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A REVIEW OF 10 YEARS OF PHOSPHORUS FERTILITY RESEARCH CONDUCTED IN ARIZONA

Randall Norton
University of Arizona
Safford, AZ
Jeffrey C. Silvertooth
University of Arizona
Tucson, AZ

Abstract

Management of phosphorus (P) fertilizer in cotton production systems of Arizona has been studied for many years. A series of field experiments have been conducted across Arizona since 1989 with the most recent trial conducted in 2004. These trials represent over 15 site-years of research investigating the response of upland cotton (*Gossypium hirsutum* L.) to the application of P fertilizers and have been conducted over a wide range of environmental conditions. A summary of these field trials is presented in this paper. All trials were structured in a similar fashion with a control being compared to various rates of applied P fertilizer ranging from 0 to over 120 lbs P_2O_5 per acre. All trials had a similar experimental design with large plots (minimum of 0.16 acres) and treatments arranged in a randomized complete block design with a minimum of three replications in all cases. All applications were made either pre-plant or shortly after stand establishment. A wide range of soil test P levels were evaluated at many locations across the State. Results indicate that the critical level for sodium bicarbonate extractable P is 5 parts per million (ppm) with a 90% probability of a positive lint yield response when soil test levels fall below the critical level. Effective (positive crop response) fertilization rates range from 60-90 lbs of P_2O_5 per acre.

Introduction

Phosphorus (P) is one of the major nutrients required for growth and development in all higher plants. Major physiological processes within the plant require sufficient levels of P for proper function. These processes include energy storage and the synthesis of structural components of the plant including nucleic acids. Sufficient levels of P within the plant are critical for the proper development of root systems (Borkert and Barber, 1985; and Yao and Barber, 1986). Specifically in Upland cotton (*Gossypium hirsutum* L.) systems, root growth stimulation has been observed with the addition of P fertilizers (Mullins, 1993). Deficiency of P in cotton is generally manifested by stunted growth and dark green foliage while extreme P deficiencies may result in the expression of anthocyanin pigments resulting in a purple coloration of the older leaf tissue. A delay in the onset of fruiting forms in cotton may also be attributed to deficient levels of P within the plant. Fiber quality may also be affected by P deficiency resulting in shortened fiber length and decreased seed weight (Mikkelsen and Hoover, 1952).

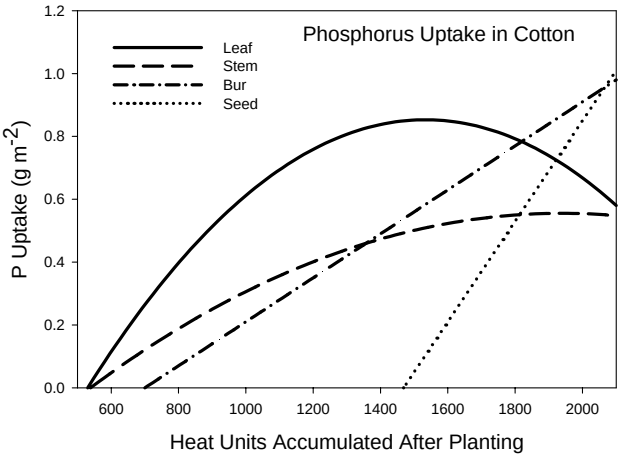


Figure 1. Phosphorus uptake patterns as a function of heat units accumulated after planting for various components of the cotton plant.

As with any other nutrient in crop production, P fertilizer management is critical to achieving optimum yields. Research has shown that approximately 11 lbs. P/acre are required by a cotton crop to produce one bale (490 lbs.) of lint (Unruh and Silvertooth, 1996). Figure 1 illustrates the uptake pattern of P in cotton as a function of heat units accumulated after planting (HUAP, 86/55^{o}F). Phosphorus uptake is partitioned into plant parts in relation to primary sinks such as fruiting forms, specifically the burs and seeds. The P taken up by a cotton crop must come from either native soil P or from supplemental fertilizers. Therefore, an assessment of plant-available soil P is important in determining the P supplying power of the soil. This may be accomplished through the process of obtaining a soil sample and having the sample appropriately analyzed for extractable P.

Phosphorus is a very dynamic nutrient in the soil-plant system. Numerous reactions can occur in the soil environment that affects P availability to the plant. Precipitation of soluble phosphates to insoluble complexes with Fe, Al, or Ca can result in soil P forms that are not available for plant uptake. Many soil P reactions are strongly dependent upon the dominant chemical environment of the soil. Arizona soils are dominated by the basic cations (calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na)) which can contribute to the formation of insoluble P complexes, predominately with Ca. In order for a cotton plant to utilize P from the soil solution, the preferable form for uptake is orthophosphate (HPO_4^{2-}). Both the pyro and polyphosphate fertilizers must first break down to orthophosphate prior to plant uptake. Insoluble complexes of either Ca or Mg phosphates are entirely unavailable for plant uptake and utilization. Therefore, total soil P levels are not necessarily indicative of plant-available P levels.

The dominant reactions that effect plant-available forms of P and many other plant nutrients are a function of soil solution pH. This has a tremendous effect on the solubility of various phosphate molecules such as di-calcium phosphate ($CaHPO_4$) or tri-calcium phosphate ($Ca_3(PO_4)_2$. Most of the agricultural soils in the cotton producing regions of Arizona are alkaline, calcareous, and have a pH range from 7.5 to 8.5. Figure 2 illustrates the relative availability of soil P as a function of soil solution pH. Highest plant availability of soil P occurs in the range of pH 5.0 to 6.0, well below the common range for Arizona's agricultural soils.

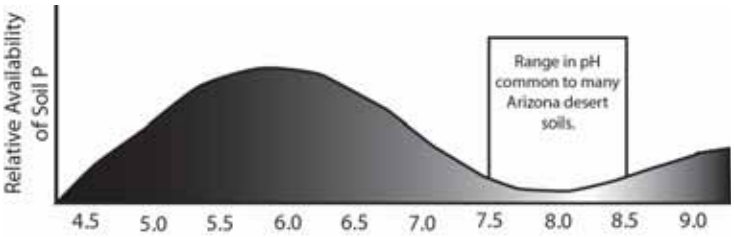
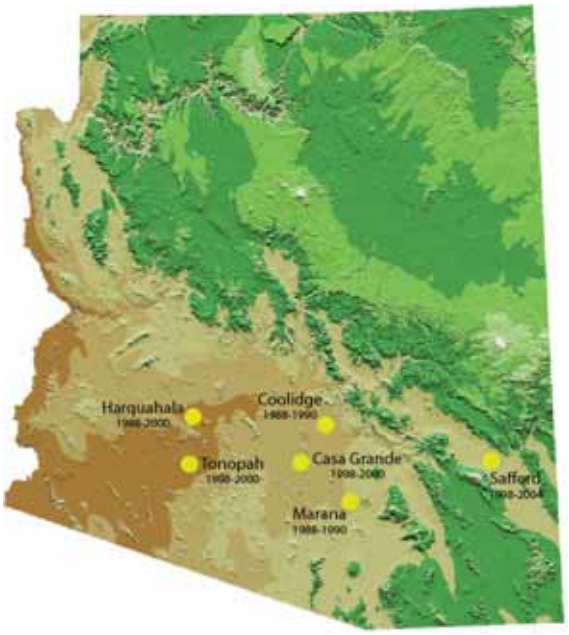


Figure 2. Relative availability of soil P as a function of soil solution pH. This figure demonstrates the potentially low availability of soil P due to the range in pH common to many cotton producing soils in Arizona.

Due to the inherently low availability of soil P in Arizona soils, supplemental P is often required to meet crop demands. Soil critical levels are a valuable and useful technique for determining the need for P fertilization. The extraction technique for soil test P analysis that has proven most effective in calcareous, high pH soils is sodium bicarbonate ($NaHCO_3$, Olsen et. al., 1954). Soil test correlation and calibration research performed in the cotton producing regions of California have revealed a critical soil P level of 5 ppm ($NaHCO_3$ extractable) for cotton production (Reisenauer, et al., 1978). Prior to the work described in this project, this critical level had yet to be validated under the high pH Sonoran desert soil conditions common to the cotton production regions in Arizona.



In an effort to conduct this validation, several field trials were implemented in the lower desert cotton producing regions of Arizona in the late 1980's and early 1990's. These trials consisted of comparing various rates of applied P fertilizer to a control receiving no fertilizer P. Many of the locations where these trials were conducted had soil test levels well above the assumed 5 ppm critical level for soil phosphorus. A consistent positive lint yield response to P fertilization of cotton was never realized (Silvertooth et. al., 1989). This was consistent with earlier work in Arizona as well (Openshaw et. al., 1972; and Tucker, et. al., 1965). These more recent studies served to confirm and further refine the established recommendations for cotton fertilization in Arizona indicating that soil test P levels of greater than 5 ppm would provide sufficient P for cotton production. However, these experimental conditions did not allow for validation of soil test levels less than 5 ppm due to the fact that sites were sought but difficult to find with less than 5 ppm P.

Beginning in 1998 a renewed effort of P fertility testing began, particularly including sites in southeastern Arizona. These locations included the lower desert regions of Arizona but importantly included some locations at higher elevations in the eastern cotton producing region of Arizona. These experiments utilized an approach consisting of a control (0 P applied) to varying rates of P fertilizer. Positive lint yield responses to applied fertilizer P were observed in a limited number of sites where soil test levels measured between 5 and 8 ppm (Thelander and Silvertooth, 2000). This work was expanded (2000-2004) and continued in the higher elevations near Safford where consistent positive lint yield responses were observed on soils with test levels less than 5 ppm (Norton and Clark, 2004; Norton et. al., 2005).

The objective of this paper is to summarize over 15 site-years of P fertility research conducted across the state of Arizona since the late 1980s in an effort to validate and refine current P fertilization recommendations to cotton growers in the Chihuahuan and Sonoran Desert regions including Arizona.

Materials and Methods

A series of field experiments were conducted across the state of Arizona from 1989-2004. These trials were conducted in a similar manner. Each experiment had a control treatment receiving 0 P fertilizer other treatments with varying rates of applied P fertilizer. All plots were arranged in a randomized complete block design with four replications. Soil samples were collected pre-season at each site to determine soil test P levels and general soil chemical characteristics. Crop response from P fertilizer applications was measured by collecting yield data from each plot. Subsamples of seedcotton were collected from each plot for determining percent lint (turnout) and fiber quality characteristics (HVI analyses) among the treatments. Plant growth measurements were also made on each

experiment (by treatment) throughout the growing season. Detailed reports for each of the trials have been published previously (Silvertooth et. al., 1988; Silvertooth et. al., 1989; Silvertooth et. al., 1990; Silvertooth et. al., 1991; Thelander and Silvertooth, 2000; Norton et. al., 2002; Norton and Clark, 2003; Norton and Clark, 2004; Norton et. al., 2005).

Results and Discussion

A large and extensive data set has been developed with these experiments over the course of the time frame in question. In an effort to summarize the projects only yield response data are being included in this paper. Fiber quality and plant growth and development data was collected from these various locations as well. However, no significant differences were observed among the different P fertilizer treatments with respect to fiber quality or plant growth and development.

In order to investigate the response to applied P fertilizer as it relates to soil test P levels, percent relative yield was plotted as a function of soil test P. A clear relationship between percent relative yield and soil test P was observed. At soil test levels less than 5 ppm a consistent positive lint yield was observed with applied P fertilizer. As soil test levels increased the probability of realizing a positive lint yield response to applied P fertilizer declines.

Over 80 cases have resulted from this series of trials. The distribution of comparisons was divided into three categories based upon soil test P levels and probability of lint yield response. These categories include high probability (<5 ppm), moderate probability (5-8 ppm), and a low probability of response (>8 ppm).

A wide range of application rates were used in this series of studies. Rates ranged from 0 to over 160 lbs. P_2O_5 per acre. In the soil test range of 5-8 ppm P that an application rate of approximately 60-80 lbs. P_2O_5/acre provided a consistent positive lint yield response. At lower soil test levels (<5 ppm), applications rates of over 100 lbs. P_2O_5/acre provided close to a 20% increase in yield over the control.

Conclusions

Results from these projects serve to validate the original proposed soil test critical level for Arizona cotton production of 5 ppm $NaHCO_3$ extractable P. This set of data allows a more thorough evaluation than had previously been conducted with test locations ranging in soil P levels from approximately 2 ppm to over 12 ppm P. A definite response gradient was observed with this data set with a 90% probability of positive yield response when soil test levels are below 5 ppm P to an approximate 50% probability level when soil test levels are above 8 ppm P. These results have led to the development of a working recommendation for Arizona cotton production systems regarding P fertility management.

The data also suggests that at or slightly below the critical level a minimum rate of 60 lbs. P_2O_5/acre should be applied to achieve a high probability for a positive yield response. At extremely low levels of soil test P rates as high as 100 lbs. P_2O_5/acre may be required to reach full yield potentials.

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