Fertility Management and Calibration Evaluations on Upland and Pima Cotton

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Abstract

Numerous field experiments were conducted during the 1997 through 1999 cotton seasons involving macro and micronutrient fertilization. The purpose of these experiments was to evaluate University of Arizona (UA) fertility guidelines with respect to soil test results and to possibly fine-tune or better calibrate these guidelines for common Arizona soils and cotton growing regimes. Field experiments studied the effects of a single nutrient or nutrient combinations on both Upland and Pima varieties. Results from these experiments, based on soil test information, quantitative plant measurements, and lint yield showed no significant difference due to treatments for all sites except for a phosphorus study conducted during the 1998 season in Graham County and a phosphorus study conducted during the 1999 season in Pinal County. All results reinforce current UA soil testing guidelines for cotton.

Introduction

In cotton (*Gossypium spp*.) production there are many nutrients that are integral to good yield and profit. Nutrient management is important in an effort to optimize plant response and yield. The basic construct of many plant nutrient studies should include guidelines for soil and plant tissue analysis. These guidelines should be established through soil test and plant tissue correlation and calibration procedures, and then utilized in developing nutrient management recommendations for that region. The purpose of soil test calibration is to describe the soil test results in easily understood terminology and to simplify the process of making fertilizer recommendations by placing soils in response categories (Dahnke and Olson, 1990). These response categories cannot be used to predict yield, but can provide and estimate on the probability that a response to fertilization will occur. Usually, three types of categories are used regarding soil test values: low, medium, and high. A low soil test value offers a high probability of response to added fertilization. A medium soil test value offers a medium probability of response from added fertilization and a high soil test value exhibits a low probability of getting a response. For example, sodium bicarbonate ($NaHCO_3$) extractable levels of phosphorus (P) > 5 ppm are usually considered sufficient for cotton production in Arizona and the desert Southwest, and levels below 5 ppm P are indicative of possible deficient levels (Silvertooth et al., 1991). However, fertilizer P is often applied under conditions with ($NaHCO_3$ extractable) levels of P > 5 ppm. Soil test levels less than 5 ppm P would be considered a low soil test category, while a soil test level above 5 ppm would constitute a medium or high soil test category or lower probability of response to P fertilization. Past field experiments on cotton in Arizona have shown no significant response in lint yield to the addition of a P fertilizer with preseason $NaHCO_3$ extractable P levels ranging from 5 to 11 (Silvertooth et al., 1989b, 1990, 1991).

Potassium (K) fertility requirements for cotton have been a matter of concern due to increasing interest and emphasis on fiber quality and numerous reports of K deficiencies in various cotton producing regions outside of Arizona (Unruh et al., 1994). The plant available forms of soil K are a function of soil mineralogy. Unruh et al. (1994) found that the majority of soils used for agricultural production in Arizona contain K-bearing mica and very little vermiculite. Vermiculite is a soil mineral that has a tendency to fix K. Thus, it was concluded that as mineral weathering continues, K should not be deficient in most of the soils in agricultural production areas in Arizona. The critical level for K for cotton production in Arizona is 150 ppm ammonium acetate (NH_4OAc) extractable K.

Guidelines for developing recommendations for zinc (Zn) fertilization on cotton often use a baseline of 0.65 ppm Zn (DTPA extraction). Below this level, cotton may experience a yield limiting Zn deficiency (Silvertooth, et al.

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1989a). A 1998 study conducted in Buckeye, AZ (Bollset) evaluated the effects of adding a calcium (Ca) and Zn fertilizer to the crop during a period of the season (summer monsoon) when the cotton plants have a tendency to abort bolls due to heat stress (Brown, 1997).

Phosphorus plays an important role in the energy metabolism of the plant cell and is required in large amounts by reproductive organs. Phosphorus can have a significant effect on boll development, size, and time to maturity (Marcus-Wyner and Rains, 1982). The amount of plant available P in solution is controlled by several factors such as pH and calcium carbonate ($CaCO_3$) concentrations. Soil pH has a strong influence on plant available P. The desert soils of Arizona common to cultivation often exhibit high pH, well above 7.5. These high pH and lightly weathered soil conditions allow for solution P to form insoluble complexes with $CaCO_3$ and other Ca species in solution. This can reduce concentrations of plant available P in solution. For soils rich in $CaCO_3$, the solubility of P may be controlled by solid phase dicalcium phosphate (Cole and Olsen, 1959) or by chemisorption of P on $CaCO_3$ with the formation of a surface complex of calcium carbonate-P with a well defined chemical composition (Samadi and Gilkes, 1999). Such soil conditions are known to be quite conducive to the fixation of broadcast applications of P fertilizer, rendering the fertilizer P largely unavailable to the crop (Silvertooth et. al., 1990). To minimize P adsorption and the precipitation of Ca-P minerals, banding the P fertilizer near the seedline has been proposed as a better cultural practice than simple broadcast methods (Evans et al., 1970).

Zinc is a micronutrient or metallic trace element that plays a major role in enzyme related activities (Streeter and Barta, 1984). It has been suggested that high applications of P fertilizers may cause a precipitation of Zn and induce a Zn deficiency (Marcus-Wyner and Rains, 1982). The influence of high soil P soil on mycorrhizal uptake of Zn might also be a factor in Zn deficiency (Tisdale et al., 1993). It has been reported that in sweet corn (*Zea Mays* L.) applied P fertilizer accentuated Zn deficiency on soil with no added Zn, and applied Zn accentuated P deficiency on a soil with no added P (Brown et. al., 1970). The outcome of this study showed that a deficiency was corrected by supplying the soil with an appropriate element above its critical response category. Whether or not a Zn deficiency may be induced by applying fertilizer P, the natural plant available Zn concentrations of Arizona soils can be limited due to high pH and calcareous conditions. As the pH of the soil increases, the amount of plant available Zn in solution decreases. Zinc can be absorbed by $CaCO_3$ and form insoluble complexes that cannot be utilized by the crop.

The soil test critical levels for micronutrients are not well documented for Arizona soils. Many of these soil test levels were apparently taken from other regions. Further studies possibly involving the calibration of soil test extractions for various micronutrients may be needed. The objective for the studies in 1998 was to evaluate the effects of P, Ca, Zn, K and micronutrients such as iron (Fe), manganese (Mn), boron (B) and copper (Cu) on the growth, development, and nutrient status of Upland (*G. hirsutum* L.) and American Pima (*G. barbadense* L.) varieties. The objectives of the 1999 studies were similar to the 1998 season, but with a primary focus placed on P.

Materials and Methods

For the studies examined in this report, we commonly evaluated a comparison between a check (no fertilizer in question added) and that of a given fertilization treatment with all other nutrients provided at an adequate level. Evans (1987) discussed this aspect of soil test calibration as an essential ingredient for successful fertilizer recommendations to be valid. Following this approach allows us to analyze the validity of soil test information and its use in fertility management for the soil types and cotton production systems common to Arizona.

To study the effects of the addition of a specific nutrient, each location utilized a randomized complete block design during the 1997, 1998, and 1999 growing seasons. Treatments were replicated three to four times in all cases. The plot sizes used for the studies ranged from 6 to 75 rows wide and ran the entire length of the field. The soil test analyses are presented in Tables 3, 7, 11, 15, 19, 23, 27, 31, 35, 39, 43, 47, and 51 for each field experiment and for all years. The soil and foliar treatments for the various studies can be found in Tables 2, 6, 10, 14, 18, 22, 26, 30, 34, 38, 42, 46, and 50. All of the studies were conducted on Upland varieties except for the studies conducted in Graham County in 1998, where the Pima variety HTO was used. The Pima variety HTO was also used in one experiment conducted in 1999 (Layton, Graham County). Studies were conducted in the following locations: Graham County (Thatcher and Safford), Pinal County (La Palma and Maricopa), Maricopa County (Sierra Negra),

and Yuma County (North Gila Valley).

Common soil test extraction methods were used for the various nutrients under study. Soil test levels for P were determined by $NaHCO_3$ extractable P (Olsen and Sommers, 1982). The K and Ca soil test levels were determined by ammonium acetate (Knudsen et al., 1982, Lanyon & Heald, 1982). Micronutrients (Zn, Fe, and Mn) were extracted with DTPA (Lindsay & Norvell, 1978). Soil boron (B) levels were determined using the hot water extraction method (Mahler et al., 1984). Soil samples were collected from the field prior to planting. Twenty-five to 30 random samples were taken to a depth of 6-10 inches at various locations around the field prior to fertilizer applications and mixed thoroughly into a composite sample. Sub-samples were then taken from these composite samples for laboratory analysis.

Plant measurements were initiated at all sites early in the season to monitor crop growth and development. These measurements were taken within each plot at approximately 14-day intervals. Measurements included: plant height, number of mainstem nodes, number of flowers per 50 feet of row, percentage canopy closure, and the number of nodes from the top first position fresh flower to the terminal (NAWF). The purpose for these measurements was to detect any possible differences in plant growth and development that may have resulted from the fertilizer treatments and to evaluate growth in relation to established baselines for Arizona (Silvertooth and Norton, 1998). Plant tissue samples were also collected at several dates during the season in each experiment. Samples of both the leaf blade and petiole of the uppermost, fully-developed leaf on a plant were taken from a random selection of 40-50 plants within each plot, in an effort to monitor in-season plant nutrient status.

All plots were harvested by use of a two, four, or six-row mechanical picker (depending on location and equipment available) in the center rows of each plot to minimize border effects.

All experimental data were subjected to analysis of variance procedures and LSD multiple comparison test, as outlined by Gomez and Gomez (1984) and the SAS Institute (1996).

Results

Potassium Study, La Palma, Pinal County, 1997

An application of 22 lbs. K_2O/acre (100 lbs./acre K-Mag) was done at preplant (Table 2). Table 3 shows that preseason soil tests for K were 490 ppm K. The fruit retention (FR) and height to node ratio (HNR) levels from the production conditions in 1997 were quite favorable for high yield potentials (Figure 1). The blade concentrations of K varied towards the end of the season for the different treatments (Figure 2). There was not a significant difference ($P \leq 0.05$) in lint yield between the treatments (Table 4).

Bollset Study, Buckeye, Maricopa County, 1998

The 1998 Bollset study consisted of 1X and 2X rates of Bollset that were compared to a check plot (Table 6). The concept behind the foliar application of Bollset is to help curb fruit abortion losses during heat stress (Brown and Zeiher, 1996) that may be associated with Ca and/ or Zn deficiencies. Soil test levels for Ca and Zn were 5600 ppm Ca and 1.6 ppm Zn (Table 7). Plants in the Bollset study experienced low FR levels in the latter part of the season as compared to University of Arizona (UA) baselines (Silvertooth and Norton, 1998) (Figure 3). Height to node ratio (HNR) levels decreased very slightly in the latter part of the season (Figure 3). The FR graph (Figure 3) illustrates that there were similar FR levels between the check and the treatments. Figure 4 shows that there were higher amounts of Ca in the petioles of the check plot versus the treated plots and more Zn in the petioles of the treated plots than the check. No significant differences ($P \leq 0.05$) in lint yield were expressed among the treatments (Table 8).

Micronutrient Study, Coolidge, Pinal County, 1998

Treatments for this study may be found in Table 10. Table 11 shows the soil test results for this study. Figure 5 shows that plants in this study had relatively uniform FR and HNR values all season among all treatments. Figure

6, 7, 8, and 9 show the levels of nutrients in the petioles and/or blades of the sampled plants. The levels of the nutrients in the plants were relatively uniform throughout the season for all nutrients. No significant differences in lint yield were found between the control and all other treatments (Table 12). There were significant differences ($P \leq 0.05$) between treatment 5 and treatment 4 and 6 with an OSL of 0.0110. However, it is most important to emphasize that the lint yield in the check was not significantly different from any of the other treatments.

Phosphorus Study, Layton, Graham County, 1998

Treatment 2 received a pre-plant application of 114 lbs. P_2O_5/acre (Table 14). The soil test level for P in this study was 6.8 ppm P (Table 15). Fruit retention and HNR levels were both below the average baseline as seen in Figure 10. Figure 11 shows that the blades of the treated plots had higher P concentrations than in the blades of the check plots . There was not a significant difference ($P \leq 0.05$) in lint yield between the two treatments (Table 16).

Phosphorus Study, Claridge, Graham County, 1998

The treatments are described in Table 18. The preseason soil tests were 7.6 ppm P (Table 19). The FR and HNR values were more favorable for the studies conducted in Graham County for the 1998 season than with other studies conducted in other parts of the state (Figure 12). Blade concentrations of P were similar for the treatments throughout the season (Figure 13). There were significant differences between the control and other treatments (Table 20). The added preplant nitrogen (N) did not have a significant effect on yield. There was a significant difference ($P \leq 0.05$) between the check and treatments 2, 3, and 4 with an OSL of 0.0126.

Phosphorus Study, Ollerton, Coolidge, Pinal County, 1998

Seventy-five lbs. P_2O_5/acre was applied (10-34-0) to the treated areas (Table 22). Sodium bicarbonate extractable P and Zn (DTPA extractable) levels were both below the UA soil test guideline critical levels (Table 23). The FR and HNR levels for this study were close to normal for the 1998 season in central Arizona (Figure 14). The FR pattern revealed a general decline towards the end of the season, while the HNR levels had an increasing trend. Generally unfavorable weather conditions of 1998 (heat stress) resulted in a loss of the fruit load and more vegetative growth (Brown and Zeiher, 1996). The check plot exhibited more P in the blades than the treated plot (Figure 15). There were no significant differences ($P \leq 0.05$) in lint yield between treatments (Table 24). There may be a concern that a crop response to P cannot be realized in this case since Zn levels were below the described critical level.

Zinc Study, Ollerton, Coolidge, Pinal County, 1998

Treatment 2 received 35 lbs. N/acre (10 gal UN 32/acre) plus 10 lbs. Zn/acre as Nulex Zn (16-0-0-20 (Zn))(Table 26). The preseason soil test detected a 0.40 ppm Zn level. (Table 27). The FR dropped rapidly towards the lower baseline early in the season (about 1000 heat units after planting (HUAP), 86/55 ^{o}F thresholds), which is just prior to first bloom and at this same time the HNR experienced a steep increase (Figure 16). Figure 17 shows that there were similar concentrations of Zn in the petioles throughout the season for both treatments. There were no significant differences ($P \leq 0.05$) in lint yield between the treatments (Table 28). The C.V. (%) was relatively high for the yield data from this experiment with a value of 21.53%. The yield was indicative of the lower yields that were common throughout this portion of Arizona during the 1998 season.

Phosphorus Study, Layton, Graham County, 1999

Eighty-four lbs. P_2O_5/ acre (24 gal. 10-34-0/acre) was applied preplant to the treated areas (Table 30). The preseason $NaHCO_3$ extractable P was 7.1 ppm (Table 31). The FR for this crop was above normal throughout the entire season, while the HNR was below normal (Figure 18). The treated plots exhibited a more consistent and higher level of P in the blades about midway through the season (Figure 19). There were no significant differences ($P \leq 0.05$) in yield between treatments (Table 32).

Phosphorus Study, Claridge, Graham County, 1999

This study utilized three different rates of applied P in the form of 9-26-0, with 22, 43, and 65 lbs. P_2O_5/acre applied (Table 34). The preseason $NaHCO_3$ extractable P was 11.0 ppm (Table 35). The FR and HNR for this study was similar to that shown by the Layton study (Figure 20). The FR was close to or above normal, while the HNR was below normal throughout the entire season. The total % P found in the blades of the plants followed roughly the same pattern. This was not the case for the last plant tissue sampling date where the check plot was analyzed with having the highest total % P (Figure 21). There were no significant differences ($P \leq 0.05$) in yield among treatments (Table 36).

Phosphorus Study, Sierra Negra, Maricopa County, 1999

A preplant application of 38 lbs. P_2O_5/acre was applied in the form of 10-34-0 (Table 38). The preseason $NaHCO_3$ extractable P was 11.0 ppm (Table 39). The FR for this study was about normal during the season, while the HNR was below normal (Figure 22). The plant tissue results indicated that both the treated and check plots had similar levels of P throughout the season (Figure 23). There were no significant differences ($P \leq 0.05$) in yield between treatments (Table 40).

Phosphorus Study, Harrison, Yuma County, 1999

A preplant application of 84 lbs. P_2O_5/acre was applied in the form of 10-34-0 (Table 42). The preseason $NaHCO_3$ extractable P was 8 ppm (Table 43). The plant measurements for this study were favorable with respect to FR retention and HNR except for a slight drop in HNR towards the end of the season (Figure 24). The total % P accumulated in the leaves was similar for both the treated and check plots (Figure 25). Towards the end of the season it appears that both the check and treated plots increased in concentrations of P relative to other sampling dates. There were no significant differences ($P \leq 0.05$) in yield between treatments (Table 44).

Phosphorus Study, Hart, Maricopa County, 1999

Various combinations of soil and foliar applied treatments were utilized in this study (Table 46). The preseason $NaHCO_3$ extractable P was 8.6 ppm (Table 47). All treatments were similar with respect to FR and HNR except for treatment 4 which exhibited a relatively low FR at the beginning of the season (Figure 26). The plant tissue analysis revealed that all of the treatments followed roughly the same pattern throughout the season (Figure 27). There were no significant differences ($P \leq 0.05$) in yield among treatments (Table 48).

Phosphorus and Zinc Study, Coolidge, Pinal County, 1999

The three treatments used in this study are outlined in Table 50. The preseason $NaHCO_3$ extractable P was 3.0 ppm (Table 51). The FR for this study was below normal for the entire season (Figure 28). The HNR results show that all of the treatments followed the same pattern until the latter portion of the season where treatment 1 was below normal (Figure 28). The percent total P in the check plot leaves (treatment 1) was consistently lower than the other treatments after the first sampling date (Figure 29). The plant tissue sampling also showed that all of the treatments followed the same trend throughout the entire season with respect to Zn (Figure 29). The check plot, where no P or Zn was applied, yielded significantly lower ($P \leq 0.05$) than the other treatments with an OSL = 0.0053 and a C.V. = 2.74% (Table 52).

Conclusion

The 1997 K study had a soil test level of 680 ppm K, which is substantially higher than the UA critical level of 150 ppm extractable K. No significant differences in lint yield between the K fertilized treatment and the check was detected.

In conclusion, the Claridge P study in Graham County was the only site of the seven field experiments conducted in 1997 and 1998 that showed significant differences in lint yield in response to the applied nutrients in question. The soil test results showed there was 7.6 ppm P. Using UA soil test extraction guidelines and recommendations for cotton, this amount of P in the soil would not necessarily warrant a P application for cotton. In contrast, the Layton P experiment in Graham County showed no response to applied P when the soil test extraction

level was also between 5 ppm and 10 ppm P. No significant differences in yield between treatments was found at a P soil test level of 6.8 ppm P for the Layton study. The 1998 P study in Coolidge allowed us to study a case with soil test levels of extractable P and Zn below the UA critical levels. No significant difference in lint yield was found in that case, having a preseason soil test level of 3.5 ppm P.

The Bollset study results were consistent with soil test extractions for both Ca and Zn and their respective UA critical levels. The Zn study conducted in Coolidge found preseason soil test levels of around 0.40 ppm Zn (below the current UA critical level) and no yield response was detected. The soil test levels of micronutrients for the study conducted in Coolidge were above the critical level for the Zn and Mn, while the soil test levels for B and Fe were below or right at the UA critical level. It is hard to ascertain what particular nutrient in these packages had positive or negative effects on yield. Further studies concerning micronutrients should be carried out with respect to the comparison of a single nutrient versus a check plot.

A significant difference in lint yield was detected with the Ollerton P and Zn study in Coolidge, AZ, 1999. The untreated check plot had a significantly lower yield when compared to the other treatments with a preseason soil test value of 3.0 ppm $NaHCO_3$ extractable P. There was not a significant difference between the P and P plus Zn, treatments, thus an interaction between the two nutrients was not evident. No significant differences in lint yield between treatments were found for any of the studies carried out during the 1999 season with a preseason soil test > 5 ppm $NaHCO_3$ extractable P. A good representative range of soil test values were used in the 1999 selected study sites. We conclude that $NaHCO_3$ extractable P soil test levels less than 5 ppm are low soil test levels, 5 ppm through 10 ppm are medium soil test levels, and soil test levels greater than 10 represent a high soil test level.

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Table 1. Agronomic information, potassium study, Cockrill, Pinal County, AZ, 1997.

Soil Type	Toltec fine sandy loam
Variety	Deltapine 33B
Planting Date	23 April 1997
Harvest Date	30 October 1997

Table 2. Treatment information, potassium study, Cockrill, Pinal County, AZ, 1997**.**

Treatment 1	Check – No Application of K
Treatment 2	22 lbs.K_2O/acre (100 lbs./acre K-Mag preplant broadcast)

K-Mag = (0-0-22S-11Mg)

Table 3. Soil test results, potassium study, Cockrill, Pinal County, AZ, 1997**.**

pH (1:1 H_2O)	**Ca* (ppm)**	**Mg (ppm)**	**Na (ppm)**	**K (ppm)**	**EC_e (mmhos/cm)**	**NO_3^--N** (ppm)**	**P*** (ppm)**	**ESP§**	**Free Lime**
8.3	-	-	-	490	2.0	17	10	-	-

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 4. Yield results, potassium study, Cockrill, Pinal County, AZ, 1997**.**

Treatment	**Lint Yield (lbs./acre)**
1	1431 a*
2	1381 a
LSD**	NS
OSL±	0.7346
C.V. (%)	13.31

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
±Observed Significance Level
Coefficient of Variation

Table 5. Agronomic information, Boll Set* study, Heiden, Buckeye, AZ, 1998**.**

Soil Type	Antho sandy loam / Laveen sandy loam complex
Variety	Deltapine 33B
Planting Date	4 May 1998
Harvest Date	9 November 1998

*1 application of Boll set consists of the following: Foligro Maximize (2 qts./acre), Potassium nitrate (8.5 lbs./acre), Biolator (4 oz./acre), and Sylgard 309 (0.4 oz./acre).

Table 6. Treatment information, Boll Set study, Heiden, Buckeye, AZ, 1998**.**

Treatment 1	Check – No Application of Boll set
Treatment 2	1 Application of Boll set – 18 July
Treatment 3	2 Applications of Boll set – 18 July and 3 August

*1 application of Boll Set consists of the following: Foligro Maximize (2 qts./acre). Potassium nitrate (8.5 lbs./acre), Biolator (4 oz./acre), and Sylgard 309 (0.4 oz./acre).

Table 7. Soil test results, Boll Set study, Heiden, Buckeye, AZ, 1998.

pH (1:1 H_2O)	**Ca* (ppm)**	**Mg (ppm)**	**Na (ppm)**	**K (ppm)**	**EC_e (mmhos/cm)**	**NO_3^--N** (ppm)**	**P*** (ppm)**	**ESP§**	**Zn (ppm)**
8.5	5600	420	450	350	3.0	19.8	27	5.7	1.6

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 8. Lint yield results, Boll Set study, Heiden,Buckeye, AZ, 1998.

Treatment	**Yield**
2	1212 a*
1	1195 a
3	1151 a
LSD**	NS
OSL†	0.1090
C.V. (%)	1.30

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 9. Agronomic information, micronutrient study, Skousen, Coolidge, AZ, 1998.

Soil Type	Laveen Loam
Variety	Deltapine 33B
Planting Date	4 May 1998
Harvest Date	27 October 1998

Table 10. Treatment information, micronutrient study, Skousen, Coolidge, AZ, 1998.

Treatment 1	80 lbs. N/acre (Urea) pre-plant
Treatment 2	Meister + 1 qt. HM9424 at planting
Treatment 3	Same as 2 + 1 qt. HM9014 + 1 qt. HM9664 At PHS and at PHS + 2 weeks + 4 qt. HM9716 at peak bloom
Treatment 4	Meister (95 lbs. N/acre) pre-plant
Treatment 5	80 lbs. N/acre (Urea) + 1 qt. HM9424 at planting
Treatment 6	Same as 5 + 1 qt. HM9014 At PHS and at PHS + 2 weeks
Treatment 7	Same as 6 + 4 qt. HM9716 at peak bloom

*Products have the following analysis:

Meister: slow release nitrogen (poly-coated) 40-0-0
HM9716: (Coron) slow release liquid nitrogen 28-0-0
HM9424: (Asset) soil applied 6-20-5 + 0.02% B, 0.05% Cu, 0.1% Fe, 0.05% Mn, 0.05% Zn, 0.0005% Mo
HM9014: (Bayfolan) foliar applied 11-8-5 + 0.02% B, 0.0005% Co, 0.05% Cu, 0.1% Fe, 0.05% Mn, 0.05% Zn, 00005% Mo
HM9664: (Empower) foliar applied 5-0-0 + cytokinins, trace amounts of B and Mo

Table 11. Soil test results, micronutrient study, Skousen, Coolidge, AZ, 1998.

pH (1:1 H_2O)	Ca* (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	EC_e (mmhos/cm)	NO_3^--N** (ppm)	P*** (ppm)	ESP§	Zn (ppm)
8.5	6200	340	230	360	1.4	22.2	42	2.8	1.3

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 12. Lint yield results, micronutrient study, Skousen, Coolidge, AZ, 1997.

Treatment	Yield
5	1748 a*
1	1617 ab
3	1583 ab
2	1518 ab
7	1518 ab
4	1441 b
6	1391 b
LSD**	177
OSL†	0.0110
C.V. (%)	7.73

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 13. Agronomic information, phosphorus study, Layton, Graham County, AZ, 1998.

Soil Type	Grabe clay loam / Anthony sandy loam complex
Variety	Pima HTO
Planting Date	21 April 1998
Harvest Date	23 October 1998

Table 14. Treatment information, phosphorus study, Layton, Graham County, AZ, 1998.

Treatment 1	Check – No Application of P
Treatment 2	114 lbs. P_2O_5 /acre (11-52-0) Pre-plant

Table 15. Soil test results, phosphorus study, Layton, Graham County, AZ, 1998.

pH (1:1 H_2O)	**Ca* (ppm)**	**Mg (ppm)**	**Na (ppm)**	**K (ppm)**	**EC_e (mmhos/cm)**	**NO_3^--N** (ppm)**	**P*** (ppm)**	**ESP§**	**Free Lime**
7.9	7200	580	720	530	6.8	212	6.8	6.9	High

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 16. Lint yield results, phosphorus study, Layton, Graham County, AZ, 1998.

Treatment	**Yield**
1	812 a*
2	868 a
LSD**	NS
OSL†	0.3713
C.V. (%)	10.32

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 17. Agronomic information, phosphorus study, Claridge, Graham County, AZ, 1998.

Soil Type	Grabe clay loam
Variety	Pima HTO
Planting Date	20 April 1998
Harvest Date	10 November 1998

Table 18. Treatment information, phosphorus study, Claridge, Graham County, AZ, 1998.

Treatment 1	Check – No Application of P
Treatment 2	30 lbs./ P_2O_5 /acre (10 gal./acre 9-26-0:) pre-plant
Treatment 3	30 lbs./ P_2O_5 / acre (10 gal/acre 9-26-0:) pre-plant + 12 gal/acre UAN32 (42.5 lbs N)
Treatment 4	30 lbs./ P_2O_5 / acre (10 gal/acre 9-26-0:) pre-plant + 25 gal/acre UAN32 (88.5 lbs N)

Table 19. Soil test results, phosphorus study, Claridge, Graham County, AZ, 1998.

pH (1:1 H_2O)	Ca* (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	EC_e (mmhos/cm)	NO_3^--N** (ppm)	P*** (ppm)	ESP§	Free Lime
8.2	6700	770	440	680	1.2	17	7.6	4.4	High

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 20. Lint yield results, phosphorus study, Claridge, Graham County, AZ, 1998.

Treatment	Yield
1	1103 b*
2	1198 a
3	1192 a
4	1202 a
LSD**	59.9
OSL†	0.0126
C.V. (%)	3.19

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 21. Agronomic information, phosphorus study, Ollerton, Coolidge, AZ, 1998.

Soil Type	LaPalma sandy loam
Variety	Deltapine 9834BRR
Planting Date	12 May 1998
Harvest Date	17 November 1998

Table 22. Treatment information, phosphorus study, Ollerton, Coolidge, AZ, 1998.

Treatment 1	Check – No Application of P
Treatment 2	75 lbs.P_2O_5 /acre (20 gal/acre 10-34-0)

Table 23. Soil test results, phosphorus study, Ollerton, Coolidge, AZ, 1998.

pH (1:1 H_2O)	**Ca* (ppm)**	**Mg (ppm)**	**Na (ppm)**	**K (ppm)**	**EC_e (mmhos/cm)**	**NO_3^- N** (ppm)**	**P*** (ppm)**	**ESP§**	**Free Lime**
8.5	6000	330	140	320	0.7	6.0	3.5	1.8	High

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 24. Lint yield results, phosphorus study, Ollerton, Coolidge, AZ, 1998.

Treatment	**Yield**
1	1026 a*
2	950 a
LSD**	NS
OSL†	0.2986
C.V. (%)	8.73

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 25. Agronomic information, zinc study, Ollerton, Coolidge, AZ, 1998.

Soil Type	LaPalma sandy loam
Variety	Deltapine 90
Planting Date	30 April 1998
Harvest Date	15 November 1998

Table 26. Treatment information, zinc study, Ollerton, Coolidge, AZ, 1998.

Treatment 1	Check – No Application of Zn
Treatment 2	35 lbs./acre (10 gal./acre UN32) + 10 lbs. Zn/acre (50 lbs./acre Nulex)

Table 27. Soil test results, zinc study, Ollerton, Coolidge, AZ, 1998.

pH (1:1 H_2O)	Ca* (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	EC_e (mmhos/cm)	NO_3^- N** (ppm)	P*** (ppm)	ESP§	Zn (ppm)
8.7	5900	420	160	600	1.1	2.8	5.7	2.0	0.40

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 28. Lint yield results, zinc study, Ollerton, Coolidge, AZ, 1998.

Treatment	Yield
1	536 a*
2	555 a
LSD**	NS
OSL†	0.837
C.V. (%)	21.53

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 29. Agronomic information, phosphorus study, Layton, Graham County, AZ, 1999.

Soil Type	Grabe clay loam / Anthony sandy loam complex
Variety	Pima HTO
Planting Date	25 April 1999
Harvest Date	11 November 1999

Table 30. Treatment information, phosphorus study, Layton, Graham County, AZ, 1999.

Treatment 1	Check – No Application of P
Treatment 2	84 lbs. P_2O_5 /acre (10-34-0) Pre-plant

Table 31. Soil test results, phosphorus study, Layton, Graham County, AZ, 1999.

pH (1:1 H_2O)	Ca* (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	EC_e (mmhos/cm)	NO_3^--N** (ppm)	P*** (ppm)	ESP§	Free Lime
8.3	7700	820	620	620	2.0	25.4	7.1	5.4	High

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 32. Lint yield results, phosphorus study, Layton, Graham County, AZ, 1999.

Treatment	Yield
1	951 a*
2	976 a
LSD**	NS
OSL†	0.4435
C.V. (%)	4.23

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 33. Agronomic information, phosphorus study, Claridge, Graham County, AZ, 1999.

Soil Type	Grabe clay loam
Variety	Pima HTO
Planting Date	20 April 1998
Harvest Date	10 November 1998

Table 34. Treatment information, phosphorus study, Claridge, Graham County, AZ, 1999.

Treatment 1	Check – No Application of P
Treatment 2	22 lbs./ P_2O_5 /acre (7.5 gal./acre 9-26-0:) pre-plant
Treatment 3	43 lbs./ P_2O_5 / acre (15 gal/acre 9-26-0:) pre-plant
Treatment 4	65 lbs./ P_2O_5 / acre (22.5 gal/acre 9-26-0:) pre-plant
Treatment 5	22 lbs./P_2O_5 /acre (7.5 gal/acre 9-26-0) pre-plant

Table 35. Soil test results, phosphorus study, Claridge, Graham County, AZ, 1999.

pH (1:1 H_2O)	Ca* (ppm)	Mg (ppm)	Na (ppm)	K (ppm)	EC_e (mmhos/cm)	NO_3^--N** (ppm)	P*** (ppm)	ESP§	Free Lime
8.3	6300	560	390	550	1.6	17.2	11.0	4.3	High

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 36. Lint yield results, phosphorus study, Claridge, Graham County, AZ, 1999.

Treatment	Yield
1	1268 a*
2	1255 a
3	1278 a
4	1250 a
LSD**	NS
OSL†	0.8857
C.V. (%)	4.34

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 37. Agronomic information, phosphorus study, Sierra Negra, Maricopa County, AZ, 1999.

Soil Type	Gilman loam
Variety	Deltapine 33B
Planting Date	17 April 1999
Harvest Date	11 November 1999

Table 38. Treatment information, phosphorus study, Sierra Negra, Maricopa County, AZ, 1999.

Treatment 1	Check – No Application of P
Treatment 2	38 lbs. P_2O_5 /acre (10-34-0) Pre-plant

Table 39. Soil test results, phosphorus study, Sierra Negra, Maricopa County, AZ, 1999.

pH (1:1 H_2O)	**Ca* (ppm)**	**Mg (ppm)**	**Na (ppm)**	**K (ppm)**	**EC_e (mmhos/cm)**	**NO_3^--N** (ppm)**	**P*** (ppm)**	**ESP§**	**Free Lime**
8.2	6600	230	480	530	3.8	48.6	11.0	5.4	High

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 40. Lint yield results, phosphorus study, Sierra Negra, Maricopa County, AZ, 1999.

Treatment	**Yield**
1	1199 a*
2	1129 a
LSD**	NS
OSL†	0.278
C.V. (%)	6.44

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 41. Agronomic information, phosphorus study, Harrrison, Yuma County, AZ, 1999.

Soil Type	Kofa clay
Variety	Deltapine 50B
Planting Date	10 April 1999
Harvest Date	11 November 1999

Table 42. Treatment information, phosphorus study, Harrison, Yuma County, AZ, 1999.

Treatment 1	Check – No Application of P
Treatment 2	114 lbs. P_2O_5 /acre (0-52-0) Pre-plant

Table 43. Soil test results, phosphorus study, Harrison, Yuma County, AZ, 1999.

pH (1:1 H_2O)	**Ca* (ppm)**	**Mg (ppm)**	**Na (ppm)**	**K (ppm)**	**EC_e (mmhos/cm)**	**NO_3^--N** (ppm)**	**P*** (ppm)**	**ESP§**	**Free Lime**
8.0	7400	950	400	400	3.0	6.0	8	4.0	High

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 44. Lint yield results, phosphorus study, Harrrison, Yuma County, AZ, 1999.

Treatment	**Yield**
1	1172 a*
2	1154 a
LSD**	NS
OSL†	0.506
C.V. (%)	2.403

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 45. Agronomic information, phosphorus study, Hart, Maricopa County, AZ, 1999.

Soil Type	Grabe clay loam
Variety	Sure Grow 125
Planting Date	16 April 1998
Harvest Date	27 November 1998

Table 46. Treatment information, phosphorus study, Hart, Maricopa County, AZ, 1999.

Treatment 1	Check – No Application of P
Treatment 2	0 soil + standard foliar (5 lbs./acre of 20-20-20 with Nomate PBW)
Treatment 3	soil (75 lbs. P_2O_5 /acre, 20 gal./acre 10-34-0) + standard foliar (5 lbs./acre of 20-20-20 with Nomate PBW)
Treatment 4	0 soil + foliar (1 quart Nutra Flow ZMP + 1 pint Sorba Spray ZBK/acre with NOmate PBW)
Treatment 5	soil (75 lbs. P_2O_5/acre, 20 gal./acre 10-34-0) + foliar (1 quart Nutrea Flo ZMP + 1 pint Sorba Spray ZBK/acre with Nomate PBW)

Products have the following analysis:

Nutra Flow ZMP: Available Phosphate = 6%, Calcium = 3%, Manganese = 6%, Zinc = 6%, Sulfur = 1.2%
Sorba Spray ZBK: Available N = 1%, Available Potassium = 6%, Zinc = 1%, Boron = 1%

Table 47. Soil test results, phosphorus study, Hart, Maricopa County, AZ, 1999.

pH (1:1 H_2O)	**Ca* (ppm)**	**Mg (ppm)**	**Na (ppm)**	**K (ppm)**	**EC_e (mmhos/cm)**	**NO_3^--N** (ppm)**	**P*** (ppm)**	**ESP§**	**Free Lime**
8.3	4400	490	350	490	3.0	13.6	8.6	5.3	Medium

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 48. Lint yield results, phosphorus study, Hart, Maricopa County, AZ, 1999.

Treatment	**Yield**
1	1310 ab*
2	1256 ab
3	1385 a
4	1199 b
5	1225 ab
LSD**	NS
OSL†	0.2075
C.V. (%)	7.33

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

Table 49. Agronomic information, phosphorus and zinc study, Ollerton, Pinal County, AZ, 1999.

Soil Type	Toltec fine sandy loam
Variety	Agropro 6101
Planting Date	20 April 1999
Harvest Date	29 November 1999

Table 50. Treatment information, phosphorus and zinc study, Ollerton, Pinal County, AZ, 1999.

Treatment 1	Check – No Application of P
Treatment 2	56 lbs. P_2O_5 /acre (10-34-0) Pre-plant
Treatment 3	56 lbs. P_2O_5 /acre (10-34-0) Pre-plant + 10 lbs. Zn/acre (5 gal./acre Nulex Zn)

Table 51. Soil test results, phosphorus and zinc study, Ollerton, Pinal County, AZ, 1999.

pH (1:1 H_2O)	**Ca* (ppm)**	**Mg (ppm)**	**Na (ppm)**	**K (ppm)**	**Zn (ppm)**	**NO_3^--N** (ppm)**	**P*** (ppm)**	**ESP§**	**Free Lime**
8.2	7100	360	210	460	0.32	15	3.0	5.3	High

* Exchangeable cations using neutral molar ammonium acetate.
** NO_3^--N using specific ion electrode.
*** $NaHCO_3$ extractable P.
§ Computed - exchangeable sodium percentage.

Table 52. Lint yield results, phosphorus and zinc study, Ollerton, Pinal County, AZ, 1999.

Treatment	**Yield**
1	976 b*
2	1131 a
3	1085 a
LSD**	65.87
OSL†	0.0053
C.V. (%)	2.74

* Means followed by the same letter are not significantly different according to a Fisher's means separation test.
**Least Significant Difference
†Observed Significance Level
Coefficient of Variation

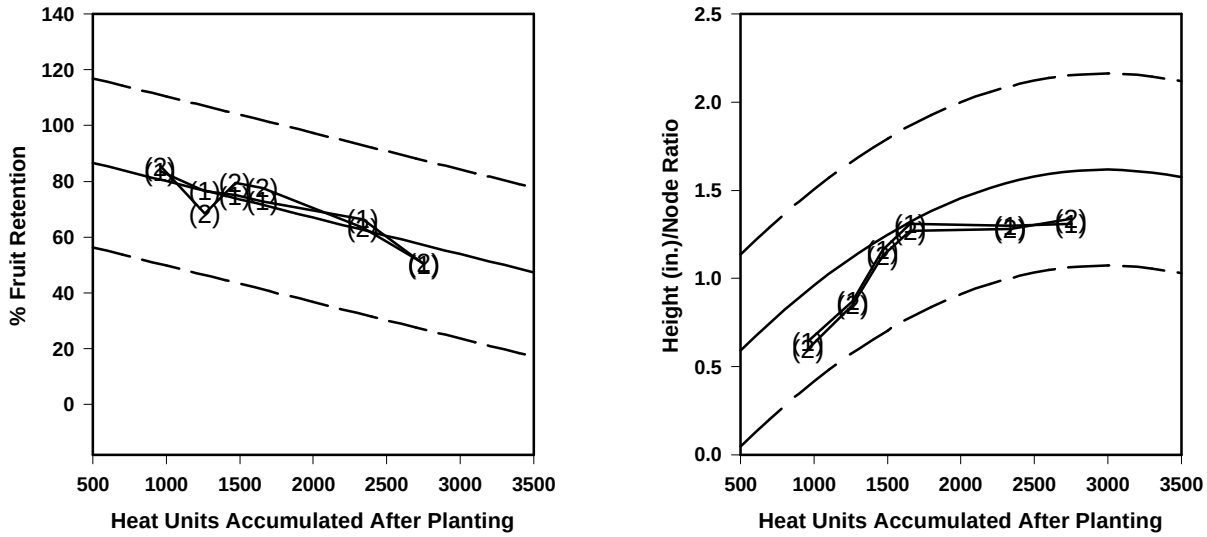

Figure 1. Fruit retention and height to node ratio results, potassium study, Cockrill, Coolidge, AZ, 1997.

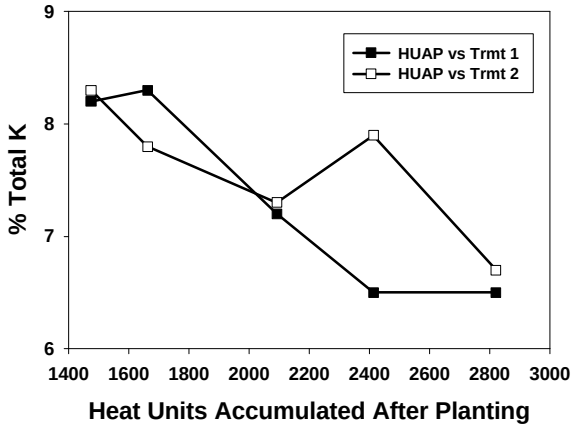

Figure 2. Plant tissue analysis results, potassium, potassium study, Cockrill, Coolidge, AZ, 1997.

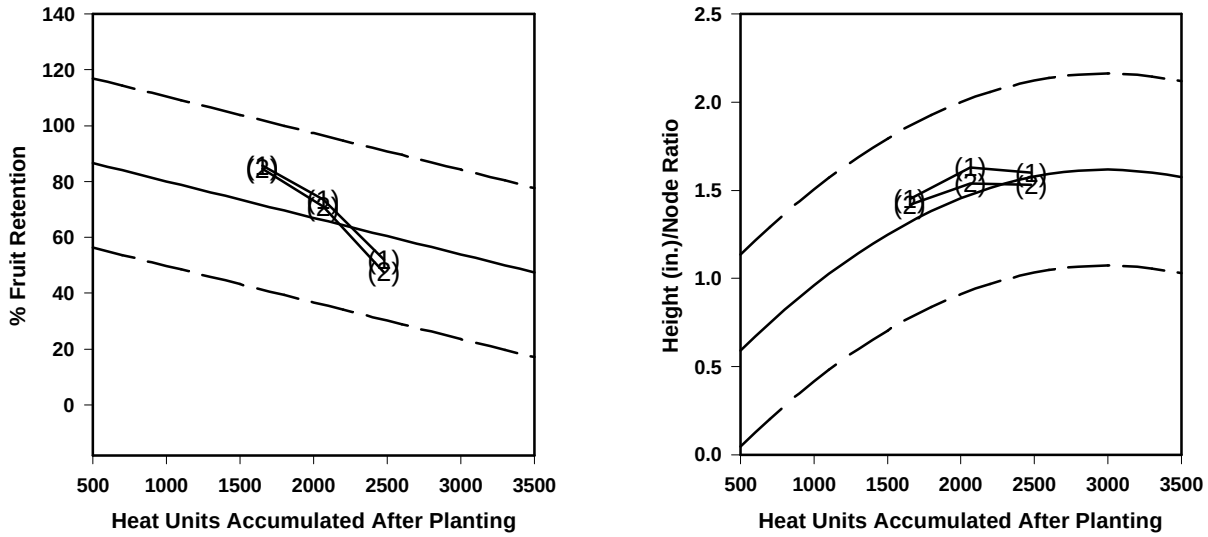

Figure 3. Fruit retention and height to node ratio results, Boll Set Study, Buckeye, AZ, 1998.

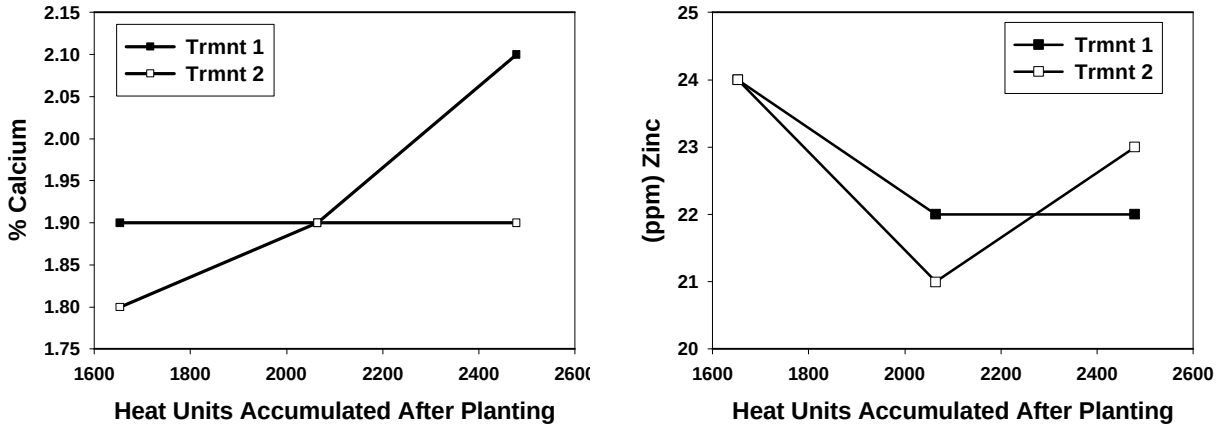

Figure 4. Plant tissue results, calcium and zinc, Boll Set study, Buckeye, AZ, 1999.

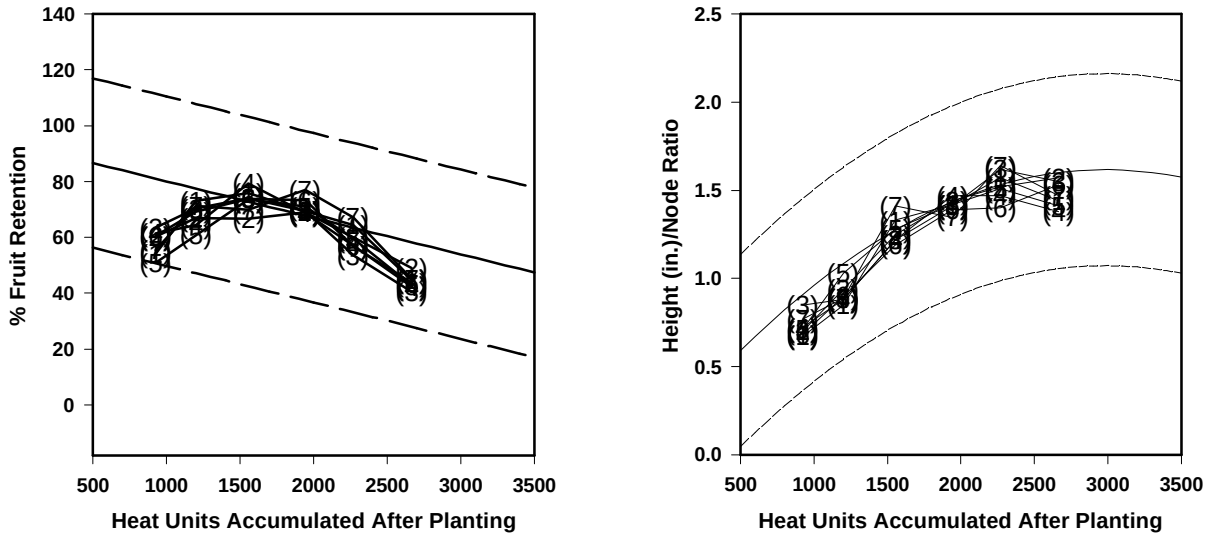

Figure 5. Fruit retention and height to node ratio results, micronutrient study, Skousen, Coolidge, AZ, 1998.

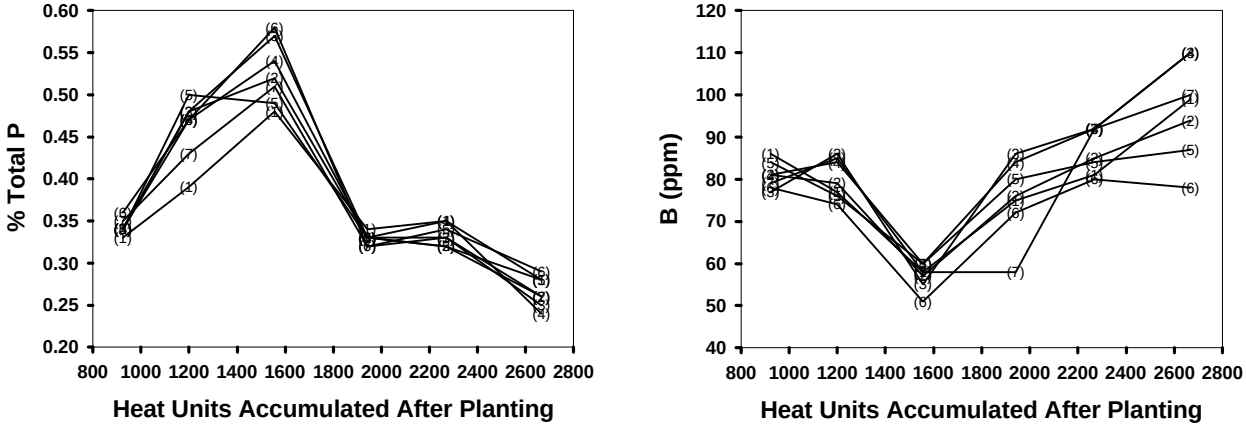

Figure 6. Plant tissue analysis results, phosphorus and boron, micronutrient study, Skousen, Coolidge, AZ, 1998.

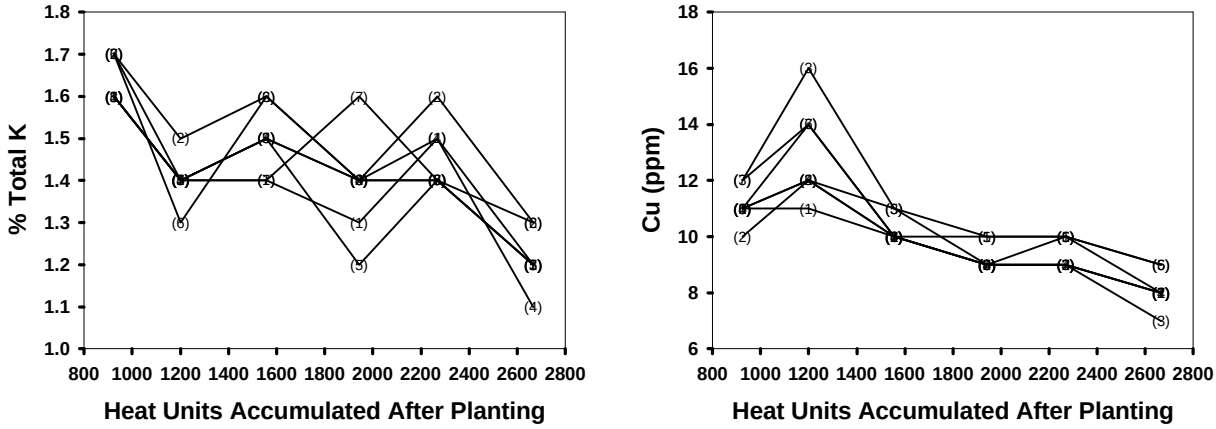

Figure 7. Plant tissue analysis results, potassium and copper, micronutrient study, Skousen, Coolidge, AZ, 1998.

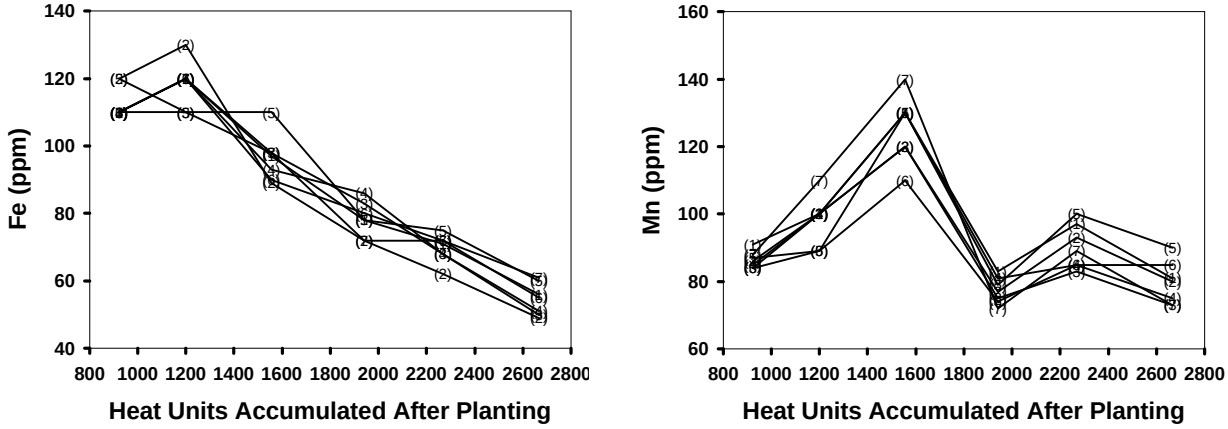

Figure 8. Plant tissue analysis results, iron and manganese, micronutrient study, Skousen, Coolidge, AZ, 1998.

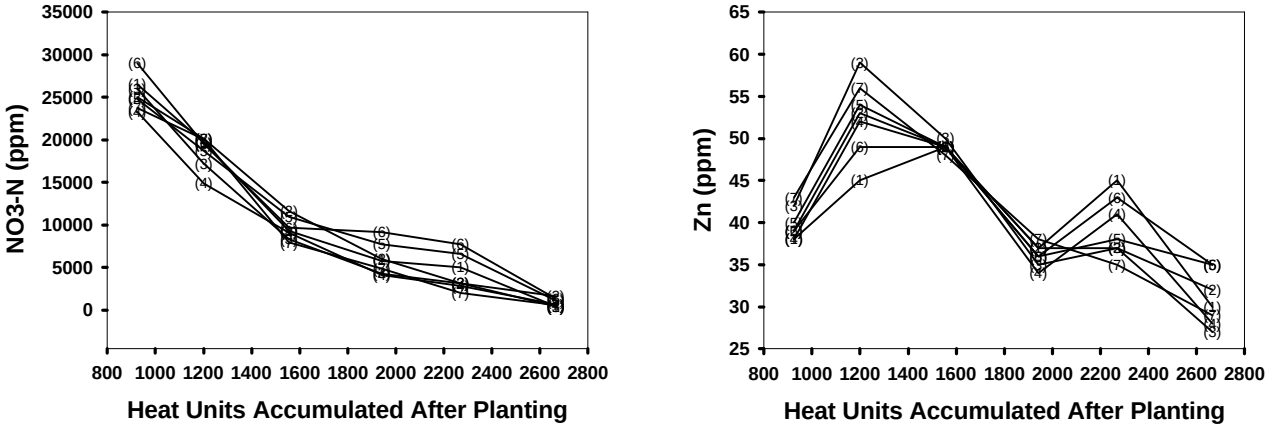

Figure 9. Plant tissue analysis results, nitrate nitrogen and zinc, micronutrient study, Skousen, Coolidge, AZ, 1998.

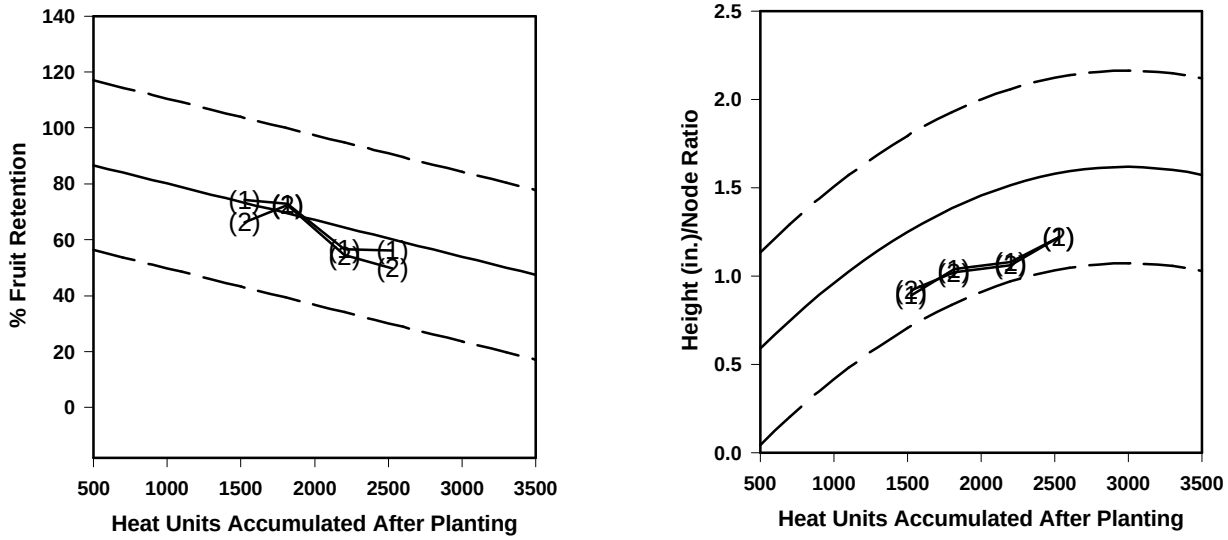

Figure 10. Fruit retention and height to node ratio results, phosphorus study, Layton, Graham County, AZ, 1998.

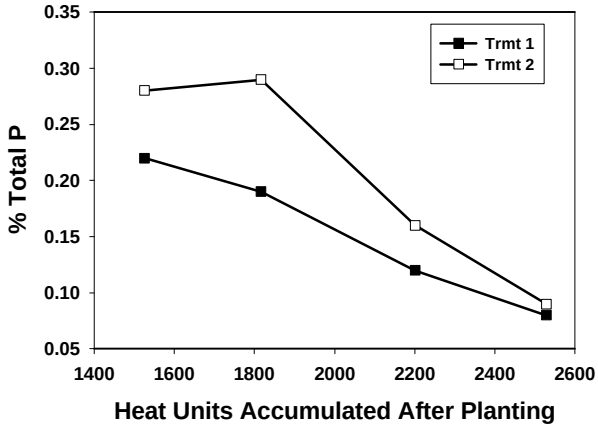

Figure 11. Plant tissue analysis results, phosphorus, phosphorus study, Layton, Graham County, AZ, 1999.

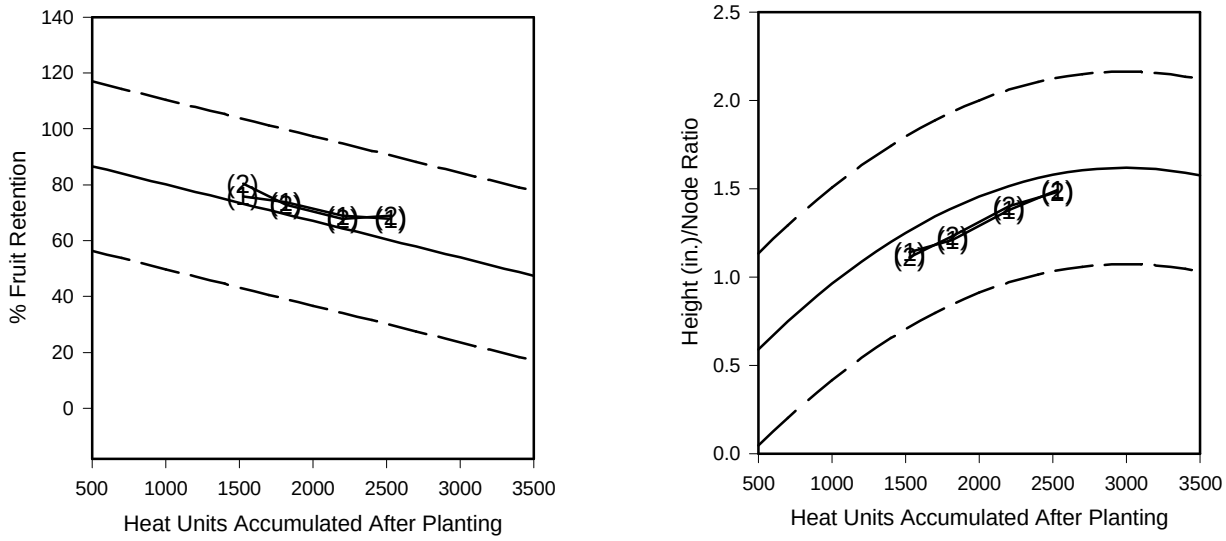

Figure 12. Fruit retention and height to node ratio results, Claridge, Graham County, AZ, 1998.

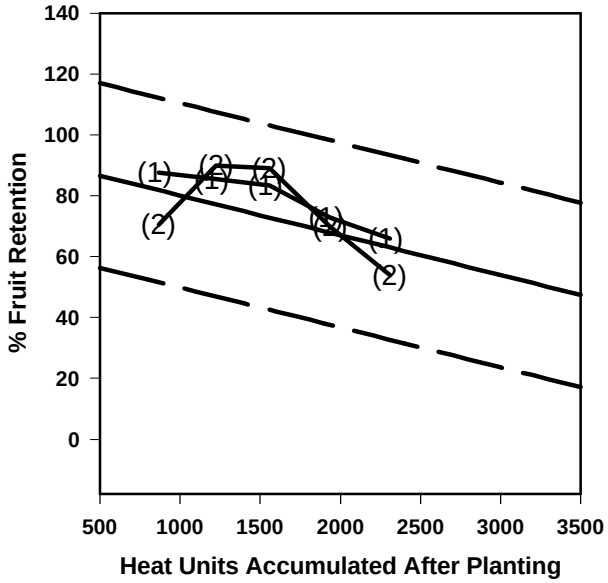

Figure 13. Plant tissue analysis results, phosphorus, phosphorus study, Claridge, Graham County, AZ, 1998.

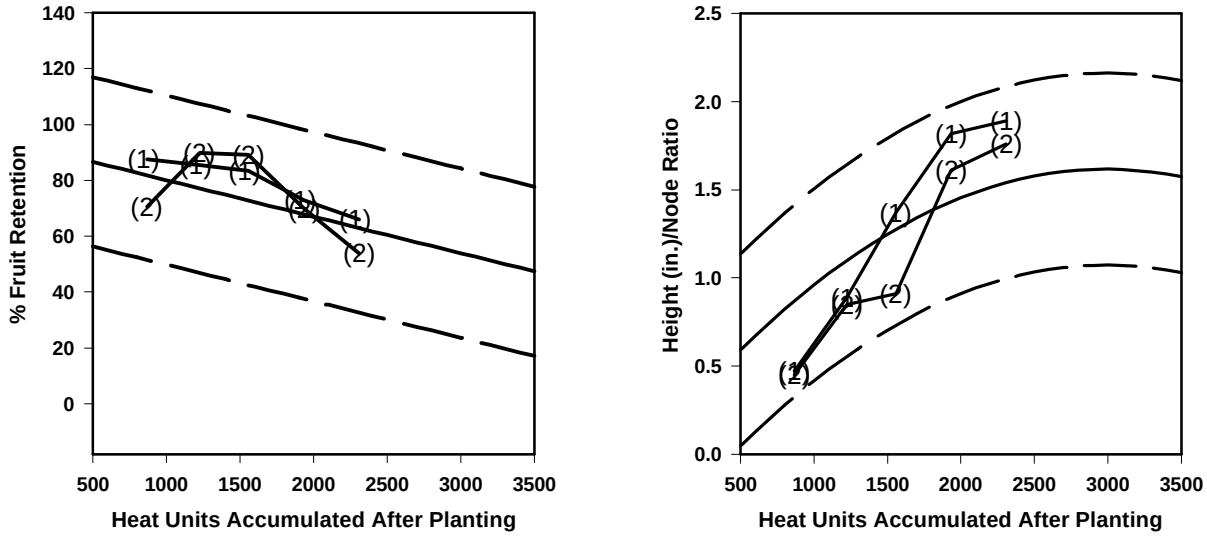

Figure 14. Fruit retention and height to node ratio results, phosphorus study, Ollerton, Coolidge, AZ, 1998.

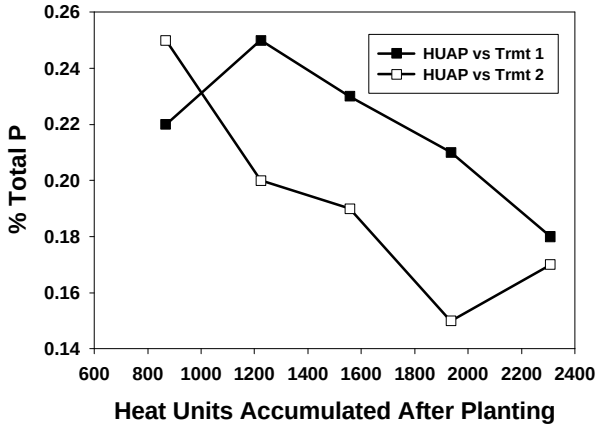

Figure 15. Plant tissue analysis results, phosphorus, phosphorus study, Ollerton, Coolidge, AZ, 1998.

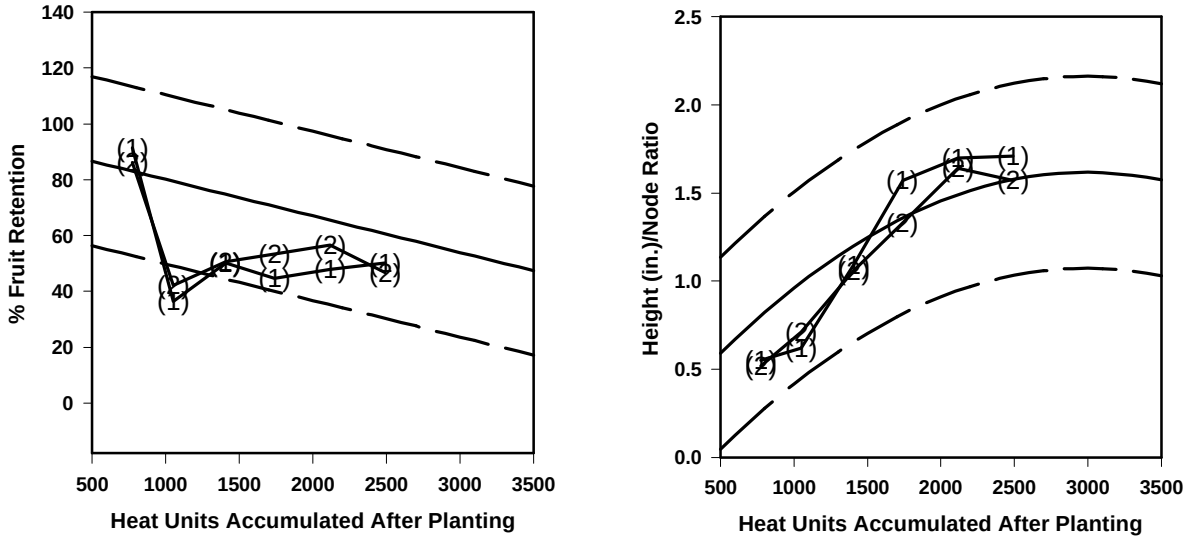

Figure 16. Fruit retention and height to node ratio results, zinc study, Ollerton, Coolidge, AZ, 1998.

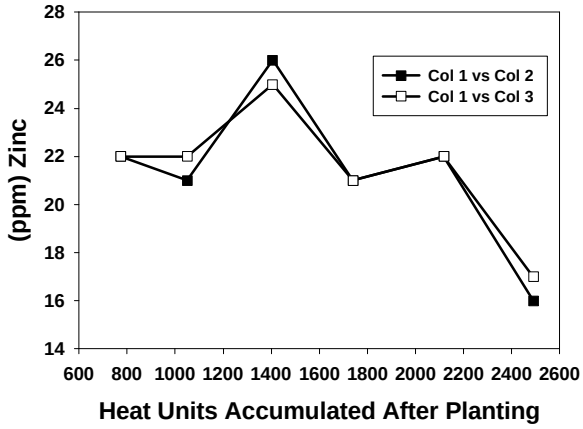

Figure 17. Plant tissue analysis results, zinc, zinc study, Ollerton, Coolidge, AZ, 1998.

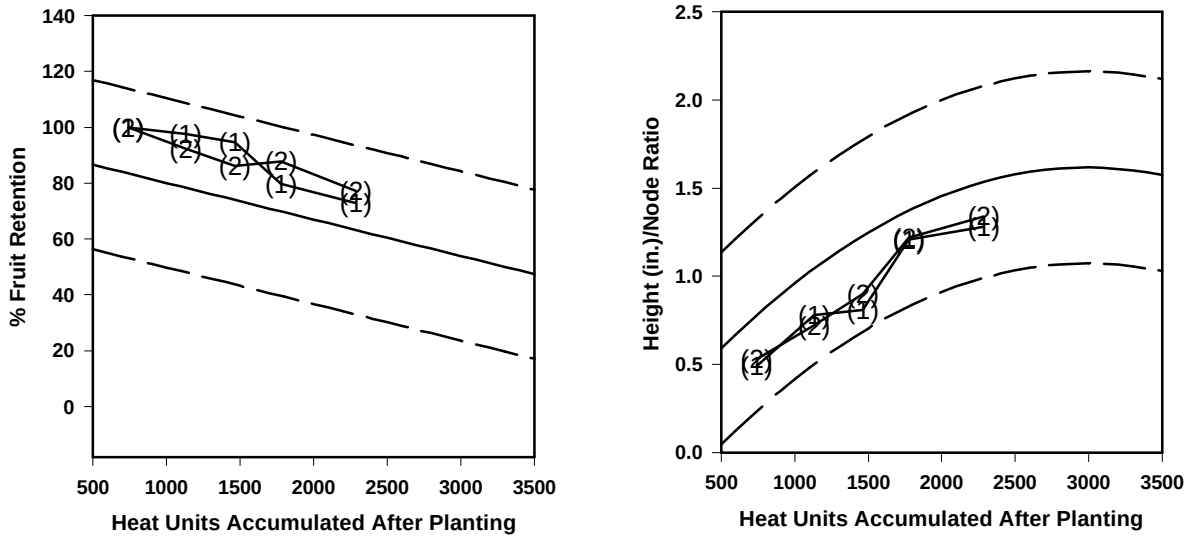

Figure 18. Fruit retention and height to node ratio results, phosphorus study, Layton, Graham County, AZ, 1999.

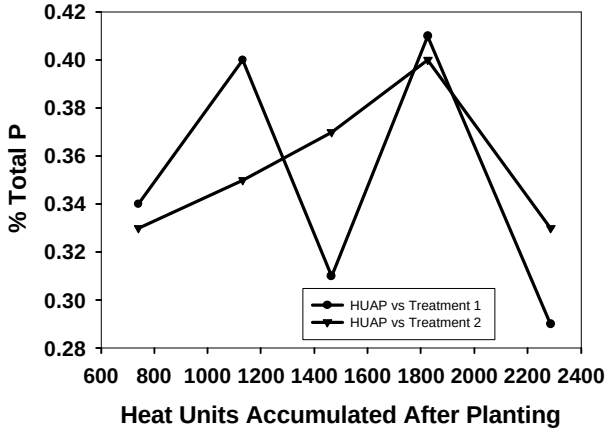

Figure 19. Plant tissue analysis results, phosphorus, phosphorus study, Layton, Graham County, AZ, 1999.

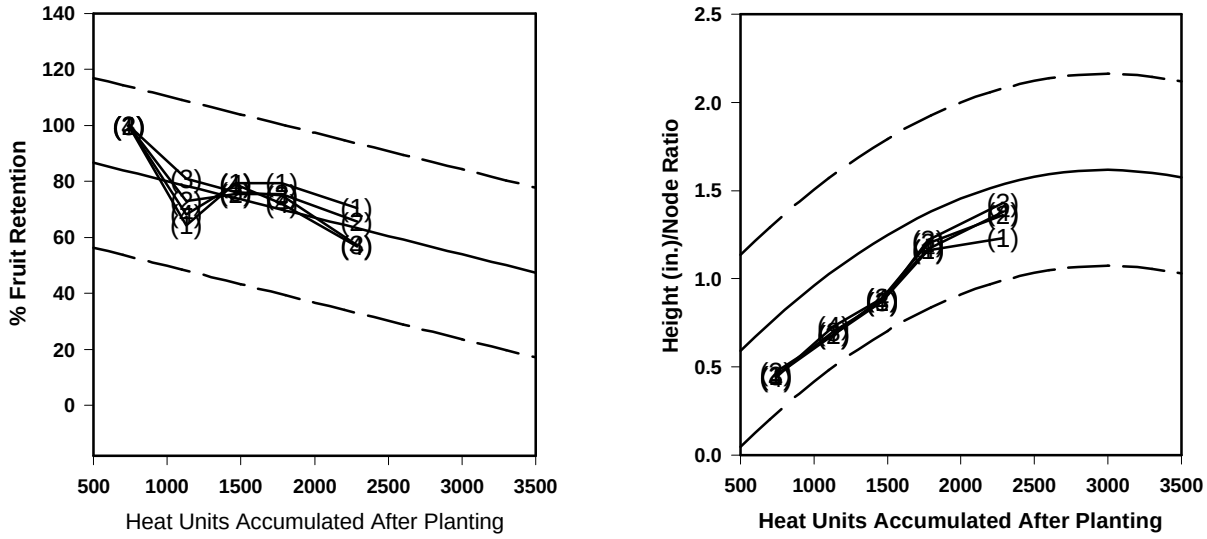

Figure 20. Fruit retention and height to node ratio results, phosphorus study, Claridge, Graham County, AZ, 1999.

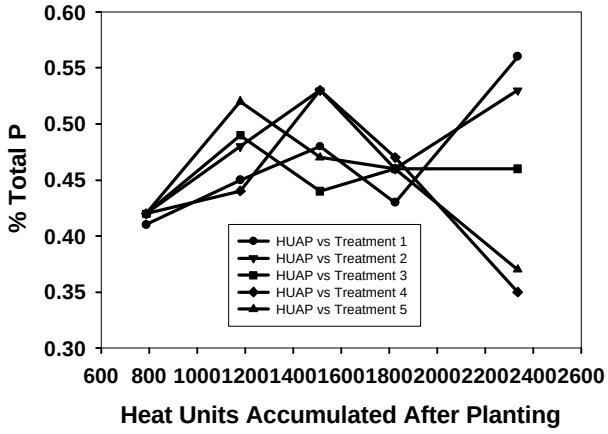

Figure 21. Plant tissue analysis results, phosphorus, phosphorus study, Claridge, Graham County, AZ, 1999.

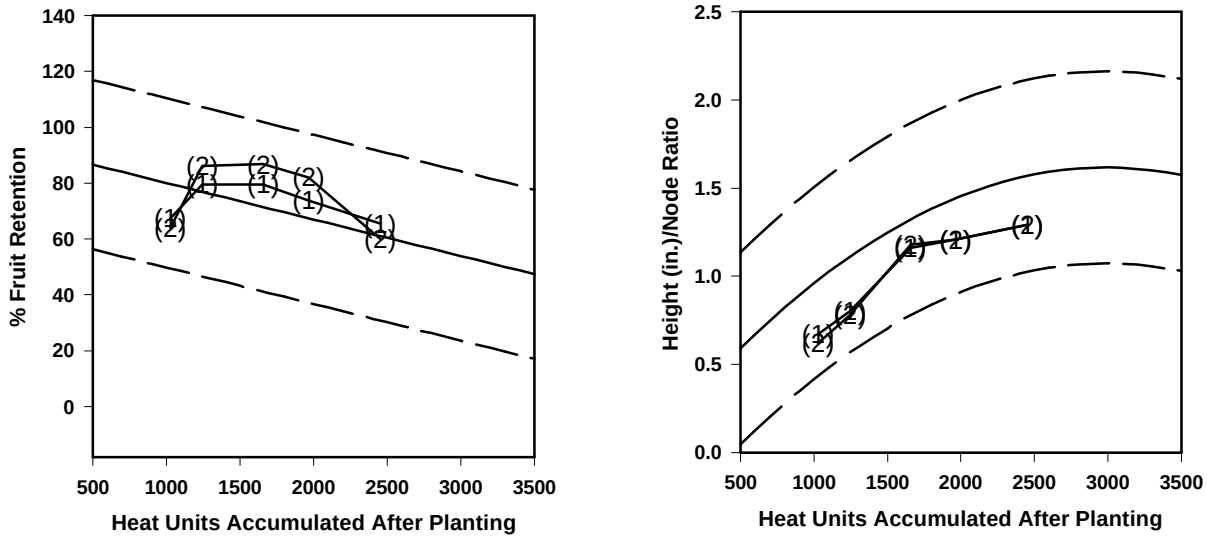

Figure 22. Fruit retention and height to node ratio results, phosphorus study, Sierra Negra, Maricopa County, AZ, 1999.

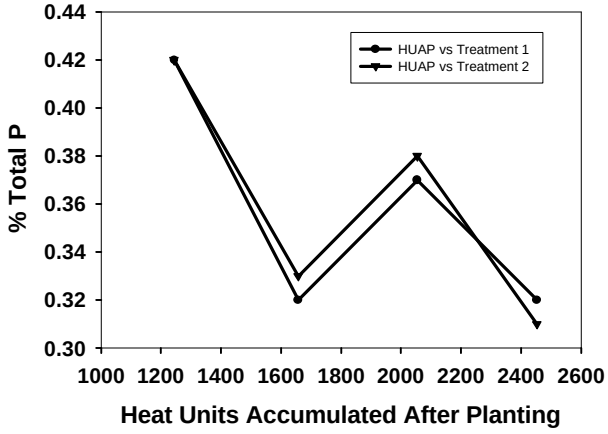

Figure 23. Plant tissue analysis results, phosphorus, phosphorus study, Sierra Negra, Maricopa County, AZ, 1999.

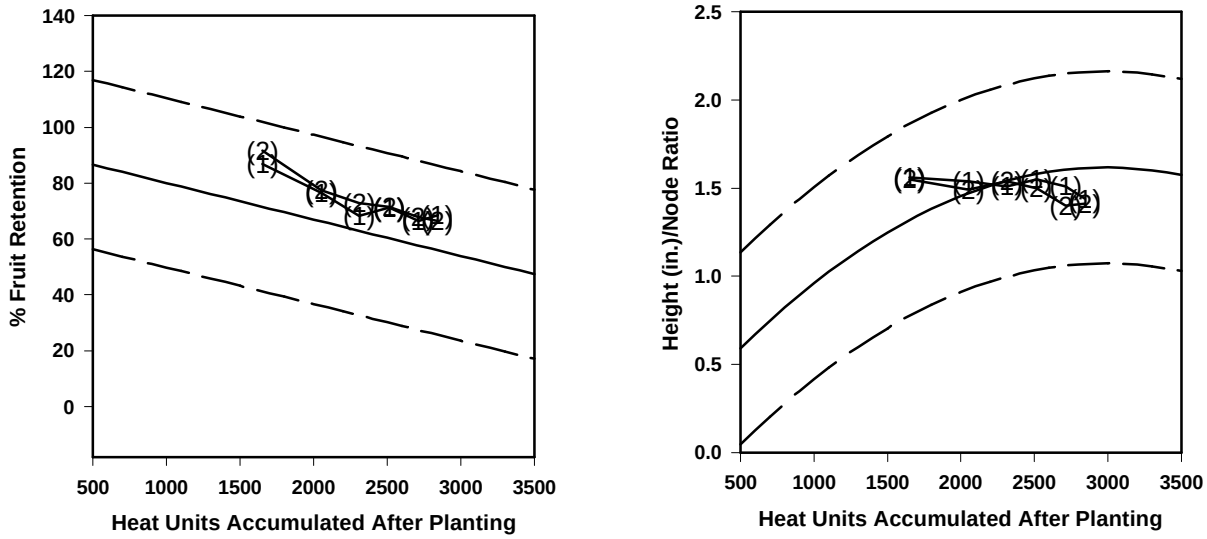

Figure 24. Fruit retention and height to node ratio results, phosphorus study, Harrison, Yuma County, AZ, 1999.

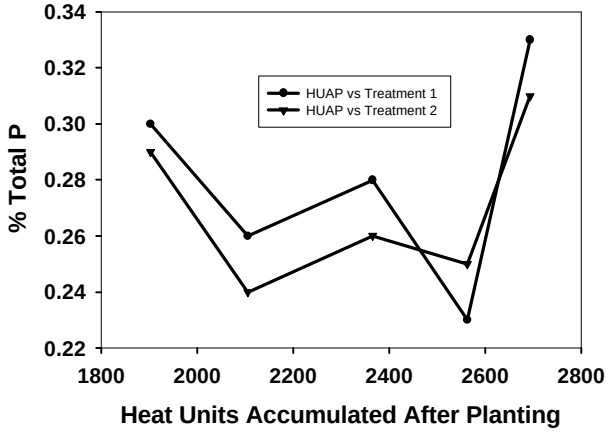

Figure 25. Plant tissue analysis results, phosphorus, phosphorus study, Harrison, Yuma County, AZ, 1999.

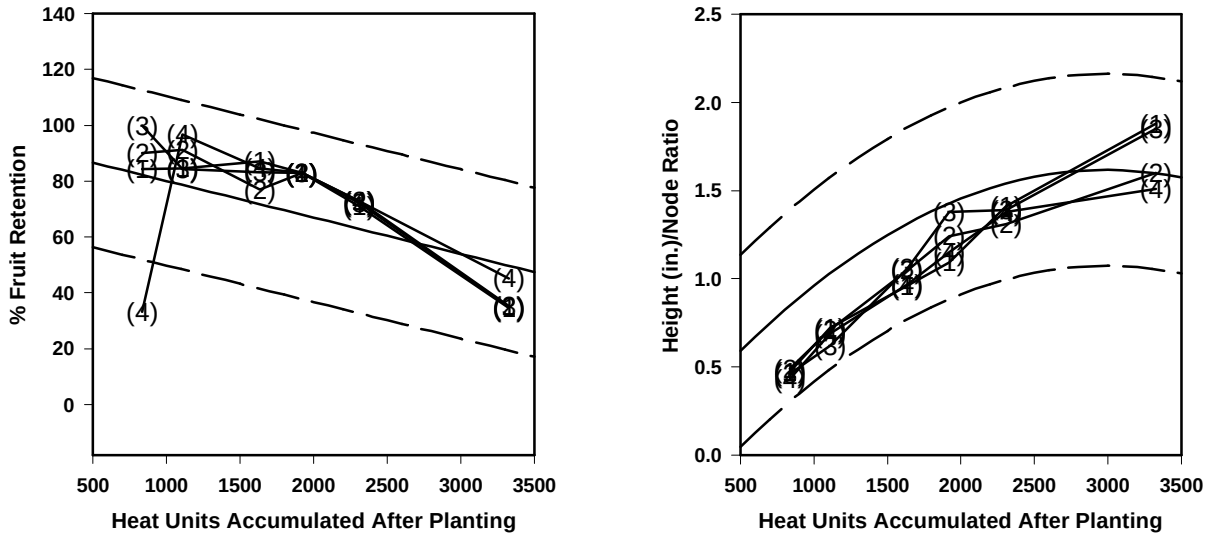

Figure 26. Fruit retention and height to node ratio results, phosphorus study, Hart, Maricopa County, AZ, 1999.

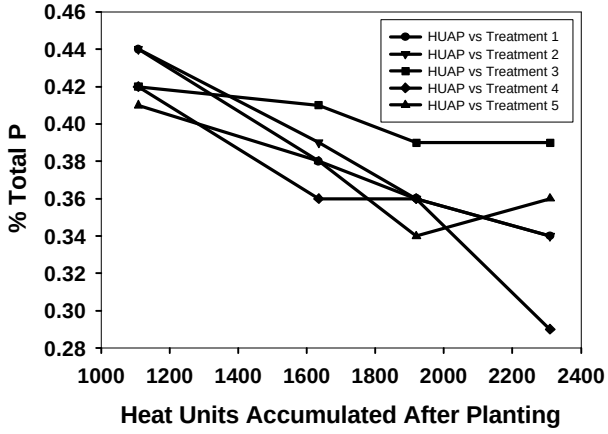

Figure 27. Plant tissue analysis results, phosphorus, phosphorus study, Hart, Maricopa County, AZ, 1999.

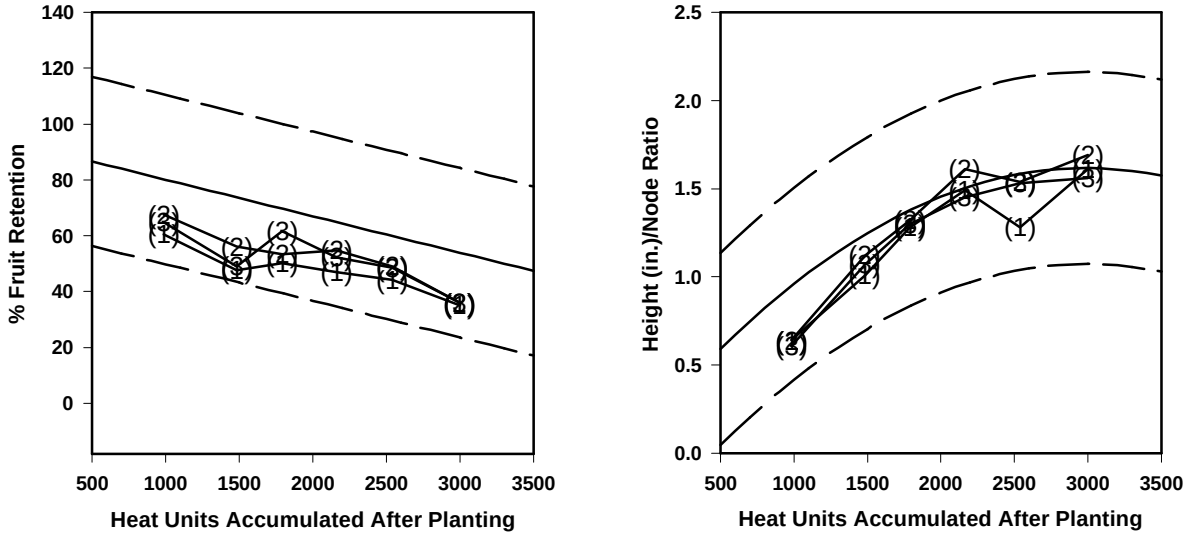

Figure 28. Fruit retention and height to node ratio results, phosphorus and zinc study, Ollerton, Pinal County, AZ, 1999.

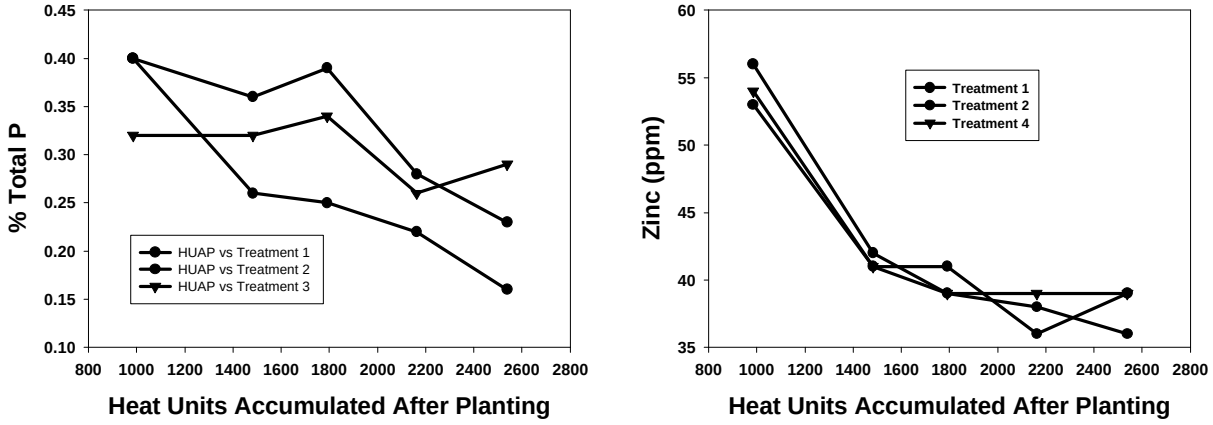

Figure 29. Plant tissue analysis results, phosphorus and zinc, phosphorus and zinc study, Ollerton, Pinal County, AZ, 1999.