Foliar Fertilization as a Strategy to Increase the Proportion of Mature Pods in Peanut (*Arachis hypogaea* L.)

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ABSTRACT

Foliar application of nutrients is used by growers to remediate crop nutrient deficiencies, but anecdotal reports indicate there may be associated effects of accelerated crop maturity, particularly for irrigated peanut (*Arachis hypogaea* L.). Research was conducted to determine whether application of foliar fertilizers during early pod set could increase the proportion of early-maturing pods, and thereby increase the mature proportion of the profile under irrigated conditions. Field experiments were conducted in Florida at Citra in 2016, Jay in 2016 and 2017 with a randomized complete block with four foliar fertilizer treatments, applied to GA-06G at R1 and again two wks later at R2. Treatments consisted of no foliar fertilizer (control), 10.0 kg N/ha, 1.0 kg P_2O_5/ha, and 0.34 kg B/ha at each application and two harvest timings. Harvest treatments were based on the adjusted growing degree d model for peanut and were timed to represent early and optimal crop maturity. Leaf tissue nutrient concentrations were determined from samples collected 24h after each foliar treatment application. Yield and proportion of mature pods were quantified after each digging date. Normalized difference vegetation index data showed no treatment differences. The maturity profile (percentage of mature pods present in the sample) was not consistently different from respective controls during either harvest period. Results indicate foliar fertilizer applied during flowering had little effect on maturity acceleration in peanut, though foliar fertilization may still be effective at alleviating in-season nutrient deficiencies. Within site-year, application of foliar fertilizer did not increase yield. Under sound soil fertility management programs, foliar fertilizers did not increase yield or the maturity profile of peanut.

Key Words: Foliar fertilizer, digital imaging, profile board, maturity

It has become increasingly apparent that crop maturity in seed peanut (*Arachis hypogaea* L.) should be a priority for the peanut industry (Carter, 2015). Cultural practices that influence reproductive growth can affect the maturity profile and seed peanut quality. Lamb *et al.* (2017) noted that timely applications of glyphosate and diflufenzopyr advanced the maturity profile of peanut via late-season flower abortion. Similarly, foliar fertilization may impact timeliness and viability of flowers, pegs, and pods, and may be expected to impact crop maturity.

Growers often apply foliar nutrients to improve overall peanut crop performance and yield. Claimed benefits of peanut foliar fertilizer products include increased number of pegs and pods, overall improved plant health, and improved yield and grade (Peg Power, Triangle Chemical Sycamore, GA), though these claims have not been validated by peer-reviewed research. Previous research on foliar fertilizer in peanut using a nitrogen (N), phosphorus (P), potassium (K), sulphur (S) solution did not provide significant yield increases (Halevy *et al.*, 1987; Walker *et al.*, 1982). These results are similar for other crops. For example, soybean (*Glycine max* (L.) Merr.) yield response to foliar fertilizer has been inconsistent, showing both increases and decreases (Garcia and Hanway, 1976; Moreira *et al.*, 2017; Poole *et al.*, 1983). Although foliar fertilizers can be tank-mixed with fungicides, the added product cost represents an additional economic input for the grower.

Peanut maturity is assessed by many growers using color classification of the mesocarp with the aid of a color board developed by Williams and Drexler (1981). Near maturity, samples of pods are collected for mesocarp color assessment typically

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resulting in a Gaussian distribution with varying amplitude (Carter *et al.*, 2017). Anecdotal reports from the field suggest that application of foliar fertilizers promote the overall maturity progress of the crop (D. Anthony Drew, personal communication), thus advancing pods towards the more mature classes in a shorter time frame. Such reports require research to either support or refute these observations. If validated, accelerated crop maturity could aid growers by providing management options for harvest timing control. If refuted, growers could save the added cost of foliar fertilizer applications.

Foliar fertilization of peanut is a common practice in the Southeastern United States. One of the most common foliar applied nutrient is N, which is important for many different plant constituents and processes, including photosynthesis since N is a component of chlorophyll and protein molecules (Bryson and Mills, 2014). Phosphorus although not commonly applied as a foliar fertilizer, is essential for the synthesis of ATP (Bryson and Mills, 2014). Foliar fertilization of boron (B) promotes cell wall structure and prevents "hollow heart" of peanut (Hänsch and Mendel, 2009). Martens and Westermann (1991) reported soil B to be deficient in 43 states of the U.S., and B is commonly deficient in sandy soils where peanut is grown. Nutrient deficiency in general is often due to soil factors such as low-organic matter, soil pH, soil texture and excessive rainfall leading to nutrient leaching. Although the mechanism by which foliar fertilization may lead to increased maturity is unclear, it has been suggested that foliar fertilization may increase photosynthate production via improved leaf tissue nutrient status, thereby increasing flowering, reproductive viability, and pegging (Hardy and Havelka, 1977). To directly manipulate peanut maturity rate, N, P, and B would be likely targets as effectors in seed development and plant allocation to seed filling. For peanut, foliar fertilizer could be particularly important during early reproductive growth when N and P absorption can lag behind plant requirements (Garcia and Hanway, 1976). Thus, early season applications timed around early flowering are likely to have the greatest probability of altering peanut maturity advancement.

The maturity development of peanut can be monitored using the adjusted growing degree d model (aGDD), which consists of adding the seasonal cumulative water received to the Mills (1964) degree d model (Rowland *et al.*, 2006). To address these questions regarding foliar fertilization effects on peanut maturity, a multi-year and location test was conducted, with the hypothesis that foliar fertilization would amplify pod maturation and increase the proportion of mature pods compared to non-foliar fertilized peanut. The objectives of this research were to determine the effects of foliar N, P, and B applications during early flowering on yield and the maturity profile of peanut.

Materials and Methods

Site Description

The experiment was conducted during 2016 and 2017 at the West Florida Research and Education Center near Jay, FL (30°46′32.5″N 87°08′13.5″W, 62 m above sea level) on a Red Bay sandy loam (0-2% slope, fine-loamy, kaolinitic, thermic Rhodic Kandiudults) and one yr (2016) at the Plant Science Research and Education Unit near Citra, FL (29°24′28.9″N 82°08′43.4″W, 21 masl) on a Candler sand (0-5% slopes, hyperthermic, uncoated Lamellic Quartzipsamments) for three site-yrs.

Experimental Design

Cultural practices were consistent with local production recommendations (Wright *et al.* 2016) with modifications as described below. All fields were fertilized and limed prior to planting according to soil test recommendations. Plots consisted of eight rows spaced 0.9 m apart and 7.6 m long. The experiments were planted on 27 and 10 May for 2016 and 2017, respectively. The experiments were strip-tilled into rye (*Secale cereal* L.) residue at Jay, FL and triticale (*Triticosecale spp.*) residue at Citra, FL. Seed of the peanut cultivar, Georgia-06G (Branch, 2007), was treated with azoxystrobin, fludioxonil, and mefenozam (Dynasty, Syngenta, North Carolina USA) as a fungicidal seed treatment. Final peanut stands were six plants per 0.31 m-row. Gypsum was applied at 2242 kg/ha 40 d after planting (DAP). Weeds were controlled as needed, avoiding the use of paraquat dichloride in order to obviate foliar damage and potentially affect foliar fertilizer uptake. Sites were irrigated as needed using overhead lateral irrigation.

A four (foliar fertilization) by two (digging date) factorial experiment was employed using a randomized complete block design with four replications. The two digging dates were approximately 2200 and 2500 aGDD, tracked using the aGDD model, representing early and optimal digging dates (Colvin *et al.*, 2014; Rowland *et al.*, 2006).

Foliar Fertilizer Treatments Applications

Foliar fertilization treatments were 10.0 kg N/ha as urea, 1.0 kg P_2O_5/ha as triple super phosphate (TSP), 0.34 kg B/ha (Max-In® Boron, Winfield Solutions, LLC, St. Paul, MN) during each

application and a control. A low rate of N was applied in order to avoid leaf tissue damage (Nicoulaud and Bloom, 1996), though at the rate applied in this study, some leaf burn was observed at times. Applications were made twice during the season, one at R1 and again two wks later at R2 (Boote, 1982), corresponding to maximum nutrient uptake during early reproductive growth (Garcia and Hanway, 1976). Foliar fertilizer treatments were applied using an eight-row sprayer fitted with Cone-Jet TXVS-18 nozzles (Cone-Jet®, TeeJet Technologies, Spraying Systems Co., Wheaton, IL) at 187 L/ha (Bi and Scagel, 2007; Halevy et al., 1987). The first foliar application was made at R1 approximately 40 DAP (or 750 aGDD) and the second application at R2, two wks later (approximately 1000 aGDD). In 2016, foliar applications occurred on July 7 and 26 at Jay, FL. The one-wk delay in the second application during this site-year was necessitated by 85 mm precipitation between july 20th to 22nd 2016. Citra, FL applications were made on July 12th and 25th 2016. In 2017, applications were made on June 27th and July 12th in Jay, FL. Twenty-four hr after each foliar application, 25 leaf tissue samples were collected randomly in the middle two rows to quantify leaf tissue nutrient status. Leaf tissue samples consisted of leaflets and the petiole from second nodal leaves on the apex stem in a representative area in each plot. The leaves were washed, dried and ground using a Cyclone Lab Sample Mill (UDY Corporation, Fort Collins, Co) to pass a 1 mm sieve. Leaf tissue nutrient concentration was determined using a peroxide digestion followed by inductively coupled plasma mass spectrometry (Beauchemin, 2006).

Canopy Growth

During both years in Jay, normalized difference vegetation index (NDVI) was measured periodically throughout the experiment. NDVI is the amount of near-infrared and red light reflected by vegetation and is derived from the red near-infrared reflectance ratio (Pettorelli et al., 2005) and is often considered as being indicative of plant canopy photosynthetic area (Thelen et al., 2004). NDVI data were recorded weekly using a GeoScout GLS-400 (Holland Scientific Inc, Lincoln, NE) prior to first flower until after canopy closure. The sensor was placed approximately 60 cm over the canopy while walking through the experimental treatments. NDVI data were not recorded in Citra.

Harvest

Digging dates were monitored using aGDD models (Anonymous 2013; Colvin et al., 2014; Rowland et al., 2006). Harvest treatments were targeted for 2200 and 2500 aGDD, representing early and optimal harvest timings, respectively (Rowland et al., 2006). The digging dates at Jay, FL in 2016 were 2184 aGDD (or 112 DAP, considered early) and 2504 aGDD (or 130 DAP, considered optimal), and in 2017, 2326 aGDD (or 117 DAP, considered early) and 2497 aGDD (or 132 DAP, considered optimal). The digging dates in Citra, FL during 2016 were 2430 aGDD (or 126 DAP, considered optimal) and 2650 aGDD (or 137 DAP, considered past optimal). The delay in digging dates at Citra were caused by 52 mm precipitation from Sept 12th to 15th 2016.

The four middle rows of the eight-row plots were dug using a four-row digger creating two windrows. One windrow was used to determine the percent mature pods and the second windrow was used to determine yield. To determine the percentage of mature pods, immediately after digging, all pods were removed from sampled plants until 180 to 220 pods were collected. Pods were blasted using a pressure washer with a turbo nozzle to remove the exocarp and expose the mesocarp color (Carter et al., 2017). The maturity profile was determined using two methodologies described below. One classified pods as mature and immature based on the mesocarp color using a peanut profile board (Carter et al., 2017; Williams and Drexler, 1981). Brown and black pods were considered mature. White, yellow, and orange pods were not used for analysis to ensure only the most mature pods were considered in maturity evaluations. The second method scanned blasted pods on a digital scanner (HP OfficeJet 7612, Palo Alto, CA). The resulting images were analyzed using the PeanutFARM (Anonymous 2013) tool to quantify the percentage of brown/black (mature) pods (Colvin et al., 2014). Peanut pod yield was recorded using the second windrow, approximately one wk after digging, using a plot combine. Final yield data were adjusted to 10% moisture.

Statistical Analysis

Repeated measures analysis of variance for a randomized complete block was conducted for leaf tissue nutrient, NDVI, and yield data using the PROC MIXED procedure in SAS (Version 9.4, SAS Institute Inc., 2017) at 95% confidence level unless otherwise indicated. Individual analyses were performed for each site-year. For leaf tissue nutrient analyses, foliar fertilizer and application time were considered fixed effects. For yield analyses, foliar fertilizer and harvest time were considered fixed effects. NDVI analyses considered foliar fertilizer and time of observation as fixed effects. In all cases, replication and its interactions were considered random effects. Pairwise least square means were separated using least significant

Table 1. Elemental leaf tissue analysis after two foliar fertilizer applications to peanut in Florida; three site years (Citra 2016, Jay 2016 and Jay 2017).

FACTORS	N	P	K	Mg	Ca	S	B	Zn	Mn	Fe	Cu
				%					ppm		
Citra 2016											
Fertilizer (F)											
Control	4.52 bc[a]	0.27 b	2.41 a	0.38 a	1.86 a	0.37 b	72.5 b	44.1 a	71.1 a	91.4 a	7.5 a
Nitrogen	4.81 a	0.27 b	2.52 a	0.38 a	1.82 a	0.50 a	65.4 b	47.2 a	76.7 a	99.1 a	9.3 a
Phosphorus	4.64 ab	0.29 a	2.44 a	0.39 a	1.93 a	0.37 b	64.3 b	44.4 a	74.5 a	99.8 a	7.8 a
Boron	4.35 c	0.27 b	2.46 a	0.37 a	1.84 a	0.37 b	192.1 a	48.2 a	79.7 a	98.3 a	8.6 a
Application time (A)											
At flowering	4.37 b	0.28 a	2.57 a	0.31 b	1.69 b	0.30 b	95.0 a	40.4 b	57.6 b	98.0 a	9.7 a
14 DAF	4.79 a	0.27 a	2.34 b	0.45 a	2.03 a	0.51 a	102.2 a	51.6 a	93.4 a	96.3 a	6.9 b
F × A	ns[b]	ns	ns	ns	ns	***	ns	ns	ns	ns	ns
Jay 2016											
Fertilizer (F)											
Control	3.88 a	0.28 a	3.02 a	0.45 a	1.40 a	0.25 a	41.1 b	34.2 a	84.9 a	115.3 a	9.1 a
Nitrogen	4.03 a	0.28 a	2.91 a	0.44 ab	1.34 b	0.25 a	32.4 b	34.2 a	79.7 a	114.3 a	8.3 a
Phosphorus	3.93 a	0.29 a	2.97 a	0.44a b	1.41 a	0.25 a	34.6 b	36.3 a	80.8 a	122.9 a	9.7 a
Boron	3.88 a	0.28 a	2.93 a	0.43 b	1.37 ab	0.24 a	135.6 a	32.7 a	81.0 a	113.2 a	8.9 a
Application time (A)											
At flowering	3.98 a	0.31 a	3.22 a	0.40 b	1.28 b	0.26 a	62.9 a	40.6 a	97.7 a	148.0 a	10.7 a
14 DAF	3.88 a	0.25 b	2.70 b	0.47 a	1.48 a	0.24 b	58.9 a	28.1 b	65.5 b	84.8 b	7.2 b
F × A	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Jay 2017											
Fertilizer (F)											
Control	3.85 b	0.29 b	2.86 a	0.46 ab	1.52 ab	0.28 ab	38.3 b	30.6 a	113.2 ab	223.3 a	11.7 a
Nitrogen	4.63 a	0.29 b	2.90 a	0.45 ab	1.45 b	0.28 ab	36.6 b	32.3 a	106.6 b	236.7 a	16.3 a
Phosphorus	3.92 b	0.33 a	2.98 a	0.47 a	1.58 a	0.29 a	41.0 b	32.1 a	110.0 ab	214.7 a	12.1 a
Boron	3.86 b	0.29 b	2.74 b	0.44 b	1.53 ab	0.27 b	241.7 a	32.1 a	118.2 a	212.2 a	11.3 a
Application time (A)											
At flowering	4.07 a	0.30 a	3.17 a	0.49 a	1.36 b	0.26 b	83.3 b	31.5 a	101.1 b	280.6 a	13.7 a
14 DAF	4.05 a	0.30 a	2.57 b	0.42 b	1.68 a	0.30 a	95.5 a	32.1 a	122.8 a	162.9 b	12.0 a
F × A	ns	ns	ns	ns	ns	ns	***	ns	ns	ns	ns

[a]Means followed by the same letter within a column, factor and site year were not significantly different at P≤0.05.

[b]Abbreviations: significant at P≤0.0001, ***; not significant, ns; d after flowering, DAF.

differences (LSD) at the 95% confidence level with the %PDMIX800 macro (Saxton, 1998) within SAS 9.4. Figures were generated using R software version 3.6.0 (R Core Team, 2019).
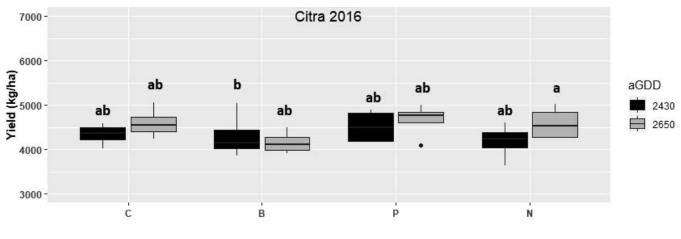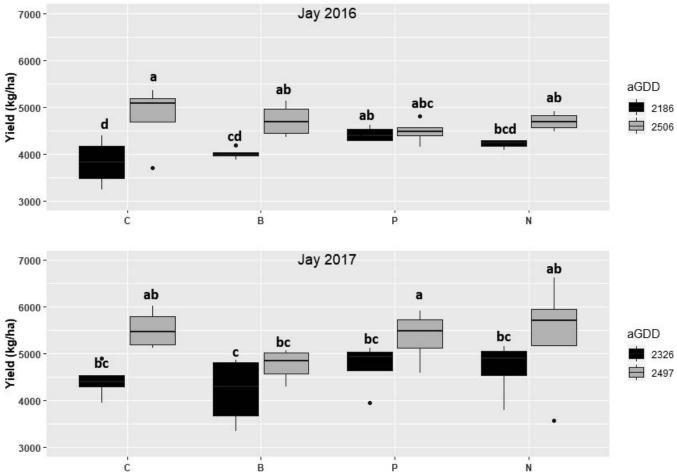
Results and Discussion

Canopy Growth

NDVI values did not differ among foliar fertilizer treatments (data not shown), indicating very little effect of added nutrients on canopy condition. However, NDVI is most effective at detecting nutrient impacts when deficiencies are present. For example, nutrient deficiencies have been detected by NDVI measurement of crops such as soybean and corn (*Zea mays* L.) (Milton, *et al*., 1991; Osborne, *et al*., 2002; Thenkabail, *et al*., 2000). The lack of differences in NDVI values in the present study indicate that nutrient deficiencies were likely not present so that foliar fertilization had little relative impact on plant nutrient status (Bryson and Mills, 2014). NDVI did differ by aGDD as the crop developed, a common result in other studies since NDVI increases with leaf area index as the crop matures (Elvidge and Chen, 1995; Huete *et al*., 1985).

Foliar Tissue Nutrient Concentrations

Even though foliar fertilization did not affect NDVI, direct measures of leaf tissue N concentrations were affected by fertilization treatments (Table 1). Compared to the control, leaf tissue N measured 24 hr after foliar N application increased during two of three site-years. The lack of consistent response in leaf tissue N concentration may be due to the relatively quick translocation of N from leaves to fruits (Wittwer *et al*., 1963). Uptake and translocation toward the developing

Fig. 1. Peanut yield as affected by two harvest timings based on adjusted growing degree d (aGDD) and four foliar fertilizer treatments at Citra (2016) and Jay (2016 and 2017). Abbreviations: C=control; N=10 kg N/ha; P=1.0 kg P$_2$O$_5$/ha; B=0.3 kg B/ha; all split-applied during the season at first flower and again approximately two wk later. Different letters represent different means at P<0.05 (LSD). Black bars represent early harvest timing and gray bars represent optimal harvest timing.
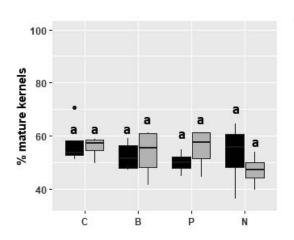
seed may have already occurred when the leaves were sampled 24 hr after application, particularly given the relatively low amount of foliar N applied.

After foliar P application, leaf P concentration increased during two of three site-years compared to
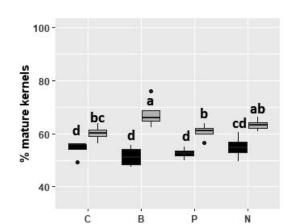
the control (Table 1). These results are somewhat more consistent than those reported by Walker *et al.* (1982), who generally noted no leaf tissue P response after foliar P application, even at rates up to 5.8 kg P/ ha. However, that study sampled tissue 10 to 14 d after application and every 28 d thereafter, whereas
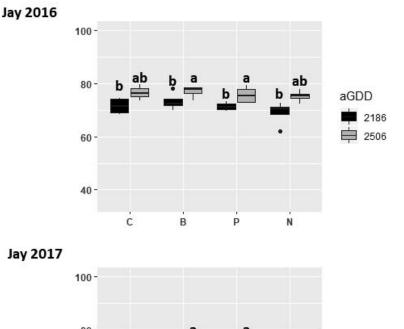
Profile Board

Digital Imaging

Citra 2016
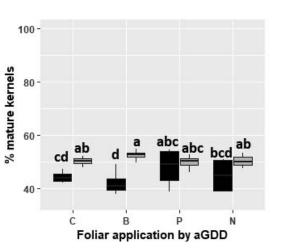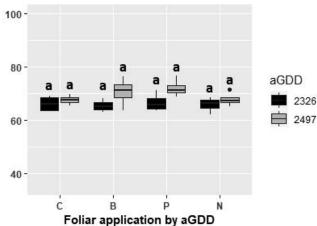

Jay 2016

Jay 2017

Fig. 2. Percentage of mature kernels between two harvest timings based on adjusted growing degree d (aGDD) and foliar fertilizer applications using the peanut profile board (left) and digital imaging (right) at Citra (2016) and Jay (2016 and 2017). Abbreviations: C=control; N=10 kg N/ha; P=1.0 kg P₂O₅/ha; B=0.3 kg B/ha: all split-applied during the season at first flower and again approximately two wk later. Different letters represent different means at P<0.05 (LSD). Black bars represent early harvest timing and gray bars represent optimal harvest timing.

the current study sampled tissue 24 hr after application. The shorter interval between application and sampling may explain the greater tissue P response compared to the control in the present study.

Boron fertilization consistently resulted in an increase in leaf tissue B concentration compared to the control (Table 1) in Jay and Citra after each application. The high tissue B concentrations indi-

cated the nutrient was absorbed by the leaf. Konsaeng *et al.* (2010) reported that upper foliar B concentration decreased with time concomitant with an increase in lower foliage B concentration, demonstrating a remobilization of B during a 13-d span.

Yield and Maturity Profile

In 2016 at Citra, FL, yield was not affected by foliar treatment (Figure 1). This location was harvested at optimum maturity (2430 aGDD, or 126 DAP) and 150 aGDD past-optimum (at 2650 aGDD, or 137 DAP), though it bears noting that 137 DAP would be considered within the optimal harvest range by most growers. Furthermore, Georgia-06G is a medium maturity genotype, considered ready for harvest at 135 to 140 DAP (Branch, 2007; Branch and Brenneman, 2009). The 2016 Jay, FL site was harvested at both an early (2184 aGDD, or 112 DAP) and optimum digging date (2504 aGDD, or 130 DAP), resulting in lower yield during the earliest harvest date (p=0.0004, Figure 1). Yield increased by 560 kg/ha during the early digging date in Jay when foliar P was applied compared to the control, but this effect was significant only during one of the three site-yrs. Foliar applications of B or N did not increase yield at any digging date, nor did P application when peanut was dug during an optimal time. In 2017, yield was lower (Figure 1) at the early harvest date (2326 aGDD, or 117 DAP) compared to the later harvest (2497 aGDD, or 132 DAP). During both harvest timings, foliar treatments did not affect yield.

Within harvest date, the percentage of mature pods was not generally affected by foliar fertilization treatments during any site-year using both methodologies (Figure 2), except for boron foliar fertilizer which increased the percentage of mature kernels assessed by profile board during the second digging date in Jay 2016. As expected, the percentage of mature pods increased when pods were dug at optimal timing compared to early digging, except in 2017 using the digital imaging method. Maturity assessment using the profile board showed more variation than the digital imaging method, likely because immature pods can often be smaller than mature pods. Results from this study did not support the hypothesis that foliar fertilization affects the peanut maturity profile under these conditions. However, foliar fertilizers might influence the maturity profile of peanut, under nutrient limiting conditions.

Conclusions

Foliar applications did not improve maturity when digging early at any site-year using the profile

board. Compared to the control, B application increased the percentage of mature pods during one of three site-years (Jay 2016) during the second digging date when assessed using the profile board. When the digital imaging model was used to assess maturity, no foliar application increased maturity, and there was a significant decrease in the percent mature pods at one site-year (Citra 2016) when foliar N was applied and dug at the second digging date. Though an increase in B leaf tissue concentration one d after foliar applications was observed, it did not affect growth, yield or maturity. Foliar P applications increased yield by 560 kg/ha when pods were dug early in one site-year, but the result did not affect peanut maturity. The maturity profile of peanut was generally not affected by foliar fertilization with N, P or B under the conditions of this experiment.

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