than that brought about by either Tween 80 or control solutions. The treatment of organosilicone surfactant resulted in numerous dark green spots of 1 - 4 mm diameter due to the penetration of liquids into the leaf interior. Also, the amount of irriversibility bound P was increased ten-fold in the leaves tested. They also reported in later experiments suggested that the organosilicone enhanced the absorption of non-exchangeable Fe onto the leaf was more than two times in both dip and spray treatments.

Jansen, Gentner, and Shaw (22) summarized their experiment on the effect of surfactants on herbicidal activities in aqueous spray system with corn and soybeans. They reported that surfactants play three major roles on herbicidal activities since they might enhance, suppress, or not affect herbicidal activities. Many surfactants showed prominent inherent phytotoxicity at higher concentrations in the absence of herbicides. No correlation between the effect and iongenic class of a surfactant was found.

Barel and Black (2) reported the effect of neutralization and addition of urea, sucrose, and various glycols on P absorption and leaf damage from foliar-applied P. They revealed that the solute suction of a concentrated solution of urea and glucose together created minor leaf damage even though its concentration exceeded that of H_3PO_4, thus, the acidity tended to cause the leaf damage. However, H_3PO_4 neutralized with ethylamine, diethylamine, triethylamine, triethanolamine, choline, or gaunylurea caused as much or greater leaf damage than non-neutralized phosphoric acid due to toxicity of the resulting compounds. The best result obtained was the neutralization of the acid with NH_4OH. Eventually, they summarized that P absorption by corn was significantly greater than that by soybeans. The translocation of orthophosphate within the first 24 hours and 10 days after application was seemingly little affected by the pH.

CHAPTER III

METHODS AND MATERIALS

Experiment I

The experiment was performed to compare the effect of phosphorus (P) on the growth of peanuts as a result of P application by foliar and root feeding and by a combination of both. Vegetative and reproductive developments were observed, and plant contents of P, nitrogen (N), potassium (K), and calcium (Ca) were determined in this investigation.

Spanish peanuts (EM-12) were planted in No. 10 cans as shown in Figure 1. The containers were lined with polyethlene bags to prevent the contact of nutrient solution and roots with the walls of the cans. In order to allow frequent flushing and eliminate water logging with excess nutrient solution, a drainage outlet was made just above the bottom of the can, and plugged with a one-holed rubber stopper (No. 4) fitted with a 1/4 inch x 1 3/4 inch bent tube. The cans of three replications were placed on 6 x 6 x 3/8 inch plywood tops fixed with 3 3/8 x 3 3/8 x 12 inch high wood stands attached to a 3/4 inch plywood sheet. Cans of fourth replication pots were set directly on the 3/4 inch plywood sheet. The spacing of plants was 16 x 16 inch (see Figure 2).

Each can was filled with 4200 grams of medium grain acid washed silica sand on September 8, 1979. Subsequently, the silica sand was

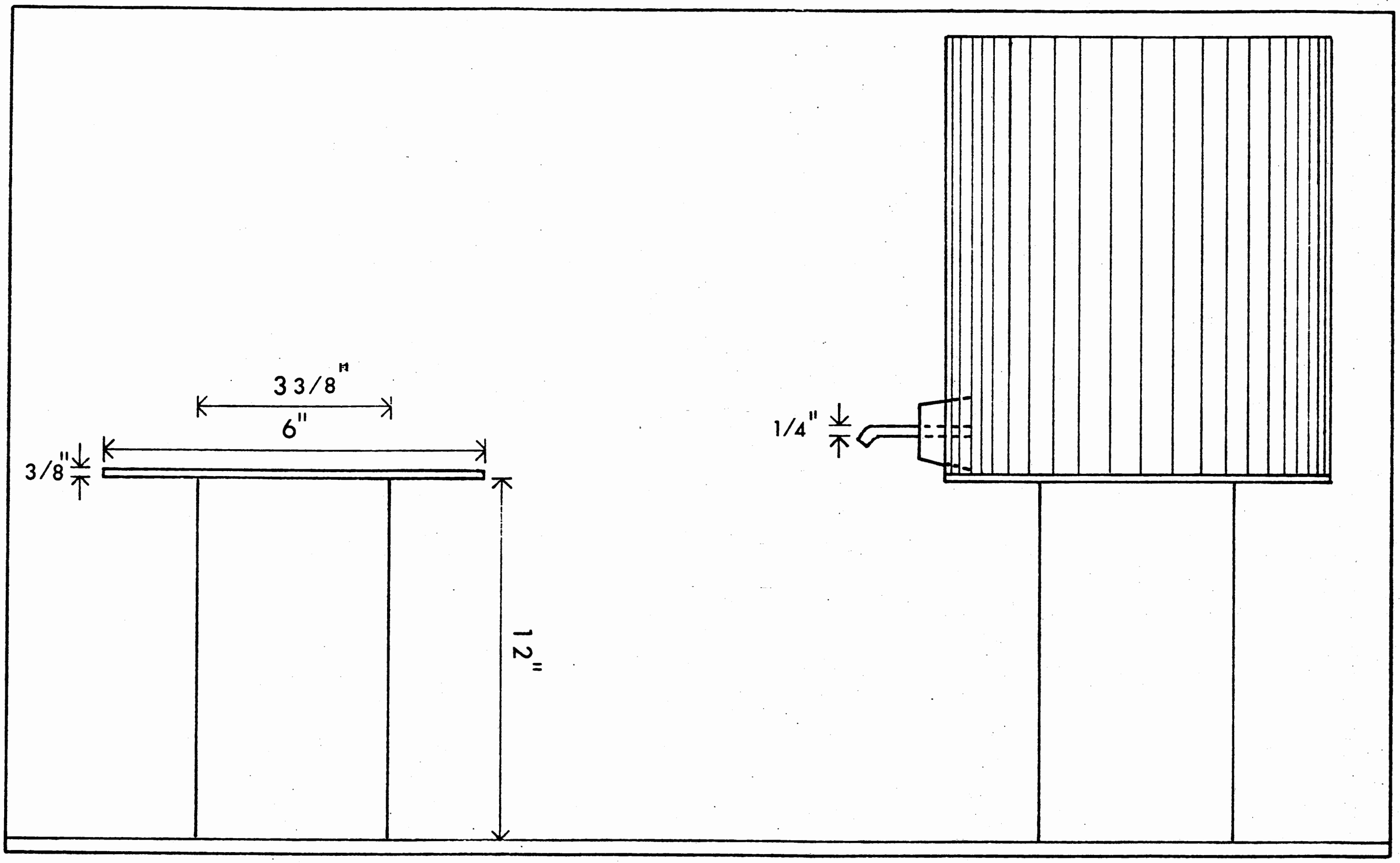

Figure 1. Method of Pot Placement Above the Table Top for P Foliar Application Studies

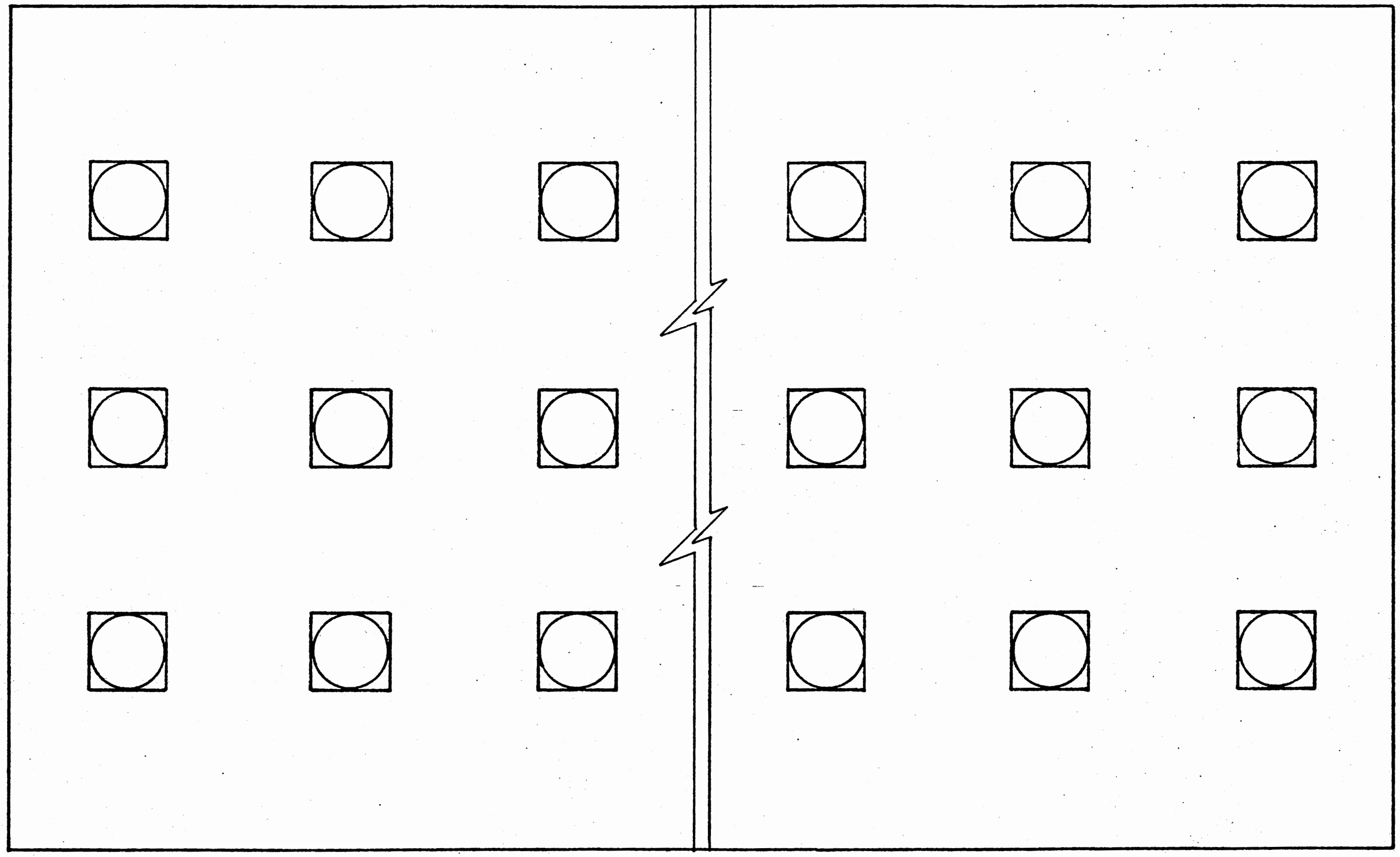

Figure 2. Arrangement of Pots on a Greenhouse Bench for P Foliar Application Studies

TABLE II

EXPERIMENTAL TREATMENT IDENTIFICATION IN TERMS OF POT P, FOLIAR P AND STICKATIVE RATES

Treatment No.	Pot P* (ppm)	Foliar P (0.35% p)	Stickative Concentration (ppt)
1	0	0	0
2	0	P	0
3	0	P	0.5
4	0	P	1.0
5	0	P	2.0
6	1.55	0	0
7	1.55	P	0
8	1.55	P	0.5
9	1.55	P	1.0
10	1.55	P	2.0
11	15.50	0	0
12	15.50	P	0
13	15.50	P	0.5
14	15.50	P	1.0
15	15.50	P	2.0

*P applied in the sand culture.

flushed with distilled water four times, September 14, 16, 17, and 23, 1979, to remove possible soluble P contaminants.

The Spanish peanut seeds treated with a fungicide (Granox) were placed in a growth chamber for germination on October 13, 1979. The seeds were laid between moist paper towels, then enclosed with wax paper, prior to placement in a growth chamber. On October 19, sprouted peanut seeds were transplanted at a depth of 1 - 2 inches, two seeds per can into the pots containing the washed sand. The peanut seedlings emerged on October 24. A complete nutrient solution was applied to the sand culture at a concentration of 1/8 of the highest strength as a starter solution. After moistening the pots with distilled-deionized water on November 4, 1979, nutrient solutions with various P treatments were begun.

Nutrient solutions were prepared according to Hoagland and Arnon with a slight modification by Slack (37), but some changes were made for treatment needs. All nutrient solutions were primarily prepared from "stock solutions" by using reagent grade chemicals and distilled-deionized water. For each application, nutrient solutions were freshly prepared from stock solutions and distilled-deionized water. The composition of the nutrient solution used is shown in Table III.

The experiment was conducted in a greenhouse with a randomized complete block design, with 3 x 5 factorial arrangement, three rates of P were applied to the sand culture as one factor and five P solutions with and without stickative as the second factor. Each treatment was replicated four times. Cans for one replication were set directly on the plywood table whereas the other three replications were placed on the stands as previously mentioned. Phosphorus (P) treatments were

TABLE III

BASIC COMPOSITION OF A COMPLETE NUTRIENT SOLUTION

Source	Nutrient Supplied	Concentration of Nutrient (ppm)
$Ca(NO_3)_2.4H_2O$	Ca	80.00
	NO_3	248.00
KNO_3	K	117.00
	NO_3	186.00
$MgSO_4.7H_2O$	Mg	24.00
	S	32.00
KH_2PO_4	K	19.55
	P	15.50
H_3BO_3	B	0.10
$CuSO_4.7H_2O$	Cu	0.004
$ZnSO_4.7H_2O$	Zn	0.010
$H_2MoO_4.7H_2O$	Mo	0.010
Fe-EDTA	Fe	1.000
$MnCl_2$	Mn	0.06

added to the sand culture at rates of 0, 1.55 and 15.50 ppm as potassium dihydrogen phosphate (KH_2PO_4) with other nutrients shown in Table III. Each can received 200 ml of nutrient solution twice weekly. The first application was on November 4, 1979, while the last one was on February 17, 1980.

Foliar applications of P were made in a wooden chamber two feet wide x two feet long and three feet high. A one-quart hand sprayer was used for each P + stickative (St.) solution concentration. Mist sprays were applied to both upper and lower sides of the peanut leaves until they nearly dripped. The silica sand was covered by two polyethlene sheets to prevent contamination with the mist. Foliar spray applications of P + St. treatments were made on November 15, December 18, 1979, and January 15, 1980. After each spray, treatments within each replication were interchangeably re-randomized. Thus, the treatments were presumeably in a location super-replication. More or less, each foliar spray was considered to be a super-replication. The P + St. solutions were sprayed on the peanut leaves at rates of 0, P, P + 0.5 ppt, P + 1.0 ppt, P + 2.0 ppt. The solution P (0.35 percent P) in distilled-deionized water, with the BL-2142 "surfactant stickative" (St.) indicated in parts per thousand (ppt). The P solution for the first foliar spray was 80 percent of the designated concentration because it was feared the treatment might cause leaf burn on young plants.

Flowers of the two plants in each can were counted daily, since the peanut flower is ephemeral and will wilt within a few hours (37). Total number of peanut flowers were recorded. Plant height was measured on December 6, 1979, January 6, and February 21, 1980.

Some pesticides were sprayed to eliminate the insects normally residing in the greenhouse, but chemicals used were not P containing materials.

All peanut plants were harvested February 21, 1980 (125 days after transplanting). The whole tops were washed three times in distilled-deionized water in sequence of one, two, and three five-gallon plastic buckets to remove residual P from the plant leaves. The water in the buckets were changed after washing tops of five pots. The washed plant samples were blotted with paper towels. The peanut plant tops were dried in a forced air oven at 70^{o}-80^{o} C for 72 hours, and then ground within a Wiley mill. A nitric-perchloric digestion was performed in a digestion block, subsequently, aliquots were analyzed for P by Murphy and Riley method cited by Watanabe and Olsen (39) and with a Perkin-Elmer model 403 Spectrophotometer for Ca and K. Total N analysis was made by the micro-Kjeldahl method.

Experiment II

This experiment was similar to Experiment I. Experiment II methodology was improved, mainly through experience, for planting, treatment, and analytical technique. Experiment II used a different Spanish peanut variety, number of foliar sprays, and technique in preventing rooting medium contamination for foliar sprays.

Spanish peanut seeds of EC-5 variety were placed in the growth chamber for germination on April 15, 1980, the sprouted seeds were transplanted into the sand culture in the greenhouse on April 22. Nutrient solution was first applied to sand culture on April 30, and foliar applications of P + St. were made on May 11, June 11, 1980, respectively. Paper towels were used to cover the sand culture to avoid the contamination with sprayed mists, instead of polyethylene sheets. All plants were harvested on July 10, 1980 (80 days after transplanting). Everything else was carried out exactly as given for Experiment I.

Statistical evaluations were made by AOV of zero P vs. P foliar spray and AOV of no St. vs. St. levels separately. The results seemed compatible for a combined AOV to show treatment effects based on the observed MS and EMS values obtained. Results of the combined statistical evaluation shows the same treatments to be significant as in the individual AOVs. Tables shown are from the combined AOV with Duncan's multiple range analyses run to identify significant values.

CHAPTER IV

RESULTS AND DISCUSSION

Experiment I

Variability in results obtained from Experiment I was higher than expected. Two sets of results indicated further experimental work was needed and justified. Figure 3 shows that a growth response was obtained from foliar applications of P. The percent P and total P content of treated peanut plants were affected by foliar P and P + St. treatments, with an indicated benefit of P + St. on the low pot P treatment (1.55 ppm) for St. levels of 1 and 2 ppt as reported in Figures 4 and 5. The corresponding relationship to soils with low P availability where foliar applications might be useful is obvious. Data collected for the other measurements in this first experiment are found in Table IV, and V.

Experiment II

Plant Height

Plant height was significantly increased (see Table VI and Figure 6) when foliar P was applied to all pot P treatments. Plants from 15.5 ppm P pot treatments were significantly higher than the other P treatments when no foliar P was applied. There was no difference, statistically, in any plants when foliar P was applied. Use of the experimental stick-ative did not cause a significant difference in plant heights.

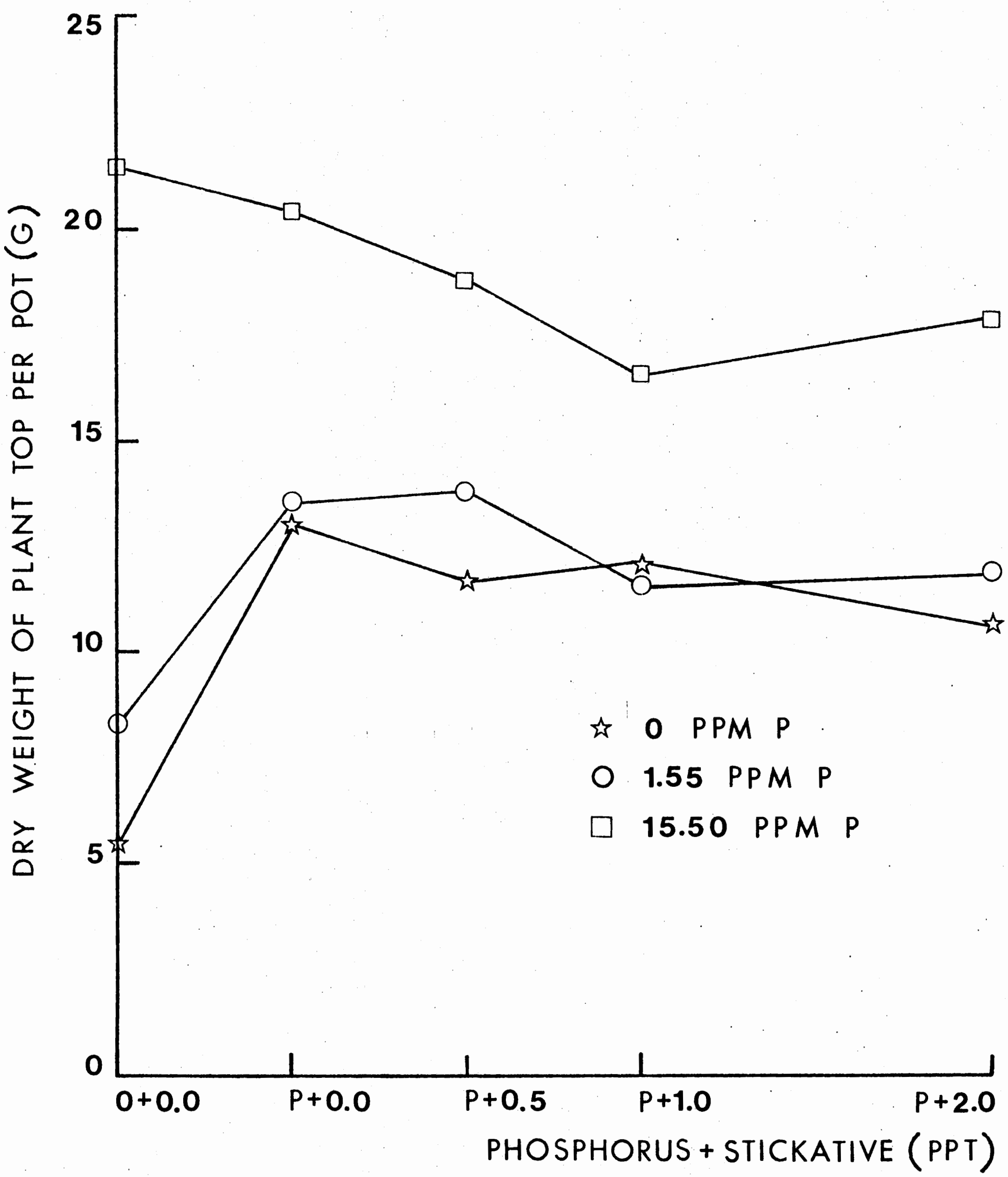

Figure 3. Dry Weight of Peanuts

(The 0 + 0.0, P + 0.0, P + 0.5 etc. designations refer to whether or not foliar P was applied (first position) and the amount of stickative included, in the second position, given in parts per thousand, ppt.)

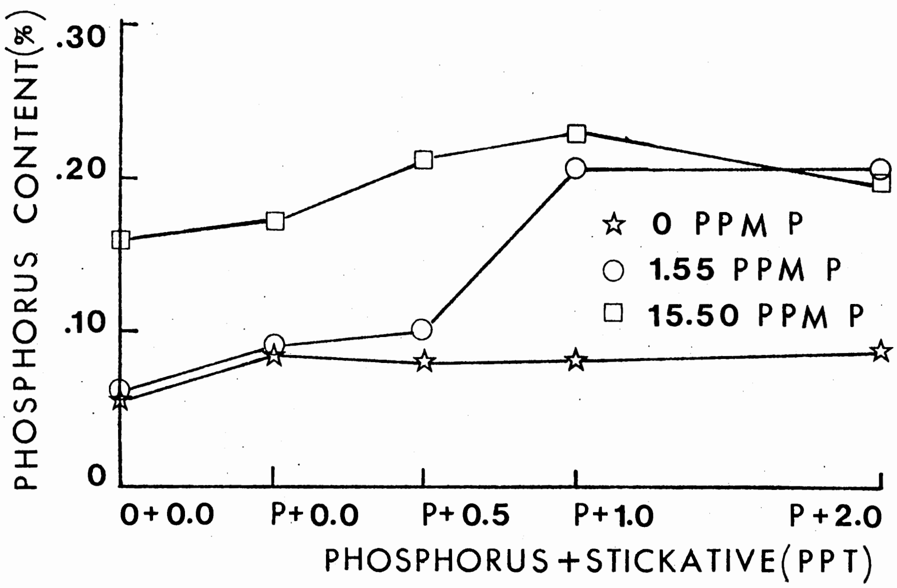

Figure 4. Percent P as Affected by Foliar P Spray (0.35%) and Stickative Treatments

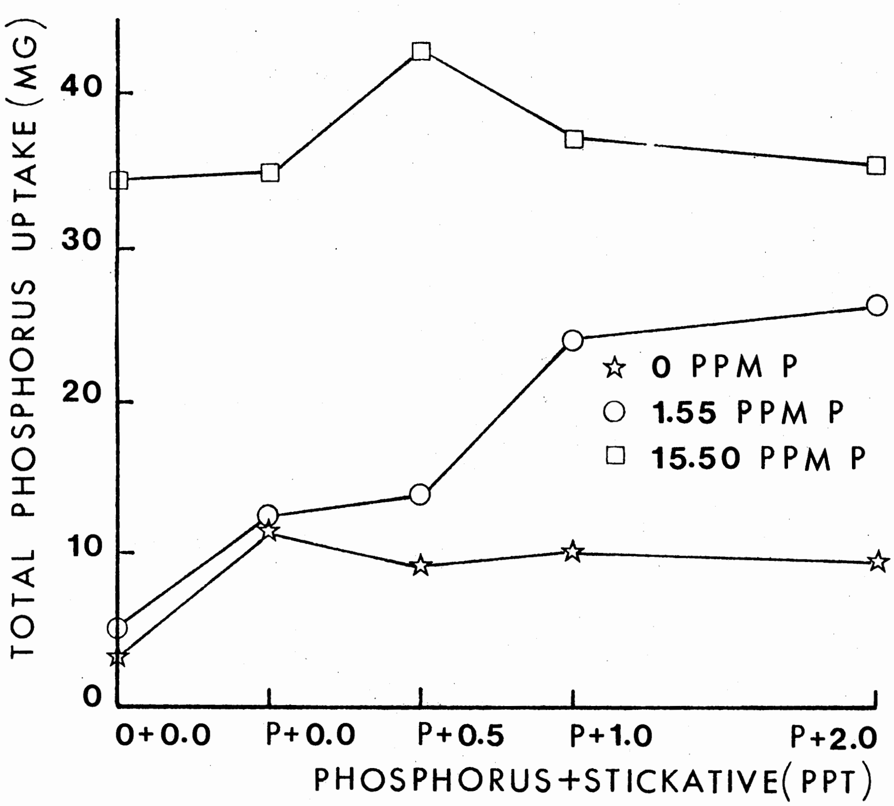

Figure 5. Total P as Affected by Foliar P Spray (0.35%) and Stickative Treatments

TABLE IV

MEASURED GROWTH FACTORS OF EXPERIMENTAL PLANTS IN RELATION TO P TREATMENTS* (EXPERIMENT I)

Treatments	Plant Height (CM) Dec. 6	Jan. 6	Feb. 21	No. of Flowers	Fresh Weight (G)	Dry Weight (G)
1	16.7	18.5	18.8	29.5	23.0	5.4
2	18.0	21.2	23.5	43.3	44.0	13.0
3	16.1	20.5	23.6	31.3	40.2	11.7
4	14.8	17.8	20.4	33.8	41.9	12.2
5	16.2	18.8	21.3	35.3	38.4	10.7
6	16.1	19.6	19.7	24.5	33.7	8.4
7	16.8	21.6	23.1	25.3	46.9	13.6
8	17.3	21.9	23.6	40.8	47.1	13.8
9	15.4	19.4	22.3	31.5	41.5	11.6
10	15.9	19.9	21.3	24.8	41.4	11.9
11	20.6	25.2	26.9	25.0	73.5	21.5
12	17.9	23.2	24.0	30.5	70.8	20.5
13	18.3	23.6	23.9	25.0	65.5	18.8
14	17.8	22.3	23.4	24.5	59.3	16.6
15	17.8	22.4	23.4	28.5	62.1	17.9
Mean Square	8.1961	17.3671	16.5350	139.4952	832.5704	80.0703
Error Mean Square	8.3902	6.4391	7.4241	103.1587	42.5197	4.4219

*All values are the means of four replications.

TABLE V

NUTRIENT CONTENT OF PLANT TOPS RESULTING FROM P (POT AND FOLIAR) AND STICKATIVE TREATMENTS* (EXPERIMENT I)

Treatment No.	N Content (%)	Total N Uptake (MG)	P Content (%)	Total P Uptake (MG)	K Content (%)	Total K Uptake (MG)	Ca Content (%)	Total Ca Uptake (MG)
1	2.19	115.12	0.06	3.07	2.12	115.26	1.54	86.56
2	2.08	272.31	0.09	11.44	1.81	235.88	1.21	154.40
3	2.17	254.78	0.08	9.37	1.68	194.08	1.26	147.40
4	2.16	259.60	0.08	10.20	1.92	230.89	1.17	141.36
5	2.40	255.38	0.09	9.50	1.86	197.31	1.03	111.66
6	2.38	200.62	0.06	5.12	2.01	167.74	1.30	111.20
7	2.22	300.85	0.09	12.49	1.86	252.24	1.99	268.92
8	2.30	317.90	0.10	13.83	2.04	281.19	1.73	247.17
9	2.59	300.77	0.21	23.96	1.98	229.68	1.16	136.13
10	2.25	267.76	0.21	26.28	2.49	301.59	1.30	157.31
11	2.01	434.84	0.16	34.47	2.03	436.29	1.05	225.78
12	2.13	435.06	0.17	35.10	2.22	452.51	0.96	196.87
13	2.02	381.64	0.21	41.31	2.38	447.54	1.84	348.39
14	2.25	373.13	0.23	37.29	2.42	402.06	1.03	172.25
15	2.43	420.35	0.20	35.53	2.51	437.08	0.90	160.00
Mean Square	0.2062	0.0332	0.0328	0.0007	0.5443	0.0519	0.8820	0.0192
Error Mean Square	0.1571	0.0032	0.0126	0.0001	0.1552	0.0025	0.8593	0.0097

*All values are the means of four replications.

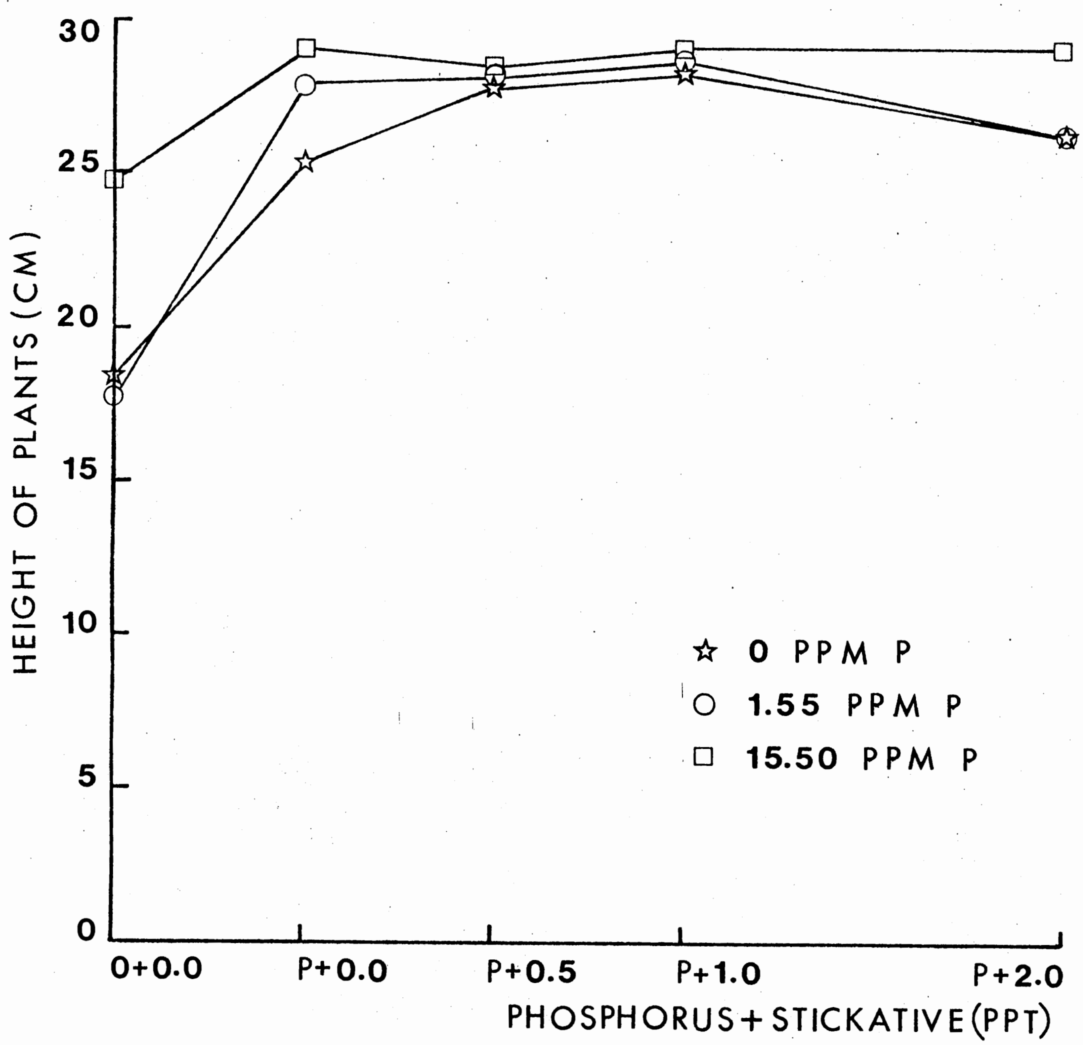

Figure 6. Height Response of Peanuts to Foliar P Spray (0.35%) and Experimental Stickative Variable

Number of Flowers

Application of foliar P to 0.0 and 1.55 ppm P pot treatments increased the number of flowers produced significantly (see Table VI and Figure 7) number of flowers for plants where no foliar P was applied was significantly larger for pot P 15.5 ppm than for the lower pot P treatments. There was no significant effect of stickative on flower numbers.

A decrease in number of flowers due to foliar P application to the high pot P treatment (15.5 ppm) is indicated in Figure 7 but not significant statistically. Note was made that leaf necrosis-leaf burn from foliar applied P occurred on plants in high pot P treatments (15.5 ppm P) but not on the lower pot P treatments. The apparent reduction in number of flowers is thought to be related.

Fresh and Dry weights of Peanut Tops

Foliar applied P to pot P treatments of 0.0 and 1.55 ppm P significantly increased fresh and dry weights of the plants grown (see Table VI and Figure 8, and 9). Fresh and dry weights when no foliar P was applied were significantly greater for the highest pot P treatment. There was no significant effect due to St. treatments though 1.0 and 2.0 ppt St. treatments on 0.0 pot P plants approached a significant decrease for fresh weights of so treated plants, and approached significance (greater) for 2.0 ppt St. treatment on dry weights (see Table VI).

Percent Composition and Total Nitrogen Contents

Percent N content of peanut plants was effected by foliar P application to 0.0 and 1.55 ppm pot P treatment plants (see Table VII and

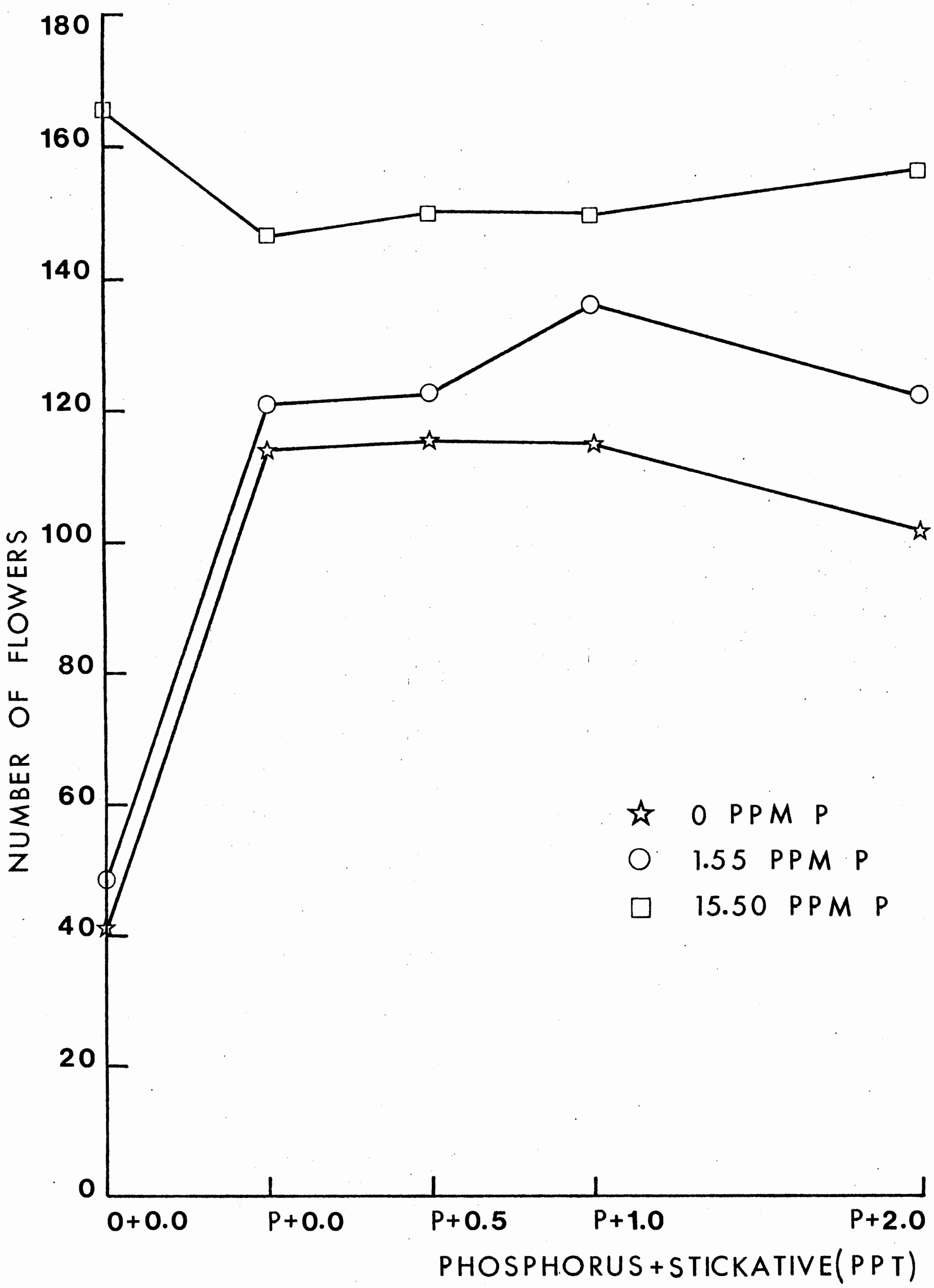

Figure 7. Number of Flowers on Peanuts in Response to Foliar Application of P (0.35%) and Experimental Stickative

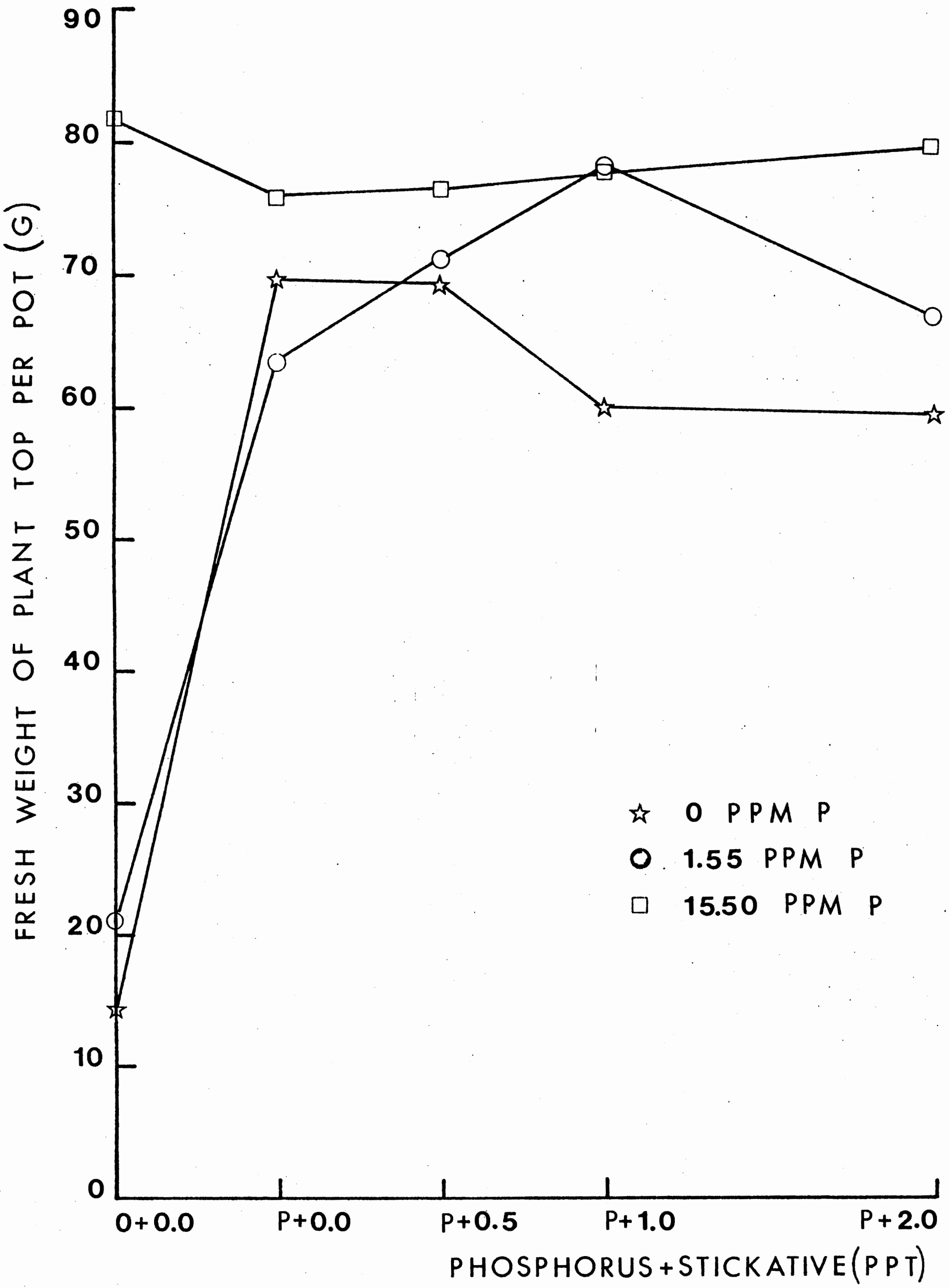

Figure 8. Growth of Peanuts

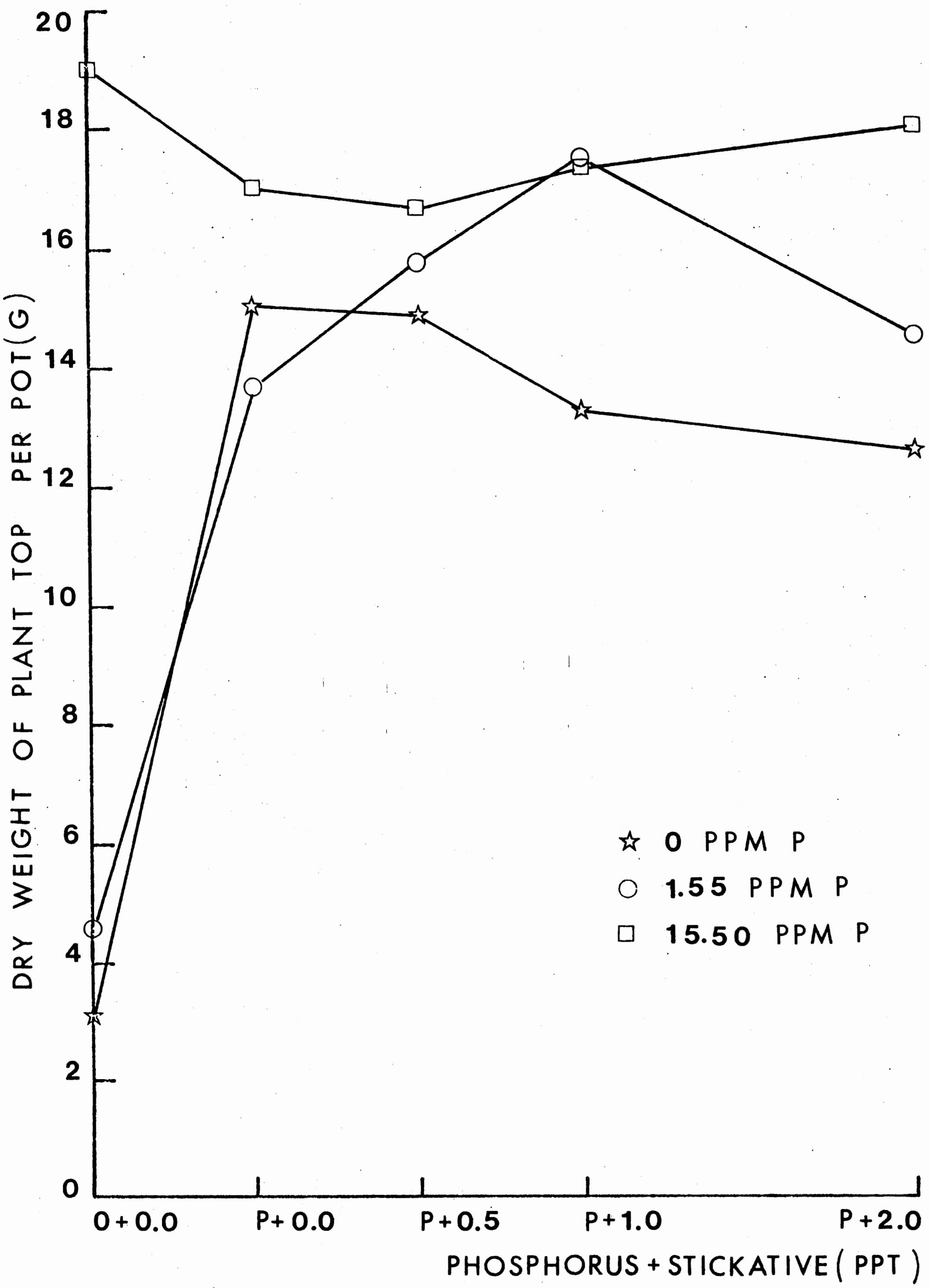

Figure 9. Dry Weight of Peanuts

TABLE VII

NUTRIENT CONTENT OF PLANT TOPS RESULTING FROM P (POT AND FOLIAR) AND STICKATIVE TREATMENTS* (EXPERIMENT II)

Treatment No.	N Content (%)	Total N Uptake (MG)	P Content (%)	Total P Uptake (MG)	K Content (%)	Total K Uptake (MG)	Ca Content (%)	Total Ca Uptake (MG)
1	2.82 a	85.86 b	0.07 f	2.04 e	3.31 a	101.08 c	0.87	26.42 e
2	1.58 c	236.54 a	0.09 ef	13.64 cd	2.41 b	378.82 a	0.88	133.83 bc
3	1.50 cde	217.17 a	0.11 de	16.08 cd	2.01 bc	293.25 ab	0.85	125.77 bc
4	1.56 cd	203.99 a	0.12 d	15.64 cd	2.06 bc	265.69 ab	0.84	110.50 c
5	1.84 b	230.88 a	0.09 ef	11.92 d	2.14 bc	267.76 ab	0.78	97.69 cd
6	2.71 a	123.71 b	0.07 f	3.15 e	3.32 a	151.66 c	0.94	43.09 de
7	1.52 cd	208.10 a	0.11 de	14.65 cd	2.18 bc	298.91 ab	0.86	117.46 bc
8	1.33 def	209.40 a	0.11 de	17.87 cd	1.94 bc	305.19 ab	0.94	147.15 abc
9	1.28 efg	223.60 a	0.12 d	20.29 c	1.73 cd	302.17 ab	0.86	150.63 abc
10	1.46 cdef	212.42 a	0.10 de	14.80 cd	1.96 bc	281.53 ab	0.77	110.95 c
11	1.08 g	206.55 a	0.16 c	30.93 b	1.34 d	258.36 b	1.02	200.19 a
12	1.24 fg	210.66 a	0.29 b	48.66 a	1.73 cd	294.09 ab	0.78	132.69 bc
13	1.23 fg	208.99 a	0.31 ab	53.09 a	1.92 c	323.66 ab	0.80	133.79 bc
14	1.23 fg	214.66 a	0.32 a	55.81 a	1.88 c	327.43 ab	0.80	140.60 bc
15	1.27 efg	229.01 a	0.30 ab	53.19 a	1.83 c	329.96 ab	0.97	174.89 ab
MS	2.1472	0.0067	0.0358	0.0014	2.3494	0.0193	0.0455	0.0078
EMS	0.0442	0.0011	0.0003	0.0002	0.1675	0.0046	0.0455	0.0013

*All values are the means of four replications.

and Figure 10 and 11). The decrease in percent N composition (Figure 10) is a true dilution effect. This is confirmed by an increase in total N content shown in Figure 11. These effects were significant statistically. Significant difference between percent N content when no foliar P was applied is noted for the high pot P treatment as compared to the lower pot P treatment plants. Significant differences are also indicated for no foliar P treatment for each of the pot P levels. The effect of St. produced no significance statistically.

Percent Composition and Total Phosphorus Content

Application of St. produced no significant effect on percent or total P content of peanut plants in this experiment (see Table VII and Figure 12, and 13). Foliar P produced significant increases in percent P for the high pot P treatment (see Table VII and Figure 12) apparently P levels in the peanut plants at the two lower pot P treatments were so limited that the minimum percent composition for P was never exceeded for these two pot P treatments.

Significant increase in total P contents were effected for all pot P treatments by foliar P applications (see Table VII and Figure 13). Also, percent P and total P content were significantly higher for the highest pot P treatment (15.5 ppm P) compared to the two lower pot P treatments.

Percent Composition and Total Potassium Contents

The effects of the experimental St. on percent K and total K content of the experimental plants were not significant statistically. Significant decrease in percent K composition for the 0.0 and 1.55 ppm pot P

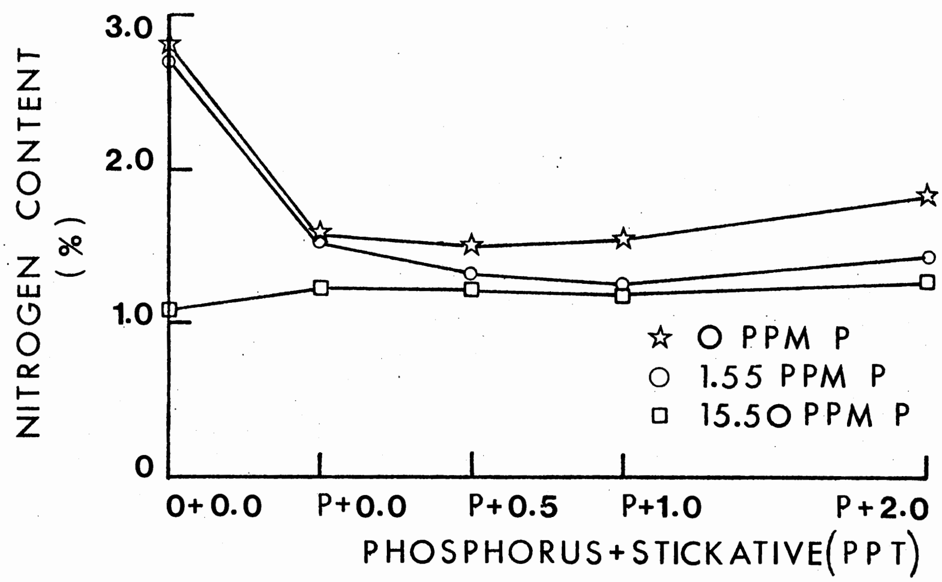

Figure 10. Percent N as Affected by Foliar P Spray (0.35%) and Stickative Treatments

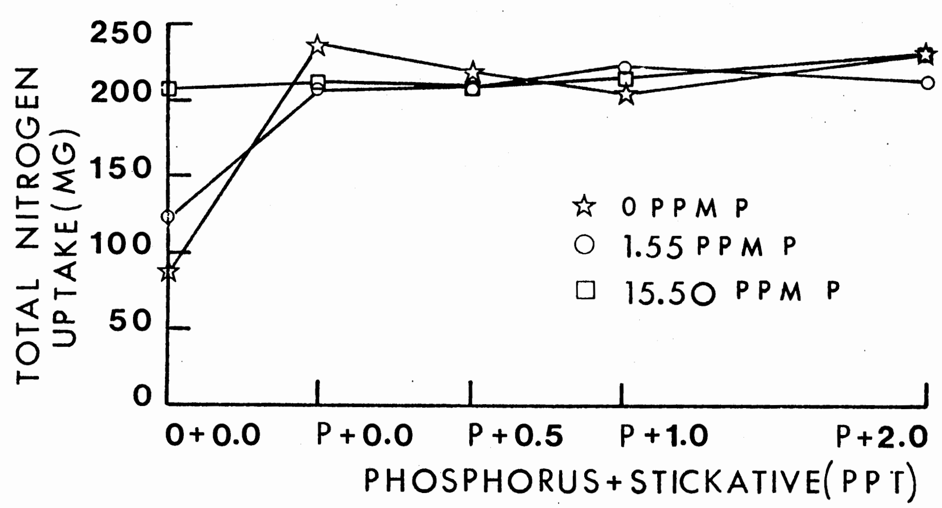

Figure 11. Total N as Affected by Foliar P Spray (0.35%) and Stickative Treatments

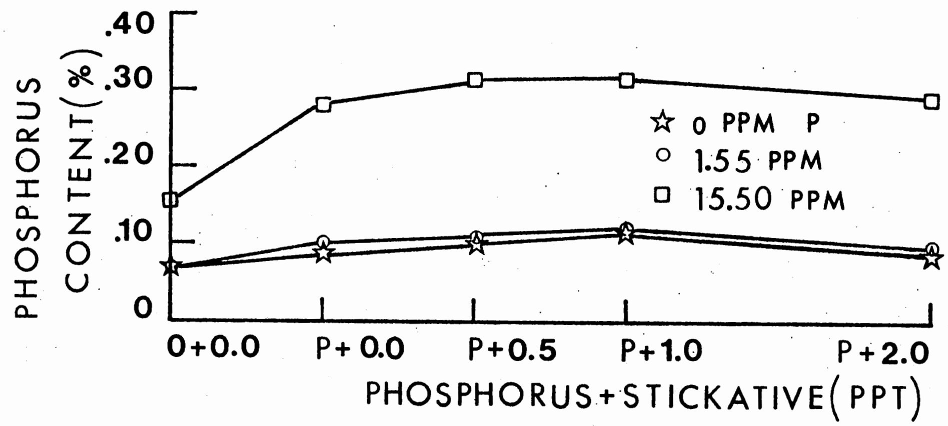

Figure 12. Percent P as Affected by Foliar P Spray (0.35%) and Stickative Treatments

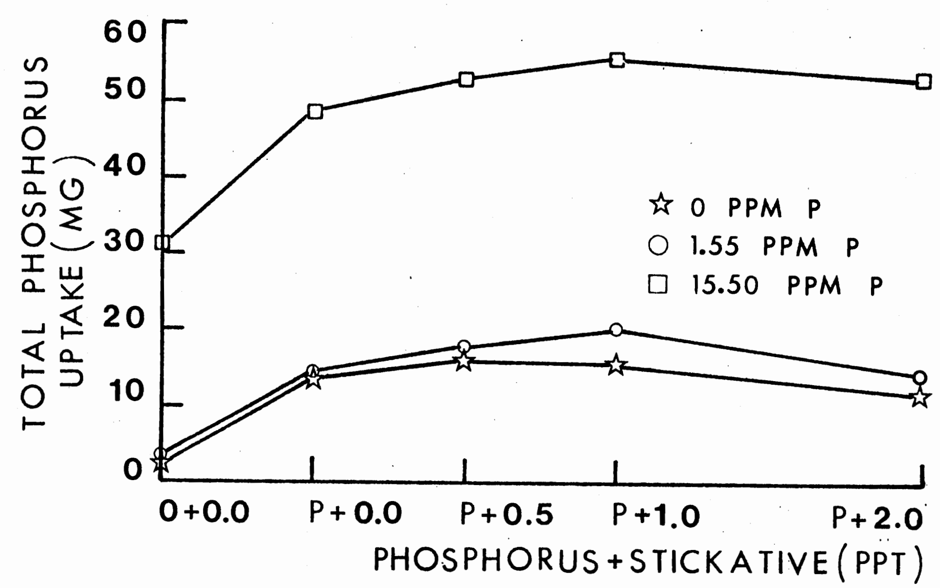

Figure 13. Total P as Affected by Foliar P Spray (0.35%) and Stickative Treatments

treatments were occasioned by foliar P treatments. This is a dilution effect, a result of increased total dry matter production (see Table VII and Figure 14) and confirmed by a significant increase in total K content (see Table VII and Figure 15). Also, both percent K and total K increased for the highest pot P treatment resulting from foliar P treatments approached significance. The highest pot P treatments showed significantly higher K contents than the two lower treatments when no foliar P was involved.

Percent Composition and Total Calcium Contents

No significant effect was noted on percent Ca content by phosphorus treatments, either pot or foliar, or by St. (see Table VII and Figure 16). Total Ca content in the plant tops was significantly effected by P treatments. Foliar P application increased Ca content for 0.0 and 1.55 ppm P pot treatments and without foliar application 15.5 ppm pot P had significantly higher Ca contents than the two lower pot P treatments. Decrease in total Ca because of foliar P treatment to pot P treatment of 15.5 ppm is thought to be due to leaf damage occurring for that series when foliar P was applied, as noted earlier (see Figure 17). It appears that the highest treatment rate for the St. may have been beneficial to total Ca content for the highest pot P treatments though the increase only approached significance statistically (see Table VII and Figures 16, and 17).

Table Top Placement (Height) Effects

The positioning of the Spanish peanut growth containers

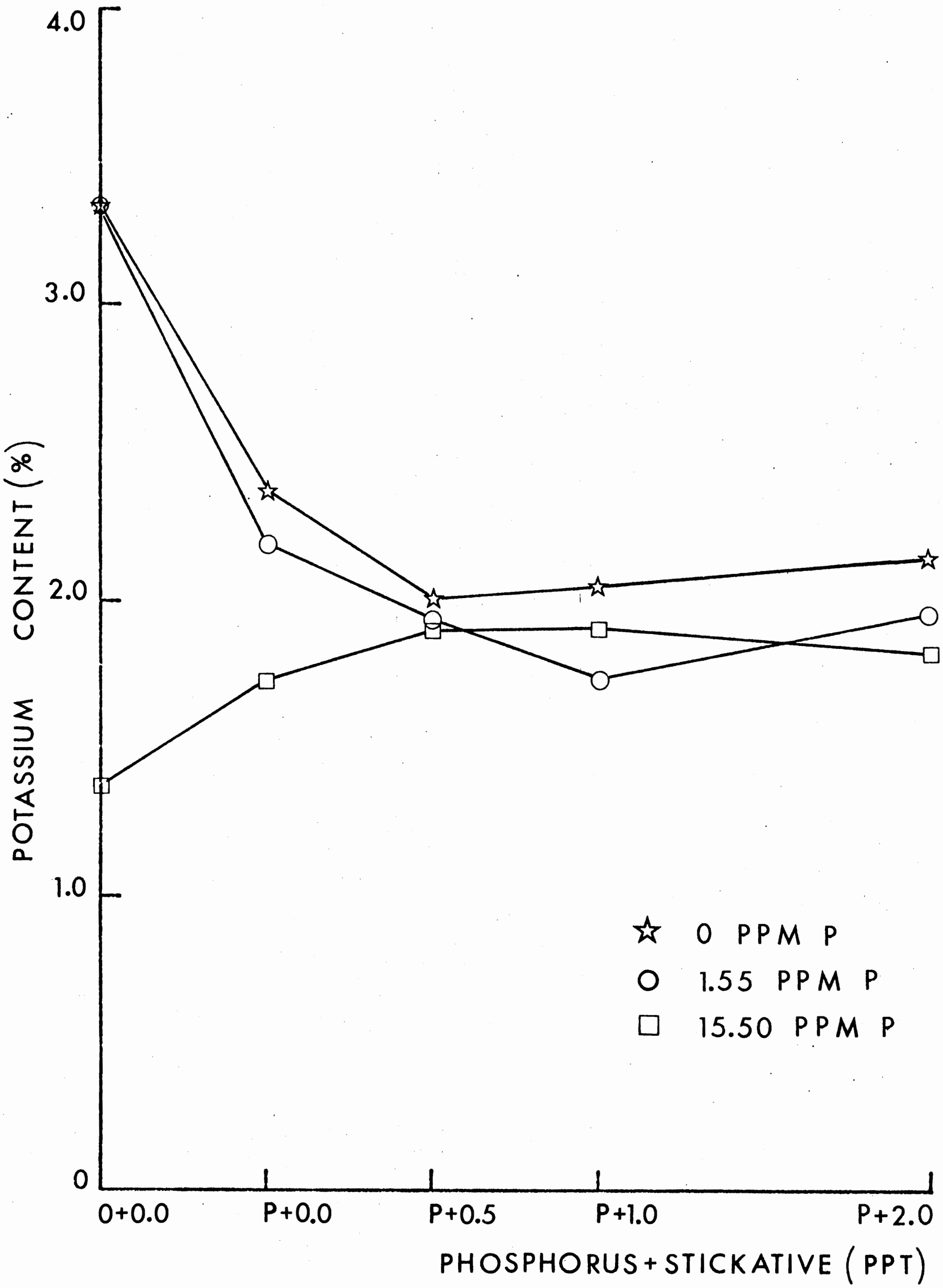

Figure 14. Percent K as Affected by Foliar P Spray (0.35%) and Stickative Treatments

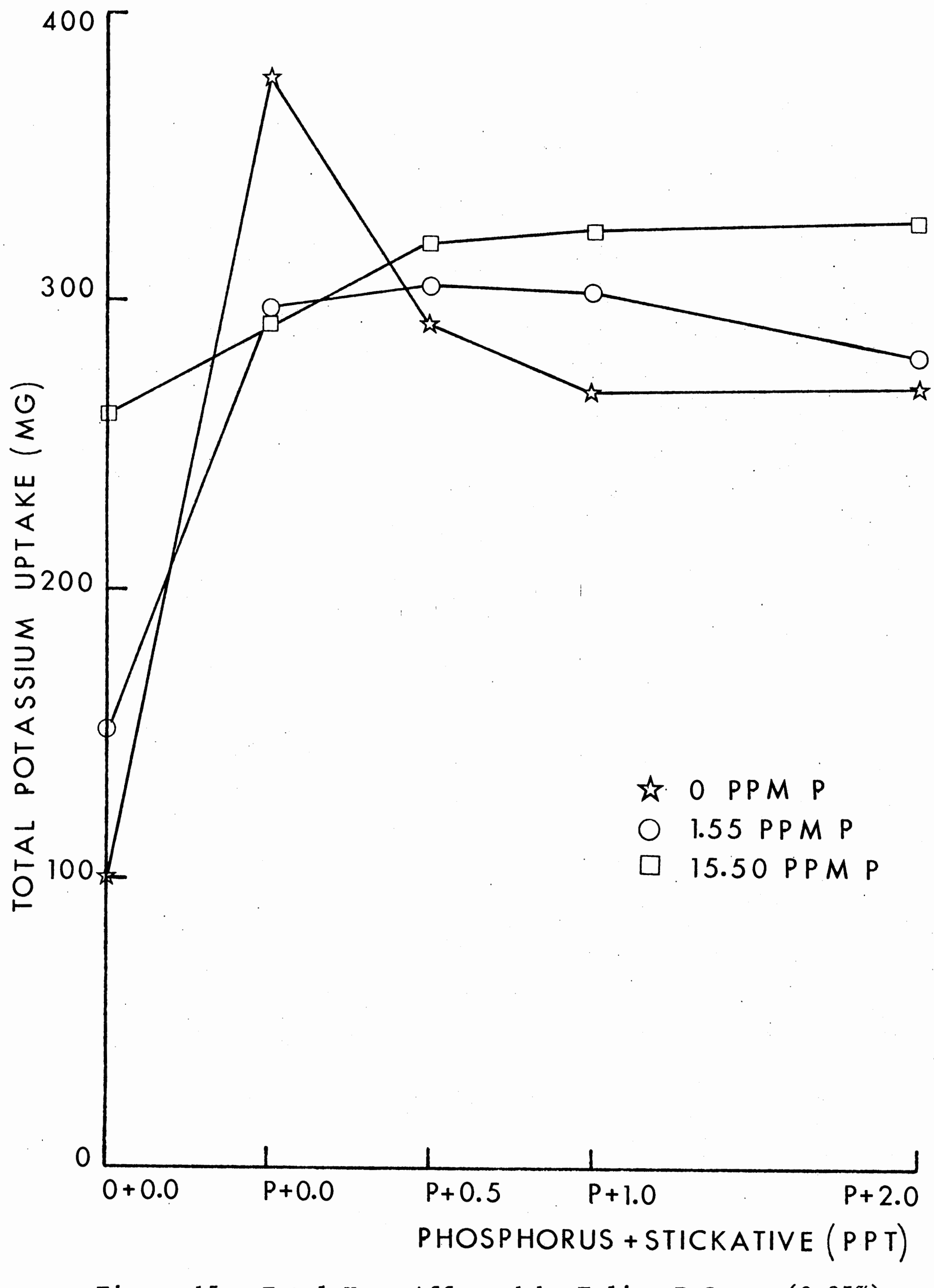

Figure 15. Total K as Affected by Foliar P Spray (0.35%) and Stickative Treatments

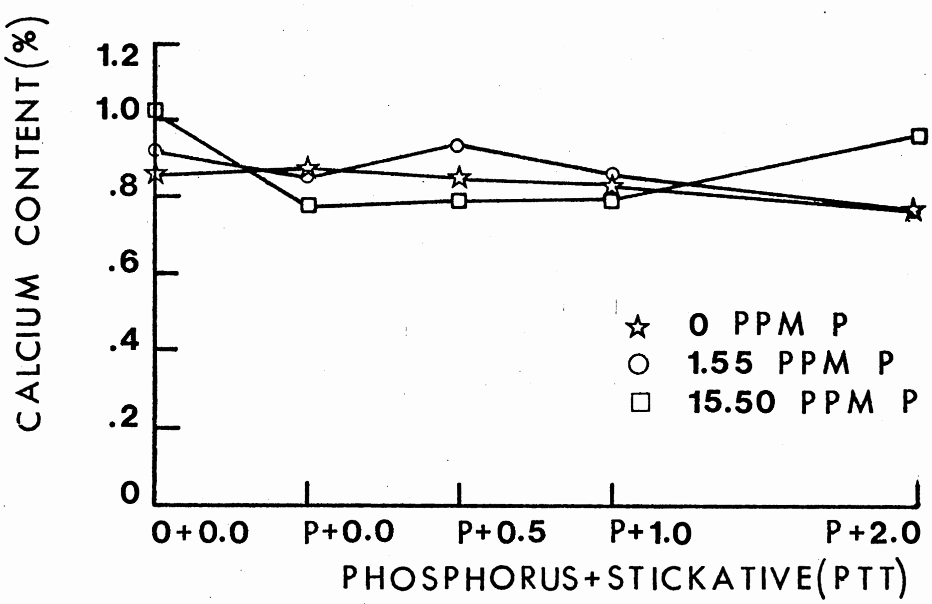

Figure 16. Percent Ca as Affected by Foliar P Spray (0.35%) and Stickative Treatments

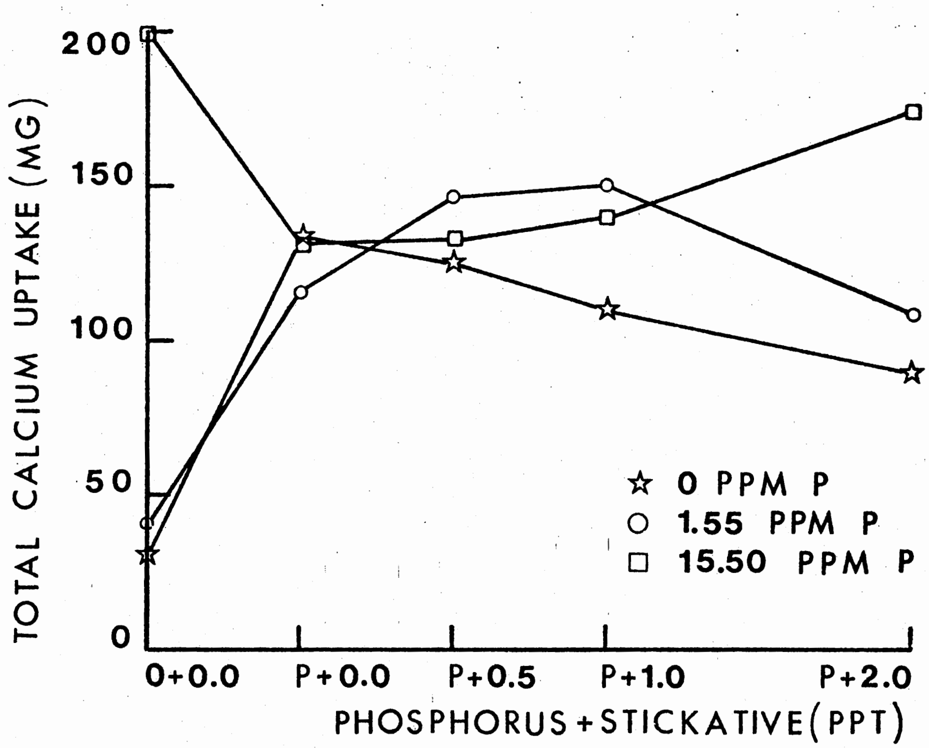

Figure 17. Total Ca as Affected by Foliar P Spray (0.35%) and Stickative Treatments

approximately 12 inches above the table top was suggested by Morrison[1] to eliminate or greatly reduce edge effects in greenhouse experimentation, thought to be due, primarily, to restriction in air flow patterns. Tables VIII, IX, X, and XI show the AOV from the data collected for dry weight, total N, and percent P and total P content of the peanuts grown in this experiment. These measurements should be more sensitive or at least of equal sensitivity to other measurements made. Placement of the plant containers directly on the table top was not significantly different from those placed 12 inches above the table top for the indicated measurements. Perhaps re-randomization when foliar treatments were made contributed to the obtained result.

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[1]R. D. Morrison, personal communication.

TABLE VIII

DRY MATTER OF PLANT TOPS INFLUENCED BY PLACEMENT
12" ABOVE VS. TABLE TOP (EXPERIMENT II)

Anaylsis of Variance

Source of Variance	DF	Sum of Square	Mean Square	F Value
Replication	3	8.60713	2.8690417	0.4039 NS
R_4 vs. (R_1 + R_2 + R_3)	1	7.9590143	7.9590143	1.1204 NS
Among R_1, R_2, R_3	2	0.6481157	0.3240579	0.0456 NS
Residuals (Error)	42	298.36350	7.1038929	

R_1, R_2, R_3 = Replication I, II, and III placed above the table.
R_4 = Replication IV placed on the table top.
NS = Non-significant difference.

TABLE IX

TOTAL NITROGEN CONTENT IN PLANTS INFLUENCED BY PLACEMENT 12" ABOVE VS. TABLE TOP (EXPERIMENT II)

Analysis of Variance				
Source of Variance	DF	Sum of Square	Mean Square	F Value
Replication	3	0.002994735	0.0009982449	0.9278 NS
R_4 vs. ($R_1 + R_2 + R_3$)	1	0.0002153	0.0002153	0.2001 NS
Among R_1, R_2, R_3	2	0.00277944	0.001389718	1.2916 NS
Residuals (Error)	42	0.04519019	0.00107596	

NS = Non-significant difference.

TABLE X

PERCENT PHOSPHORUS COMPOSITION IN PLANTS INFLUENCED BY PLACEMENT 12" ABOVE VS. TABLE TOP (EXPERIMENT II)

Analysis of Variance				
Source of Variance	DF	Sum of Square	Mean Square	F Value
Replication	3	0.003724369	0.001241456	3.7779*
R_4 vs. $(R_1 + R_2 + R_3)$	1	0.00016994	0.00016994	0.5172 NS
Among R_1, R_2, R_3	2	0.00355443	0.00177721	5.4084**
Residuals (Error)	42	0.013801366	0.000328604	

NS = Non-significant difference.
* = Significant difference.
** = Highly significant difference.

TABLE XI

TOTAL PHOSPHORUS CONTENT IN PLANTS INFLUENCED BY PLACEMENT 12" ABOVE VS. TABLE TOP (EXPERIMENT II)

Analysis of Variance				
Source of Variance	DF	Sum of Square	Mean Square	F Value
Replication	3	0.0000679005	0.00002263349	0.9512 NS
R_4 vs. ($R_1 + R_2 + R_3$)	1	0.000021006	0.000021660	0.8828 NS
Among R_1, R_2, R_3	2	0.000046894	0.000023447	0.9854 NS
Residuals (Error)	42	0.0009993827	0.00002379483	

NS = Non-significant difference.

CHAPTER V

SUMMARY AND CONCLUSIONS

Greenhouse experiments were conducted to study foliar application of P and a surfactant, the experimental stickative (St.) on two varieties of Spanish peanuts. Modified Hoagland nutrient solution with variable P was supplied in sand cultures. The main objective is to find out if foliar feeding of P might partially or entirely substitute for conventional P fertilization. The benefit of the experimental St. on foliar P absorption was simultaneously tested. The results were interpreted in the aspects of the plant growth and nutrient uptake.

Experiment I

This preliminary study gave the following information:

1. Spanish peanuts can utilize P from foliar feeding almost as well as from root uptake, but growth increase was obsecure where 15.5 ppm P was present in root media. This effect is also reported in the literature (4).

2. The experimental St. did not apparently enhance the penetration, and absorption of foliar P. Adverse effects were found at 2.0 ppt and in the event of high pot P.

3. P contents in peanut plants where root P is high, was predominantly obtained from P in the nutrient solution. Thus, foliar sprays of P might be a supplementary application only when root P availability is

low.

Experiment II

Some improvements in foliar feeding and measurement techniques were applied to this subsequent study. From this study the following information was obtained:

1. In general, spanish peanuts can effectively utilize P from foliar application.

2. The experimental St. seemed to stimulate foliar absorption of P in a minute extent in the concentration range of 0.5 to 1.0 ppt, however the changes observed were not statistically significant. Others have found surfactants beneficial to P absorption via plant leaves (22).

3. The uptake of foliar P and some nutrient elements was prominently affected by P in the nutrient solution. A significant benefit from foliar feeding being noted when root accessibility to P is low and a possible negative trend noted when plant root P level was high. Leaf damage to plants from foliar applications were noted for the high root P levels.

4. Foliar P application as a supplementary source of P for peanuts grown on soils where plant P availability is low is indicated to be feasible. Foliar rates and frequency of application in the field will require field studies and the economic benefits will be dependant upon soil P release-fixation characteristics and costs of foliar vs. high rates of soil applications.

5. Other St. or wetting agents may be helpful, however, the experimental St. (Buckman BL-2142) seems to have been of little benefit in these greenhouse studies.

6. The use of foliar P applications in the field is visualized as a useful technique for investigation of soil P availability as affected by soil pH and Ca levels.

7. Table top placement of the Spanish peanut plant containers 12 inches above or directly on the table top surface did not produce a significant difference in the measure parameters of this experiment.

Biotic and environmental factors, as well as manipulated effects, are involved in plant response to foliar feeding of P. These factors have also been reported by other investigators (4, 21, 36). Additional trials with other surfactants and root P levels should be made before a field study is begun.

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