Effect of Calcium Source and Irrigation on Soil and Plant Cation Concentrations in Peanut (*Arachis hypogaea* L.)

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ABSTRACT

Calcium improves seed formation and development of peanut kernels. Two primary sources of Ca fertilization in peanut are gypsum ($CaSO_4$) and dolomitic lime ($CaMg[CO_3]_2$+$CaCO_3$). Objectives of this research are to determine whether gypsum, lime, or application of both influences pH, extractable [Ca], [Mg], and [K] in the soil along with nutrient absorption, yield, and total sound mature kernels (TSMK) in peanut pods in irrigated compared to non-irrigated conditions. Experiments conducted in Tifton, GA in 2016 and 2017 evaluated Ca treatments with no supplemental Ca fertilizer, gypsum (330 kg Ca/ha) applied at first bloom, lime (897 kg Ca/ha) applied at planting, and lime (897 kg Ca/ha) applied at planting followed by gypsum (330 kg Ca/ha) applied at first bloom. Irrigating increased soil pH, [Ca] and [Mg] in pods, plus yield and TSMK of peanut. Irrigation also decreased [K] in pods, which was correlated with increased pod [Ca]. Soil pH and soil [Ca], [Mg], and [K] were influenced by fertilizer treatment, along with [Ca] and [Mg] in pods. Applications of lime increased pH and soil [Ca]. Lime also increased soil [Mg] when applied alone, but not when gypsum was also included. Application of gypsum reduced soil [Mg] when applied alone, but not when lime was included. The inclusion of both lime and gypsum reduced soil [K] compared to no application. These results display the competition of cations in soil. In peanut pods, using lime and gypsum increased [Ca] compared to no application, or only lime. However, when only gypsum was used, it reduced [Mg] in pods compared to a lime application or no fertilization. Although Ca fertilization did not affect yield, TSMK was greater when lime followed by gypsum were applied in sequence than where neither were applied in 2016. It is important to realize that applications of Ca can also influence concentrations of other cations important for growth. Peanut growers are encouraged to conduct soil tests to ensure soil [Mg] is not deficient or borderline before choosing to apply gypsum, and may require a supplemental Mg fertilizer if dolomitic lime was not applied.

Key Words: Dolomitic lime, flue gas desulfurized gypsum, magnesium, total sound mature kernels.

Georgia is the largest peanut producing state in the United States with an average of 269,000 ha harvested from 2013-2017 (NASS, 2017). The sandy Coastal Plain soils of the South are ideal for peanut production (Walker and Keisling, 1978). Since peanut is a legume, nitrogen (N) needs are met through N fixation (Elkan, 1995). Also, phosphorus (P) and potassium (K) requirements are often less than other crops and minimal fertilization is needed because of residual quantities after fertilization of crops in rotation prior to peanut. Thus, N, P, and K are rarely the most limiting nutrients in the U.S. for peanut (Cope *et al*., 1984; Scarsbrook and Cope, 1956; and Walker *et al*., 1979). However, Ca can be a limiting nutrient in peanut (Cox *et al*., 1982). Fertilizers that supply Ca are more common applications than N, P, and K fertilizers. University of Georgia (UGA) Extension recommends applying Ca when soil levels are less than 250 mg/kg, or the Ca/K ratio is less than 3/1 in the top 8 cm of soil (Alva *et al*., 1989; Harris, 2013).

Calcium deficiencies result in lack of pod formation, underdeveloped kernels (also known as "pops"), and reduced seed germination if used to plant next year's crop (Howe *et al*., 2012; Tillman *et al*., 2010). Pod rot (*Pythium myriotylum* Drechs.) is exacerbated by Ca deficiency and may be reduced by Ca fertilization (Gascho *et al*., 1993). Calcium deficiencies can reduce yield and total sound mature kernels (TSMK) (Sorensen and Butts, 2008). Calcium must be absorbed directly by developing pods from soil solution (Sorensen and Butts, 2008) as Ca is not very mobile in the phloem (Wiersum, 1951). In order to produce high-yielding, quality peanuts, the top 8 cm of soil must have adequate Ca and approximately 0.7 cm of

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water per day during pegging and pod fill (Gascho *et al*., 1993; Stansell *et al*. 1976).

With the limitations of Ca mobility, the fertilizer source can affect availability in the soil to developing pods. Gypsum ($CaSO_4$) is the primary fertilizer used in peanut. UGA Extension recommends applying 1,121 kg gypsum/ha at the R1 growth stage (Boote, 1982), or first bloom, when soil [Ca] is below 250 mg/kg (Harris, 2013). Gypsum is often applied at first bloom to increase soil [Ca] (Gascho *et al*., 1993). Since it is a relatively soluble material subject to leaching, it should be timed when pods will most readily absorb it (Daughtry and Cox, 1974). Research has shown that gypsum application increases seed [Ca] but does not affect yield when soil [Ca] is at or above the recommended level (Arnold III, *et al*., 2017; Howe *et al*., 2012).

Dolomitic limestone ($CaMg(CO_3)_2$+$CaCO_3$) is another common Ca source. However, lime is mainly used when tests recommend increasing soil pH. Dolomitic lime has been shown to increase soil pH and soil Ca levels (Sullivan *et al*., 1974). UGA Extension recommends adding lime when soil test reports indicate low soil pH (Harris, 2013). Lime is not as soluble as gypsum; therefore, it should be applied at planting to be available to developing peanut pods.

Soil moisture also plays a critical role in Ca uptake. Studies have found significant correlation between nutrient uptake and soil moisture (Bennett *et al*., 1990; Junjittakarn *et al*., 2013; Sexton *et al*., 1997). Irrigation can improve plant health while also producing moisture that can move nutrients into the plant. The addition of gypsum can increase yield and TSMK in non-irrigated peanuts when soil Ca is below the minimum recommended level (Howe *et al*., 2012). Calcium availability to peanut pods increases when irrigation is utilized (Cox *et al*., 1976). Although, too much irrigation or rainfall can cause Ca leaching from sandy soils and no longer be accessible to developing pods when moved below the fruiting zone (Gascho *et al*., 1993).

The primary objective of this study is to determine the effects of Ca fertilization and irrigation on soil and peanut pod concentration of Ca, Mg, and K. The secondary objective is to assess the impact of Ca fertilization and irrigation on yield and TSMK. The information from this research will aid in decision making regarding which Ca source should be used in either irrigated or non-irrigated management.

Materials and Methods

Field trials were conducted in 2016 and 2017 at the Lang-Rigdon Farm on the UGA Coastal Plain Experiment Station in Tifton, GA (31.517, -83.547), on a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) (USDA-NRCS, 2017). The experiment was conducted in a split-plot design in 2016 and a split-split-plot design in 2017, with eight replications in each year. The main effect was two irrigation treatments (irrigated and non-irrigated). The sub-effect was Ca fertilization from flue gas desulfurization (FGD) gypsum ($CaSO_4$) and dolomitic lime ($CaMg(CO_3)_2$+$CaCO_3$). The four sub-treatments were no added Ca (non-treated), gypsum (330 kg Ca/ha) applied at first bloom, lime (897 kg Ca/ha) applied at planting, and lime (897 kg Ca/ha) applied at planting followed by gypsum (330 kg Ca/ha) applied at first bloom. Rates were based on UGA Extension recommendations (Harris, 2013). In 2016, 'Georgia-06G' (Branch, 2007) was planted for the entire study. In 2017, Georgia-06G and 'Georgia-14N' (Branch and Brenneman, 2015) were planted as a split-split plot effect in a field with minor populations of peanut root-knot nematode (*Meloidogyne arenaria*). The 2016 sub-plots (each fertilization treatment) were 5.5 m wide (six peanut rows) by 12.2 m long and the 2017 sub-plots were 6.7 m wide (eight peanut rows), by 12.2 m long, split into four rows of Georgia-06G and four rows of Georgia-14N.

Field preparations for all experiments included deep turning the soil to 30 cm deep with a John Deere 975 moldboard plow (John Deere, Moline, IL) followed by a Roto-Tiller (1.83 m spacing) (Kelley Mfg. Co., Tifton, GA). Peanuts were planted on 2 June 2016 and 19 April 2017. All experiments were planted with a Monosem Single-Row Precision Vacuum Planter (Monosem Inc., Edwardsville, KS) at 20 seed/m of row (Beasley et al, 1997). Irrigation was applied through a lateral irrigation system (Valley® Irrigation, Valley, NE). Irrigation amount was determined based on the weekly water use by peanut (UGA checkbook irrigation scheduling method) (Porter, 2017; Stansell *et al*. 1976).

Lime treatments were applied within 48 hr after planting (3 June 2016 and 21 April 2017). The lime used was 305 g Ca/kg and 50 g Mg/kg (Waters Agricultural Laboratories [WAL], Inc., Camilla, GA). The gypsum treatments were applied at the R1 growth stage (Boote, 1982), approximately 35 d after planting (7 July 2016 and 24 May 2017). The FGD gypsum analysis was 242 g Ca/kg and 184 g Sulfur (S)/kg (WAL, Inc., Camilla, GA). Lime and gypsum were applied by hand.

The herbicide program followed recommendations from the Georgia Pest Management Handbook (Prostko, 2016). A protective fungicide program was also adopted from the Georgia Pest Management Handbook (Kemerait *et al*., 2016b) and the Peanut-Rx high-risk management program (Kemerait *et al*., 2016a). Fungicides were applied starting around first bloom and continued throughout the season on 14 d spray intervals. Liquid Boron (B) (10%) was applied at 0.56 kg/ha with the first fungicide application (Harris, 2013). All other management was based on UGA Extension recommendations for peanut.

Soil was sampled from 0-8 cm depth on 2 June 2016 and 20 April 2017 and again on 26 October 2016 and on 26 September 2017, respectively. Routine analysis was performed using Mehlich-I extraction (Kissel and Sonon, 2008; Mehlich, 1953). Pod (shell plus kernels) samples (representative of the maturity profile) were removed on 26 October 2016 and 28 September 2017 and analyzed for nutrient concentration.

Peanut maturity was determined according to the maturity profile/mesocarp color method (Williams and Drexler, 1981). Digging and inversion of the plants were conducted with a 2-row digger/shaker/inverter (Kelley Mfg. Co., Tifton, GA). Peanuts were dug 20 October 2016 and 20 September 2017. After the peanuts had cured in the field to approximately 12 to 15% moisture, harvest was with a 2-row KMC harvester (Kelley Mfg. Co., Tifton, GA). Harvest occurred on 27 October 2016 and 28 September 2017. Yields were adjusted to 7% moisture for uniformity of comparisons. Determination of TSMK was according to USDA-AMS grade standards (USDA-AMS, 1997).

Statistical analyses were conducted using PROC GLIMMIX and PROC CORR in SAS 9.4 (SAS Institute Inc., Cary, NC). Data were analyzed by analysis of variance (ANOVA), and mean separation with Tukey's Honestly Significant post-hoc test ($P=0.10$). After a comparison of cultivar data in 2017, few relevant differences with regard to the objectives of the study were observed so Georgia-14N was removed from the analyses and the Georgia-06G data were combined over years for all variables except for TSMK based on similar trends in treatment effects. Soil nutrient concentrations were based on four replications of data because of cost associated with sample analysis, while peanut pod yield was analyzed over all eight replications. TSMK was analyzed separately for each year because it was collected on eight replications in 2016, but only four in 2017 because of cost associated with two cultivars. Year, replication, and replication by irrigation were treated as random effects.

Results and Discussion

Interactions between the main and sub-plot treatment effects were not observed for the reported variables. Data are presented either by irrigation effect pooled over Ca fertilization treatments or Ca fertilization effect pooled over irrigation treatments unless specifically noted.

Environmental Data

Temperature, rainfall, and irrigation data on a monthly basis for the growing season at the Coastal Plain Experiment Station for 2016 and 2017 are presented in Table 1. The initial extractable soil [Ca] before fertilizer applications (with respect to the sub-plot treatment randomization) ranged from 332 to 361 mg/kg in 2016 and 195 to 204 mg/kg in 2017, with a Ca/K ratio of 7/1 in 2016 and 6/1 in 2017. This is above the minimum soil [Ca] recommendation of 250 mg Ca/kg and Ca/K ratio of 3/1 to trigger the need for application in 2016. However, it was below the minimum [Ca] in 2017 (Harris, 2013) which would have initiated a recommendation to apply Ca fertilizer. It is also noted that soil pH was 5.5 to 5.6 in 2016 and 5.6 in 2017, which would normally recommend a lime application to increase pH. The initial extractable soil [K] was 48-52 mg/kg (medium/adequate range) in 2016 and 31-32 mg/kg (borderline low/medium) in 2017. Extractable soil [Mg] was 35 to 41 mg/kg in 2016 (medium/adequate range) and 23 to 26 mg/kg in 2017 (considered low) (Kissel and Harris, 2008).

Irrigation Treatment Effects

Supplemental irrigation impacted several variables in this experiment (Table 2). Soil pH increased more substantially where irrigation was applied than non-irrigated soils. Additional moisture also assisted with uptake of Ca and Mg, increasing the concentration of these nutrients in peanut pods, which would corroborate with increased [Ca] in peanut pods in irrigated conditions as observed by Cox *et al*. (1976). However, the increase of these nutrients resulted in a decrease in pod [K]. Yield and grade (TSMK) were both greater in irrigated conditions than non-irrigated, also similar to results by Cox *et al*. (1976).

Ca Fertilization Treatment Effects

Soil Nutrient Concentrations

The application of dolomitic lime (whether alone or with gypsum) increased soil pH (Fig. 1) and extractable soil [Ca] (Fig. 2) compared to where lime was not applied. Gypsum alone did not adequately improve readily-available soil [Ca] in the pegging zone when measured at season's end compared to no application. One reason that lime and gypsum did not follow a similar pattern could

Table 1. Temperature[a], rainfall[a], and irrigation for the Coastal Plain Experiment Station, Tifton, GA in 2016 and 2017.

	Maximum Temperature °C[b]		Minimum Temperature °C[b]		Rainfall (cm)[c]		Irrigation (cm)[c]	
	2016	2017	2016	2017	2016	2017	2016	2017
April	x	28.4	x	16.1	x	0.81	x	1.27
May	x	28.9	x	16.3	x	6.73	x	0
June	32.3	29.9	20.9	20.4	9.96	12.98	1.27	0
July	34.0	32.3	22.2	22.4	8.59	12.37	7.62	1.27
August	32.7	32.5	22.2	22.3	16.03	13.49	3.81	6.10
September	31.1	29.9	19.9	18.8	15.65	9.45	5.08	0
October	27.9	x	14.1	x	0.15	x	3.81	x
Season	31.7	30.6	20.9	19.8	50.40	55.83	20.32	7.37

[a]Temperature and rainfall data obtained from georgiaweather.net.
[b]Average of daily values for time period listed.
[c]Sum of daily values for each time period.

be related to total volume of Ca applied (since lime applied nearly three times as much Ca [897 kg Ca/ha] as gypsum [330 kg Ca/ha]). Since gypsum is also more soluble than lime, it is possible that there was short-term availability of supplemental Ca in the pegging zone during mid-season growth, but was diluted by the time of harvest. It is noted that soil samples were taken after digging had occurred at the end of season, causing disruption and some mixing of soils that were initially below the pegging zone depth compared to the initial soil sample. The dig depth was approximately 15 cm, although most mixing occurs where pods were actively growing in the upper 0-8 cm of the soil as evidenced by essentially no change in extractable soil [Ca] in the non-fertilized treatment from initial sampling to final sampling. There was also a proportional difference in the lime only and gypsum only treatments when compared to lime + gypsum treatments for soil [Ca]. Soil [Ca] in the final sample (data not shown) had the same response to all fertilizer treatments as the change in [Ca] over time as well. These results indicate that the addition of lime tends to greatly increase soil [Ca] when initial soil [Ca] was above or below the recommended level. However, according to Alva *et al.* (1990) and Yang *et al.*, (2017), Mehlich-I is likely to overestimate Ca available to peanut pods especially when lime has been applied to a field.

Changes in soil [K] and [Mg] were also affected by fertilizer application. When gypsum was applied (whether alone or in combination with lime), soil [K] was decreased compared to the non-treated soil (Fig. 3). Flooding of the pegging zone with an abundant quantity of readily-available Ca cations causes displacement of K cations on soil exchange sites. This is supported by observations of extractable Ca being increased with gypsum applications but decreasing extractable K and Mg through leaching (Sullivan *et al.*, 1974; Yang *et al.*, 2017). This same result did not occur with lime (despite nearly three times as much Ca applied in this study) since it takes more time to react with soil, increasing the availability of Ca over a longer period of time instead of an instantaneous flush of the competing cation. However, that is in contrast to the results by Yang *et al.* (2017) which observed decreased [K] from either gypsum or lime application.

With regard to soil [Mg], application of lime greatly increased soil [Mg] compared to the non-treated soil since dolomitic lime contains Mg (Fig. 3). Although the magnitude of increase in soil [Mg] was suppressed when lime was followed by gypsum because of competition for exchange sites by

Table 2. Effect of irrigation on soil pH, pod nutrient concentrations, and production of peanut, averaged over Ca fertilization treatments, Tifton, GA, 2016-17.

	Δ pH[a]	Pod [Ca] mg/kg	Pod [K] mg/kg	Pod [Mg] mg/kg	Pod Yield kg/ha	TSMK[b] %
Irrigated	0.4 a	920 a	6760 b	1750 a	5500 a	76.8 a
Non-Irrigated	0.2 b	760 b	7750 a	1680 b	4980 b	74.5 b
Standard Error	± 0.03	± 50	± 110	± 20	± 250	± 0.4

[a]Means within a column followed by the same lowercase letter are not significantly different according to Tukey's Honestly Significant test (P=0.10).
[b]TSMK = total sound mature kernels (only 2016 data included).

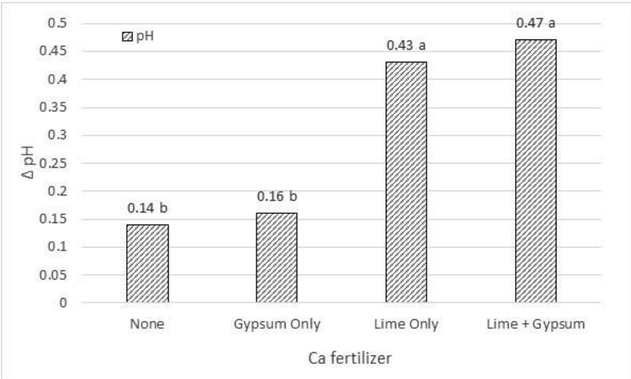

Fig. 1. Change in soil pH from planting to harvest from Ca fertilizers. Tifton, GA 2016-17. Different letters indicate significant differences according to Tukey's Honestly Significant test (P=0.10).

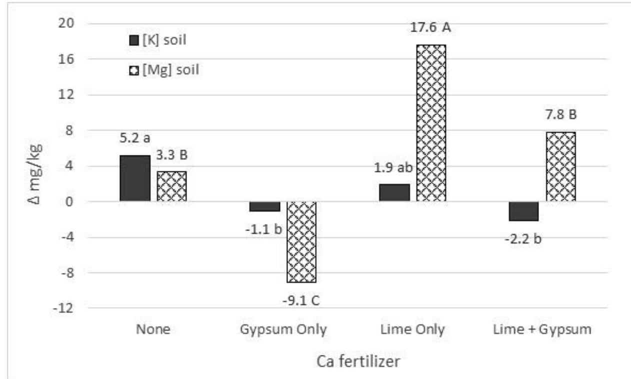

Fig. 3. Change in extractable soil [K] and [Mg] from planting to harvest from Ca fertilizers. Tifton, GA 2016-17. Different letters indicate significant differences according to Tukey's Honestly Significant test (P=0.10); lowercase for [K], uppercase for [Mg].

additional Ca not allowing as much Mg to adhere. This was also observed in the gypsum alone treatment compared to the non-fertilized treatment. Since no supplemental Mg was applied with gypsum treatments, the flush of Ca greatly reduced soil [Mg] in comparison. This can be a cause for concern to peanut growers that use gypsum as their sole Ca fertilization source and may have a deficiency or borderline deficient soil concentration of either [K] or [Mg]. It is important to consider all of these cations from the soil test and apply fertilizers based on recommendations, especially if a competing cation is also being applied. Otherwise an induced nutrient deficiency may be caused unintentionally.

Pod Nutrient Concentrations

Pod [Ca] was greatest when lime and gypsum were both applied, and was greater than when lime alone or no fertilizer was applied (Fig. 4). There were no differences for fertilization treatments regarding pod [K], although there was an inverse correlation of pod [K] with pod [Ca] ($p=0.023$, Pearson coefficient = -0.28) where every 69 mg/kg decrease in [Ca] would result in a 100 mg/kg increase in [K]. Pod [Mg] was similar to soil [Mg] results where the application of gypsum caused a reduction in [Mg] for soil and pods compared to the lime alone or non-fertilized treatments (Fig. 5). These are further indications that caution should be taken when gypsum is applied as the only source of Ca fertilizer so it does not induce a deficiency of another cation nutrient.

Yield and Grade (TSMK)

Despite differences in soil and pod nutrient concentrations due to fertilization treatments, there was no effect on pod yield of peanut in this study. This is similar to results observed by Howe *et al.* (2012) in soils with [Ca] greater than 150 mg/kg. Although, there was not a decrease in yield with this rate of gypsum application at this pH, unlike what was demonstrated on virginia pods in North Carolina (Jordan and Hare, 2018). There was an improvement in TSMK when both lime and gypsum were applied in sequence (76.3%) compared to no fertilization (75.2%) in 2016. There were no differences among Ca fertilizer treatments for TSMK in 2017. The 2016 growing season

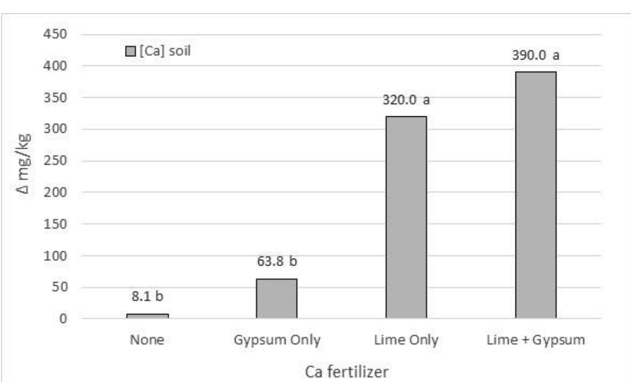

Fig. 2. Change in extractable soil [Ca] from planting to harvest from Ca fertilizers. Tifton, GA 2016-17. Different letters indicate significant differences according to Tukey's Honestly Significant test (P=0.10).

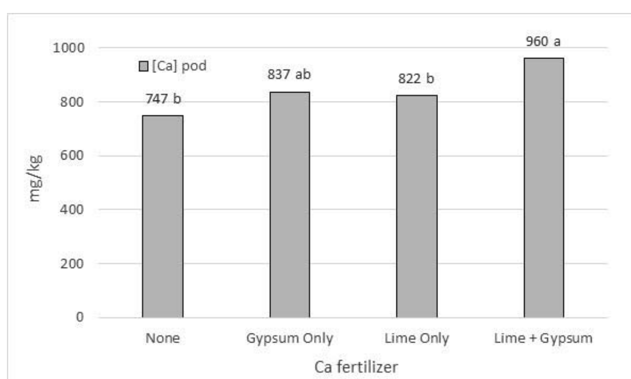

Fig. 4. Concentration of Ca in peanut pods at harvest from Ca fertilizers. Tifton, GA 2016-17. Different letters indicate significant differences according to Tukey's Honestly Significant test (P=0.10).

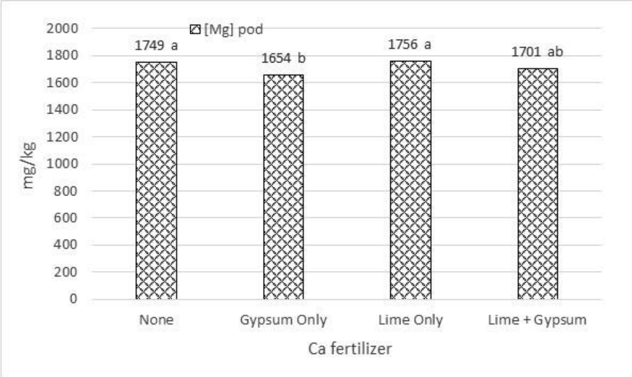

Fig. 5. Concentration of Mg in peanut pods at harvest from Ca fertilizers. Tifton, GA 2016-17. Different letters indicate significant differences according to Tukey's Honestly Significant test (P=0.10).

included more moisture in the latter half of the season during peak pod development stages (Table 1) which may have influenced the difference in TSMK results between years (2 to 4% reduction in TSMK from 2016 to 2017 depending on fertilization treatment).

Summary and Conclusions

Irrigation was necessary to improve yield and grade of peanut, and likewise increased soil pH, and [Ca] and [Mg] in pods. Water is still the most yield-limiting factor in peanut production in most production areas. Gypsum and/or lime are the most cost-effective methods of Ca fertilization for peanut and are critical in pod development. However, it is important to understand the relationship of cations and the potential counter-effects of their competition. The availability of nutrients at different pH levels is also a relevant factor in determining fertilizer sources and rates. When pH is low, even the application of gypsum may not provide benefits because of availability and residence time for absorption since adherence to soil particles may be limited. At recommended pH levels, the application of large quantities of Ca can influence peanut growth and development when needed, but can also impact concentrations of other cations that are important in peanut growth. This is evidenced in this study by reduced soil [Mg] with the application of gypsum to levels considered low/below adequate, and an inverse correlation of pod [Ca] with pod [K]. Peanut growers are encouraged to conduct soil tests to ensure soil [Mg] is not deficient or borderline before choosing to apply gypsum. A supplemental fertilizer for other nutrients that are deficient or borderline should be considered since they could become deficient before the end of the season with pod development removing even greater quantities of nutrients from the soil.

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