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Effect of phosphorus and potassium fertility on fruit quality and growth of Tabasco pepper (Capsicum frutescens) in hydroponic culture

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EFFECT OF PHOSPHORUS AND POTASSIUM FERTILITY ON FRUIT QUALITY AND GROWTH OF TABASCO PEPPER (*CAPSICUM FRUTESCENS*) IN HYDROPONIC CULTURE

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ABSTRACT

The effects of P and K fertilization on Tabasco plant growth and fruit quality were evaluated in a preliminary experiment conducted in fall 2002; 4 levels of P (0.25, 1.0, 1.75, and 2.5 mM) and 4 levels of K (0.75, 1.75, 2.75, and 3.75 mM) in hydroponic culture with a factorial randomized design. The main growth experiment was conducted in spring/summer growing period of 2003. This experiment consisted of 8 treatments; 4 levels of P (P1 0.25, P2 1.25, P3 2.5, and P4 3.75 mM) and 4 levels of K (K1 0.25, K2 1.25, K3 2.5, and K4 3.75 mM). The same treatments were used to evaluate fruit quality characteristics in an experiment that was conducted simultaneously. Tabasco pepper "McIlhenny Select" seed were sown in trays, and at the fourth true leaf stage, individual plants were transplanted into 3-gallon round plastic pots filled with agricultural grade perlite. Plants were harvested once every month; stem diameter and plant measurements were taken every fifteen days. The Preliminary growth experiment showed that P affected plant height, leaf area, root, stem and leaf dry weights as well as overall plant dry weight. Potassium affected root dry weight at both harvests with no influence on other growth variables. The dry root weights of plants grown with the highest K rate (K4) were significantly higher than the lowest k rate (K1). Potassium source was changed for the main plant growth experiment. Phosphorus and potassium rates significantly affected plant growth, increasing plant height, weight, stem diameter, leaf area, and dry weights of plant sections with increasing rates in nutrient solution. For the fruit quality experiment, all plants were grown until the flowering stage with the same nutrient solution (2 mM P; and 3.75 mM K). At the beginning of the flowering stage different nutrient treatments were applied. Increasing P and K rates also affected plant yield and some fruit quality variables. Results were consistent for most of the variables, suggesting that the 0.25 mM concentration for both P and K was insufficient for pepper

production. Concentrations higher than 1.25 mM and close to 2.5 mM are the most appropriate for hydroponic tabasco pepper production.

CHAPTER 1

INTRODUCTION

At the present time, fertilizers are applied to almost every crop that is grown commercially. Prior to World War II inorganic commercial fertilizers were not used, if so, they were used on a much smaller scale and were primarily phosphate and potash. After the war the use of fertilizers increased dramatically. Technologies created to fix atmospheric nitrogen, developed during the war, reduced the cost and increased the availability of nitrogen fertilizers. Use of synthetic fertilizers increased dramatically until the mid 70's and started to level off. After this period, concerns about movement of nitrogen fertilizers and herbicides into surface and underground waters was expressed as well as significant concentrations of phosphorus in surface waters.

Death and decomposition of phytoplankton of the coastal waters adjacent to the Mississippi and the Atchafalaya river outflows caused hypoxic conditions in the bottom waters of the Louisiana coast. Regulations to agricultural related activities, in this case fertilization practices, are likely to increase in the future due to these environmental concerns over the use of excessive amounts of fertilizers and their effects on water supplies.

Louisiana has been known for its historical tabasco (*Capsicum frutescens L.*) pepper production. The McIlhenny® Company's history about the origins of the plant in the U.S. started when tabasco pepper seeds were obtained from a traveler who recently arrived to Louisiana from Central America and were planted in Avery Island. In the later 1860's Tabasco pepper sauce was commercially being made and by the late 1870's the sauce was sold throughout the United States. Very little research however, has been conducted regarding the nutritional needs of this crop. Currently producers base the plants nutritional needs on requirements of other *Capsicum* species and follow the same tissue nutrient concentration as a method to determine the plants optimal nutrition. Nutritional research is therefore needed for this crop species to determine precise nutritional requirements.

Most of the studies investigating fertility and plant nutrition have focused on nitrogen, and its requirements as well as it effects in the plants response to increased nitrogen rates are well known (Jones et al., 1988; Everet and Subramaya, 1983). Nitrogen (N) has been shown to increase the number and size of jalapeño marketable fruits, fruit pungency and overall yield (Johnson and Decoteau, 1996; Gill et al., 1974). Sundstrom et al. (1984) in a study of N and plant spacing with mechanically harvested tabasco pepper, concluded that higher N rates increased red pepper fruit yield. Few studies examining phosphorus and potassium fertility in pepper have been conducted, but, they are not specific to the tabasco plant.

Tabasco pepper is produced in several Latin American countries. Fertilization requirements vary due to soil and different climate conditions where these peppers are grown. Guidelines and nutrient requirement recommendations for pepper production in the different countries, therefore, require an enormous amount of research often impossible to be carried out by the private industry. It is important to address these issues and provide general guidelines that will help producers to identify deficiencies and mineral sufficiency ranges that could apply to all growing conditions.

This study will determine the minimum requirements of hydroponic tabasco pepper, and also identify deficiency symptoms that would be helpful to treat deficiencies. The effects on Phosphorus (P) and Potassium (K) on fruit quality will also determine the impact of the nutrients on fruit characteristics that may affect processing and sauce quality. A specific study on P and K nutrition of tabasco pepper will provide a future reference for research on this pepper variety.

The objectives of the present study are:

- To determine the effect of P and K rates on plant growth and fruit quality variables.

- To determine tissue levels of phosphorus and potassium that lead to optimum plant growth, fruit quality, and yield of tabasco pepper.
- To determine the effect of P and K on minor elements in the plants tissue.

CHAPTER 2

LITERATURE REVIEW

2.1 Potassium Nutrition

2.1.1 Uptake and Mineral Interactions

Potassium (K), in contrast to nitrogen (N), phosphorus (P) and most other nutrients, forms no compounds in the plant and exists solely as K^+, either in solution or bound to negative charges on tissue surfaces. Potassium is absorbed by the roots as a K^+ ion. In a study on nutrient uptake and solute movement of drip irrigated bell peppers, element uptake followed the order of K>N>Ca>P>Mg (Santiago and Goyal, 1985). The highest nutrient uptake occurred during the third part of the growing season, indicating the importance of K in bell pepper fruit mineral nutrition. A slightly different order was reported by Olsen et al. (1993) in their study of N uptake and utilization by pepper plants. They reported that at high N rates the order of elements that are taken up by the plant are K>Ca>Mg>P.

Coltman and Riede (1992) tested different levels of K (25, 50, 100, 200 and 300 $mg \cdot L^{-1}$) in a greenhouse experiment of potted tomato plants and monitored the petiole sap K concentration. Plant height, and stem diameter were significantly different due to K concentrations while yield was quadratically related to increasing external K concentrations.

In potato, larger tuber yield was associated with increased concentration of K in the plant tissue with an accompanying decrease in Ca and Mg (MacGregor and Rost, 1946). Three soil types with four fertility levels indicated increased K tissue concentration in the higher yielding plants were associated with soil fertility. Tissue Ca, Mg, P, S and Cl concentrations were not related to soil fertility levels (MacGregor and Rost, 1946). Locascio et al. (1992) also reported a reduction in Ca concentration in the potato petiole and tuber medula with increased K rate applied to the soil in two of the three seasons, and periderm tissue Ca in one of three seasons.

Petiole K concentration was not influenced by Ca rate. High concentrations of soil K also decreased Ca and Mg leaf content in an experiment on the effect of potassium and farmyard manure on potato yields (Singh and Brar, 1985). Conrad and Sundstrom (1987) studied the effect of calcium and ethephon on Tabasco fruit color. The researchers found that foliar applications of a combination of 0.1 M $Ca(OH)_2$ with ethephon rates of up to 15,000 ppm, increased the percentage of orange and red fruits on the plants. In Irish potato, K fertility negatively impacted Mg (-0.83), and Ca (-0.48) uptake without the application of farmyard manure. This negative correlation of K on Ca and Mg was reduced with the application of farmyard manure (Singh and Brar, 1985). Potassium fertilization also decreased leaf Mg at 58 days after planting (DAP) while leaf Ca decreased significantly at the last sampling date (105 DAP) in a potato crop grown on a sandy soil in 1981 (Rhue et al., 1986). In 1982 and 1983, K treatments were found to significantly reduce leaf Mg and Ca of the potato plants at all sampling dates.

Potassium levels of hydroponically grown tomato fruit decreased with increasing Ca concentration in the nutrient solution (Paiva et al., 1998). Reduced K and Mg fruit concentrations were attributed to the competitive effect of Ca for absorption sites in the plant. The researchers speculated that due to the influence of K on carotenoid synthesis and lycopene in particular, the production of these pigments could have been reduced.

Potassium content of hydroponically grown young tomato plants was sufficient after 3.25 mM K (Gunes et al., 1998). Increasing K concentrations also increased N, P, and Zn content of the plants. Williumsen et al. (1996) reported that high levels of K in tomato fruit stimulated the formation of organic acids that reduce fruit Ca availability and permeability of cell membranes. The high level of organic acids caused increased loss of cell constituents and the occurrence of blossom-end rot.

The effect of salinity on increasing K concentrations of hydroponically grown tomato has been previously investigated. Potassium concentrations in the growing medium enhanced shoot and root dry matter (Al-Karaki, 2000). In contrast, salinity decreased K uptake and translocation. This reduction was more dramatic at 0.2 mM than 2.0 mM K. Increasing the EC of the solution also decreased fruit number and weight, and the number of potential fruits was reduced by about 40% in eggplant (Zipelevish et al., 2000). To avoid increasing salt accumulation in the rizosphere and to minimize nutritional fluctuations of tomato plants, Coltman and Riede (1992) increased the irrigation volume by 25% to promote leaching of the pots.

The effect of high nitrogen rates and other elements has been previously investigated. High NO_3 supply on hydroponically grown tomato plants tended to increase K concentration, and to decrease Ca and Mg (He et al., 1999). No effect, however, was reported on the concentration of P in the petiole sap of different leaf positions. Simonne et al. (1998) also found that higher N rates tended to increase K foliar concentration of bell pepper grown in the field. In contrast, Ca concentration increased with higher N rates.

High nitrogen rates reduced the amount of total P (organic and inorganic) during senescence of pepper plants, and total P showed a quadratic response to N fertilization (Baghour et al., 2001). Total P decreased as K rates increased but fruit yield increased at higher K rates. Foliar P showed a linear response with increasing K rates having the largest amount of accumulated P at the lowest K rate.

To examine the relationship between K nutrition and fruit quality for processing, a survey of 140 processing tomato fields in central California was conducted (Hartz et al., 1999). Soil exchangeable K, expressed as meq/kg, was negatively correlated with the incidence of yellow shoulder (YS) (r^2=-0.38), and internal white tissue (IWT) (r^2=-0.36). Soil exchangeable Mg was positively correlated with the disorders (r^2=0.36 for YS, and r^2=0.30 for IWT), while exchangeable Ca was unrelated. Soil K/√Mg ratio was more closely correlated with the percentage of total color disorders (r^2=0.41 for YS and r^2=0.38 for IWT) than was either soil exchangeable K (r^2=-0.34 for YS and r^2=-0.33 for IWT) or K activity ratio (r^2=-0.38 for YS and r^2=-0.36 for IWT). Fields with less than 0.7 $cmol \cdot kg^{-1}$ soil exchangeable K showed a wide range of color disorder, with an average of 20% fruit affected. Fields with >0.7 $cmol \cdot kg^{-1}$ exchangeable K averaged only 7% color disorders. Most of the fields in this category showing higher levels of color disorders also had low K/√Mg ratios. Fields with soil K/√Mg >0.25 had only 4% color disorders. Midseason leaf K concentration, which was 25 $g \cdot kg^{-1}$, was positively correlated with fruit soluble solids (r^2=0.28) while YS (r^2=-0.34) and IWT (r^2=-0.33) were correlated to soil K (Hartz et al., 1999).

In a study of the effect of nitrogen source and fertilizer application type (band or drip) on tomato fruit yield, leaf K concentration was measured (Motis et. al, 1998). Leaf K concentrations were 2.5% with ammonium nitrate and 2.7% with polymer-coated urea in the spring season, but averaged 3.1% in the fall. This result was consistent with greater fall tomato production with polymer-coated urea than ammonium nitrate. Leaf K concentrations decreased linearly from 3.2% to 2.5% with increasing percentages of drip-applied ammonium nitrate, but increased linearly from 2.2% to 2.6% with increasing percentage of band applied polymer-coated urea. These results suggest that yields were influenced by the effect of N placement on plant uptake of K.

2.1.2 Yield

Research to investigate the potassium requirements of plants is often difficult due to the high status of the nutrient in the soil. Sahu (1973) reported no response of potato tuber yield to varying levels of P and K in field studies with a content of 34.04 and 124.76 $kg \cdot ha^{-1}$ of P and K, respectively. Locascio et al. (1992) reported no effect of different K rates on marketable tuber yields of potato. Specific gravity of the tubers however, was significantly influenced by K. Potatoes fertilized with K 225 kg·ha^{-1} had a higher specific gravity than the 450 kg·ha^{-1} rate two of the three seasons. Potassium rates (0, 60, 120, and 180 kg·ha^{-1} K_2O) and farmyard manure, increased potato tuber yield to 120 kg·ha^{-1} (Singh and Brar, 1985). High rates of K depressed tuber production. The highest potato yields were obtained with the combination of 120 kg?ha^{-1} K_2O?and the application of 50 t?ha^{-1} of farmyard manure.

Potato field experiments for optimum potassium fertilization showed that increasing K rates significantly affected tuber yield (Trehan and Grewal, 1994). "Kufri Jyoti" responded significantly up to 66 kg·ha^{-1}. A combination of preplant and side-dressed fertilizer application produced the highest yields. "Kufri Chandramukhi" produced the highest yields at 99 kg·ha^{-1} applied either preplant or as a combination of preplant and side-dressed.

Increased tabasco pepper red fruit yields as a result of seed treatment methods were reported by Sundstrom et al. (1987). The researchers found that plug planted pregerminated seed increased red fruit yields. Plots established by transplanting or by use of pregerminated seed produced higher total fruit yields. The study concluded that of all the seed treatment, and planting methods that were tested, crop performance of pregerminated seeds was superior.

In a potato study, with varying soil K levels, yields were higher with increased soil K up to 196 kg·ha^{-1} with no further increase with higher soil K levels (Peterson et al., 1971). Yields, specific gravity of the tubers, and tissue K concentrations were significantly correlated with soil K. Specific gravity and soil K as well as specific gravity and K concentration in the tissue were positively correlated

In a study investigating K source and rate for polyethylene mulched tomatoes, K had no effect on marketable yield in two of three studies (spring 1991 and fall 1992) (Locascio et al., 1997). In the spring 1992 study, however, a significant response to K source was reported.

Marketable yields were 19% higher with KNO_3 than KCl, however, yield differences between other sources were not significant. Marketable fruit yields were not affected by K source, but yields were significantly higher with increased K fertilization rates. Tomato yields increased in 1990 from 52.9 $t{\cdot}ha^{-1}$ with 0 K to 72.8 $t{\cdot}ha^{-1}$ with the highest K rate. In 1991 yields increased with each increase in K application from 75 to 150 $kg{\cdot}ha^{-1}$.

Potassium application rates ranging from 22 to 255 kg ha^{-1} in combination with N were tested in four Florida locations low in Mehlich-I extractable soils for their effect on bell pepper yield (Hochmuth et al., 1988). Increasing K rate did not affect plant growth, however, plant and fruit K content was increased. High K rates did not result in higher fruit yield in any location. Another study investigating K nutrition on seed yield and quality in field grown sweet pepper reported that the higher K rate increased the number of fruits per plant and seed yield of sweet pepper (Osman and George, 1984). Everet and Subramanya (1983) in a study of plant spacing and N and K rates of field grown pepper plants, reported that increased N-K_2O rates from 150-210 to 294-415 $lb{\cdot}acre^{-1}$, respectively, had no effect on pepper yield, fruit number, and average fruit weight of pepper in any of the three seasons that the study was performed.

Hochmuth et al. (1993), in a study of eggplant yield response to K fertilization on sandy soils in two different seasons, showed that increased K fertilization resulted in quadratic yield increases. Yield responses to no K vs. K fertilizer were significant; however, there was no significant yield effect at higher K rates than 45 $kg{\cdot}ha^{-1}$.

Increasing K by addition of KCl fertilizers increased the EC of the irrigation solution (Zipelevish et al., 2000). Increased EC values from 2.3 to 3.9 dS/m lowered eggplant yield. The real effect is not clear, however, lower yield may have been due to high K or Cl concentrations of the nutrient solution.

2.1.3 Vegetative Growth

Symptoms of K deficiency in sunflower first affect the lower leaves, with younger leaves showing symptoms of the disorder only in severe cases (Blamey et al., 1987). In seedlings, the oldest leaves develop a generally yellow color and large necrotic patches develop accompanied by severe buckling on the leaf. In severe cases, this distortion affects most leaves on the plant. In older plants, K deficiency symptoms first appear as a chlorosis of the margins and interveinal regions of the lower leaves. The leaves with chlorotic areas often develop an upward cupping, especially towards the tips, although downward cupping of the leaves has been observed. The chlorotic areas of the lower leaves eventually become necrotic and complete senescence of the lower leaves may occur.

Field grown bell pepper plant height was affected by K rate (Everet and Subramanya, 1983). Medium and high rates of N-K_2O, 205-290 and 295-415 lb?$acre^{-1}$, respectively, were equal and taller than plants fertilized with the low 150-210 lb?acre N-K_2O rate during the two spring seasons. In the fall season N-K_2O rates did not affect plant height.

Dry weight of hydroponically grown tomato plants was increased by increasing K in the culture solution from 0.82 to 4.88 mmol (Gunes et al., 1998). A high 6.50 mmol K concentration decreased plant dry matter. Plant K content was increased with higher concentrations of K in culture.

Dry weight of field grown pepper plants was linearly significant in only one of four locations with increasing K rates, from 22 to 255 kg ha^{-1} (Hochmuth et al., 1988). None of the other locations showed differences in dry weights of the plants due to K rate.

Hydroponically grown jalapeño pepper plant biomass, dry weight of leaves, and stems, and pods per plant responded curvilinearly to N fertility rate (Johnson and Decoteau, 1996). Nitrogen rate also affected pod pungency, as measured by capsaicinoid production and Scoville units. Levels of capsaicin and Scoville units responded curvilinearly to increasing N rates. Dihydrocapsaicin increased linearly with increasing N rates up to 15 mM and then leveled off. Unlike N, K fertility rate had no effect on pod pungency. Leaf and total biomass per plant responded curvilinearly to K rate, while stem biomass and K levels in leaves and petioles increased linearly with increasing K rate. Potassium rate did not affect pod count and dry weight per plant. Jalapeño pepper plants receiving 1 mM K in both experiments were smaller than plants in the higher K treatments. The researchers suggested that at least 6 mM K was needed for acceptable biomass development while pod production required at least 3 mM K. In addition, an excess of 3 mM K did not increase pod production.

Increasing external rates of K of young potato plants in solution culture showed significant differences in dry matter accumulation as well as root length (Trehan and Claassen, 1998). Root length and dry matter increased with increasing external K solution concentrations reaching their highest values at 50 μM K. In another potato study, dry matter yields significantly increased more than tenfold with increasing rates of K (Eppendorfer and Eggum, 1994). Tuber dry matter percentage, in contrast, was higher for the 0 K treatment than the highest K treatment with values of 19.4 compared to 16.7%, respectively. In addition, lignin content of the 0 K treatment was more than four times higher than the highest K treatment.

A study investigating K uptake of tomato plants, reports that from anthesis of the first cluster, K content of stems and leaves maintained a 1:1 relationship with values of 47% and 42% of the whole plant K in stems and leaves, respectively, and 11% for the roots (Tapia and Gutierrez, 1997). Plant roots were the least K demanding organ with values from 23% to 2% of whole plant K. Fruit growth and development became the most K demanding organ with the highest values from 42% to 61% of total plant K.

2.2 Phosphorus Nutrition

2.2.1 Uptake and Mineral Interactions

Dry weights of phosphorus and potassium maintained a constant relationship of 1:1 in leaves and stems through ontogenesis of hydroponically grown tomato (Tapia and Gutierrez, 1997). Phosphorus ranged from 43% to 13% in the leaves and 40% to 19% in the stems with respect to the whole plant. The potassium content of stems and leaves had values of 47% and 42%, respectively. The roots appeared to be the least demanding organ for both nutrients with values ranging from 17% to 2% with relation of total plant P and 23% to 2% of total plant K. Results show that the highest uptake was for the element K followed by N and P, which occurred in the last third part of the ontogenic cycle. The uptake in this phase for N, P, and K during this phase was 47%, 65%, and 56% of the total element absorbed, respectively. Unlike K, P can exist in plants as both inorganic phosphate anions and organophosphate compounds.

Antagonistic and synergistic relationships among nutrients were studied on NFT-grown young tomato plants. Increasing concentrations of external P caused a significant increase in plant P, N, K, and Mg, while Fe and Mn decreased as a result of P nutrition (Gunes et al., 1998). Plant P was positively correlated with plant N, K, Ca, and Mg, and negatively correlated with plant Fe and Mn (Gunes et al., 1998). Unlike nitrate and sulphate, phosphate is not reduced in plants during assimilation. Extremely high phosphate levels in the root medium can depress growth; such effects can be dependent on phosphate retarding the uptake and translocation of some of the micronutrients including Zn, Fe and Cu.

Baghour et al. (2001) in their study on metabolism and efficiency of phosphorus during senescence of field grown pepper plants, reported that total P had a quadratic response to N fertilization with maximum concentrations at low N dosages of 6 and 12 g m^{-2} at the onset of flowering. High N concentrations caused a negative effect on P absorption and transport. Total P, inorganic, and organic concentrations responded linearly to K, with the highest values at the lowest K treatment. Potassium fertilization reduced P concentrations while the highest K treatment significantly increased yields.

In a two year study on N and P fertilization of potato, P application rates increased N and P uptake slightly but did not affect plant K uptake (Gupta and Saxena, 1981). Total plant P uptake for maximum yield was 25.3 and 26.1 $kg{\cdot}ha^{-1}$ in the two years of the study. The researchers suggested that P supply from the soil was high, and resulted in yield increases that were less than expected.

Application of 0 P in combination of the highest dose of N resulted in increased pepper plant dry matter content as well as 0 N and highest P rate (Bajaj et al., 1979). The combination of N and P fertilizers applied at any selected rates reduced plant dry matter content when compared to the 0 P high N, and 0 N high P treatments.

2.2.2 Yield

The effect of mineral nutrition on seed yield and seed quality of sweet pepper plants was reported by Osman and George (1984). Combinations of N, P, and K at two different rates resulted in significant differences between the two phosphorus rates on fruit and seed yield of sweet pepper. There were no differences on plant height, foliage dry weight, and number of fruits per plant.

In a study of the effect of nitrogen and phosphorus application rates on seed yield of sweet pepper, phosphorus rates decreased the days to flower (Gill et al., 1974). Phosphorus rates alone increased the number of branches per plant from 4.1 to 5.8. Increased P rates resulted in significant yield increases; higher P rates increased considerably the number of fruits per plant as well as seed yield.

The effect of phosphate and plant densities on growth and yield of field grown chillies were studied (Wanknade and Morey, 1982). Higher P rates increased plant height, dry matter, and yield. Bajaj et al. (1979) reported an increase in capsaicin content of pepper pods with increasing P rates. The combination of the highest N and highest P rate reduced capsaicin content 0.40 g/100 g compared to 0.52 g/100 g obtained with the combination of lower P and highest N rate. This suggests that capsaicin content of chillies is increased by phosphorus application.

The yield response of eggplant to increased nitrogen and phosphorus fertilization has been previously studied (López-Cantarero et al., 1998). The higher P rate significantly increased total and commercial yields compared to low P rate. In addition, the higher P rate sharply decreased noncommercial yield regardless of the N level. Similar results on the effect of P in increasing eggplant fruit yield were also reported by Zipelevish et al. (2000). The researchers suggested that P was important to overcome the salinity effect on fruit yield of eggplants in irrigation solution. Increased P concentration from 18 to 54 g/m significantly increased the number of high quality fruits at both salinity levels of the irrigation solutions (2.3 and 3.9 dS/m).

Papadopoulos (1992) studied phosphorus fertigation of trickle irrigated potato at four different P concentrations (0, 20, 40 and 60 $mg \cdot l^{-1}$) in irrigation water; 40 $mg \cdot l^{-1}$ resulted in the highest yields. There were also significant differences in P uptake as well as specific gravity of the tubers due to P fertility. Tuber dry weight was significantly affected by P fertility, reaching a maximum at 40 $mg \cdot l^{-1}$. There were no differences between 40 and 60 $mg \cdot l^{-1}$.

There is enough evidence to support the effect of P on fruit yield of plants, but no significant response from increasing soil P fertilization has been found. Peterson et al. (1971) in a study of potato response to varying levels of soil P, reported that yield did not increase with increasing soil P. In addition, no P deficiency symptoms were observed in either of the years of the experiments.

2.2.3 Vegetative Growth

Low P in solution culture has sometimes been found to reduce plant growth without any characteristic symptoms (Blamey et al., 1987). Senescence of older leaves is triggered by a deficiency in a mobile element such as P; young leaves remain healthy, presumably because of nutrient remobilization from the older leaves to reproductive structures and younger leaves needed for photosynthesis (Smart, 1994).

Lignin content of potatoes was also reported to increase in the low P treatment in a study of the effect of several nutrients on potato tuber quality (Eppendorf and Eggum, 1994). Plants suffering from P deficiency are thus retarded in growth and the shoot/root dry matter ratio is usually low.

Color changes due to low phosphorus and potassium fertility in pepper were not significantly different from the control treatment in a study of the influence of substrates and low levels of P and K fertilization (Boronat et al., 2002). Three different fertilization treatments were used, a control (C), low P (1/4 C), and low K (1/2 C). The low fertility treatment resulted in lower pod color values although the differences from the control values were not significant. Zipelevish et al., (2000) also reported that there was no effect of EC or P on eggplant skin color but, a more uniform color was found at concentrations above 18 $g \cdot m^{-1}$.

In field-grown crops and in plants grown in solution culture, a P deficiency is first evident as reduced growth compared with plants adequately supplied with P (Blamey et al., 1987). Indeed this reduction in growth may persist through the growth of the crop without any other symptoms of P deficiency. This lack of characteristic symptoms renders diagnosis of P deficiency difficult.

P deficient plants have evolved strategies for obtaining P from the soil. An example of an alteration in root architecture was found by Biddinger et al. 1998, in aeroponically grown tomato plants under P deficiency, a progressive reduction in plant growth and biomass production by shoots and roots was observed. The root:shoot ratio doubled in P starved (0 µm) plants relative to that of P sufficient (250 µm) plants. Therefore, plants can modify their root system to low P availability; modify their structure and function at the cellular and organ system levels.

Weston and Zandstra (1989) in evaluations of the effect of transplant age and N and P nutrition on growth and yield of tomatoes, found that P levels had no effect on root:shoot ratio. No differences in total yield between seedlings fertilized with various N and P treatments were observed and no interaction between transplant age and nutrient level was reported.

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CHAPTER 3

EFFECT OF PHOSPHORUS AND POTASSIUM FERTILITY ON FRUIT QUALITY AND GROWTH OF TABASCO PEPPER (*CAPSICUM FRUTESCENS*) IN HYDROPONIC CULTURE

3.1. Materials and Methods

Greenhouse experiments were conducted to evaluate the effect of phosphorus and potassium fertility on hydroponic tabasco pepper growth and fruit quality. Experiments were conducted during fall 2002, and spring/summer 2003 growing seasons, at the Hill Farm Teaching Facility, LSU campus, Baton Rouge, Louisiana.

3.1.1 Preliminary Experiment

A preliminary experiment was conducted during fall 2002 to evaluate the rates to use in hydroponic culture. The preliminary experiment consisted of a factorial combination of 4 levels of P (0.25, 1.0, 1.75, and 2.5 mM) and 4 levels of K (0.75, 1.75, 2.75, and 3.75 mM) for a total of 16 treatments in a completely randomized design.

3.1.2 Plant Growth Experiment

A second experiment studying plant growth was conducted during the Spring/Summer growing season of 2003. Treatments were modified slightly based on the results of the preliminary experiment. This experiment was conducted with 8 treatments in a completely randomized design. The treatments were 4 levels of P (P1 0.25, P2 1.25, P3 2.5, and P4 3.75 mM) and 4 levels of K (K1 0.25, K2 1.25, K3 2.5, and K4 3.75 mM).

3.1.3 Fruit Quality Experiment

During the same Spring/Summer growing season of 2003, an experiment evaluating fruit quality characteristics was conducted. For this experiment, all plants were grown until the flowering stage with the same nutrient solution (2 mM P; and 3.75 mM K). At the beginning of flowering, different nutrient treatments were applied. The treatments used were the same 4 levels of P and K mentioned previously in the plant growth experiment.

3.1.4 Plant Material

Tabasco pepper "McIlhenny Select" (Motsenbocker, 1996) seed were sown on August 31, 2002 in 98 cell black polyethylene trays filled with commercial soiless mix (Metromix 350; W.R. Grace & Co., Cambridge, Mass.) and placed in a greenhouse for the preliminary experiment. At the fourth true leaf stage, individual plants were transplanted into 3-gallon round plastic blow molded pots (24.13 cm x 27.94 cm) filled with agricultural grade perlite. Seeds for the plant growth experiment and fruit quality experiments were sown on March 12, and transplanted April 14 into similar 3-gallon round plastic pots filled with perlite media.

3.1.5 Nutrient Solutions

The basic formula for the preliminary growth study was composed of the following nutrients in ppm: 225 N, 7.74 P, 29.32 K, 175 Ca, 40 Mg, 56 S, 2.8 Fe, 0.7 B, 0.2 Cu, 0.8 Mn, 0.2 Zn, and 0.05 Mo. The formula supplied 0.25 mM P and 0.75 mM K. For the nutrient treatment solutions, P and K was increased by adding phosphoric acid and potassium hydroxide. The fertilizer sources used for the preliminary growth experiment were calcium nitrate ($Ca(NO_3)_2$, ammonium nitrate (NH_4NO_3), potassium hydroxide (KOH), magnesium sulphate (Epsom salts) ($MgSO_4$), phosphoric acid (H_3PO_4), iron chelate (FeEDTA), Boric Acid (H_3BO_3), copper sulphate ($CuSO_4$), manganese sulphate ($MnSO_4$), zinc sulphate ($ZnSO_4$), and ammonium molibdate ($(NH_4)Mo_7O_{24}$).

For the plant growth and fruit quality experiments, the basic formula was composed of the following nutrients in ppm: 225 N, 7.74 P, 9.77 K, 175 Ca, 40 Mg, 56 S, 2.8 Fe, 0.7 B, 0.2 Cu, 0.8 Mn, 0.2 Zn, and 0.05 Mo. The fertilizer sources used were the same as the preliminary experiment except for potassium chloride (KCl) which was used instead of potassium hydroxide (KOH).

Stock solutions of 100x concentration mentioned above were prepared for all the experiments. To avoid precipitation, two separate stock solutions were prepared. Stock A was composed of potassium nitrate (KNO_3), ammonium nitrate (NH_4NO_3), and calcium nitrate ($Ca(NO_3)_2$). Stock B was composed of all the rest of the fertilizers above. A separate stock solution at 100x concentration was also prepared for iron chelate (FeEDTA) and was kept in a dark glass container to avoid photodegradation.

For plant growth and fruit quality experiments, monopotassium phosphate was added. Separate stock A solution was prepared (1 mM P) using monopotassium phosphate to reduce the incidence of low pH of the nutrient solutions by the addition of phosphoric acid to P4 treatment. Different stock A solutions were also prepared for treatments K2, K3, and K4; KCl, KNO_3; and NH_4NO_3 concentrations were adjusted to maintain pH and N concentration.

Nutrient solution pH was monitored with a manual pH tester (Oakton, Vernon Hills, IL) and adjusted on a daily basis with citric acid. Solution pH was kept between 5.8 and 6.2.

3.1.6 Irrigation

Plastic containers (121 L.) were filled with the nutrient treatment solutions for the experiment. A small submersible pump (1/6 HP, Little Giant Pump Co., Oklahoma city, OK) was placed inside each individual container to distribute the nutrient solutions to the plants through individual drippers located in the pots.

For the preliminary growth experiment, the irrigation scheduling requirement was determined by pan evaporation. Evapotranspiration estimates were calculated using average monthly evaporation records from historical data obtained from the Ben Hur experimental station, Baton Rouge, LA. Monthly evaporation data was multiplied by evapotranspiration coefficients from greenhouse bell pepper data and adjusted to the crop stage of growth. An extra 25% of solution was added to the calculated irrigation amounts by the pan evaporation system to prevent salt accumulation in pots.

Irrigation was scheduled in 12 hour cycles with clock timers which automatically activated the pumps for 2, 3 and 4.5 minutes every half hour for growing periods of 0-15, 15-45, and 45-90 days after transplanting (DAT) respectively. The irrigation system delivered 20 ml of nutrient solution per minute for a total of 960 ml, 1440 ml, and 2160 ml for the 3 irrigation periods, respectively.

Prior to transplanting, pots were filled with perlite and preconditioned by saturating the media with water. A 10% hypochlorite solution was then passed through the media, and the media washed with tap water. After conditioning the media, nutrient solution was applied until saturation of the pots. Plants were then transplanted into moistened media to prevent dehydration.

3.1.7 Harvest

For the fruit quality experiment, red fruit were harvested every 10 days for a total of 3 harvests. Yield was calculated for the harvested period. At the last harvest period, unripened green and red ripened fruit were harvested to estimate plant yield. Fruits were harvested based on commercial red fruit color standards for processing. Fruits from each sample were counted and weighed immediately after harvest. Fruits were then stored and frozen at -20 ºC prior to lab analysis.

3.1.8 Variables Measured

For the preliminary growth experiment, plant height was measured every two weeks. Plants were harvested and separated into roots, stems, and leaves 30 and 60 DAT. Leaf area was measured at each plant harvest. Plant fraction samples were oven dried for 5 days at 70°C, and weights of roots, stems, and leaves were measured for each plant harvest.

Plant height (measured from the soil to the top of the canopy) and stem diameter (measured with a caliper at 1” above the soil surface) were measured every 15 days. In the second growth experiment, plants were harvested at 30, 60, and 90 DAT and leaf area (LA) was determined by a leaf area meter (Delta-T devices, Cambridge, England), dry weights (dried at 70°C for 5 days) of root, stem and leaf fractions were measured. Specific LA (SLA) (LA/leaf dry weight), and LA ratio (LAR) (LA/total plant dry weight) were also calculated.

Yield, alcohol insoluble solids (AIS), titratable acidity, fruit total dry matter, color, brix, capsaicin content, and pH were measured for the fruit quality experiment.

3.2 Laboratory Analysis

To determine fruit total dry matter content, a sample of 5-10 fruits from each treatment was taken and fruits were weighed before and after lyofilization (The Virtis Co., Gardiner, N.Y.).

Fruit titratable acidity and pH was measured by taking a sample of 10 g of defrosted pepper fruits. Fruits were ground with 10 g of distilled water and initial pH of the mash was taken prior titration with a 0.1 N sodium hydroxide (NaOH) concentration until pH reached 8.1. Mash color was measured using a spectrophotometer (CM-3500d Minolta, Konica Minolta Co., Ramsey, N. J.).

Dry leaf samples were ground and prepared for mineral analysis. Tissue samples were prepared for elemental analysis by ICP (Inductively Coupled Plasma). To prepare the samples, 0.5 g of plant material were placed into a digestion tube with 5 ml of concentrated nitric acid (70%) and heated slowly using a block heater. Before the sample reached 90 degrees Centigrade, 3 ml of hydrogen peroxide (30%) was added. Heating continued for about 2-3 hours until sample became clear and volume had been reduced to 0.5 ml. Sample was then cooled and brought to

12.5 ml volume, mixed, and filtered. Filtrate was analyzed in ICP, with the torch in the axial position (CIROS, Spectro Co., Germany).

3.3 Statistical Analysis

Statistical analysis of all the results were conducted using Statistical Analysis System (SAS®) program. Multivariate analysis of variance (MANOVA) in the general linear model was done for preliminary statistical analysis as well as for the growth experiment and the fruit quality experiment. After MANOVA analysis, when no significant results were found, individual analysis of variance (ANOVA) using the mixed procedure were applied to evaluate the significance of the individual variables that were studied. Means were separated by Tukey-Kramer test (P= 0.05). Polynomial orthogonal contrasts were constructed to describe and analyze behavioral trends of the quantitative factors and their effects on the significant variables. Correlations between P and K nutrient solution rates and selected significant variables were also performed.

3.4. Results and Discussion

3.4.1 Phosphorus Results

3.4.1.1 Phosphorus on Preliminary Study Results

Phosphorus significantly influenced all the variables measured: plant height, leaf area, and plant fraction dry weights. The lowest phosphorus rate (P1) had lower plant height than the other P rates at 30 DAT. There were no differences, however, between the rest of the P treatments on plant height at 30 and 60 DAT. Preliminary study analysis is presented in appendix Table A.

Leaf area resulting from P1 at 30 and 60 DAT was significantly different from the other P treatments. There were no differences among the other P treatments for leaf area at 30 DAT. However, plants with P4 had a higher leaf area when compared with P2 at 60 DAT.

There were no significant differences in dry root weight among P treatments at 30 DAT. At 60 DAT, however, the dry root weight of plants grown in P3 and P4 solutions had a higher root weight than P1 and P2. P1 had the lowest dry root weight of the P treatments. The results for plant leaf dry weight were similar to root weight. Plant stem dry weights, however, were not affected by treatment at 30 DAT period. In contrast, at 60 DAT, P1 had the lowest dry stem weight and was significantly different than the other P treatments while plants in the P2 solution had a significantly lower dry stem weight than the P4 treated plants. The results for total plant dry weight were similar to the results of dry stem weights.

3.4.1.2 Plant Growth Experiment

3.4.1.2.1 Phosphorus Effect on Plant Growth Variables

Phosphorus nutrition had a highly significant effect on most of the measured variables. Multivariate analysis of variance, MANOVA, showed that treatment, time, and the interaction between both effects as highly significant on plant growth variables. Increasing P rates in the nutrient solution had a significant effect on the plants dry matter accumulation and its root: shoot ratio.

The root to shoot ratio shows that plants with the lowest P treatment had a significantly higher ratio when compared to the rest of the treatments at all time periods (Table 3.1). In addition, P1 had a significantly higher root: shoot ratio than P3 and P4 at all harvests. Treatment P1 also had a significantly higher root: shoot ratio than P2 at 30 and 90 DAT. Treatment P2, however, was not significantly different than P3 and P4. An increase in root compared to shoot was also reported by Biddinger et al. (1998), aeroponically grown tomato plants doubled their root: shoot ratio when compared to P sufficient (250 µM) plants. These results are also supported by research conducted with corn, reporting that P deficiency resulted in reduced shoot growth and increased root proliferation (Anghioni and Barber, 1980).

Table 3.1 ANOVA of phosphorus effect on root to shoot ratios of tabasco pepper plants grown in hydroponic culture at 30, 60 and 90 days after transplant (DAT).

	DAT		
P concentration	30	60	90
Treatment- mM P		Root:Shoot ratio	
P1 0.25	0.49 a[x]	0.24 bcd	0.19 cde
P2 1.25	0.27 b	0.17 def	0.11 f
P3 2.5	0.25 bc	0.12 ef	0.10 f
P4 3.75	0.24 bcd	0.13 ef	0.12 ef
Trend		**L[y], **Q	
Statistical Analysis			
P treatment		**[z]	
Time		**	
P Treatment x Time		**	

[x] Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method ($P<0.05$).
[y] Trends are described by L linear, Q cuadratic, C cubic, with respective level of significance.
[z] SAS mixed procedure, ** highly significant at $P<0.01$.

Plant dry matter showed differences within treatments and time (Table 3.2). Higher P rates resulted in higher dry matter content in roots, stems, and leaves. Treatment P1 produced the lowest dry matter and its value was significantly different from all the other P treatments, indicating reduced plant growth. The results of aeroponically grown tomato plants with varying P levels by Biddinger et al. (1998) are similar to our findings. The researchers reported that P deficiency in tomato resulted in a progressive reduction in plant growth and shoot biomass production. Low P leaf concentration was reported for hydroponically grown tomato plants with high Zn levels in the nutrient solution, and resulted in a marked depression in dry matter production (Kaya et al., 2000). In addition, a significant reduction in vegetative plant fresh weight resulted from hydroponically grown tomato plants with 0.2 mM P in nutrient solution (Peñalosa et al., 1989).

The highest P rate (P4) produced the highest dry matter for all plant fractions; this treatment was significantly different from the rest of the P treatments suggesting that higher P rates could produce a higher dry matter content. No significant differences were found between

Table 3.2 Phosphorus effect on root, stem, leaf, and total plant dry weight of tabasco plants grown in hydroponic greenhouse culture at 30, 60, 90 days after transplant (DAT).

	RDW[v]			SDW			LDW			TDW		
DAT	30	60	90	30	60	90	30	60	90	30	60	90
Treatment-Rate (mM P)												
P1 0.25	3.30 e[w]	12.71 de	24.40 cd	3.30 e	31.55 e	86.74 d	3.36 f	21.05 e	42.94 d	9.95 f	65.31 e	154.06 d
P2 1.25	4.77 e	28.00 bcd	41.72 b	8.26 e	106.28 cd	292.67 b	9.80 ef	60.49 c	82.87 b	22.83 f	194.78 cd	417.25 b
P3 2.5	6.37 e	18.01 de	40.17 bc	11.80 e	101.54 cd	308.13 b	13.60 e f	55.03 cd	82.91 b	31.76 e f	174.58 cd	429.24 b
P4 3.75	6.05 e	23.88 d	58.09 a	11.23 e	119.36 c	357.59 a	13.82 e f	65.27 c	107.09 a	31.10 e f	208.51 c	522.77 a
Trend[x]		**Q, **C			**L, **Q, **C			**L, **Q, **C			**L, **Q, **C	
Statistical Analysis												
P treatment		**[y]			**			**			**	
Time		**			**			**			**	
P Treatment x Time		**			**			**			**	

[v] RDW root dry weight, SDW stem dry weight, LDW leaf dry weight, and TDW total dry weight

[w]. Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method (P=0.05).

[x] Trends are described by L linear, Q cuadratic, C cubic, with respective level of significance.

[y] SAS mixed procedure, ** highly significant at P>0.01.

P2 and P3 for the 3 plant fractions at 30, 60 and 90 DAP, nor for total plant dry matter. This explains the cubic trend that is significant to all growing patterns for all dry weight variables. The non significant differences between treatments P2 and P3 at all time periods allows for the growing curve to produce 2 different inflexion points where growth is reduced from P2 to P3 and dramatically increased from P3 to P4, making P4 the treatment with the most dry matter accumulation.

Plant leaf area (LA) was significantly higher with higher P rates (Figure 3.1). Treatment P1 had the lowest LA at all time periods. It was observed that lower leaf number resulted in reduced plant growth and reduced branching in plants treated with low P. The highest phosphorus rate (P4) had the highest LA of all the P treatments, especially at 90 DAT. The P2 and P3 treatments, at all growing periods, as well as P3 and P4 at 30 and 60 DAT resulted in no significant differences in leaf area.

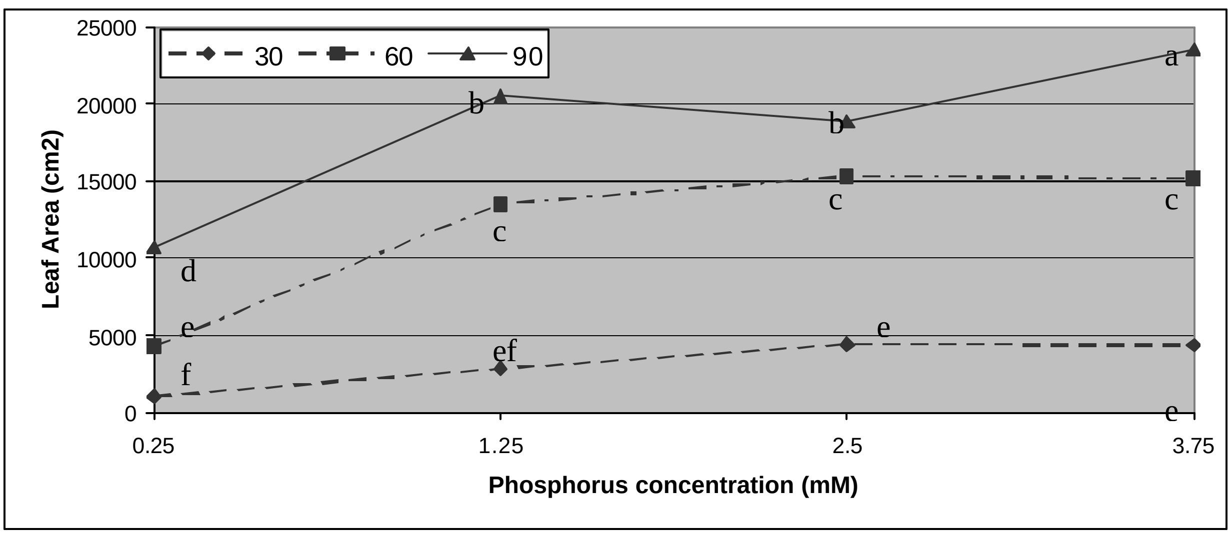

Figure 3.1 Effect of phosphorus concentration on leaf area of tabasco pepper plants grown in hydroponic greenhouse culture at 30, 60, and 90 DAT. Observations with the same letter are not significantly different, means separation by Tukey Kramer method ($P<0.05$).

Specific leaf area (SLA) was not significant between treatments (Data not presented). This finding suggest that leaves were of similar area:weight ratio between treatments and that differences in leaf area were mostly due to plant size and enhanced growth at higher P rates.

Previous research with melon reported that leaf P deficiency leads to sensescence and reduced photosynthetic activity (Ben-Oliel and Kafkafi, 2002). Higher SLA was found for the 30 DAP period than the later harvest times. This is probably due to rapid growth in the early season and higher dry matter production in later stages of growth. No differences in SLA were found between the 60 and 90 DAT periods.

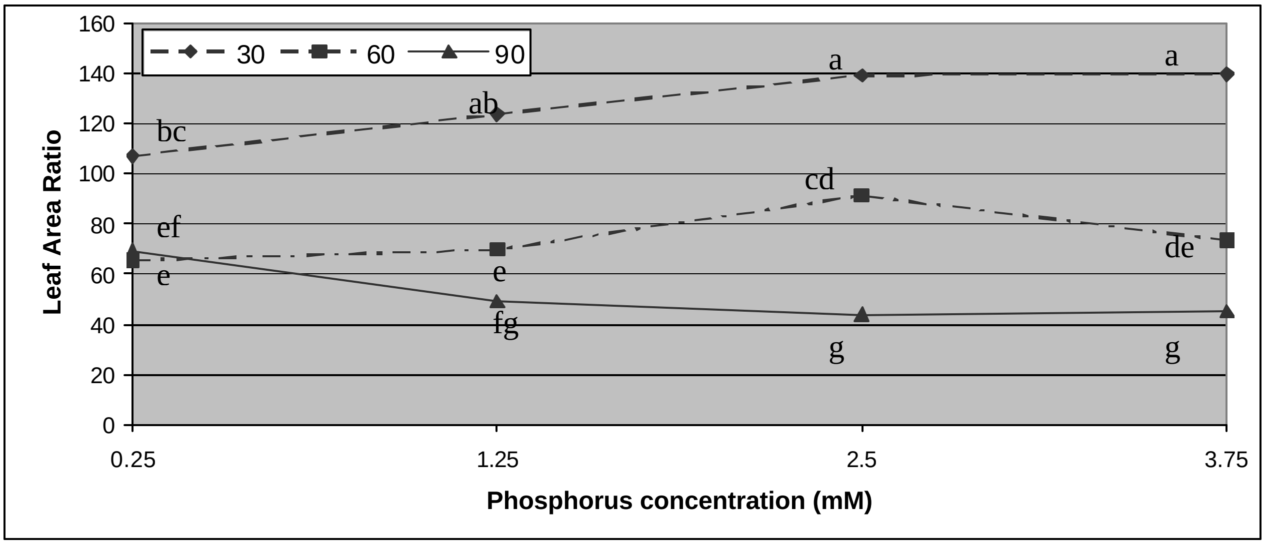

Figure 3.2 Effect of phosphorus concentration on leaf area ratio of tabasco pepper plants grown in hydroponic greenhouse culture at 30, 60, and 90 DAT. Observations with the letter are not significantly different, means separation by Tukey Kramer method (P<0.05).

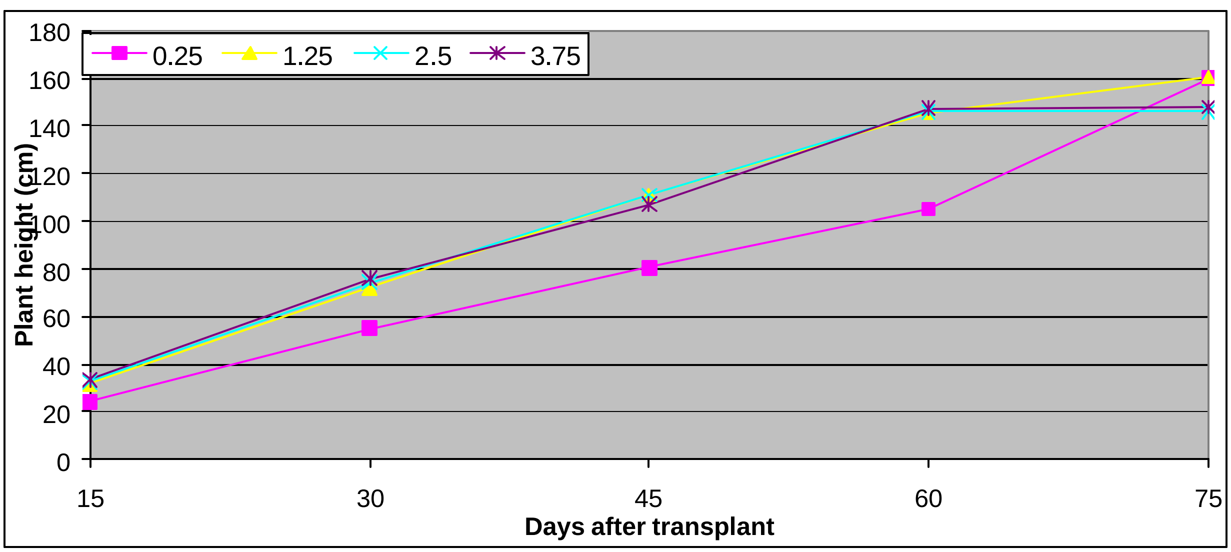

Figure 3.3 Phosphorus rates (mM) on plant height of tabasco pepper plants grown in hydroponic greenhouse culture at 15 DAT intervals.

Plant leaf area ratio (LAR) decreased over time with significant differences between the three time periods (Figure 3.2). Higher LAR at 30 days was due to low total plant dry matter at that growing period compared to higher dry matter accumulation and lower growth rate later in the season.

Sundstom et al. (1984) found that increasing N rates also increased plant height and stem diameter in their study of N and plant spacing on mechanically harvested tabasco pepper. Phosphorus rates significantly affected plant height (Figure 3.3), and stem diameter (Figure 3.4). Higher P rates resulted in greater plant height and stem diameter. There were no differences between P2, P3, and P4 treatments. Differences in stem diameter and plant height over time were mainly between P1 and the rest of the P treatments. Phosphorus rates influenced plant height cubically and stem diameter quadratically. The difference in plant height and stem diameter is explained by the trends.

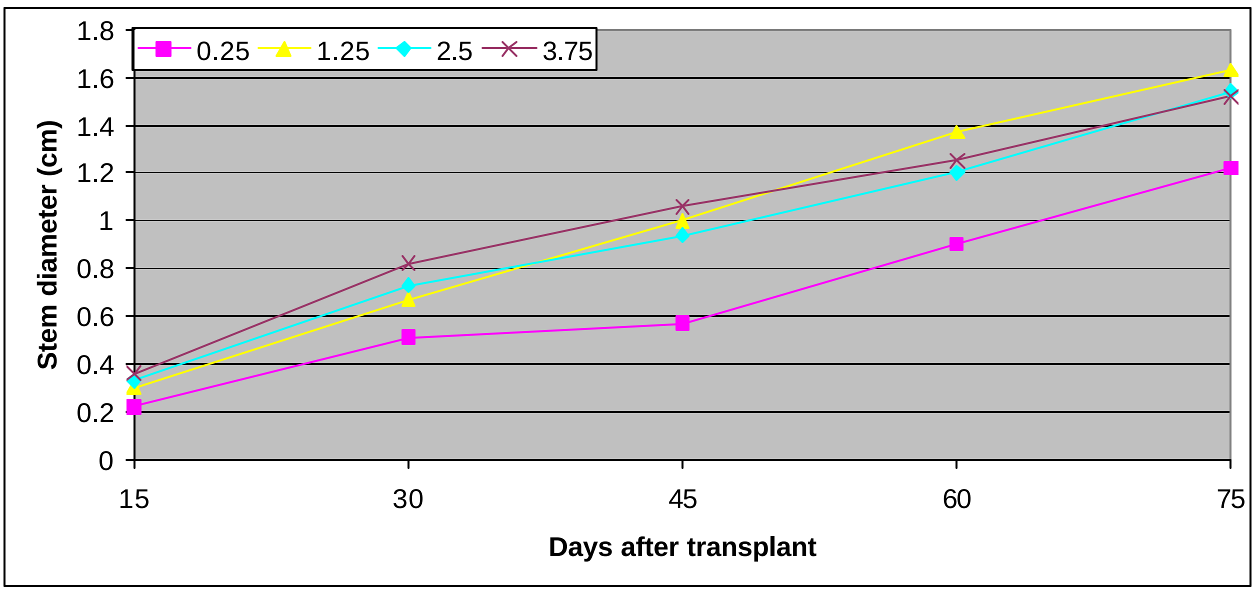

Figure 3.4 Changes in stem diameter due to increasing phosphorus concentrations (mM) of tabasco pepper plants grown in hydroponic greenhouse culture at 15 DAT intervals.

The cubic response of plant height shows a very rapid increase in plant height from 15 to 60 days where the first inflexion point is noted and after that period of time the curves leveled off increasing at a decreasing rate. The quadratic trend line that represents stem diameter has only one inflexion point where stem diameter increased rapidly in the early vegetative stage and then reached a point of where it increased at a decreasing rate of growth. The increase of the trend lines at a decreasing rate reflects the fruiting stage of the plant, where nutrients and photosynthates are translocated to the most demanding organs at that time.

3.4.1.2.2 Phosphorus Effect on Leaf Mineral Content

Phosphorus rates significantly affected the leaf P, K, Ca, B, Fe, Mg, Mn, Na, and Zn concentrations (Table 3.2). All the elements showed a highly significant quadratic trend with increasing P rates with the exception of Cu, Mo, and S which were not significant. Iron and Mn elements showed a significant cubic behavior with increasing P rates. Zipelevish et al. (2000) reported that in fertigation solutions with the same composition of micronutrients, their concentration in eggplant leaves and roots was influenced by the P concentration in the plant. Similar results were also obtained by Lopez-Cantarero et al. (1992).

Our results indicate that increased P concentrations in nutrient solution positively affected leaf P, B, and Mg resulting in positive correlations of 0.66, 0.38, and 0.29, respectively. Plant P uptake increased with increasing P concentration in the solution. When continuously supplied during the growing period, stem and leaf P concentration increased linearly. Peñalosa et al. (1989) also reported that P concentration in the leaves increased with increasing K rates in the nutrient solution. Phosphorus concentration gradually increased at 30 and 60 DAT reaching its highest levels at P4; but, no significant differences with P3 were found. After comparing our results with established mineral requirements for bell pepper, treatment P1 was found to be under the sufficiency range for the 30 DAT. Treatments P2,P3, and P4 were all between the sufficiency range of 0.25-0.50 percent P (Maynard and Olson, 2001). At 90 DAT, leaf P levels dropped and no significant differences were found between any of the P treatments. The decrease in P concentration in the leaves might be due to plant translocation of P to fruits; the fruits of tomato plants are reported to be the greatest sink organ with values from 46% to 66% of total plant P in the last third of the growing cycle (Tapia and Gutierrez, 1997). In our experiment, total P responded quadratically to increasing P rates. The significant quadratic trend and the lack of significant differences between P3 and P4 suggest that a plateau was reached and that further increases in P concentrations in the nutrient solution wouldn't have resulted in higher leaf concentrations.

Boron leaf concentrations increased due to higher P rates. Differences were not significant at the 30 DAT period, however, P1 treatment had the lowest leaf B concentration compared to the other treatments at 60 and 90 DAT. Magnesium generally increased with increasing P rates in the nutrient solution, especially at 30 and 60 DAT, At 90 DAT, leaf Mg concentrations for treatments P2 and P3 were significantly higher than P1, while treatment P4 had similar concentrations.

Increasing P rates in the nutrient solution negatively impacted K, Ca, Fe, Mn, and Zn tissue concentration with negative correlations of -0.44, -0.31, -0.84, -0.63, and -0.74, respectively. Results for K and Ca were similar with increasing P rates. No significant differences were found for either element at 30 or 60 DAT. Potassium and Ca were between the sufficiency range when compared to bell pepper plant tissue analysis at early bloom between 2.5-5.0, and 0.6-1.5 percent, respectively. There were significant differences, however, between treatments P4 and P1 for K and between P4 and P2 for calcium, in both cases P4 resulted in the lowest K or Ca concentration. Phosphoric acid (H_2PO_4?) is the primary form of P transported into the root cells. A specific high affinity transport mechanism has been identified for P transport by the plants (Buchanan et al. 2000). Our study suggests that increased P concentrations in the nutrient solution increased P content of the leaves, while the reason for the negative impact on K, Ca, and Fe is unclear. Potassium, Ca, and Mg are known to enter the plant as single elements, they are all cations, but the positive relation towards Mg and the negative relation of higher P concentrations in the nutrient solution towards K and Ca is controversial. An imbalance due to high anionic concentrations of H_2PO_4? inside the root cell would suggest the need to keep an electrochemical balance and promote import of cations such as K and Ca inside the cell.

Increasing P rates had a negative impact on leaf Fe content. Reductions in leaf Fe were found at all time periods. Treatment P4 resulted in the lowest Fe concentration with no significant differences with P3. Both P3 and P4, at 60 DAT, were similar to P2, while P1 and P2 showed no statistical differences. When comparing our tissue concentrations to the requirements for bell pepper we noticed that Fe leaf concentrations at the 30 DAT were lower than the recommended sufficiency range of 30-150 ppm for P3 and P4. Without any soil redox potential for Fe^{3+} in hydroponic systems, the availability of Fe to the plant depends on its mineral source and availability to the plant. Chelated micronutrients are known to increase availability of micronutrients due to the cationic exchange of H^+ from the plant that releases Fe^{2+} from the chelator making it ready for plant absorption (Buchanan et al., 2002) Our results showed that an increase in P concentration in the form of phosphoric acid reduced plant Fe concentrations, especially for treatments P3 and P4.

Results for leaf Mn show that P1 had the highest Mn concentrations. No significant differences between the treatments were found at the 60 DAT period, however, P3 and P4 were statistically lower than P1 at 60 and 90 DAT. For Zn at 30 DAT, treatment P1 had the highest Zn concentration and was significantly different from the rest of the treatments. While at 60 and 90 DAT, treatments P3 and P4 had the lowest Zn concentrations with significant statistical differences with P1. The inverse relationship between Zn and P was also reported by Kaya et al. (2000) where the authors found that P concentrations were at almost toxic levels in plants with a low Zn treatment. Plants with high Zn treatment, 5 mg $Zn \cdot L^{-1}$, produced P-deficient plants as evidenced by low P leaf concentrations and a marked depression in dry matter production.

For both Fe and Mn a cubic trend was found, it suggests the restrictive effect of higher P concentrations in the nutrient solutions. This cubic trend was observed at all time periods, especially for Mn at the 30 and 60 DAP. The increase in leaf Fe and Mn concentrations at the 90 DAT for the lower P treatments could be due to an increased mineral demand by the plant to satisfy a heavier fruit production requirement.

3.4.1.3 Fruit Quality Experiment

3.4.1.3.1 Phosphorus Effect on Fruit Quality Variables

Treatment and time effects on fruit quality variables of the experiment were highly significant in the MANOVA analysis (data not presented). The interaction between time and treatment variables was not significant.

Increasing P rates in the nutrient solution resulted in differences in average fruit weight, titratable acidity, and color (Hue); the relationship was quadratic. Individual ANOVA of the variables (Table 3.4) indicate that phosphorus rates did not affect fruit AIS, Brix, pH, and pod dry matter (PDM). No interaction between time and treatment was found by the MANOVA analysis, while time was significant for all the variables with the exception of titratable acidity. Even though there was no significant effect on fruit sugar content in our research, a hydroponic melon experiment conducted by Oliel and Kafkafi (2002) showed that there was a significant effect of P on fruit total soluble solids. Total soluble solids of melons increased with increasing P concentration in the nutrient solution. Concentrations of 0.5-1.0 mM P applied until fruit netting produced the best combination of highest yield and total soluble solids of 10.1-10.7%.

Table 3.3 ANOVA of Phosphorus effect on nutrient element composition of dry leaves of tabasco pepper plants grown in hydroponic culture at 30, 60, and 90 days after transplant (DAT)

DAT	Nutrient Concentration Trt. (mM P)	P	K	Ca	B	Cu	Fe	Mg	Mn	Mo	Na	Zn
		----------------Percent (%)--------------			---ppm---							
30	P1 0.25	0.22 cd[w]	4.73 a	1.41 ab	102.39 abc	10.03 a	83.89 a	0.7 bcd	157 a	5.74 a	233.53 d	47.04 a
	P2 1.25	0.31 bc	4.57 a	1.52 ab	124.4 abc	9.09 ab	62.61 abc	0.92 abc	72.33 cde	5.72 a	620.71 ab	31.91 bc
	P3 2.50	0.46 ab	4.37 a	1.5 ab	110.42 abc	9.04 ab	24.54 d	0.9 abcd	110.47 bc	4.90 abc	603.89 abc	28.13 c
	P4 3.75	0.51 a	4.64 a	1.32 ab	123.16 abc	7.28 bc	23.19 d	0.9 abcd	88.11 cd	4.31 abc	895.42 a	25.41 c
60	P1 0.25	0.19 cd	4.46 a	1.56 ab	79.11 bc	7.95 ab	61.5 abc	0.72 bcd	93.79 cd	3.89 abc	154.66 d	48.27 a
	P2 1.25	0.25 cd	4.56 a	1.87 a	158.94 a	8.7 ab	40.41 bcd	1.13 a	81.76 cde	4.19 abc	230.91 d	45.05 ab
	P3 2.50	0.35 abc	4 ab	1.78 a	146.61 abc	9.54 ab	18.94 d	1.12 ab	55.83 de	5.41 abc	408.91 abcd	19.18 cd
	P4 3.75	0.45 ab	4 ab	1.41 ab	146.88 ab	8.39 ab	16.27 d	1.03 ab	72.88 cde	5.50 ab	340.67 bcd	23.62 cd
90	P1 0.25	0.14 d	4.82 a	1.38 ab	61.84 c	4.89 cd	64.64 ab	0.56 d	147.09 ab	3.09 c	151.16 d	33.17 bc
	P2 1.25	0.16 cd	4.04 ab	1.71 a	135.91 ab	4.35 d	56.56 bc	0.94 abc	96.4 cd	4.21 bc	177.84 d	26.84 c
	P3 2.50	0.26 cd	3.75 ab	1.49 ab	137.36 abc	4.89 cd	35.05 cd	0.95 abc	67.65 cde	4.22 abc	296.83 bcd	21.13 cd
	P4 3.75	0.23 cd	2.72 b	1.01 b	111.95 abc	4.21d	24.77d	0.63 cd	43.57 e	3.34 c	299.74 cd	10.95 d
Trend[x]		**Q	**Q	**L, *Q	**L, **Q	Ns	**Q, *C	**L, **Q	**L, **Q, *C	ns	**Q	**Q
Statistical analysis[y]												
P treatment		**	**	**	**	NS	**	**	**	NS	**	**
Time		**	**	*	NS	**	**	**	**	**	**	**
Treatment x Time		NS	NS	NS	NS	NS	NS	NS	**	**	*	*

[w]. Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method (P=0.05).

[x] Trends are described by L linear, Q quadratic, C cubic, with respective level of significance.

[y] SAS mixed procedure, * significant at $P<0.05$, ** significant at $P<0.01$, ns= not significant

Table 3.4 ANOVA of phosphorus effect on fruit quality variables of hydroponically grown tabasco pepper fruits.

	Yield	AFW[x]	AIS	BRIX	pH	TA	PDM	Hue
Treatment	**	**	NS	NS	NS	**	NS	**
Time	NS	**	**	**	**	NS	**	**
Treatment x Time	*	NS	NS	NS	NS	NS	NS	NS
Trend[y]	**L[z], **Q	**L, **Q	NS	NS	NS	*L, **Q	NS	**Q

[x] AFW average fruit weight, AIS alcohol insoluble solids, PDM pod dry matter. SAS mixed procedure (P=0.05).
[y] Trends are described by L linear, Q quadratic, with respective level of significance.
[z] SAS mixed procedure, * significant at P<0.05, ** significant at P<0.01, NS= not significant

Yield correlated positively with P rates (0.31) producing a highly significant quadratic response (Table 3.5). Treatment P3 overall had the highest number of fruit and fruit weight (171.56 g), although it was not different from P2 (133.14 g). Ben-Oliel and Kafkafi (2002) found that a concentration of 0.5 mM P in the nutrient solution applied for a period of 10-60 days after germination produced a significantly higher yield of hydroponic melons compared to lower (0.3 mM) and higher (1.0 mM) concentrations applied for the same amount of time. Carrijo and Hochmuth (2000) with increasing P rates on soils testing low in P, suggest that tomato fruit total marketable yield followed a quadratic effect, while, average fruit weight was not influenced by increasing P rates. Tabasco pepper also responded quadratically to increasing P rates producing higher total yield, however, average fruit weight was also affected. Zipelevish et al. (2000) also found that increasing P solution concentration from 18 to 54 g m^{-3} significantly increased eggplant number and total fruit yield.

Average fruit weight and color (Hue) were negatively affected by increased P rates in the nutrient solution, with negative correlations of 0.33 and 0.31 for average fruit weight and color, respectively (Table 3.5). Analysis of variance showed that there were only significant differences in fruit weight between P4 and the rest of the treatments, with the P4 treatment having the lowest value. There was also a reduction in fruit weight with every harvest over time; the third harvest, had the lowest fruit average of 0.59 grams compared to 0.72, and 0.76 grams for the second and first harvests, respectively. Color values were also affected by P rates; treatment P4 had a lower hue value than P1. Differences between harvest periods were also found for color variable; lower overall color values were found in the first harvest compared with second and third harvest periods.

Titratable acidity increased with increasing P rates. Increasing P rates in the nutrient solution correlated (0.42) to titratable acidity, however, only the TA of P4 was significantly higher than the rest of the P treatments (Table 3.5). There was no significant difference in titratable acidity between P1, P2, and P3 treatments. Carrijo and Hochmuth (2000) also reported that increasing P rates on soils varying in Mehlich-1 extractable P, did not affect pH or soluble solids of tomato fruits. In contrast to our results, however, titratable acidity was not affected by P rates in their study.

Table 3.5 Phosphorus effect on fruit quality variables of tabasco pepper fruit at first, second, and third harvests.

Harvest	Nutrient Concentration Trt. (mM P)	Yield	AFW[x]	AIS	BRIX	pH	TA	PDM	Hue
1	P1 0.25	97.44 bc	0.78 a	2.08 c	16.95 ab	5.31 ab	4.52 b	28.52 e	51.12 bc
	P2 1.25	141.41abc	0.79 a	2.07 bc	15.13 ab	5.15 abc	4.83 b	29.82 cde	50.90 bc
	P3 2.50	115.67 abc	0.80 a	2.27 bc	18.55 a	5.36 ab	4.52 b	30.94 bcde	49.65 c
	P4 3.75	153.86 abc	0.66 a	2.11 bc	16.93 ab	5.29 abc	5.03 a	30.12 bcde	49.00 c
2	P1 0.25	78.25 bc	0.70 a	2.32 bc	13.60 b	5.11 abc	4.72 b	30.99 bcde	54.49 a
	P2 1.25	135.74 abc	0.76 a	2.16 bc	12.87 b	5.05 abc	4.30 b	30.11 bcde	54.21 ab
	P3 2.50	187.31 ab	0.75 a	2.17 bc	13.60 b	4.95 c	4.43 b	28.93 de	53.88 ab
	P4 3.75	139..38 abc	0.67 a	2.21 bc	13.40 b	5.09 abc	5.32 a	30.34 bcde	53.54 ab
3	P1 0.25	55.03 c	0.64 ab	2.55 ab	14.20 ab	5.31 ab	4.25 b	33.48 abc	54.55 a
	P2 1.25	122.27 abc	0.62 ab	2.50 abc	13.20 b	5.22 abc	4.32 b	34.09 ab	53.71 ab
	P3 2.50	211.70 a	0.65 ab	2.40 bc	13.80 b	5.31 ab	4.56 b	32.28 abcd	53.12 ab
	P4 3.75	62.43 c	0.47 b	2.85 a	16.50 ab	5.38 a	5.46 a	35.15 a	51.83 abc

[x] AFW average fruit weight, AIS alcohol insoluble solids, PDM pod dry matter. SAS mixed procedure (P=0.05).
[w] Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method (P=0.05).

3.4.1.3.2 Phosphorus Effect on Fruit Mineral Composition

Increasing P rates in the nutrient solution had a significant effect on fruit Ca, Cu, P, Mg, and Zn fruit concentrations (Table 3.6). Increasing P rates in the nutrient solution resulted in positive correlations for fruit P, Ca, and Mg concentrations 0.93, 0.27 and 0.66, respectively, while negatively impacting fruit Cu and Zn, -0.37, and -0.22, respectively. Fruit K and S were not affected by P rates, although, these elements decreased over time.

Phosphorus and Mg concentration in the fruits was increased by increasing P rates (Table 3.6). Phosphorus treatments increased P fruit content; P4 had the highest fruit P while treatment P1 had the lowest concentration within each harvest. Fruit P was a quadratic response to increasing P rates in the nutrient solution. Calcium content increased primarily for P3 and P4 at the third harvest period, however no statistical significance was found. Fruit Mg differences at all individual time periods were found between P1 and the rest of the treatments. No significant differences were found between the different P treatments for fruit Cu and Zn, however, Cu and Zn fruit concentrations resulted in gradually decreased in fruit.

Table 3.6 Phosphorus effect on fruit quality variables of tabasco pepper fruit at first, second, and third harvest.

Harvest	mM P	P	K	Ca	Mg	Cu	S	Zn
		--------------Percent (%)--------------			------------------------Ppm------------------------			
1	P1 0.25	0.18 ef	2.36 a	0.09 cd	0.15 cde	11.4 a	0.26 a	15.64 ab
	P2 1.25	0.31 cd	2.32 a	0.09 cd	0.19 a	10.09 a	0.27 a	18.98 a
	P3 2.50	0.36 abc	2.15 a	0.09 cd	0.19 a	7.75 a	0.26 a	14.7 ab
	P4 3.75	0.41 a	2.21 a	0.09 cd	0.18 ab	7.71 a	0.25 a	13.81 ab
2	P1 0.25	0.16 f	2.22 a	0.09 cd	0.13 e	8.28 a	0.24 a	13.01 b
	P2 1.25	0.24 de	2.09 a	0.09 cd	0.15 bcde	7.8 a	0.24 a	14.34 ab
	P3 2.50	0.29 cd	2.01 a	0.09 cd	0.16 abcd	5.85 a	0.23 a	11.39 b
	P4 3.75	0.39 ab	2.11 a	0.11 bcd	0.17 abc	7.07 a	0.23 a	13.15 b
3	P1 0.25	0.19 ef	2.11 a	0.11 bc	0.14 de	8.11 a	0.24 a	13.38 ab
	P2 1.25	0.23 def	2.01 a	0.11 bcd	0.16 bcde	11.47 a	0.24 a	16.17 ab
	P3 2.50	0.32 bc	2.01 a	0.12 ab	0.18 ab	8.26 a	0.25 a	13.28 ab
	P4 3.75	0.39 ab	2.09 a	0.14 a	0.17 abc	7.29 a	0.25 a	12.81 b
Trend[x]		**Q	NS	**Q	**L, **Q	**Q	**Q	**C
Statistical Analysis[y]								
Treatment		**	NS	*	**	**	NS	**
Time		**	**	**	**	NS	*	**
Treatment x Time		NS	NS	NS	NS	NS	NS	NS

[x] Trends are described by L linear, Q quadratic, C cubic, with respective level of significance.
[y] SAS mixed procedure, * significant at $P<0.05$, ** significant at $P<0.01$, NS= not significant. Observations with at least one same letter within column are not significantly different ($P=0.05$).

3.4.2 Potassium Results

3.4.2.1 Potassium on Preliminary Study Results

Potassium did not influence tabasco plant height, leaf area or dry leaf, stem, and total dry weight at 30 or 60 DAT. Dry root weight was not influenced by K nutrition at 30 DAT. Dry root weight at 60 DAT, however, was significantly affected by potassium and the K1 rate had a lower dry root weight than the K4 treatment. There was a significant interaction between P and K for dry root weight. Collected data for Preliminary study is presented on appendix Table A.

3.4.2.2. Plant Growth Experiment

3.4.2.2.1 Potassium on Plant Growth Variables

Potassium (K) rates had a significant effect on plant growth variables; differences in dry weights of plant fractions were found (Table 3.7). Increasing K rates increased the dry weights of roots, stems, and leaves at the three time periods. The K1 treatment had no significant differences compared with any other harvest period. This suggests that the K1 rate was too low and significantly reduced pepper plant growth.

Root dry matter at 60 DAT (Table 3.7) increased with increasing K rates. Trehan and Claassen (1998) reported that potato plants at a deficiency level of K showed a reduced K influx. Root growth also depended on K solution content; K deficiency reduced root growth in potato. The authors also concluded that increasing K levels in the solution; increased root growth rate of potato which concurs with our results, especially at late growth periods. Higher dry weight values were obtained with the highest K rate for all plant fractions with the exception of dry leaf weight at 30 DAT.

At 30 DAT there were no differences in root, stem, leaf or total dry weight. At 60 DAT, differences were mainly between K4 and the lower concentrations (K2 and K1); no significant differences were found between K4 and K3 for any of the dry weight variables. Treatments K3

Table 3.7 Effect of potassium concentration on root, stem, leaf, and total dry weight at 30, 60, 90 days after transplant (DAT).

	RDW[v]			SDW			LDW			TDW		
DAT	30	60	90	30	60	90	30	60	90	30	60	90
Treatment/ (mM K)												
K1 0.25	0.90 d[w]	2.83 d	5.32 cd	1.20 d	6.79 d	16.38 d	1.67 e	6.66 e	8.93 e	3.76 e	16.27 e	30.62 e
K2 1.25	3.73 d	13.40 c	21.82 b	6.86 d	52.66 cd	175.38 b	9.48 e	36.78 d	45.14 cd	20.06 e	102.83 d	242.33 b
K3 2.50	4.54 d	22.59 b	34.41 a	7.96 d	90.85 c	262.57 a	10.75 e	48.58 bcd	62.04 b	23.26 e	162.02 cd	359.01 a
K4 3.75	4.72 cd	24.43 b	38.95 a	7.93 d	96.72 c	300.58 a	9.02 e	55.00 bc	81.59 a	21.67 e	176.15 bc	421.12 a
Trend[x]		**L, **Q			**L, **Q			**L, **Q			**L, **Q	
Statistical Analysis [y]												
K treatment		**			**			**			**	
Time		**			**			**			**	
K treatment x Time		**			**			**			**	

[v] RDW root dry weight, SDW stem dry weight, LDW leaf dry weight, and TDW total dry weight

[w] Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method (P=0.05).

[x] Trends are described by L linear, Q quadratic, C cubic, with respective level of significance.

[y] SAS mixed procedure, ** significant at P>0.01.

and K4 at 90 DAT were statistically similar and different from both lower concentrations for all the dry weights. An increasing trend in shoot dry matter accumulation with increasing K rates was also reported by Trehan and Claassen (1998); potato plants increased shoot dry matter with 1.5 μM K up to 50 μM K with no significant differences with the 200 μM K treatment.

Root to shoot ratio exhibits significant differences between treatments to increasing K rates (Table 3.8). This is particularly true at 90 DAT, where differences between K1 and the rest of the treatments are the most apparent; a decrease in the ratio suggests enhanced shoot growth of the plants. Al-Karaki (2000) reported that tomato shoot growth was enhanced by increasing K concentration in the growth medium under saline conditions. Increasing K rates resulted in a higher root:shoot ratio for the low K treatments, especially for K1 at 30 and 90 DAT. There were no significant differences due to treatment, and no significant differences were found between K2, K3, and K4 treatments at all time periods.

Table 3.8 ANOVA of the effect of potassium fertilization rates on root to shoot ratios of tabasco pepper plants at 30, 60 and 90 DAT.

	Root:Shoot ratio		
DAT	30	60	90
Treatment mM P			
K1 0.25	0.31 a[x]	0.21 bc	0.21 bc
K2 1.25	0.23 bc	0.15 cd	0.10 d
K3 2.50	0.25 ab	0.16 cd	0.11 d
K4 3.75	0.28 ab	0.16 cd	0.10 d
Trend[y]		**L, **Q, *C	
Statistical Analysis[z]			
P treatment		**	
Time		**	
P Treatment x Time		NS	

[x] Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method (P<0.05).
[y] Trends are described by L linear, Q quadratic, C cubic, with respective level of significance.[z] SAS mixed procedure, * significant at P<0.05, ** significant at P<0.01,and NS= not significant.

Leaf area generally increased with increasing K rates in all time periods (Figure 3.5). Plant leaf area was influenced by K rate especially at 90 DAT; the K4 treatment was significantly different from all the K treatments. No differences were found between the same K1 treatments at 30, 60, and 90 DAT; this is probably due to leaf loss caused by the low K rate. Severe K deficiency symptoms were evident on the leaves of K1 and K2 treatments. Downward cupping of the leaves and necrotic borders were found especially for the K1 treatment as well as smaller leaf size. In addition, the K2 treatment showed necrosis of the leaf borders and smaller leaf size. Both treatments had severe leaf loss. At 30 DAT, K treatments had no significant differences.

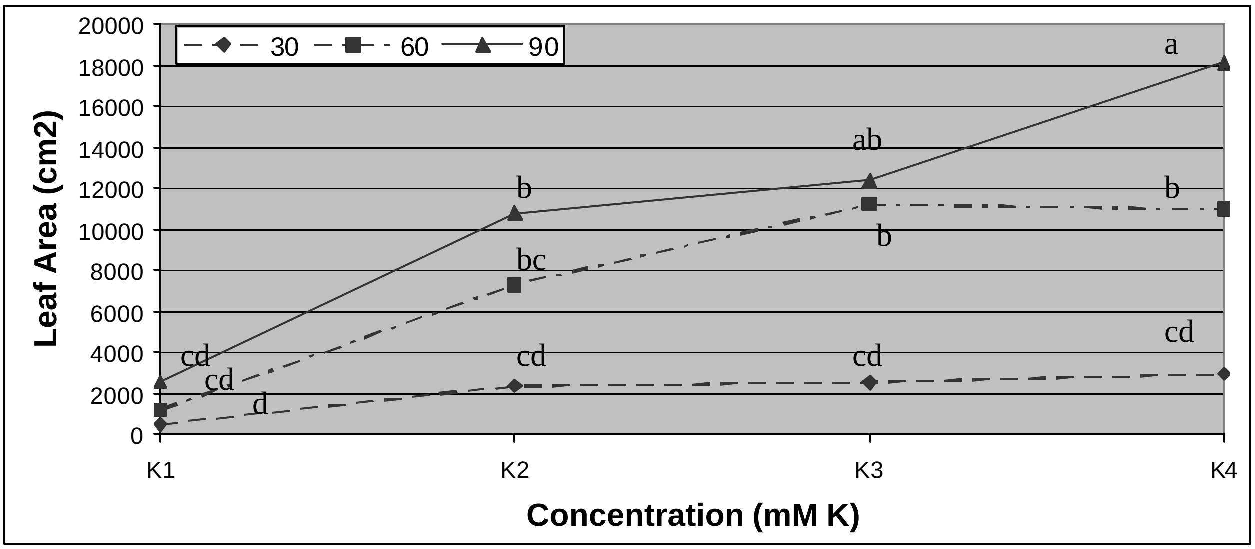

Figure 3.5 Effect of potassium rates on leaf area of tabasco pepper plants at 30, 60, and 90 DAT. Observations with at least one same letter within column are not significantly different (P<0.05).

Plant leaf area ratio (LAR) decreased over time (Figure 3.6), and significant differences between the three time periods were found. Higher LAR at 30 days is due to low total plant dry matter at that growing period compared to higher dry matter accumulation and lower growth rate at 60 and 90 DAT. At 30 and 60 DAT, no significant differences between LAR values were found between treatments. At 90 DAT, however, LAR for K1 was significantly higher than for K4. This finding suggest that higher K rates at this time period increased plant dry matter accumulation probably due to a higher photosynthetic area and sufficient K rates.

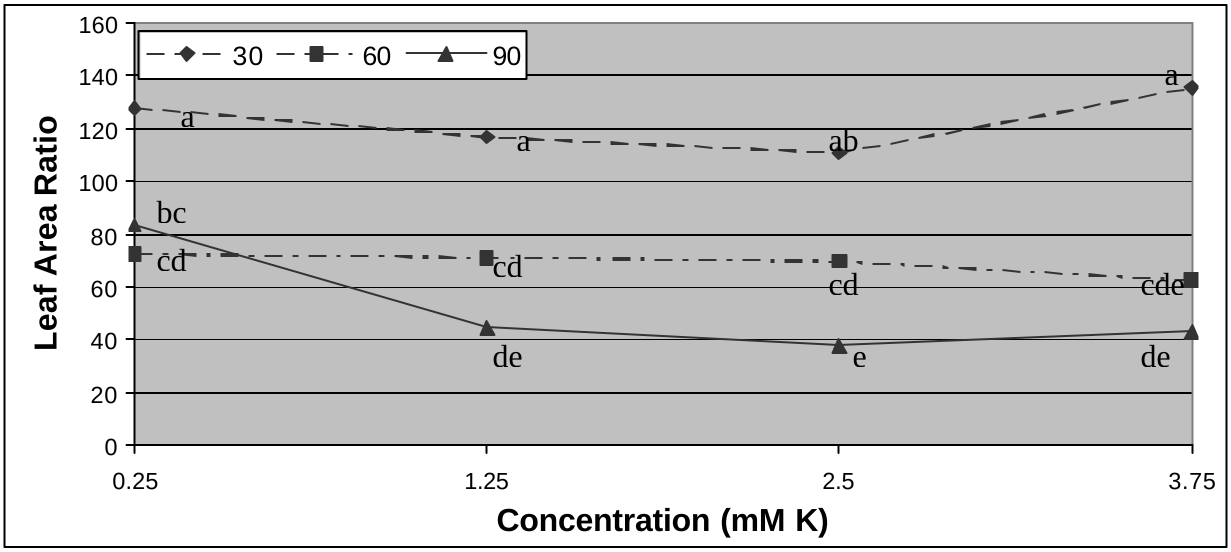

Figure 3.6 Effect of potassium rates on leaf area ratio of tabasco pepper plants at 30, 60, and 90 DAT. Observations with at least one same letter within column are not significantly different (P<0.05).

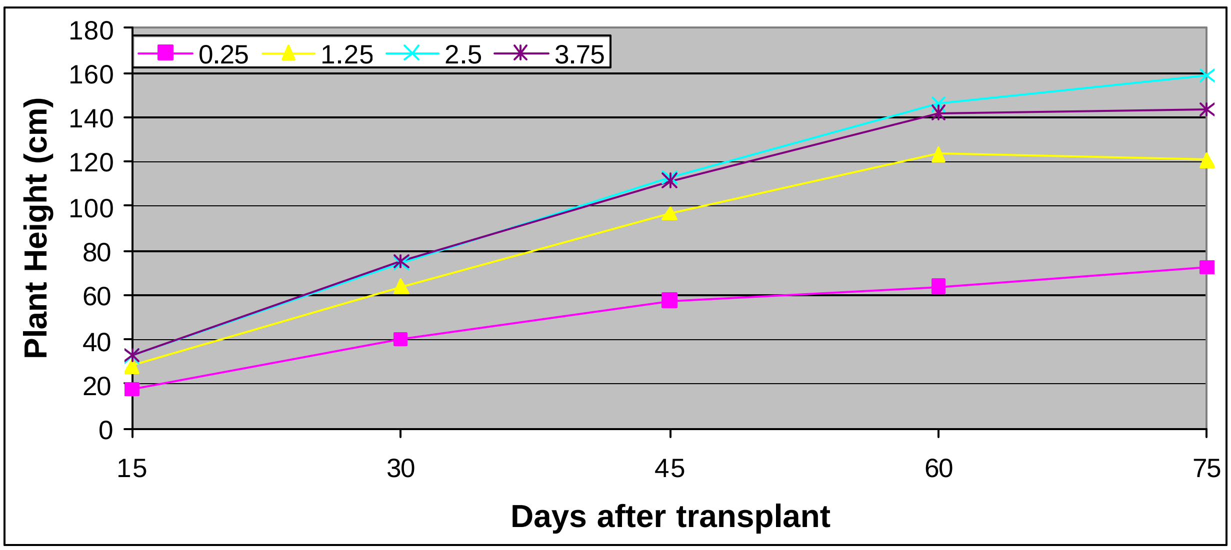

Figure 3.7 Effect of potassium concentration on plant height of tabasco pepper plants at 15, 30, 45, 60, and 75 DAT.

Specific leaf area (SLA) was not different between treatments. These results suggest that leaves were not thicker or thinner between treatments, and differences in leaf area were due mostly due to plant size and enhanced foliar growth due to higher K rates. A higher SLA was found for the 30 DAP period compared to the 60 and 90 DAT periods.

Potassium rates significantly affected plant height (Figure 3.7); higher K rates resulted in greater plant height. There were also no significant differences between K2, K3, and K4. Differences in plant height at all time periods were primarily between K1 and the other treatments. Differences at the 75 DAT period might have been due to fruit weight on the branches, which could have influenced plant height at that stage. A cubic response in plant height was observed due to increasing K rates. Everet and Subramanya (1983) reported that increasing nitrogen-potassium rates in a pepper study increased plant height. Csizinszky (1999) also found differences in plant height with different K rates and source of K on polyethylene mulched tomatoes.

Stem diameter followed the same pattern as plant height (Figure 3.8). Higher K rates resulted in higher stem diameter. There were differences in stem diameter at all time periods between K1 and the rest of the treatments. Stem diameter had a quadratic response.

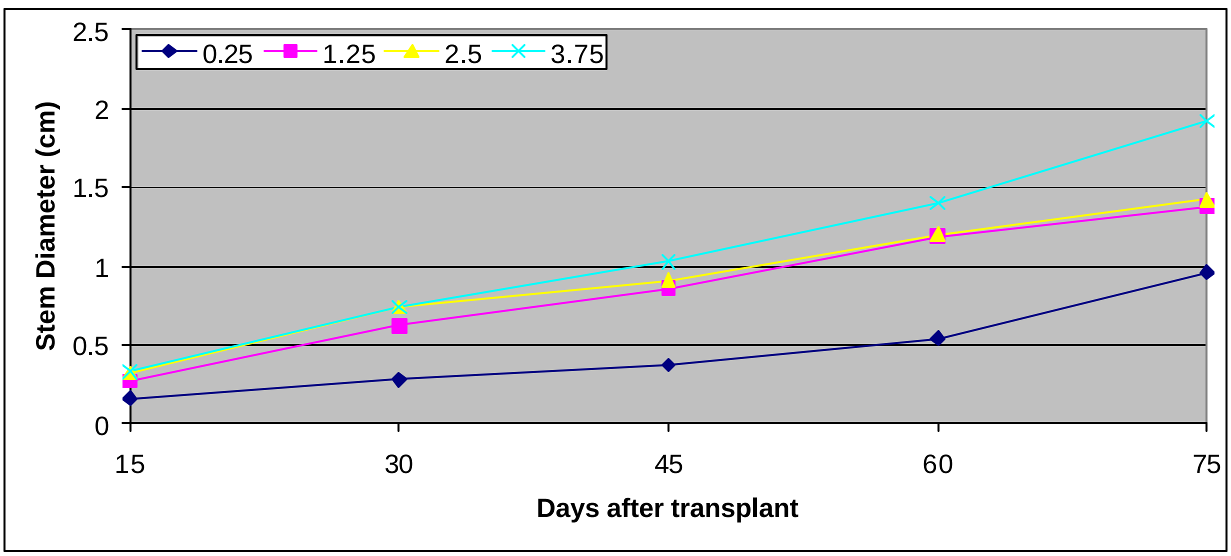

Figure 3.8 Potassium concentration on plant stem diameter of tabasco pepper plants at 15, 30, 45, 60, and 75 days after transplant.

3.4.2.2.2 Potassium Effect on Leaf Mineral Content

Potassium significantly affected leaf Zn, and had a highly significant effect on all nutrients measured (Table 3.9). Higer K rates increased the uptake of K, Ca, B, Fe, Mg, with positive correlations of 0.76, 0.63, 0.86, 0.30, and 0.55 respectively, and decreased P, Cu, Mn and Zn. Unlike P, increasing K rates in the nutrient solution increased Ca, and Fe. Eggplant leaf and root micronutrient concentrations were also found to be influenced by K nutrient solution concentrations (Zipelevish et al., 2000). Hochmuth et al., (1993), in their study on eggplant response to K fertilization, reported that increasing K rates increased K dry leaf content. The researchers also reported in their study that leaf K followed a quadratic response to increasing K rates. After comparing our results with leaf sufficiency ranges for bell pepper plants, at an early flowering stage, treatments K1 and K2 were found to be under the adequate K range of 2.5-5 percent at the 30 DAT period.

Jones et al. (1988) reported a positive relationship between K and leaf Ca, in their field study on trickle irrigated tomatoes: they found a negative relationship between K and leaf Ca content. Csizinszky (1999) reported that no significant Ca variations in the soil were found with increasing K rates on polyethylene mulched tomatoes.

Increasing K rates significantly affected plant B increasing its leaf content. Boron increased with K4 treatment and was significantly different with K1 and K2 at all times. Treatment K4 was significantly higher than K3 at 60 DAT, but no significant differences were found at 30 and 90 DAT. Leaf Fe content was not significantly different between treatments at any time period. Leaf Mg was slightly higher with increasing K rates, significant differences at 60 and 90 DAT were found between K1 and all the other treatments, but no significant differences were found between K2, K3, and K4. Csizinszky (1999) reported that in polyethylene mulched tomatoes, soil Mg concentrations increased with increasing K rates. Jones et al. (1988) reported in their study a negative relation between K and leaf Mg on trickle irrigated tomato. Molybdenum leaf content also showed an increasing trend with increasing K rates, especially at

60 and 90 DAT. Treatments K3 and K4 were not significantly different between each other but were statistically higher than K1 and K2 at 60 and 90 DAT.

Treatments K2, K3, and K4 resulted in higher Ca concentration than the recommended adequacy range of 0.6-1.5 percent for bell pepper leaf tissue concentration at an early bloom stage of growth. Leaf Ca concentrations for treatment K1 was found to be adequate. Magnesium leaf content of our plants showed a much higher concentration than the high status of 0.5 percent recommended for bell peppers leaves for all K treatments. Iron, however, was found deficient for all K treatments except K4 at the 30 DAT. Boron leaf content, when compared to adequate plant tissue analysis recommendations for bell pepper plants at early bloom, resulted in higher concentrations than the high recommended value of 50 ppm for K1, K2, and K3, and almost reached half of the toxic levels for K4 at the 30 DAT period. This finding suggests that it is possible that B utilization by tabasco pepper could be significantly different than bell pepper plants.

Negative effects of increasing K rates were noted for P, Cu, and Mn, with negative correlations of -0.80, -0.67, and -0.52, respectively. Potassium and P have an antagonistic effect; increasing P rates negatively impacted leaf K content as well as increasing K rates in the solution reduced leaf P. High K rates in the solution significantly reduced leaf P at early stages of growth. High P rates had a noticeable effect on leak K content primarily at the 90 DAT period. At 30 DAT, fruit P content was similar for treatments K1 and K2, and lower for treatments K3 and K4. At 60 and 90 DAT, all treatments were significantly different from each other resulting in a gradual reduction of fruit P content. Similar results were found by Baghour et al. (2001) where K fertilization did not affect significantly total P concentration of senescent leaves. Most of the P fractions reached their highest concentrations at the lowest K treatment; however, higher K concentrations boosted pepper plant yield. Copper leaf content was also reduced by increasing

K rates, treatments K2, K3, and K4 were significantly lower than K1 at all time periods. Manganese and Zn leaf content decreased with increasing K rates, but no significant differences were found. For all K treatments, P, Cu, and Mn leaf concentrations were found to be between the adequate bell pepper sufficiency ranges at the early bloom stage of growth.

There was a significant effect of time on all the nutrients, with the exception of Ca. The interaction of K treatment and time was only highly significant for P, K, Ca, B, Cu, Mg, and Mo, while, increasing K rates had a significant quadratic effect on Fe and a highly significant effect for all the other elements.

A significant cubic trend for K and a highly significant cubic response of Mg and Mo to increasing K concentrations in the nutrient solution was found. This response reflects the plant nutrient concentrations with increasing K rates indicating two different inflexion points in the curves. For K leaf content, a rapid increased in leaf K between K2 and K3 is noticed at 30 and 60 DAT then between K3 and K4 an increase leaf K is noticeable at a decreasing rate. Treatment K4 however, shows a dramatic reduction in K content between K1 and K2 with a gradual increase at K3 and a rapid increase in K content at the highest K concentration. Similar increases in leaf Mg were found with increasing K concentrations in the nutrient solution. The rest of the leaf mineral element concentrations that were analyzed resulted in a highly significant quadratic response to increasing K concentrations in the nutrient solution. These quadratic concentrations, for most of the elements, explain an increase or decrease in leaf concentration leveling off at a certain point. The negative or positive slope of the trend line would depend on the positive or negative effect of K concentration in the nutrient solution explained above.

Table 3.9 ANOVA of Potassium rate effect on element composition of dry leaves of tabasco pepper plants at 30, 60, and 90 DAT.

DAT	mM K	P	K	Ca	B	Cu	Fe	Mg	Mn	Mo	Zn
		Percent (%)			ppm						
30	K1 0.25	0.68 a[w]	1.31 ef	1.15 c	71.1 e	12.63 a	20.79 ab	0.84 d	98.72 ab	28.11 a	22.31 ab
	K2 1.25	0.68 a	1.7 de	1.66 ab	114.98 d	10 bc	23.42 ab	0.96 bcd	88.56 abc	20.61 c	21.86 ab
	K3 2.50	0.56 b	3.08 b	1.7 ab	119.64 cd	7.85 cde	21.14 ab	0.92 cd	65.15 bc	21.49 bc	15.55 b
	K4 3.75	0.43 c	4.11 a	1.66 ab	147.71 bc	8.94 bcd	32.04 ab	0.96 bcd	63.82 bc	24.91 ab	22.84 ab
60	K1 0.25	0.71 a	1.75 cde	0.94 c	48.72 e	11.16 ab	27.6 ab	0.9 d	79.06 abc	10.43 ef	31.62 a
	K2 1.25	0.58 b	1.64 de	1.65 ab	75.81 e	10.09 bc	7.7 b	1.13 ab	86.69 abc	10.5 ef	29.32 a
	K3 2.50	0.45 c	2.27 c	1.91 ab	107.24 d	9.77 bc	15.22 b	1.12 abc	57.5 bc	15.89 d	27.18 a
	K4 3.75	0.29 d	3.43 b	1.82 ab	184.07 a	7.47 def	18.43 ab	1.23 a	52 c	21.66 bc	22.56 ab
90	K1 0.25	0.64 ab	2.02 cd	1.02 c	49.65 e	10.15 bc	17.26 ab	0.78 d	114.4 a	6.14 g	29.9 a
	K2 1.25	0.37 c	1.09 f	1.96 a	119.74 cd	7.06 def	17.29 ab	1.26 a	115.18 a	7.32 fg	24.83 ab
	K3 2.50	0.25 d	1.65 de	1.98 a	170.97 ab	5.36 f	36.4 ab	1.27 a	99.33 ab	12.99 de	27.23 a
	K4 3.75	0.21 d	3.05 b	1.55 b	147.92 bc	5.66 ef	47.97 a	1.14 ab	80.41 abc	13.07 de	23.63 ab
Trend[x]		**Q	**L, **Q, *C	**L, **Q	**L, **Q	**L, **Q	*Q	**L, **Q, **C	**Q	**L, **Q, **C	**Q
Statistical analysis [y]											
K treatment		**	**	**	**	**	*	**	**	**	*
Time		**	**	NS	**	**	*	**	**	**	**
Treatment x Time		**	**	**	**	**	NS	**	NS	**	NS

[w]. Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method (P=0.05).

[x] Trends are described by L linear, Q quadratic, C cubic, with respective level of significance.

[y] SAS mixed procedure, * significant at P<0.05, ** significant at P<0.01, NS= not significant

3.4.2.3. Fruit Quality Experiment

3.4.2.3.1 Potassium Effect on Fruit Quality Variables

The effects of treatment and time on fruit quality variables of the experiment were highly significant in the MANOVA analysis. The interaction between time and treatment effects was not significant for the fruit quality variables.

Increasing K rates in the nutrient solution resulted in different yields, average fruit weight, alcohol insoluble solids, and pod dry matter accumulation (Table 3.10). Differences between the various harvest times were significant for all the variables, with the exception of titratable acidity and yield. Differences in the interaction between K treatments and time were only significant for alcohol insoluble solids. These results contrast with the findings of Everett and Subramanya, (1983), who studied increasing N-K_2O rates on bell peppers along with plant spacing. They found that increasing N-K_2O rates had no effect on average fruit weight, yield or the number of fruit per plant.

Table 3.10 ANOVA of potassium effect on fruit quality variables.

	Yield	AFW[x]	AIS	BRIX	pH	TA	PDM	Hue
Treatment	*	**	**	NS	NS	NS	*	NS
Time	**	**	**	**	**	NS	**	**
Treatment x Time	NS	N S	*	NS	NS	NS	NS	NS
Trend[y]	**Q[z]	*L, **Q	**L	*Q	NS	NS	**L	NS

[x]AFW average fruit weight, AIS alcohol insoluble solids, PDM pod dry matter. [y] Trends are described by L linear, Q quadratic with respective level of significance.
[z] SAS mixed procedure, * significant at $P<0.05$, ** significant at $P<0.01$, NS= not significant.

Increased K rates in the nutrient solution had no significant effect on yield between K1, K2, and K4 treatments (Table 3.11). The table shows results for time and treatment interactions, variance in such interaction was too great to detect possible differences between the treatments. The individual treatment effect on yield was significant. Treatment K3 produced the highest yield of fruits when compared with K2 and K4 which followed K3 in fruit production. The lowest K rate in the nutrient solution proved to be insufficient for fruit production when compared to the rest of the treatments. Differences in time were significant for the three harvest periods; a gradual decrease of fruit production was noticed. The interaction between K treatment and harvest period was not significant. Polyethylene mulched tomato yields were also affected by K rate and source; yields of extra-large and total marketable yield were improved with higher K rates (Csizinszki, 1999).

The average fruit weight of fresh pepper fruits was influenced by K rates (Table 3.11). Treatment K4 (0.71 g) produced the highest fruit weight of the experiment followed closely by K3 (0.67 g) and K2 (0.68 g), with no significant statistical differences between the treatments. Harvest periods significantly affected fruit weights, but the interaction between K treatment and harvest period was not significant. An overall decrease in fruit weight as harvest time progressed was noticed for all the K treatments.

Table 3.11 Potassium effect on fruit quality variables of tabasco pepper fruit at first, second, and third harvests

DAT	Nutrient Concentration Trt. (mM P)	Yield	AFW[x]	AIS	BRIX	pH	PDM	Hue
30	K1 0.25	146.01 a[y]	0.72 ab	2.12 cd	16.20 abc	5.18 cde	29.34 abc	49.88 cd
	K2 1.25	178.47 a	0.78 a	2.12 cd	14.30 abcd	5.18 cde	29.52 abc	50.05 cd
	K3 2.50	180.50 a	0.79 a	2.25 abcd	17.45 a	5.07 e	30.65 abc	50.50 bcd
	K4 3.75	224.51 a	0.81 a	2.23 bcd	16.40 ab	5.10 de	27.78 c	49.69 d
60	K1 0.25	71.40 a	0.57 bc	2.15 cd	10.80 d	5.33 abcde	28.95 bc	53.58 ab
	K2 1.25	117.18 a	0.67 abc	2.31 abc	12.40 cd	5.26 bcde	30.30 abc	53.28 ab
	K3 2.50	193.58 a	0.67 abc	2.28 abcd	13.50 bcd	5.29 bcde	31.16 abc	53.67 a
	K4 3.75	174.54 a	0.72 ab	2.20 bcd	12.75 bcd	5.36 abcd	30.29 abc	53.56 ab
90	K1 0.25	33.12 a	0.38 d	1.98 d	12.93	5.58 a	29.39 abc	53.19 abc
	K2 1.25	91.60 a	0.54 cd	2.54 ab	13.45 bcd	5.50 ab	33.71 ab	51.82 abcd
	K3 2.50	149.67 a	0.57 bc	2.58 a	13.67 abcd	5.44 abc	34.78 a	53.48 ab
	K4 3.75	94.55 a	0.59 bc	2.58 ab	14.45 abcd	5.40 abc	33.87 ab	52.41 abcd

[x] AFW average fruit weight, AIS alcohol insoluble solids, PDM pod dry matter. SAS mixed procedure (P=0.05).
[y] Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method (P=0.05).

The alcohol insoluble solids (AIS) fraction of the fruits was significantly affected by increasing K rates. Treatment K3 had the highest AIS values followed by K2 and K4 with overall values of 2.37, 2.32, and 2.16 grams, respectively. Harvest time gradually increased the

AIS fraction of the fruits, with higher AIS values at third harvest (2.48 g). Second harvest values were significantly higher than the first harvest with overall values of 2.24, and 2.12 grams, respectively. There seems to be a significant interaction between treatment and time, high K rates combined with late harvests had the highest AIS values.

No significant differences were found in soluble solids (Brix) for the K rate treatments on fruit. No differences in fruit soluble solids was also found by Hartz et al. (1999) in a tomato study where the authors reported that K treatment effects on fruit soluble solids were weakly correlated suggesting that the variability was due to other factors unrelated to K fertility.

Pod dry matter (PDM), was significantly affected by increasing K rates (Table 3.11). Treatment K3 had the highest dry matter content followed by K2 and K4 with values of 32.20, 31.18, and 30.65 grams, respectively. There were no significant differences amongst the treatments. Harvest time gradually increased PDM; dry matter values were higher at third harvest period and were statistically superior to the other harvests with an overall value of 32.94 grams.

3.4.2.3.2 Potassium Effect on Fruit Mineral Composition

Treatment and time effects on fruit mineral composition of the experiment were highly significant in the MANOVA analysis. The interaction between time and treatment variables was not significant. There were differences at all time periods for almost all fruit mineral concentrations, with the exception of P, Mn, and Mo.

Potassium rates had a significant effect on mineral fruit content when applied at flowering stage (Table 3.12). Higher fruit K concentration resulted from the K4 treatment, and these were significantly higher than all the rest of the treatments that resulted in similar fruit K concentrations. Sulphur is the only other element that increased fruit concentration with higher K rates. Treatment K4 had the highest fruit S values, but this treatment was only superior to K1 at 30 and 90 DAT.

Higher K concentrations in the nutrient solution decreased fruit mineral concentrations of P, Ca, B, Cu, Mg, and Mo (Table 3.12). Increasing K rates had similar results on fruit P than on plant dry leaves by significantly reducing P. There was a significant reduction of fruit P content at all time periods, however, no differences between time periods was observed. At 30 DAT, fruit P content was similar for all treatments. At 60 and 90 DAT, treatments K2, K3, and K4 had a significantly lower P fruit content when compared to K1. No differences between treatments K2, K3, and K4 were found at any time.

Fruit calcium decreased as K rates increased in the nutrient solution. This finding concurs with the results of Hartz et al. (1988) in their study of tomato fruit quality for processing. Paiva et al. (1998) also found a negative interaction between Ca and fruit K in tomatoes; the effect of high Ca rates produced a negative quadratic response of K due to the competitive effect of Ca for absorption sites in the plant. There were significant differences between the fruit Ca content in the three harvest periods but no significant differences were found between K3 and K4 at all times. Treatments K1 and K2 were not different at 30 DAT, however at 60 and 90 DAT, both were significantly different from the other treatments with K1 having the highest Ca concentration.

Minerals such as Mg, Mn, and Zn, showed no specific response to increasing K rates in the nutrient solution. A decrease in fruit Zn concentration was noticed with increased K rate, but there were no significant differences between the treatments. Molybdenum showed no significant differences between K treatments at 30 and 60 DAT. Molybdenum concentrations, however, dropped at 90 DAT especially for treatments K2, K3, and K4 with all significant differences from K1. Boron and Copper fruit concentrations showed no response to K treatments, however, significant fluctuations between the harvest periods were observed, probably due to flowering and fruit growth.

Table 3.12 ANOVA and potassium effect on nutrient element composition of red dry pepper fruits of tabasco pepper plants at first, second, and third harvests.

DAT	mM K	P	K	Ca	B	Cu	Mg	Mn	Mo	S	Zn
30	K1 0.25	0.40 ab	1.66 cde	0.13 def	13.16 ab	13.63 a	0.19 abc	15.88 bc	1.52 a	0.23 bc	17.9 a
	K2 1.25	0.38 abc	1.75 bcde	0.11 efg	12.96 ab	8.26 a	0.18 abc	13.62 bc	1.45 a	0.26 abc	15.47 a
	K3 2.50	0.31 bc	1.88 abcd	0.1 fg	15.23 ab	7.07 a	0.17 c	11.93 c	1.6 a	0.26 abc	14.32 a
	K4 3.75	0.35 abc	2.16 a	0.1 g	13.09 ab	7.39 a	0.19 abc	11.71 c	1.43 a	0.28 a	14.2 a
60	K1 0.25	0.44 a	1.58 de	0.16 bc	13.32 ab	7.48 a	0.2 a	20.22 ab	1.52 a	0.24 bc	16.04 a
	K2 1.25	0.37 abc	1.55 e	0.13 def	12.41 ab	6.93 a	0.18 bc	14.39 bc	1.17 a	0.25 abc	13.88 a
	K3 2.50	0.32 bc	1.48 e	0.09 g	8.99 b	6.67 a	0.18 abc	10.87 c	1.02 a	0.25 abc	13.45 a
	K4 3.75	0.32 bc	2.13 abc	0.12 defg	9.14 b	7.09 a	0.18 abc	11.87 c	0.83 ab	0.25 abc	13.08 a
90	K1 0.25	0.43 a	1.51 e	0.22 a	16.4 ab	10.12 a	0.2 ab	23.62 a	1.19 a	0.22 c	17.66 a
	K2 1.25	0.38 abc	1.59 cde	0.16 b	17.53 a	9.26 a	0.18 abc	15.52 bc	n.a. b	0.25 abc	14.67 a
	K3 2.50	0.30 c	1.63 cde	0.13 cde	15.27 ab	12.27 a	0.17 c	10.08 c	n.a. b	0.25 bc	15.64 a
	K4 3.75	0.31 bc	2.01 ab	0.14 bcd	12.86 ab	12.03 a	0.18 bc	12.09 c	n.a. b	0.27 ab	15.06 a
Trend[x]		**L, **Q, *C	**L, **Q	**L, **Q	*Q	NS	**L, **Q	**L, **Q	*L, **Q	**Q, *C	**Q
Statistical Analysis[y]											
Treatment		**	**	**	NS	NS	**	**	**	**	**
Time		NS	**	**	**	*	NS	NS	**	*	ns
Treatment x Time		NS	NS	**	NS	NS	NS	NS	*	NS	NS

[x] Trends are described by L linear, Q quadratic, C cubic, with respective level of significance.
[y] SAS mixed procedure, * significant at P<0.05, ** significant at P<0.01, NS= not significant. Observations with at least one same letter within column are not significantly different (P=0.05).

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CHAPTER 4

CONCLUSIONS

Phosphorus and potassium rates significantly affected plant growth, increasing plant height, weight, stem diameter, leaf area, and dry weights of plant sections with increasing rates in nutrient solution. Low rates drastically reduced plant growth, especially the lowest potassium rate, which restricted plant growth during the entire experiment growing period. The enhancement of all growth variables was due to P and K availability in the nutrient solution allowing plants to develop without restrictions as rates increased.

Increasing P and K rates also affected plant yield and some fruit quality variables. Results were consistent for most of the variables, suggesting that the 0.25 mM concentration for both P and K was insufficient for pepper production. Pepper yields were higher for treatments with higher rates than 0.25 mM of P and K. The lowest K rate proved to be insufficient for fruit production, and no significant differences were found between the 2, 3, and 4 treatments for both P and K. The 2.75 mM concentration for both P and K produced the highest yield. There were, however, no statistical differences in yield with 1.25 or 3.25 mM. Average fruit weight was highest at the higher P and K concentration with significant differences between the low and high rates. Titratable acidity was only influenced by P; the highest P concentration was significantly different from the rest of the treatments. Treatments 2, 3, and 4 for both elements were significantly different from each other suggesting the restrictive effect of the lowest P and K concentration in the nutrient solution. Changes in all fruit variables as time progressed were noted; fruit quality variables were significantly affected by time for both P and K, except for titratable acidity in the case of K. In contrast to other studies where fruit sugar content is significantly affected by low P or K, our study results indicate that tabasco peppers were not affected by the rates used. This suggests that our lowest P concentration was enough to provide a leaf area that was capable of providing enough energy and photosynthates to produce the normal sugar content of the fruits.

Leaf and fruit mineral concentrations were affected by P increased rates in nutrient solution. Increasing P rates primarily had a synergistic effect on plant uptake for P leaf concentrations, and an antagonistic effect on Fe and Mn. Differences in nutrient leaf concentrations that were affected by increasing P rates were mainly between the lowest and the higher P treatments, suggesting that the 0.25mM nutrient solution was insufficient. Potassium had a greater effect on leaf mineral concentrations than P, and followed a similar pattern than P on fruit mineral concentrations.

Our results suggest that concentrations higher than 1.25 mM and closer to 2.5 mM are the most appropriate for hydroponic tabasco pepper production. Potassium was more restrictive than P for the current rates that were used, and that concentrations below 1.25 mM shouldn't be used for hydroponic tabasco pepper for both elements. Field research is now necessary to determine fertilizer requirements for current production systems in Louisiana and other countries. Field P and K concentrations should be monitored, and correlated to the present study, to evaluate the impact of soil mineral content on tabasco pepper. Periodic plant leaf samples in field trials should be compared to our results to evaluate the soil concentration that allows for maximum plant growth and development in order to find the optimum fertilizer requirements that are needed on individual commercial Tabasco operations.

APPENDIX

PRELIMINARY STUDY ANOVA FOR INDIVIDUAL PHOSPHORUS AND POTASSIUM EFFECTS ON LEAF AREA, ROOT, LEAF, AND STEM DRY WEIGHTS OF TABASCO PEPPER PLANTS AT 30 AND 60 DAT

Preliminary Study ANOVA for individual phosphorus and potassium effects on leaf area, root, leaf, and stem dry weights of tabasco pepper plants at 30 and 60 DAT.

		RDW[x]	SDW	LDW	LA	Height
30 DAT	P1	0.64 a[y]	0.85 a	0.47 a	223.00 a	16.72 a
	P2	1.06 a	1.77 a	0.97 a	467.58 ab	20.29 a
	P3	1.06 a	2.31a	1.24 a	613.79 b	21.03 a
	P4	1.17 a	2.77a	1.19 a	733.32 c	22.49 a
	K1	0.86 a	1.89 a	0.93 a	468.26 a	20.48 a
	K2	0.94 a	1.90 a	1.01 a	512.07 a	20.13 a
	K3	1.01 a	2.01 a	0.91 a	527.51 a	19.99 a
	K4	1.11 a	1.89 a	1.03 a	529.85 a	19.93 a
60 DAT	P1	2.75 c	3.54 c	2.88 c	813.33 c	39.80 b
	P2	3.74 b	6.87 b	6.20 b	1648.31b	59.15 a
	P3	4.79 a	9.58 ab	8.45 a	1987.46 ab	59.50 a
	P4	4.95 a	9.67 a	9.50 a	2174.78 a	63.22 a
	K1	3.38 b	6.46 a	5.62 a	1371.53 a	51.98 a
	K2	3.91 ab	8.22 a	6.72 a	1790.70 a	56.63 a
	K3	4.00 ab	7.51 a	6.52 a	1756.18 a	55.79 a
	K4	4.86 a	6.96 a	7.60 a	1705.47 a	57.28 a

[x] RDW root dry weight, SDW stem dry weight, LDW leaf dry weight, LA leaf area. SAS mixed procedure (P=0.05).

[y] Observations with at least one same letter within column are not significantly different, means separation by Tukey Kramer method (P=0.05).

VITA

Manuel Estuardo Aldana was born on 1976, in Teculután, Zacapa, Guatemala. He attended the Escuela Agrícola Panamericana, El Zamorano, Honduras, where he received the title of Agrónomo in December, 1997, and the title of Ingeniero Agrónomo in December, 1998. In January, 2001, he enrolled in the Graduate School at Louisiana State University under the direction of Dr. Carl E. Motsenbocker to pursue the degree of Master of Science in horticulture, which will be awarded at Summer 2005.