

THE EFFECT OF IRRIGATION AND MAGNESIUM ON CALCIUM UPTAKE IN
PEANUT (*ARACHIS HYPOGAEA* L.)

by

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(Under the Direction of R. Scott Tubbs)

ABSTRACT

On the sandy Coastal Plain soils in the Southeastern United States, calcium (Ca) is often a limiting nutrient for peanut (*Arachis hypogaea* L.) production. Calcium uptake into the peanut plant can be impacted by soil moisture and the competition between Ca and other cations, such as magnesium (Mg). Field trials and greenhouse trials were conducted in 2016 and 2017 to evaluate the impact of irrigation on two Ca sources (dolomitic lime [$\text{CaMg}(\text{CO}_3)_2 + \text{CaCO}_3$] and gypsum [CaSO_4]) and the competition between Ca and Mg. Soil Ca and Mg concentrations and pod Ca and Mg concentrations along with yield and total sound mature kernels (evaluated in field trials only) were used to evaluate these impacts. Results indicated that current UGA Extension recommendations for Ca fertility of peanut are sufficient. However, there was evidence of competition between Ca and soil Mg; therefore, if Mg concentrations were large enough, this recommendation might not be sufficient.

INDEX WORDS: *Arachis hypogaea* L.; Peanut; Calcium; Gypsum; Dolomitic Lime; Magnesium; Pegging Zone; Irrigation

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DEDICATION

I would like to dedicated this thesis to my family. Without your love, support, and constant reassurance I would not be where I am today. I can always count on you to brag about my accomplishments, make me laugh, and remind me of the important things in life. I would also like to dedicate this thesis to Joseph Ford. It is your love and support that has helped me not give up and to reach for my dreams.

Psalm 119:66 *“Teach me knowledge and good judgement, for I trust Your commands.”*

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CHAPTER 1

INTRODUCTION

By 2050, the world population is expected to be over 9 billion people (United States Census Bureau, 2017). The agricultural community has the responsibility to feed all these people. Therefore, there is a push to increase yield and quality, while still providing profitability for the producer. Researchers are focused on improving every aspect of producing a crop, including soil fertility.

Sandy Coastal Plain soils, found in the Southeast are ideal for peanut (*Arachis hypogaea* L.) production (Howe et al., 2012). About 70% of peanut acreage in the United States (U.S.) is in Georgia, Alabama, Florida, and Mississippi (Pathak et al., 2013). In 2015, peanuts were the fifth highest grossing ranked commodity in the state of Georgia (University of Georgia [UGA], 2016a). From 2013 to 2017, an average of 273,972 hectares of peanuts were planted in Georgia (NASS, 2017).

Peanut is an annual dicotyledonous legume (Moss and Rao, 1995). Uniquely, peanut flowers above ground then produces fruit underground. Peanut flowers are self-pollinating. This pollination usually occurs within a few hours after sunrise (Moss and Rao, 1995). After fertilization, gynophores (known as pegs) begin to form and expand until they penetrate the soil where fruit begins to develop (Moss and Rao, 1995). The fruit develops in what is known as a pegging zone, or roughly the top 0-8 cm of the soil profile where the seeds form inside the pod (Howe et al., 2012).

Nutrients are important in plant growth because they form compounds needed in photosynthesis and respiration. Most plants require nitrogen (N) fertilizer in the greatest quantity, but peanut N needs are met through N₂ fixation. Peanut is a legume and forms a symbiotic relationship with *Bradyrhizobium* to fix N from the atmosphere that can be used by the plant (Elkan, 1995). The rhizobia form nodules on the peanut roots where N₂ fixation occurs (Elkan, 1995). In order to ensure the presence of *Bradyrhizobium*, peanut inoculants should be applied to a field that has not been planted to peanut for more than five years (Tubbs, 2018). With N requirements being met through N₂ fixation and phosphorus (P) and potassium (K) requirements being often less than other crops and normally met through fertilizers added during rotation, N, P, and K are rarely an issue in the U.S. for peanut (Cope et al., 1984; Scarsbrook and Cope, 1956; and Walker et al., 1979). With N, P, and K causing infrequent problems, calcium (Ca) is often a limiting nutrient (Cox et al., 1982). Calcium requirements are an important factor in developing a properly filled pod with a high-quality seed (Gascho and Davis, 1995). When Ca requirements are not met, deficiency symptoms can occur. These symptoms occur as unfilled pods (“pops”) and pod rot; which produce reduced yield, substandard total sound mature kernels (TSMK), and poor germination of peanut used as seed (Gascho and Davis, 1995; Tillman et al., 2010; Howe et al., 2012). Calcium can be added with fertilizers such as naturally mined gypsum, flu-gassed desulfurized (FGD) gypsum, phosphogypsum, gypsum wallboard, and dolomitic lime.

Factors that limit Ca availability can cause detrimental problems. Lack of available soil Ca, limited water for movement, and competition between cations are some of these factors that affect soil health and fertility. Soil moisture below 25% available water can reduce yield and percent TSMK, limit pod size, and cause poor germination of peanut seed (Pallas et al., 1977).

Cations such as magnesium (Mg), can inhibit Ca uptake as they compete for exchange sites along soil particle surfaces (Gascho and Davis, 1995).

Limited research has been conducted combining Ca sources with and without irrigation. Having these combinations can allow producers to make more informed decisions about the conditions under which they grow peanuts. Research has been conducted on the impact K has on Ca uptake, but limited information is available on how other cations (like Mg) can impact Ca availability. As the world population continues to rise and the agricultural community tries to increase yield and TSMK, understanding Ca source interaction with irrigation and soil cation relationships can help peanut producers make informed management decisions.

CHAPTER 2

LITERATURE REVIEW

Calcium

Calcium (Ca) is one of the most limiting nutrients in the southeastern United States for peanut (*Arachis hypogaea* L.) (Howe et al., 2012). The sandy soils with very low cation exchange capacity (CEC) often found in the Coastal Plains provide an ideal environment for Ca to leach (Alva et al., 1991). Therefore, Ca sources are one of the main fertilizers used in peanut production.

When soil Ca is limited, deficiencies can be seen as lack of pod formation, underdeveloped kernels or ‘pops’, ‘black plumule’ where the young embryo is dark in color, and reduced seed germination of next year’s crop (Howe et al., 2012; Sorensen and Butts, 2008; Tillman et al., 2010; Zharar et al., 2009a). Additionally, Walker and Csinos (1980) observed an increased amount of pod rot with no Ca compared to where gypsum was applied.

Being largely phloem immobile, Ca cannot move from older organs to actively growing regions of the plant (Wiersum, 1951). There is also very little movement of Ca from the roots to the leaves and the pods through the phloem (Wiersum, 1951; Sumner et al., 1988). With Ca not moving in the phloem, the xylem is utilized. In order for Ca to travel in the xylem, it must follow the transpiration stream (Hanger, 1979). Since developing pods are underground, they do not transpire and therefore, cannot receive xylem-transported Ca from the roots (Skelton and Shear, 1971). Skelton and Shear (1971) showed that pods exposed to air absorbed larger amounts of Ca compared to pods not exposed to the atmosphere. This is all due to Ca moving with the

transpiration stream. In order for Ca to be absorbed directly by the pod, water is required to move Ca via mass flow and diffusion from the soil to the pod (Skelton and Shear, 1971). The root system, including the pegging zone, plays an important part of absorbing water and nutrients from the soil (Girdthai et al., 2010). Calcium must enter developing fruit from the surrounding soil medium (Skelton and Shear, 1971). With the immobility of Ca in the plant, peanut must absorb Ca in the root zone (especially the pegging zone) to produce healthy vegetative and reproductive parts.

With Ca moving from the surrounding soil solution, timing is key. About 92 percent of Ca uptake by pods occurs during 20 to 80 days after gynophores (“pegs”) enter the soil, and 69% of uptake is between days 20 and 30 after soil entry (Mizuno, 1959). More Ca is needed for seed development than in the initial development of the fruit (Skelton and Shear, 1971). With this in mind, the critical period for Ca availability for peanut fruit is 25 to 65 days after flowering (Alva et al., 1991).

Current Ca applications are based on soil test results from the pegging zone (top 8 cm of soil near plant). The University of Georgia’s (UGA) Cooperative Extension Service recommends applying Ca when soil Ca levels are less than 250 mg kg⁻¹ or the Ca:K ratio is less than 3:1 (Harris, 2013). Alabama’s Cooperative Extension Service states that when soil-test Ca is greater than 150 mg kg⁻¹ supplemental Ca is not needed (Howe et al., 2012). Tillman et al. (2010) found that Ca application should be triggered when soil Ca levels are less than 200 mg kg⁻¹. Supplemental Ca fertilization can be eliminated or reduced without affecting yield when peanut is grown on soils with high soil Ca levels (Sullivan et al., 1974). Arnold III, et al. (2017) showed that yield and germination rate of Georgia-06G and Georgia Greener were not affected by gypsum application rates when soil Ca levels were at or above levels recommended by the UGA

Extension Service. However, it is recommended by UGA Extension Service and the Southern Seed Certification Association to add Ca to all peanuts grown for seed (Howe et al., 2012).

Calcium deficiencies in the soil can be amended by a Ca fertilizer. Gypsum (CaSO_4) is the main source of Ca used on peanut. The UGA Extension Service recommends adding 1,121 kg ha⁻¹ of gypsum in a broadcast pattern at bloom (Harris, 2013). Calcium concentration in the seed increases with increasing gypsum rates, but yield does not have the same positive correlation when soil Ca levels are sufficient (Howe et al., 2012).

Dolomitic lime ($\text{CaMg}(\text{CO}_3)_2 + \text{CaCO}_3$) is another Ca source that is mainly used when soil tests recommend increasing pH. The UGA Extension Service recommends adding lime based on soil-test pH. Dolomitic limestone has been shown to increase soil pH and soil Ca levels (Sullivan et al., 1974). The solubility of lime is a factor in timing of application. Lime is not as soluble as gypsum and therefore it must be applied at planting (and should not be deep turned) in order to be available to developing pods (Harris, 2013).

Potassium and Magnesium

Calcium and potassium (K) relationships are important in peanut fruiting (Hallock and Allison, 1980). Studies have shown that high soil K levels can counteract the addition of Ca (Hallock and Allison, 1980). Potassium application should be considered in relation to other cations, especially Ca, because K ions can compete for uptake by the developing pods (Gascho and Davis, 1995). A reduction in yield, TSMK, and Ca content in the pods can be caused by K_2SO_4 applications when excess K replaces Ca on exchange sites, reducing Ca availability (Hallock and Garren, 1968). Sullivan et al. (1974) also reported reductions in yield and percent TSMK with K applications. An interaction between K and gypsum was also observed because

when gypsum and K were both applied, yield and seed quality were not affected (Sullivan et al., 1974).

Along with K, magnesium (Mg) can potentially interfere with Ca uptake in pods (Gascho and Davis, 1995). Increased pod rot has been witnessed with the addition of MgSO_4 and K_2SO_4 (Hallock and Garren, 1968). Decreased Ca concentration in pods and reduced pod formation can occur with the addition of MgSO_4 when an excess of Mg replaces Ca on exchange sites, reducing Ca availability (Hallock and Garren, 1968). Therefore, excess soil Mg is thought to inhibit Ca uptake in the pegging zone, adversely affecting peanut pod development (Zharare et al., 2011). The potential inhibition of Ca uptake by K and Mg can possibly be eliminated through the application of gypsum because gypsum increases Ca levels and decreases extractable K and Mg (Sullivan et al., 1974).

Irrigation

Drought stress can decrease plant growth, yield, and mineral uptake (Htoon et al., 2014). Soil moisture plays an important role in movement of many nutrients (Junjittakarn et al., 2013). Calcium availability to peanut pods increases with irrigation which also improves TSMK (Cox et al., 1976). Research has also shown that there is a greater uptake of nutrients during wet periods throughout the growing season (Junjittakarn et al., 2013). Hence, added water from irrigation during periods of dry weather should increase nutrient uptake and therefore improve peanut production. Studies have also found significant correlations between nutrient uptake and peanut genotypes across irrigation regimes (Junjittakarn et al., 2013).

Pegging Zone

Pod initiation, pod set, seed set, and growth of the pods and seeds of peanut are affected by Ca concentration in the pegging zone (Zharare et al., 2009b). Research techniques that

separate root and pegging zones have shown that Ca must be available in the pegging zone for direct uptake by the gynophores (Bennett et al., 1990). Bennett et al. (1990) observed that a dry pegging zone reduced total number of pods and seed weights per plant, growth rates of individual pods and seeds, and individual pod and seed weights. In greenhouse studies with separate root zones from pegging zones, dry pegging zone soils also resulted in delayed pod and seed development (Sexton et al., 1997). Along with soil moisture, increased Ca in the pegging zone increases pod production (Zharare et al., 2012).

Objectives

Calcium is the most important nutrient for peanut in the southeastern United States. Producers often rely on Extension specialist, agents, and agronomists for input on fertility practices to increase yield and TSMK. Questions have been raised regarding the impact of irrigation and Mg on Ca availability to peanut. Limited research has been published on Ca uptake by large seeded runner peanut under irrigated conditions. Also, previous research has shown that high levels of K can compete with Ca during uptake (Gascho and Davis, 1995). Magnesium also has the potential to compete with Ca during uptake. This research will evaluate the potential effect that high levels of Mg have on Ca uptake in large-seeded runner peanut cultivars. This information could help producers make more educated decisions regarding their fertility management plans.

Therefore, the objectives of this research are to:

1. Determine whether lime, gypsum, or a combination is more productive under irrigated or non-irrigated conditions.
2. Determine whether irrigation impacts Ca availability in the pegging zone of runner peanut in a greenhouse environment.

3. Determine whether Mg impacts Ca uptake in runner peanut.
4. Determine whether Mg competes with Ca uptake in runner peanut in a greenhouse setting.

CHAPTER 3

CALCIUM UPTAKE IN IRRIGATED AND NON-IRRIGATED RUNNER PEANUT

*(ARACHIS HYPOGAEA L.)*¹

¹Pegues, K.D., R.S. Tubbs, G.H. Harris, and W.S. Monfort. To be submitted to *Peanut Science*

Abstract

Calcium (Ca) is important in peanut production as it improves seed formation and development. The two main sources of Ca fertilization in peanut are flue gas desulfurized (FGD) gypsum (CaSO_4) and dolomitic lime (CaCO_3). Objectives of this research are to determine whether gypsum, lime, or a combination of both increases Ca uptake, yield, and total sound mature kernels (TSMK) with or without irrigation. Peanut was grown in 2016 and 2017 on a Tifton loamy sand in Tifton, GA. Irrigated and non-irrigated blocks (main-plot effect) with four treatments of Ca sources in each block (sub-plot effect) were applied in a split plot design. The treatments in each irrigated and non-irrigated block include: 1. lime ($897 \text{ kg Ca ha}^{-1}$) at planting plus gypsum ($330 \text{ kg Ca ha}^{-1}$) at first bloom (approximately 35 days after planting), 2. gypsum ($330 \text{ kg Ca ha}^{-1}$) at first bloom, 3. lime ($897 \text{ kg Ca ha}^{-1}$) at planting, and 4. a non-treated check that received no supplemental Ca. In 2016, an interaction between irrigation blocks and Ca source treatments was observed, but not in 2017. Soil Ca concentrations increased from pre-application to harvest during both years with an application of lime (521 mg kg^{-1} in 2016 and 259 mg kg^{-1} in 2017 for the gypsum plus lime treatment and 454 mg kg^{-1} in 2016 and 198 mg kg^{-1} in 2017 for the lime treatments). In 2016, irrigated blocks had a TSMK of 77% while non-irrigated blocks were 75%. Also in 2016, irrigated blocks had a greater yield (6760 kg ha^{-1}) compared to non-irrigated blocks (5050 kg ha^{-1}). In 2017, neither TSMK nor yield was significant. Based on these results of this experiment, irrigation can increase TSMK and yield during relatively dry years. Also, soil Ca and pod Ca can be increased with the addition of Ca fertilizers.

Introduction

Georgia is the largest peanut producing state in the United States with an average of 268,954 hectares harvested during the last 5 years (NASS, 2017). The majority of peanuts grown in the state are the runner market-type. The sandy Coastal Plain soils of the South are ideal for peanut production (Walker and Keisling, 1978). With peanut being a legume, nitrogen (N) needs are met through N fixation with a symbiotic relationship with *Bradyrhizobium* (Elkan, 1995). Since N requirements being met and phosphorus (P) and potassium (K) requirements being often less than other crops and normally met through fertilizers added during rotation, N, P, and K are rarely an issue in the U.S. for peanut (Cope et al., 1984; Scarsbrook and Cope, 1956; and Walker et al., 1979). Nitrogen, P, and K normally cause infrequent problems, Ca is often a limiting nutrient in peanut (Cox et al., 1982). Fertilizers that supply Ca are more proximately used in peanut compared to N, P, and K fertilizers. The University of Georgia's (UGA) Extension Service recommends applying Ca when soil Ca levels are less than 250 mg kg⁻¹ or the Ca:K ratio is less than 3:1 in the top 8 cm of soil (Harris, 2013).

Calcium deficiencies result in lack of pod formation, underdeveloped kernels (also known as “pops”), and reduced seed germination of next year's crop ((Tillman et al., 2010; Howe et al., 2012). Pod rot (*Pythium myriotylum* Drechs.) is another result of Ca deficiency and can be reduced by Ca application (Gascho et al., 1993). Ca deficiencies can also reduce yield and total sound mature kernels (TSMK) (Sorensen and Butts, 2008). These responses correspond to how Ca moves in all plants. Moving from older organs to actively growing organs is not possible since Ca is largely immobile in the phloem (Wiersum, 1951). Since the phloem is not being used, Ca can be moved upwards from the roots to the meristematic zones and young tissue, but it must follow the transpiration stream (Hanger, 1979). However, this does not work for moving Ca into

peanut pods because they grow underground and therefore cannot transpire (Skelton and Shear, 1971) With very little movement from roots to the pods, Ca must be absorbed directly by the developing pods (Sorensen and Butts, 2008). In order to produce high yielding and good quality peanuts, the top 8 cm must have adequate soil Ca along with approximately 0.7 cm of water per day during pegging and pod fill (Stansell et al. 1976; Gascho et al., 1993).

With the limitations of Ca mobility, the source of Ca plays a role in availability to developing pods. Gypsum (CaSO_4) is the primary fertilizer source used in peanut. The UGA Extension Service recommends applying $1,121 \text{ kg ha}^{-1}$ of gypsum at the R1 growth stage (Boote, 1982), or “first bloom”, when soil Ca levels are below 560 kg ha^{-1} (Harris, 2013). Research has shown that gypsum application increases Ca concentration in the seeds but does not affect yield when soil Ca is at or above the recommended level (Howe, 2012; Arnold III, et al., 2017). Gypsum is often applied at first bloom to increase soil Ca (Gascho et al., 1993). It is applied at first bloom because gypsum is a relatively soluble material and is subject to leaching (Daughtry and Cox, 1974).

Dolomitic lime ($\text{CaMg}(\text{CO}_3)_2 + \text{CaCO}_3$) is another Ca source. However, lime is mainly used when soil tests recommend increasing pH. Dolomitic limestone has been shown to increase soil pH and soil Ca levels (Sullivan et al., 1974). The UGA Extension Service recommends adding lime when soil test reports needing an increase in soil pH (Harris, 2013). Lime is not as soluble as gypsum; therefore, it should be applied at planting in order to be available to developing pods.

Not only is Ca source important in getting Ca to pods, but soil moisture also plays a role. 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 a soil moisture that can move nutrients into the plant. Also, 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). However, when irrigation is utilized, Ca availability to peanut pods increases (Cox et al., 1976). Although, too much irrigation or rainfall can cause Ca leaching from the sandy soils and no longer be accessible to developing pods (Gascho et al., 1993).

Calcium is important for peanut production, especially with it being a limiting nutrient in the sandy soils of the Coastal Plain. Therefore, questions arise concerning source of Ca and increasing uptake. The primary objective of this study is to determine how irrigation plays a role in the amount of Ca available in the soil, the amount of Ca taken up by the peanut pods, yield and TSMK. The secondary objective is to determine the productivity of gypsum and dolomitic lime based on the amount of Ca available in the soil, the amount of Ca taken up by the peanut pods, yield, and TSMK. The information from this research could aid growers in making more educated decisions regarding which Ca source they should use in their growing conditions.

Materials and Methods

Field trials were conducted from 2016-2017 at the Lang-Rigdon Farm on the UGA Coastal Plain Experiment Station in Tifton, GA, on a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) (USDA-NRCS, 2017). The experiment was conducted in a split-plot design with eight replications in 2016 and a split-split-plot design in 2017 due to the addition of a cultivar. The main effect was irrigation (irrigated and non-irrigated). The sub-effect was calcium source including flue gas desulfurization (FGD) gypsum (CaSO_4) and dolomitic lime ($\text{CaMg}(\text{CO}_3)_2 + \text{CaCO}_3$). The four sub-treatments were: 1. lime ($897 \text{ kg Ca ha}^{-1}$) plus gypsum ($330 \text{ kg Ca ha}^{-1}$) 2. gypsum ($330 \text{ kg Ca ha}^{-1}$), 3. lime ($897 \text{ kg Ca ha}^{-1}$), and 4. no added

Ca. In 2016, the cultivar Georgia-06G (Branch, 2007) was planted for the entire study. In 2017, Georgia-06G and Georgia-14N (Branch and Brenneman, 2015) were planted to observe the difference between the two cultivars in a field with possible peanut root-knot nematode (PRKN) (*Meloidogyne arenaria*) populations. The 2016 sub-plots 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, with four rows of Georgia-06G and four rows planted to Georgia-14N.

Field preparations for both years consisted of deep turning the soil to a depth of 30 cm with the use of 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. Both years were planted with a Monosem Single-Row Precision Vacuum Planter (Monosem Inc., Edwardsville, KS) with a seeding rate of 20 seed m⁻¹ (Beasley, 1997). Irrigation was applied through a lateral irrigation system (Valley[®] Irrigation, Valley, NE). Irrigation was determined based on the weekly water use by peanut also known as the UGA checkbook irrigation scheduling method (Stansell et al. 1976; Porter, 2017).

The lime treatments were applied the day after planting (3 June 2016 and 21 April 2017). The analysis of the lime used was 305 g Ca kg⁻¹ and 50 g Mg kg⁻¹ (Waters Agricultural Laboratories [WAL], Inc., Camilla, GA). The gypsum treatments were applied at first bloom (R1 growth stage [Boote, 1982]), approximately 35 days after planting (7 July 2016 and 24 May 2017). The FGD gypsum analysis was 242 g Ca kg⁻¹ and 184 g Sulfur (S) kg⁻¹ (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) to control early leaf spot (*Cercospora arachidicola*) and late leaf spot (*Cercosporidium personatum*) as well as southern stem rot (*Sclerotium rolfsii* Sacc.). Fungicides were first applied starting approximately 35 days after planting (R1 growth stage [Boote, 1982]), and continued throughout the season on 14 d spray intervals. Liquid Boron (B) (10%) was applied at 0.56 kg ha⁻¹ with the first fungicide application (Harris, 2013).

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). Most Leaf tissue was sampled, on 30 August 2016, 29 June 2017, and 18 September 2017 for nutrient analyses. Pod (shell plus kernels) samples were removed on 26 October 2016 and 28 September 2017 and analyzed for nutrient concentration.

Peanut maturity was determined according to the hull scrape method (Williams and Drexler, 1981). Digging and inversion of the plants were done 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 been dug and dried down to approximately 12-15% moisture, harvest was carried out using 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. TSMK was determined according to USDA-AMS grade standards (USDA-AMS, 1997).

Statistical analyses were conducted using PROC MIXED, PROC PLM, and PROC CORR in SAS University 5.2.7 (SAS Institute Inc., Cary, NC). Data were analyzed by analysis of variance (ANOVA), and differences among least square means were determined by using

multiple pairwise t-tests ($P=0.05$) for each year. Each year was kept separate since the experimental design differed from 2016 to 2017.

Results and Discussion

Environmental Data

Average maximum and minimum temperatures for the Coastal Plain Experiment Station for 2016 and 2017 are presented in Table 3.1. The average amount of rainfall and irrigation for each month of the growing season is also included in Table 3.1.

The initial soil Ca concentration was 346 mg kg^{-1} in 2016 and 200 mg kg^{-1} in 2017 with a Ca:K ratio of 7:1 in 2016 and 6:1 in 2017. This is above the minimum recommended concentration of $250 \text{ mg Ca kg}^{-1}$ and 3:1 Ca:K ratio in 2016, but below the minimum recommended Ca concentration in 2017 (Harris, 2013). The initial soil K concentration was 50 mg kg^{-1} in 2016 and 31 mg kg^{-1} in 2017, while the soil Mg concentration was 38 mg kg^{-1} in 2016 and 24 mg kg^{-1} in 2017. This is in the medium concentration level for both soil K and Mg, no fertilizer application needed (Kissel and Harris, 2008).

Soil Concentrations

There was an interaction between irrigation and fertilization treatments in 2016 for the change in soil Ca concentration from pre-application to harvest, and a difference in fertilization treatments regardless of irrigation in 2017. In both years, treatments that included lime had greater concentrations of Ca compared to the gypsum alone treatment and the non-treated check (Table 3.2). The reason for the interaction in 2016 was a lower change in Ca concentration for the lime alone treatment under non-irrigated conditions. This could be due to the lower amount of rainfall in 2016 compared to 2017 accompanied with reduced ability for the lime alone treatment to dissolve and allow the Ca ions to attach to available to soil exchange sites reducing

the change in soil Ca concentration for the non-irrigated lime only treatment. These results indicate that the addition of lime tends to greatly increase soil Ca concentrations when initial soil Ca concentrations were above and below the recommended level. However, according to Alva et al. (1990), Mehlich-I was very likely to overestimate Ca available to peanut pods especially when lime had been applied to a field. Therefore, the reason the treatments with lime had higher soil Ca concentrations could be because of the soil testing extract.

There was also an interaction between irrigation and fertilization treatments in 2016 for the change in Mg concentration from pre-application to harvest, and a difference in fertilizer treatments regardless of irrigation in 2017. In all instances, the application of lime alone increased Mg concentration the most. When both gypsum and lime were applied, soil Mg did not increase as much as lime alone. However, Mg was reduced by application of gypsum alone compared to all other treatments including the non-treated, indicating that application of gypsum supplanted Mg on soil exchange sites and Mg was removed from the pegging zone. Also, in the non-irrigated treatments in 2016, gypsum plus lime had a greater concentration of Mg than the non-treated soil, but this was not true in irrigated conditions. These results are indications that the application of lime added accessible Mg to the soil, however the application of gypsum caused interference with Mg availability. There is also the indication that supplemental irrigation leaches Mg out of the pegging zone after application of gypsum since Mg concentrations with lime and gypsum were the same as the non-treated soil in irrigated conditions, but there was an increase in Mg with gypsum and lime compared to the non-treated in non-irrigated conditions. This is supported by Sullivan et al. (1974) observations of extractable Ca being increased with gypsum applications but decreasing extractable K and Mg through leaching.

In 2016 and 2017, the gypsum plus lime treatment significantly increased the Ca:K ratio in the soil by harvest (Table 3.3). None of the treatments cause the Ca:K ratio to drop below 3:1. Therefore, based on the current recommendations, there is not enough K to inhibit Ca uptake. Also in 2016 and 2017, the gypsum plus lime treatment significantly increased the Ca:K+Mg ratio in the soil by harvest (Table 3.3). Although Mg is being added as part of the lime, the ratio continued to increase. All of the treatments with Ca fertilizers increased the ratio. This was due to an increase in Ca concentrations even under potential situations of high K and Mg concentrations. Soil pH was increased in 2016 and 2017 with the addition of gypsum plus lime and lime alone treatments (Table 3.4). This increase in soil pH due to lime confirms the results observed by Sullivan et al. (1974).

Leaf Concentrations

Mid-season leaf Ca concentration was impacted by fertilization source in 2017 (Table 3.5). The gypsum treatment produced significantly greater leaf Ca concentrations than the lime or non-treated treatments. The readily available Ca in the gypsum increased the leaf Ca concentration.

Mid-season leaf Mg was affected by irrigation in 2016. Leaf Mg concentration was greater under non-irrigated conditions (4.7 g kg^{-1}) compared to irrigated conditions (3.6 g kg^{-1}). Under irrigated conditions less Mg was able to enter the leaves potentially due to reduced availability of Mg from the soil. Mid-season leaf Mg was also affected by Ca fertilization source in 2016 (Table 3.5). Gypsum plus lime and gypsum had significantly lower leaf Mg concentration compared to the non-treated treatment. This suggests that the readily available Ca in gypsum interfered with Mg uptake by the plant.

Pod Concentrations

Pod Ca was significantly affected by Ca source in 2016 and 2017 (Table 3.7). In 2016, the gypsum plus lime treatment and the lime treatment were significantly greater in pod Ca than the non-treated treatment. In 2017, the gypsum plus lime treatment was greater than any other treatment in pod Ca. This follows the same trend as the change in soil Ca. Soil Ca is positively correlated with pod Ca (Pearson Coefficient=0.43, $P=0.0126$). When soil Ca significantly increased over the peanut season, pod Ca also increased.

TSMK Data

In 2016, irrigation increased TSMK (77%) compared to non-irrigated (75%). Rainfall was less abundant in 2016 compared to 2017 (Table 3.1) and therefore the extra water through irrigation improved pod-fill. Also in 2016, Ca source was significant, as both treatments that included gypsum (76%) had greater TSMK than both treatments that did not add gypsum (75%). Thus, gypsum produced a higher quality seed. There was no difference in 2017 for TSMK.

Yield

In 2016, irrigation increased yield (6761 kg ha^{-1}) compared to non-irrigated peanut (5051 kg ha^{-1}). In 2017, the lime treatments yielded more than all other treatments under irrigation, when initial soil Ca concentrations were below the recommended level (Table 3.9) In 2017, there also was an interaction between irrigation and cultivar that significantly affected yield (Table 3.10). A non-irrigated Georgia-06G produced a higher yield than an irrigated Georgia-06G. According to Porter (2017), over-irrigation of Georgia-06G peanut in wet years can decreased yield compared to non-irrigated Georgia-06G peanut. Irrigation did not have an effect on Georgia-14N yield.

Conclusion

Peanut yields were not consistent from year-to-year. Therefore, an irrigation regiment or Ca fertilization practice does not provide a standardized benefit over another. This suggests that a universal agronomic recommendation for the best irrigation regiment and Ca application in peanut should not be made. However, adding Ca either by gypsum and/or lime, increases soil Ca concentration by the end of the season. Also, the addition of lime increases soil pH (Sullivan et al., 1974). Although, the inclusion of gypsum may interfere with Mg availability and uptake by the plant, thus if Mg concentrations in the soil are considered low, lime is the preferred method of increasing both Ca and Mg availability.

Since a specific recommendation cannot be made, a focus on irrigation scheduling and Ca soil testing extracts might be in order (Porter, 2017; Alva et al., 1990). In dry years, irrigation can increase yield, but excess irrigation in wet years can decrease yield compared to non-irrigated peanut yields according to this data and Porter (2017). When soil Ca level was above the recommended concentration of 250 mg kg^{-1} before pegging in 2016, Ca fertilization was not significant for improving yield (Harris, 2013). However, when initial soil Ca level was below the recommended concentration like in 2017, the lime treatment benefited peanut yield specifically under irrigated conditions. Based on these results, environmental conditions, especially rainfall during the growing season and initial soil Ca concentrations, play a large role in the effectiveness of irrigation and fertilization on peanut.

Table 3.1 Temperature, 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

^aTemperature and rainfall data obtained from georgiaweather.net

^bAverage of daily values for time period listed

^cSum of daily values for each time period

Table 3.2 Change in soil Ca and Mg concentrations from pre-application to harvest as affected by the interaction between irrigation and Ca fertilization or the effect of Ca fertilization in 2016 and 2017.

	Ca			Mg		
	mg kg ⁻¹					
	<u>2016</u>	<u>2017</u>		<u>2016</u>	<u>2017</u>	
	<u>Irrigated</u>	<u>Non-Irrigated</u>		<u>Irrigated</u>	<u>Non-Irrigated</u>	
Gypsum plus Lime	382 a	659 a	259 a	11.7 bc	14.4 b	2.5 b
Gypsum	87 b	97 c	36 b	-4.5 e	-14.7 d	-8.4 c
Lime	384 a	523 b	198 a	24.3 a	28.3 a	8.9 a
Non-treated	18 b	-20 c	17 b	6.2 cd	2.3 c	2.4 b

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 3.3 Soil Ca:K and Ca:K+Mg as affected by Ca fertilization in 2016 and 2017 at harvest.

	<u>Ca:K</u>		<u>Ca:K+Mg</u>	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
Gypsum plus Lime	19:1 a	21:1 a	9:1 a	9:1 a
Gypsum	9:1 c	10:1 b	6:1 b	6:1 b
Lime	15:1 b	13:1 b	7:1 b	6:1 b
Non-treated	7:1 d	7:1 b	4:1 c	4:1 c

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 3.4 Soil pH as affected by Ca fertilization in 2016 and 2017 at harvest.

	<u>2016</u>	<u>2017</u>
Gypsum plus Lime	6.1 a	6.0 a
Gypsum	5.9 b	5.7 b
Lime	6.1 a	5.9 a
Non-treated	5.8 b	5.6 b

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 3.5 Mid-Season leaf Ca and Mg as affected by Ca fertilization in 2016 and 2017.

	<u>2016</u>	<u>2017</u>
	<u>Mg</u>	<u>Ca</u>
	<u>g kg⁻¹</u>	
Gypsum plus Lime	4.0 b	11.4 ab
Gypsum	4.0 b	12.1 a
Lime	4.1 ab	11.2 b
Non-treated	4.5 a	10.9 b

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 3.6 Pod Ca as affected by Ca fertilization in 2016 and 2017.

	<u>2016</u>	<u>2017</u>
	mg kg ⁻¹	
Gypsum plus Lime	879 a	1037 a
Gypsum	801 ab	888 b
Lime	805 a	844 b
Non-treated	716 b	774 b

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 3.7 Yield as affected by the interaction between irrigation and Ca fertilization in 2017.

	<u>Irrigated</u>	<u>Non-Irrigated</u>
	kg ha ⁻¹	
Gypsum plus Lime	4630 cd	5460 abc
Gypsum	4470 d	5780 ab
Lime	5890 a	5660 ab
Non-treated	4980 bcd	5330 abcd

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 3.8 Yield as affected by the interaction between irrigation and cultivar in 2017.

	<u>Irrigated</u>	<u>Non-Irrigated</u>
	kg ha ⁻¹	
Georgia-06G	4750 b	5600 a
Georgia-14N	5230 ab	5520 ab

Means within a column or row followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

CHAPTER 4

IMPACT OF PEGGING ZONE IRRIGATION ON CALCIUM UPTAKE IN RUNNER
PEANUT (*ARACHIS HYPOGAEA* L.)¹

¹Pegues, K.D., R.S. Tubbs, G.H. Harris, and W.S. Monfort. To be submitted to *Peanut Science*

Abstract

Calcium (Ca) is very important to peanut (*Arachis hypogaea* L.) as it plays a substantial role in the formation of the peanut seed. Calcium is needed in the pegging zone and water is essential to moving the Ca into the pod. The two main sources of Ca fertilization in peanut are dolomitic lime (CaCO_3) and gypsum (CaSO_4). This study was conducted to determine whether a fully irrigated pegging zone or a partially irrigated pegging zone (dry pegging zone) combined with Ca fertilization (lime, gypsum, or a combination of both) increases Ca uptake in the seeds. The experiment occurred in a greenhouse in Tifton, GA where the root zone of the peanut plant was separated from the pegging zone by a non-permeable barrier. Fully irrigated and partially irrigated blocks (main-plot effect) with four treatments of Ca fertilization in each block (sub-plot effect) were applied in a split plot design with seven replications. The treatments in each fully irrigated and partially irrigated block included: 1. lime ($897 \text{ kg Ca ha}^{-1}$) at the time of planting plus at first bloom (approximately 35 days after planting); 2. gypsum ($330 \text{ kg Ca ha}^{-1}$) at first bloom; 3. lime ($897 \text{ kg Ca ha}^{-1}$) at planting; and 4. non-treated check that received no supplemental Ca. Soil tests for both 2016 and 2017 were below the minimum recommended rate of 250 mg kg^{-1} . Fully irrigated regiments produced an average of 0.96 pods per plant, while the limited irrigated regiments produced an average of 0.55 pods per plant. The seed weight followed a similar pattern with irrigation producing 0.53 g per plant while the partially irrigated treatments were 0.27 g per plant. Seed Ca increased with the addition of Ca fertilization compared to the non-treated check. With the use of full irrigation, the number of pods and seed weight increase.

Introduction

Nearly 50% of the peanuts produced in the United States (U.S) are grown in Georgia (NASS, 2017). The sandy soils are ideal for production but are often limited in soil calcium (Ca) (Walker and Keisling, 1978). Calcium aids in developing a properly filled pod (shell and kernels) with high quality seeds (Gascho and Davis, 1995). These pods form underground when gynophores (pegs) expand from a fertilized flower above ground and enter the soil surface (Moss and Rao, 1995). Growing underground causes some difficulties involving the movement of Ca into the pods. Calcium is largely immobile in the phloem and therefore relies largely on the xylem following the transpiration stream (Pathak et al., 2013). However, developing pods do not transpire since they are underground and require Ca to be absorbed directly from the soil solution surrounding the pods (Skeleton and Shear, 1971; Zharare et al., 2009b).

With Ca moving directly into the pods, the soil Ca in the top 8 cm (pegging zone) is the focus when determining whether to add Ca (Howe et al., 2012). The University of Georgia's (UGA) Cooperative Extension Service recommends applying Ca when soil Ca levels are less than 250 mg kg⁻¹ or the Ca to potassium (K) ratio is less than 3:1 in the pegging zone (Harris, 2013). Calcium below these levels can result in reduced seed germination, lack of pod formation (Tillman et al., 2010), and underdeveloped pods ("pops") (Howe et al., 2012).

In order to increase soil Ca, gypsum (CaSO₄) is often used. It is a relatively soluble source that is applied at first bloom (R1 growth stage) to decrease leaching (Boote, 1982; Daughtry and Cox, 1974). Dolomitic lime (CaCO₃•Mg) is another Ca source that is mainly used when soil pH is too low. Dolomitic lime can increase soil pH and soil Ca levels (Sullivan et al., 1974). Cox et al. (1976) found that irrigation increases Ca availability which affects pod fill as well as overall growth of the plant.

Since peanut is sensitive to soil surface conditions due to fruiting underground (Sexton et al., 1997), research has been conducted in greenhouses with apparatuses that separate the pegging zone from the root zone. These apparatuses allow for a detailed look into how Ca or water affects pod formation. Zharare et al. (2009b) used a split root and pod solution culture technique to examine the effects of Ca concentrations on virginia and spanish type peanut. It was found that Ca concentration in the pegging zone affects pod initiation, seed-set, and growth of pods and seeds of peanut (Zharare et al., 2009b). Pods did not form in the absence of Ca in the trial by Zharare et al. (2009b). Results could be different in runner type peanut based on the different Ca requirements for the different types.

Calcium is not the only condition that causes reduced pod development in the pegging zone. A dry pegging zone can delay pod and seed development (Sexton et al., 1997). The use of an apparatus that separated the root zone from the pegging zone of a growing peanut plant found that a dry pegging zone reduces total pod and seed weights per plant, growth rates of individual pods and seeds, and individual pod and seed weights (Bennett et al., 1990). Calcium moves with the transpiration stream to the developing fruit, therefore there was a lower Ca concentration in air-dry soil compared to pods developed in a moist pegging zone (Bennett et al., 1990). Sexton et al. (1997) also performed a greenhouse study to determine the effect of soil water content in the peanut pegging zone. An apparatus was used to separate the root zone from the pegging zone (Sexton et al., 1997). It was found that dry pegging zones delayed initiation of pod and seed development from new pods and delayed maturation (Sexton et al., 1997).

Being able to separate the root zone from the pegging zone can help focus on the importance of Ca and soil moisture in the pegging zone. The manipulation of the different zones can occur in a greenhouse but would be extremely difficult in a field setting. Being able to isolate

the growth of a peanut plant can aid in detailed knowledge for different pegging zone environments. Both Ca in the pegging zone and soil moisture in the pegging zone have been studied, but comparing different Ca fertilization with the interaction of pegging zone soil moisture has not been tested for runner type peanut. Thus, the primary objective of this study is to determine the importance of soil moisture and its influence on Ca uptake directly in the pegging zone of peanut. The secondary objective is evaluating the impact that two Ca fertilization sources (FGD gypsum and dolomitic lime) have on Ca uptake and seed weight.

Materials and Methods

Greenhouse trials were conducted in 2016 and 2017 on the UGA Coastal Plain Experiment Station in Tifton, GA. The experimental design was a split plot design with three replications in 2016 and four replications in 2017. The main effect was irrigation: 1x irrigated regiment (according to the weekly water use by peanut) (Stansell et al. 1976; Porter, 2017) and 0.33x irrigated regiment. The sub-effect was Ca source. The four sub-effect treatments include: 1. lime (897 kg Ca ha⁻¹) plus gypsum (330 kg Ca ha⁻¹), 2. gypsum (330 kg Ca ha⁻¹), 3. lime (897 kg Ca ha⁻¹), 4. non-treated check (no added Ca).

Plastic pots with tapered sides that had a top diameter of 52 cm, bottom diameter of 35 cm, and a height of 31 cm were used in 2016 and 2017 to grow peanuts. The volume of each pot was 172,002 cm³. A 27 cm by 10 cm diameter PVC pipe was affixed to the center of the pot using silicone in order to separate the root zone (inside the PVC) from the pegging zone (between PVC and planter wall) (Figure 4.1).

Two soils were mixed together to make a field soil that is below the recommended level (250 mg Ca kg⁻¹) for Ca fertilization, thus triggering an application (Harris, 2013). The first soil was a Loamy, siliceous, semiactive, thermic Aquic Arenic Paleudults and the second soil

was a Fine-loamy, kaolinitic, thermic Plinthic Kandiudults (USDA-NRCS, 2017). Both soils were pasteurized for 24 hr at 104°C. After pasteurization, a 50-50 mix was made using a small rotary mixer. A volume of 33,000 cm³ of soil was added to the pots. The bulk density for each pot was roughly 1.40 g cm⁻³. The soil level was roughly even with top of the PVC pipe.

Georgia-06G (Branch, 2007) was planted on 18 July 2016 and 14 February 2017. Three seeds were planted into the PVC in 2016 and four seeds were planted in the PVC in 2017 by hand. Seeds were planted 2.5 cm apart and 5.1 cm deep. In both years, 1 mL of Optimize[®] Liquid Inoculant for Peanut (Monsanto Company, St. Louis, MO) was added to the soil around each seed. On 17 August 2016, each pot was thinned back to one plant and on 9 March 2017 each planter was thinned back to two plants.

Irrigation was applied by measuring distilled water into graduated cylinders. The irrigation amounts were applied based on the weekly water use by peanut (Table 4.1) (Stansell et al. 1976; Porter, 2017). The root zone was kept irrigated for all treatments while the fully irrigated treatments had full irrigation applied to the pegging zone while partially irrigated treatments had one-third the rate of water applied.

The lime treatments were applied on 19 July 2016 and 15 February 2017 (the day after planting). The gypsum treatments were applied at first bloom (R1 growth stage [Boote, 1982]), on 22 August 2016 and on 29 March 2017. Based on the UGA Extension recommendation, 2242 kg ha⁻¹ of lime and 1121 kg ha⁻¹ of gypsum were used for the respective treatments receiving each fertilizer (Harris, 2013). Each of these fertilizers was weighed based on the area of the pegging zone (0.17 m²) and applied by spreading evenly across the pegging zone. The lime used was roughly 305 g Ca kg⁻¹ and 50 g Mg kg⁻¹ (Waters Agricultural Laboratories [WAL], Inc.,

Camilla, GA). The gypsum used was roughly 242 g Ca kg⁻¹ and 184 g Sulfur (S) kg⁻¹ (WAL, Inc., Camilla, GA).

Liquid Boron (B) (10%) was applied at 0.56 kg ha⁻¹ on 23 October 2016 and 10 July 2017, in accordance with the UGA Extension recommendation (Harris, 2013). The B was sprayed with a backpack sprayer at the R2 growth stage (Boote, 1982). Chlorosis was observed on peanut leaves so a solution of Miracle-Gro® 24-8-16 liquid fertilizer (The Scotts Company LLC, Marysville, OH) was applied inside the root zone on 17 November 2016 and on 30 March 2017. There was not enough leaf tissue to run a diagnostic analysis to determine the specific nutrient deficiency.

In 2016, whiteflies (*Bemisia argentifolii*) were a severe problem. Pyriproxyfen (61.8 g ai ha⁻¹) was sprayed on 26 August 2016, 16 September 2016 and 6 October 2016. Spider mites (*Tetranychus urticae*) flared in 2016 and 2017. Therefore, Abamectin (10.8 g ai ha⁻¹) was sprayed on 21 October 2016, 9 November 2016, and 30 June 2017. The few weeds that emerged were hand pulled.

Soil samples were taken at planting and harvest from the top 8 cm. In 2016, initial samples were removed on 18 July 2016 and harvest samples were taken on 8 December 2016. In 2017, initial soil samples were removed 14 February 2017 and harvest samples were taken on 18 July 2017. All the soil samples were sent to the UGA Soil, Plant, and Water Lab for routine soil analysis using Mehlich-I (Kissel and Sonon, 2008; Mehlich, 1953). On 8 December 2016 and 18 July 2017 all pods were pulled from each pot and counted. The pods were then shelled and the seeds were sent to the UGA Soil, Plant, and Water Lab in Athens, GA for routine nutrient analysis on the seeds. There was not enough leaf tissue for analysis, so the entire vegetative biomass was also sent for analysis.

Statistical analyses were conducted using PROC MIXED, PROC PLM, and PROC CORR in SAS University Edition (SAS Institute Inc., Cary, ND). Data was analyzed by analysis of variance (ANOVA) and differences among least square means were determined by using multiple pairwise t-tests ($P=0.05$, unless otherwise noted). Since there were 3 replications in 2016 and 4 replications in 2017, the data points were combined and analyzed as 7 replications. Very few seeds were produced in each individual pot; therefore, all the seeds for each treatment were combined in 2016 and again in 2017 for nutrient analysis. Analysis of seed nutrient concentrations were run with each year being a replication (2 replications).

Results and Discussion

Environmental Conditions

Average soil moistures according to treatment effects for 2017 are recorded in Table 4.1. The 2016 soil moistures were unavailable due to failure of the equipment used. The amount of irrigation according to treatment is also included in Table 4.1. The irrigation water used had a pH of 6.3, 0.01 mg Ca kg⁻¹, 0.01 mg K kg⁻¹, and 0.01 mg Mg kg⁻¹ concentrations. Average air and soil temperatures for the greenhouse in Tifton for both years are presented in Table 4.2.

Initial soil Ca concentrations was 158 mg kg⁻¹ with a Ca:K ratio of 4:1. This is below the minimum recommended level of 250 mg kg⁻¹ (Harris, 2013). Soil K was initially 37 mg kg⁻¹, while soil Mg was 30 mg kg⁻¹. This is in the medium concentration level for both soil K and Mg, no fertilizer application needed (Kissel and Harris, 2008). The initial soil pH was 6.1.

Soil Concentrations at Harvest

The interaction between pegging zone irrigation and Ca fertilization impacted soil Ca and soil Mg at harvest (Table 4.3). When Ca fertilization was combined with a 1x irrigated regiment, no significant difference was observed. However, under a 0.33x irrigated regiment, differences

among Ca fertilization treatments were observed. Both treatments that included lime had more soil Ca compared to treatments with no lime application, and treatments including lime were greater where there was 0.33x irrigation compared to the same fertilizer treatments with 1x irrigation. Thus, under the 1x irrigation regiment, the soil Ca was potentially leached below the pegging zone. Gascho et al. (1993) observed irrigation leaching Ca from the sandy soils. The increased soil Ca concentrations under the 0.33x irrigation regiment with fertilization treatments that applied lime could be due to the use of the Mehlich-1 extraction method. According to Alva et al. (1990), Mehlich-I was very likely to overestimate Ca available to peanut pods especially when lime had been applied to a field.

A similar trend occurred with soil Mg. There was a positive correlation between soil Ca and soil Mg in 2016 (Pearson Coefficient=0.78, $P=0.0001$). Inclusion of lime (either with or without gypsum) increased soil Mg in the 0.33x irrigation regiment compared to where lime was not included. Also, 0.33x irrigation with lime was greater than lime treatments with the 1x irrigation. The 1x irrigated treatments were more likely to move Mg out of the top 8 cm of soil by the end of the crop season, possibly leached in the soil. Also, the dolomitic lime used had Mg as part of its composition, which explains why the treatments with lime had increased levels of Mg in the soil.

The soil Ca:K and soil Ca:K+Mg ratio at harvest were impacted by the interaction between pegging zone irrigation and Ca fertilization (Table 4.4). The soil ratios followed similar trends compared to the soil Ca and Mg. For both the soil Ca:K and Ca:K+Mg ratios, the fertilizer treatments had no effect in the 1x irrigated regiment. The 0.33x irrigated soil Ca:K ratios were greater for the treatments that added lime compared to the fertilizer treatments without lime. Also the 0.33x irrigation regiment with an application of any Ca fertilizers resulted in a greater

Ca:K+Mg ratio compared to non-treated. For both ratios, the 0.33x irrigation resulted in a larger ratio than the 1x irrigation whenever lime was included, but there were no differences between the irrigation regimes when lime was not included. These results could be because the 0.33x irrigation treatments had less water to leach the cations out of the pegging zone and there was a potential overestimation of Ca concentration occurred due to the application of lime with the use of Mehlich-I extraction (Gascho et al., 1993; Alva et al., 1990).

Soil pH at harvest was significantly greater for the pegging zone 0.33x irrigated regiment (6.1) compared to the 1x irrigated regiment (5.8). Also, soil pH was significantly different across Ca fertilization treatments (Table 4.5). Lime plus gypsum and lime had a higher soil pH than the gypsum and non-treated treatments. This confirms that lime increases soil pH (Sullivan et al., 1974).

Vegetative Concentrations

A difference for pegging zone irrigation regiments was observed in the vegetative Ca concentrations. The 1x irrigated regiment had a greater vegetative Ca concentration (17.2 g kg^{-1}) compared to the 0.33x irrigated regiment (15.6 g kg^{-1}). There were no differences for vegetative K and Mg concentrations. There were also no differences for Ca, K, or Mg among fertilizer treatments.

Seeds

An interaction between irrigation and Ca fertilization was observed for seed Ca concentration at harvest (Table 4.6). Under a 1x pegging zone irrigation regiment, Ca fertilization had no effect. However, there was an effect of Ca fertilization under the 0.33x pegging zone irrigation regiment. Treatments that included lime had greater seed Ca concentrations compared to treatments with no lime application. The soil Ca concentration under

this irrigation regiment plus the addition of lime had greater soil Ca and potentially allowed the absorption of Ca which produced greater seed Ca concentration. There were no significant differences for seed K or Mg concentration.

The average number of pods per plant and average weight of the seeds were significant at $P=0.10$ for pegging zone irrigation. The 1x irrigated regiment produced a larger number of pods (0.96 pods per plant) compared to the 0.33x irrigation regiment (0.55 pods per plant). The average seed weight also followed the same pattern where the 1x pegging zone irrigated regiment (0.53 g) was significantly more than the 0.33x irrigated regiment (0.27 g). From these results, lack of recommended water amounts can reduce pod and seed production, which can lead to yield decline at the field scale.

Conclusion

A very limited number of pods were produced over both years of the study. This suggests that the growing conditions may have had greater restriction on peanut than the treatments themselves. Even with the limited number of pods, the fully irrigated pegging zone regiment produced more pods and heavier seed weights per plant. This suggests that having the recommended water in the pegging zone is important in pod and seed formation. The separate root zone from pegging zone apparatus allowed for the realization that irrigation in the pegging zone can maintain more pods.

When soil Ca is below 250 mg kg^{-1} (the threshold for applying a Ca fertilizer), Ca fertilization should be added (Harris, 2013). Under reduced pegging zone irrigation, the addition of lime can increase soil Ca and seed Ca. Overall, irrigation to the pegging zone at the recommended rate can lead to higher yield at the field scale. The use of the separate pegging

zone allows the specific understanding that the addition of Ca fertilizer in the pegging zone can increase soil Ca and seed Ca.



Figure 4.1 Separate root zone from pegging zone apparatus.

Table 4.1 Soil moisture^a (2017) and irrigation^b quantities for the root zone and pegging zone in 2016 and 2017.

	Avg. Soil Moisture for Root Zone Irrigation	Avg. Soil Moisture for 1x Irrigation in Pegging Zone	Avg. Soil Moisture for 0.33x Irrigation in Pegging Zone	Irrigation Root Zone		1x Irrigation in Pegging Zone		0.33x Irrigation in Pegging Zone	
	kPa			mL					
	2017	2017	2017	2016	2017	2016	2017	2016	2017
	2017	2017	2017	2016	2017	2016	2017	2016	2017
February	92.4	133.8	35.9	x	220	x	1380	x	705
March	80.4	127.5	37.6	x	740	x	2160	x	670
April	88.7	132.9	36.7	x	1480	x	3500	x	940
May	96.4	145.8	37.4	x	1520	x	9000	x	1800
June	100.4	110.5	38.6	x	1340	x	9600	x	2800
July	84.4	106.5	38.7	120	660	3880	6300	3880	1200
August	x	x	x	420	x	6800	x	1700	x
September	x	x	x	1510	x	5780	x	1868	x
October	x	x	x	570	x	5440	x	1840	x
November	x	x	x	430	x	4080	x	1170	x
December	x	x	x	60	x	500	x	160	x
Season	90.8	142.5	37.5	2540	5960	26480	31940	10618	8115

^aAverage of daily values for time period listed^bSum of daily values for time period listed

Table 4.2 Air and soil temperature^a for the greenhouse in 2016 and 2017.

	Average Air Temperature °C ^b		Average Soil Temperature °C ^b	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
February	x	25.1	x	27.5
March	x	26.0	x	28.7
April	x	28.3	x	30.0
May	x	27.7	x	29.1
June	x	28.8	x	29.7
July	n/a	31.0	n/a	32.6
August	27.2	x	26.6	x
September	25.3	x	25.3	x
October	23.7	x	23.7	x
November	19.2	x	19.7	x
December	n/a	x	n/a	x
Season	24.3	27.8	24.2	29.6

^aTemperature obtained from WatchDog^bAverage of daily values for time period listed

Table 4.3 Soil Ca as affected by the interaction between pegging zone irrigation and Ca fertilization at harvest.

	mg kg ⁻¹	
	<u>1x Irrigation</u>	<u>0.33x Irrigation</u>
Lime plus Gypsum	259 cd	552 a
Gypsum	193 cd	262 c
Lime	254 cd	426 b
Non-treated	145 cd	140 d

Means followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 4.4 Soil Mg as affected by the interaction between pegging zone irrigation and Ca fertilization at harvest.

	mg kg ⁻¹	
	<u>1x Irrigation</u>	<u>0.33x Irrigation</u>
Lime plus Gypsum	27 bc	35 a
Gypsum	20 d	20 d
Lime	28 b	37 a
Non-treated	21 cd	21 cd

Means followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 4.5 Soil Ca:K ratio as affected by the interaction between pegging zone irrigation and Ca fertilization at harvest.

	<u>1x Irrigation</u>	<u>0.33x Irrigation</u>
Lime plus Gypsum	7.3:1 c	16.0:1 a
Gypsum	5.6:1 c	7.3:1 c
Lime	7.3:1 c	11.6:1 b
Non-treated	4.1:1 c	4.0:1 c

Means followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 4.6 Soil Ca:K+Mg ratio as affected by the interaction between pegging zone irrigation and Ca fertilization at harvest.

	<u>1x Irrigation</u>	<u>0.33x Irrigation</u>
Lime plus Gypsum	4.1:1 cd	7.9:1 a
Gypsum	3.4:1 cd	4.6:1 bc
Lime	3.7:1 cd	5.7:1 b
Non-treated	2.9:1 de	2.0:1 e

Means followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 4.7 Soil pH as affected by Ca fertilization at harvest.

Lime plus Gypsum	6.1 a
Gypsum	5.9 b
Lime	6.1 a
Non-treated	5.8 b

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 4.8 Seed Ca as affected by the interaction between pegging zone irrigation and Ca fertilization at harvest.

	<u>1x Irrigation</u>	<u>0.33x Irrigation</u>
	g kg ⁻¹	
Lime plus Gypsum	1.32 ab	1.96 a
Gypsum	1.61 ab	0.93 b
Lime	1.29 ab	2.04 a
Non-treated	1.29 ab	0.18 b

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

CHAPTER 5

IMPACT OF MAGNESIUM ON CALCIUM UPTAKE IN RUNNER PEANUT (*ARACHIS*
HYPOGAEA L.)¹

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Abstract

Cations such as potassium (K) and magnesium (Mg) can compete with calcium (Ca) availability to peanut (*Arachis hypogaea* L.). This study was conducted to determine if Mg can inhibit Ca uptake depending on soil Ca, K, and Mg availability, pod nutrient concentrations, total sound mature kernels (TSMK), and yield. Peanut was grown in 2016 and 2017 on a Bonneau loamy sand in Attapulgus, GA. Six treatments of CaSO₄ and/or MgSO₄ were applied in a randomized complete block design with four replications. The treatments included: 1. a non-treated check that received no supplemental fertilization; 2. MgSO₄ (28 kg Mg ha⁻¹); 3. MgSO₄ (28 kg Mg ha⁻¹) plus gypsum (CaSO₄ [330 kg Ca ha⁻¹]); 4. MgSO₄ (56 kg Mg ha⁻¹); 5. MgSO₄ (56 kg Mg ha⁻¹) plus gypsum (330 kg Ca ha⁻¹); and 6. gypsum (330 kg Ca ha⁻¹). Treatments were applied at first bloom (approximately 35 days after planting). Gypsum applications increased soil Ca concentrations from pre-application to harvest (64 mg kg⁻¹ in 2016 and 32 mg kg⁻¹ in 2017 for the 28 kg Mg ha⁻¹ plus gypsum treatment, 39 mg kg⁻¹ in 2016 and 49 mg kg⁻¹ for the 56 kg Mg ha⁻¹ plus gypsum, and 42 mg kg⁻¹ in 2016 and 40 mg kg⁻¹ in 2017 for the gypsum treatments). When Mg alone was applied, soil Ca decreased. A similar response was observed in the pods. Pod Ca increased when gypsum was applied while pod Ca decreased when Mg alone was applied (1133 mg kg⁻¹ in 2016 and 895 mg kg⁻¹ in 2017 for the 28 kg Mg ha⁻¹ plus gypsum treatment, 1024 mg kg⁻¹ in 2016 and 1015 mg kg⁻¹ for the 56 kg Mg ha⁻¹ plus gypsum, and 1119 mg kg⁻¹ in 2016 and 951 mg kg⁻¹ in 2017 for the gypsum treatments). These results display a competition between these cations. No differences in peanut yield or TSMK were observed. Based on these results, a benefit from supplemental Mg or Ca fertilizer does not occur for peanut yield or TSMK when soil tests are above the minimum requirement for these nutrients.

Introduction

Georgia grows approximately 50% of all peanuts in the United States (U.S.) (NASS, 2017). This is approximately 268,954 hectares of the 585,823 hectares harvested per year average over the last five years the U.S. (NASS, 2017). The sandy soils found in the Coastal Plain of the Southeast are ideal for peanut production. However, these soils are often limiting in soil calcium (Ca) (Adams and Hartzog, 1979). Calcium is needed for proper seed development (Hallock and Allison, 1980). Yield, total sound mature kernels (TSMK), and germination of next year's crop can be limited by reduced Ca (Howe et al., 2012). Soils with a Ca deficiency are more likely to decrease yield than any other nutrient deficiency (Cox et al., 1982).

Peanut is unique from many other legumes since it produces fruit underground. Therefore, Ca is important in the pegging zone of peanut development, or top 0-8 cm of the soil surface (Howe et al., 2012). This zone is where peanut produces pods (hull and kernels). Calcium must be readily available in this zone because Ca is immobile in the phloem and must be absorbed directly by the pods. Without readily available Ca, empty pods (pops), lack of pod formation, and reduced seed germination by peanuts used as seed the following year can occur (Tillman et al., 2010; Howe et al., 2012).

The University of Georgia's (UGA) Extension Service recommends applying Ca when soil Ca levels are below 250 mg kg⁻¹ or the Ca:K ratio is less than 3:1 (Harris, 2013). When soil Ca is below this level, gypsum (CaSO₄) is often applied to runner-type peanut at R1 growth stage (Boote, 1982), or first bloom (approximately 35 days after planting) (Gascho et al., 1993). It has been found that peanut does not respond to gypsum when soil Ca is greater than 250 mg kg⁻¹ (Hartzog and Adams, 1973; Alva et al., 1989; Sorensen and Butts, 2008; Tillman et al., 2010).

Being a cation, Ca can compete with other cations on the exchange sites of the soil. This competition can reduce Ca availability and thus uptake by the peanut plant. Reduced seed Ca and overall plant health can occur due to competition between Ca and cations such as potassium (K) and magnesium (Mg) (Howe et al., 2012). Extractable Ca is increased with gypsum applications but decreases extractable Mg and K (Sullivan et al., 1974). Calcium is likely to replace the Mg and K on exchange sites; then the Mg and K are potentially leached from the pegging zone (Sullivan et al., 1974). The decrease of Mg and K in the pod walls and seeds has also been observed when Ca increases in the pegging zone (Zharare et al., 2009b).

Potassium can cause reductions in yield, TSMK, and cause dark plumules (Sullivan et al., 1974). However, K is less detrimental when applied in combination with gypsum (Sullivan et al., 1974). Similar to K, it is believed that Mg antagonizes Ca in the pegging zone of developing peanut pods (Zharare et al., 2011). When soil Mg or K levels are greater than soil Ca, the number of pops and pod rot (*Pythium myriotylum* Dresch. and *Rhizoctonia solani* Kühn) increases (Zharare et al., 2011). Pod rot is a common disease occurring in peanut caused by many fungi including *Rhizoctonia* and *Pythium* species (Wheeler et al., 2005). MgSO_4 fertilization has been known to increase pod breakdown, seed damage, and decrease Ca in pods (Hallock and Garren, 1968). Along with the impact on yield and TSMK, high rates of MgSO_4 and K_2SO_4 have increased pod rot (Walker and Csinos, 1980). However, high rates of gypsum have resulted in a reduction of pod rot (Garren, 1964).

The importance of Ca and the Ca:K ratio in the soil is known; however questions arise concerning the potential impact Mg can have on peanut production. The primary objective of this research is to determine whether a Mg application impacts soil Ca concentration, Ca

concentration in pods, TSMK, and yield in runner-type peanut. This information can help growers make more informed decisions on Ca fertilization under their growing conditions.

Materials and Methods

Field trials were conducted during 2016 and 2017 at the UGA Attapulgus Research and Education Center in Attapulgus, GA. The soil was a Bonneau loamy sand (loamy, siliceous, subactive, thermic Arenic Paleudults) (USDA-NRCS, 2017). The experimental design was a randomized complete block design with four replications and six treatments. The six treatments were: 1. non-treated check (no added fertilizer), 2. MgSO_4 (28 kg Mg ha⁻¹), 3. MgSO_4 (28 kg Mg ha⁻¹) plus gypsum (330 kg Ca ha⁻¹); 4. MgSO_4 (56 kg Mg ha⁻¹); 5. MgSO_4 (56 kg Mg ha⁻¹) plus gypsum (330 kg Ca ha⁻¹); and 6. gypsum (330 kg Ca ha⁻¹). All plots were 5.5 m wide (six peanut rows) and were 10.9 m long in 2016 and 12.2 m long in 2017. Field preparation for both years consisted of deep turning the soil with the use of a John Deere 975 moldboard plow (John Deere, Moline, IL) followed by a Roto-Tiller (1.83 m spacing) (Kelley Mfg. Co., Tifton, GA).

The peanut cultivar Georgia-06G (Branch, 2007) was planted 13 June 2016 and 26 April 2017. A Monosem Single-Row Precision Vacuum Planter (Monosem Inc., Edwardsville, KS) with a seeding rate of 20 seed m⁻¹ was used both years. Fertilizer treatments (gypsum and MgSO_4) were applied at the R1 growth stage, or first bloom (Boote, 1982), approximately 35 days after planting (19 July 2016 and 30 May 2017). The MgSO_4 was applied with a hand-held fertilizer spreader (The Scotts Company LLC, Marysville, OH). The gypsum used was roughly 241.5 g Ca kg⁻¹ and 183.5 g Sulfur (S) kg⁻¹ (Waters Agricultural Laboratories, Inc., Camilla, GA). Gypsum was applied by hand.

The herbicide program was representative of current production practices and 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) to control early leaf spot (*Cercospora arachidicola*) and late leaf spot (*Cercosporidium personatum*) as well as southern stem rot (*Sclerotium rolfsii* Sacc.). Fungicides were first applied starting approximately 35 days after planting, or the R1 growth stage (Boote, 1982), and continued throughout the season on 14 d spray intervals. Liquid Boron (10%) was applied at 0.56 kg ha⁻¹ with the first fungicide application (Harris, 2013). Irrigation was applied through a center pivot irrigation system. Timing of irrigation was determined based on the weekly water used by peanut also known as the UGA checkbook irrigation scheduling method (Stansell et al. 1976; Porter, 2017).

Soil was sampled from 0-8 cm depth on 13 June 2016 and 25 April 2017 and again on 25 October 2016 and 29 September 2017, respectively. Routine analysis was performed using Mehlich-I extraction (Kissel and Sonon, 2008; Mehlich, 1953). Leaf tissue was sampled halfway between the lower leaves and the top leaves on 8 September 2016, 5 July 2017, and 19 September 2017 for nutrient analyses. Pod samples were taken on 26 October 2016 and 29 September 2017 and analyzed for routine nutrient analyses.

Peanut maturity was determined by the hull scrape method (Williams and Drexler, 1981). Digging and inversion of the plants were done with a 2-row digger/shaker/inverter (Kelley Mfg. Co., Tifton, GA) on 25 October 2016 and 21 September 2017. After the peanuts had been dried to approximately 12-15% moisture, harvest occurred with a 2-row KMC harvester (Kelly Mfg. Co., Tifton, GA) on 31 October 2016 and 26 September 2017. Yields were adjusted to 7% moisture for uniformity of comparisons and TSMK was determined according to USDA-AMS grade standards (USDA-AMS, 1997).

Statistical analyses were conducted using PROC MIXED, PROC PLM, and PROC CORR in SAS University 5.2.7 (SAS Institute Inc., Cary, NC). Data were analyzed by analysis of variance (ANOVA) and differences among least square means were determined by using multiple pairwise t-tests ($P=0.05$) for each year (Table 5.1).

Results and Discussion

Environmental Data

Average maximum and minimum temperatures for the Attapulgis Research and Education Center for 2016 and 2017 are presented in Table 5.2. The average amount of rainfall and irrigation for each month of the growing season are also included in Table 5.2. The initial soil Ca concentration was 321 mg kg^{-1} in 2016 and 310 mg kg^{-1} in 2017. This was above the minimum recommended concentration of 250 mg kg^{-1} of Ca that would normally trigger a Ca fertilizer application (Harris, 2013). The initial soil K concentration was 54 mg kg^{-1} in 2016 and 50 mg kg^{-1} in 2017; and the initial soil Mg concentration was 73 mg kg^{-1} in 2016 and 45 mg kg^{-1} in 2017. This is in the medium concentration level for both soil K and Mg, no fertilizer application needed (Kissel and Harris, 2008).

Soil Concentrations

A significant difference was observed across fertilizer treatments for the change in soil Ca concentration from pre-application to harvest in 2016 and 2017 (Table 5.3). In 2016, the addition of gypsum increased soil Ca over the season while the treatments without a gypsum application decreased in soil Ca over the season. In 2017, a gypsum application also increased soil Ca while the treatments with a 28 kg Mg ha^{-1} and 56 kg Mg ha^{-1} decreased in soil Ca over the season. Sullivan et al. (1974) also observed that gypsum applications increased extractable Ca.

Soil K and Mg concentrations were significant at harvest in 2017 (Table 5.4). Soil K concentrations at harvest were lower for all fertilization treatments that add Ca, Mg, or both compared to the non-treated treatment. Therefore, the addition of Ca and/or Mg can compete with the initial K in the soil, decreasing soil K levels over the season. Soil Mg concentration at harvest in 2017 decreased for treatments with a gypsum application. There was a positive correlation between soil K and soil Mg at harvest (Pearson Coefficient=0.74, $P<0.0001$ in 2016, Pearson Coefficient=0.47, $P=0.0191$ in 2017). Zharare et al. (2009b) observed similar competition when Mg and K concentrations would decrease with added Ca. Also, Sullivan et al. (1974) observed the decrease of K and Mg with gypsum applications because Ca was likely to replace K and Mg on exchange sites.

There was a significant difference in soil Ca:K ratio at harvest for 2017 (Table 5.5). The 56 kg Mg ha⁻¹ plus gypsum treatment added Ca to the soil which increased the Ca:K ratio. Even when Ca was not added, the added Mg increased the Ca:K ratio also observed as reducing the K concentration. The addition of Ca, Mg or both impacted the soil K concentration. There was also a significant difference in soil Ca:K+Mg ratio in 2016 and 2017 at harvest (Table 5.5). In 2016, the addition of gypsum increased the soil Ca:K+Mg ratio even when 28 kg Mg ha⁻¹ and 56 kg Mg ha⁻¹ were added. In 2017, the addition of gypsum also increased the Ca:K+Mg ratio compared to treatments with no gypsum application.

Leaf Concentrations

There were no significant differences for Ca, K, or Mg leaf concentrations for 2016 or 2017.

Pod Concentrations

There was a significant difference in pod Ca for both 2016 and 2017 (Table 5.6). In 2016, the treatments 28 kg Mg ha⁻¹ plus gypsum and gypsum had greater pod Ca concentrations than the 28 kg Mg ha⁻¹ and 58 kg Mg ha⁻¹. In 2017, the 56 kg Mg ha⁻¹ plus gypsum and gypsum treatments had a higher Ca concentration in the pods than the non-treated, 28 kg Mg ha⁻¹, and 56 kg Mg ha⁻¹ treatments. This shows that adding gypsum can increase pod Ca. Similar results in seeds had been observed by Howe et al. (2012) where reduced seed Ca was caused due to competition between Ca and Mg. A negative correlation occurred between harvest soil Mg concentrations and pod Ca in 2017 (Pearson Coefficient= -0.68, P=0.0003). This negative correlation could indicate competition between Ca and Mg impacting uptake of Ca into the peanut pods.

Yield and TSMK

There were no significant differences for TSMK or yield for 2016 and 2017.

Conclusion

The results for peanut yield and TSMK were not significant for this study; therefore, the fertilizer treatments do not provide an overall benefit over another based on the end goals of a producer when initial soil Ca concentrations are above the recommended rate. This suggests that even a 56 kg ha⁻¹ rate of Mg is not enough Mg to cause detrimental problems. The study did show that when Ca was added to the soil through gypsum, soil Ca concentration increased, soil Ca:K+Mg ratios increased, and pod Ca increased. The increase of Ca even when Mg was applied and the decrease in soil K and Mg in 2017 support potential competition between Ca, K, and Mg. This competition was also witnessed by Sullivan et al. (1974), Zharare et al. (2009b), and Howe et al. (2012).

The current recommendations for Ca fertilization should remain as applying Ca when initial soil Ca levels are below 250 mg kg⁻¹ or the Ca:K ratio is less than 3:1 (Harris, 2013). The Mg levels used did not have a large impact in this study. Continued research on the competition Mg and even K has with Ca and vice versa would be recommended. There seems to be competition between cations, but it was unclear when the competition becomes detrimental.

Table 5.1 Analysis of variance probability values for soil, leaf, pod concentrations, yield, and TSMK for 2016 and 2017.

Sources of Variation	df ^b	Chang in Soil Ca	Harvest Soil K	Harvest Soil Mg	Soil pH	Leaf Ca	Leaf K	Leaf Mg	Pod Ca	Pod K	Pod Mg	Yield	TSMK
<u>2016</u>		p-values ^a											
Treatments	5	0.0034	ns	ns	ns	ns	ns	ns	0.0491	ns	ns	ns	ns
<u>2017</u>		p-values ^a											
Treatments	5	0.0039	0.0002	0.0001	ns	ns	ns	ns	0.0002	ns	ns	ns	ns

^a p-values were obtained from ANOVA table in output of SAS using PROC MIXED and PROC PLM procedure

^b df = degrees of freedom

^c ns = not significant

Table 5.2 Temperature, rainfall^a, and irrigation for the Attapulgis Research and Education Center, Attapulgis, GA in 2016 and 2017.

	Maximum		Minimum		Rainfall (cm) ^c		Irrigation (cm) ^c	
	Temperature °C ^b		Temperature °C ^b					
	2016	2017	2016	2017	2016	2017	2016	2017
April	x	29.9	x	17.6	x	0.0	x	1.3
May	x	29.4	x	16.3	x	9.5	x	3.8
June	32.7	30.0	21.2	20.8	1.2	26.8	3.8	2.5
July	34.0	32.5	22.0	22.0	14.8	10.7	5.1	2.5
August	32.7	32.2	22.5	22.1	12.7	10.9	3.8	3.8
September	31.2	29.8	20.4	19.1	14.1	10.8	5.1	1.3
October	28.3	X	14.1	x	5.7	x	2.5	x
Season	31.7	30.8	19.9	20.0	48.0	68.6	20.3	15.2

^aTemperature and rainfall data obtained from georgiaweather.net

^bAverage of daily values for time period listed

^cSum of daily values for each time period

Table 5.3 Change in soil Ca concentration from pre-application to end of the season as affected by fertilizer treatment in 2016 and 2017.

	<u>2016</u>	<u>2017</u>
	mg kg ⁻¹	
Non-treated	-15.5 b	0.5 bc
28 kg Mg ha ⁻¹	- 4.7 b	-4.0 c
28 kg Mg ha ⁻¹ plus Gypsum	63.5 a	32.0 ab
56 kg Mg ha ⁻¹	-17.8 b	-12.0 c
56 kg Mg ha ⁻¹ plus Gypsum	39.0 a	49.0 a
Gypsum	42.0 a	40.0 a

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 5.4 Soil K and Mg as affected by fertilizer treatment in 2017 at harvest .

	<u>Soil K</u>	<u>Soil Mg</u>
	mg kg ⁻¹	
Non-treated	61 a	57 a
28 kg Mg ha ⁻¹	51 b	65 a
28 kg Mg ha ⁻¹ plus Gypsum	45 c	41 b
56 kg Mg ha ⁻¹	50 bc	63 a
56 kg Mg ha ⁻¹ plus Gypsum	45 c	45 b
Gypsum	48 bc	43 b

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 5.5 Soil Ca:K ratio and Ca:K+Mg ratio as affected by fertilizer treatment in 2016 and 2017 at harvest.

	<u>Ca:K</u>	<u>Ca:K+Mg</u>	
	<u>2017</u>	<u>2016</u>	<u>2017</u>
Non-treated	5.0:1 c	2.8:1 bc	2.3:1 c
28 kg Mg ha ⁻¹	6.3:1 b	2.5:1 cd	2.8:1 bc
28 kg Mg ha ⁻¹ plus Gypsum	7.0:1 b	3.5:1 a	4.0:1 a
56 kg Mg ha ⁻¹	6.3:1 b	2.0:1 d	3.0:1 b
56 kg Mg ha ⁻¹ plus Gypsum	8.3:1 a	3.3:1 ab	4.0:1 a
Gypsum	7.3:1 ab	3.5:1 a	4.0:1 a

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

Table 5.6 Pod Ca as affected by fertilizer treatment in 2017.

	<u>2016</u>	<u>2017</u>
	mg kg ⁻¹	
Non-treated	967 ab	762 d
28 kg Mg ha ⁻¹	765 b	795 cd
28 kg Mg ha ⁻¹ plus Gypsum	1133 a	895 bc
56 kg Mg ha ⁻¹	700 b	729 d
56 kg Mg ha ⁻¹ plus Gypsum	1024 ab	1015 a
Gypsum	1119 a	951 ab

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-test at P=0.05.

CHAPTER 6

MAGNESIUM INTERACTION WITH CALCIUM IMPACTING RUNNER PEANUT

*(ARACHIS HYPOGAEA L.)*¹

¹Pegues, K.D., R.S. Tubbs, G.H. Harris, and W.S. Monfort. To be submitted to *Peanut Science*

Abstract

Magnesium (Mg) can compete with calcium (Ca) in the soil reducing Ca availability. In turn, this can lead to a reduction in seed Ca and cause pod rot in peanut (*Arachis hypogaea* L.). This study was conducted to determine if Mg inhibits Ca uptake depending on soil Ca concentration, vegetative nutrient concentrations, and seed nutrient concentrations in peanut. Peanut was grown in a greenhouse in soil with initial Ca concentrations of 134 mg kg⁻¹ in 2016 and 173 mg kg⁻¹ in 2017. Six treatments of CaSO₄ and/or MgSO₄ (fixed effect) were applied in a randomized complete block design with four replications. The treatments included: 1. a non-treated check that received no supplemental fertilization; 2. MgSO₄ (28 kg Mg ha⁻¹); 3. MgSO₄ (28 kg Mg ha⁻¹) plus gypsum (CaSO₄) (330 kg Ca ha⁻¹); 4. MgSO₄ (56 kg Mg ha⁻¹); 5. MgSO₄ (56 kg Mg ha⁻¹) plus gypsum (330 kg Ca ha⁻¹); and 6. gypsum (330 kg Ca ha⁻¹). Treatments were applied at first bloom (approximately 35 days after planting). When Ca was added with MgSO₄, soil Mg concentration decreased (23 mg kg⁻¹ in 2016 and 2017 for the 28 kg Mg ha⁻¹ plus gypsum and 21 mg kg⁻¹ in 2016 and 2017 for the 56 kg Mg ha⁻¹ plus gypsum treatments) compared to the 56 kg Mg ha⁻¹ rate of MgSO₄ alone (31 mg kg⁻¹ in 2016 and 32 mg kg⁻¹ in 2017). In 2017, seed Ca concentration was greater for treatments that had a gypsum application (1405 mg kg⁻¹ for the 28 kg Mg ha⁻¹ plus gypsum, 991 mg kg⁻¹ 56 kg Mg ha⁻¹ plus gypsum, and 1455 mg kg⁻¹ for the gypsum treatments). However, an application of 56 kg Mg ha⁻¹ reduced Ca concentration and increased Mg concentration in the seed (692 mg Ca kg⁻¹ and 1870 mg Mg kg⁻¹). Overall, even the 56 kg Mg ha⁻¹ rate of Mg is not inhibiting Ca to detrimental levels, but the gypsum applications could be impacting Mg.

Introduction

From 2013 to 2017 an average of 273,972 hectares of peanut (*Arachis hypogaea* L.) were planted in Georgia (NASS, 2017). In 2017 Georgia produced close to 50% of all peanuts in the U.S. with the next highest producing state (Alabama) producing roughly 10% (NASS, 2018). The sandy Coastal Plain soils of South Georgia are ideal for peanut production, but are often limited in soil Ca (Adams and Hartzog, 1979). Calcium helps develop pods, seeds, and reduce “pops” or underdeveloped kernels (Gascho and Davis, 1995; Howe et al., 2012). Reduced yield, total sound mature kernels (TSMK), and seed germination of next year’s crop can occur with reduced Ca (Howe et al., 2012).

Peanut is a unique plant because it flowers above ground then produces fruit underground. The pegging zone (top 0-8 cm of soil) is where the pods are formed (Howe et al., 2012). Pods must absorb Ca directly from the soil because Ca is immobile in the phloem of plants (Wiersum, 1951). Since the phloem is not used, the xylem is used to transport Ca via the transportation stream (Hanger, 1979). However, pods grow underground and do not transpire so Ca must be available directly to the pods (Skelton and Shear, 1971). Therefore, soil Ca in the pegging zone is important (Zharare et al., 2009a). The University of Georgia’s (UGA) Cooperative Extension Service recommends applying Ca when soil Ca levels are below 250 mg kg⁻¹ or the Ca to potassium (K) ratio is less than 3:1 in the pegging zone (Harris, 2013). The 3:1 Ca:K ratio is because cations can compete with each other for exchange sites on the soil structure. Calcium can compete with K and Mg which can reduce seed Ca and overall plant health (Gascho and Davis, 1995; Howe et al., 2012). Potassium can cause a reduction in yield and TSMK (Sullivan et al., 1974). When soil K and Mg concentrations are greater than soil Ca, the number of pops increases along with the occurrence of pod rot (*Pythium myriotylum* Drechs.,

a common disease occurring in peanut) (Zharare et al., 2011). Seed damage and decreased pod Ca concentration have been evaluated with the addition of MgSO_4 (Hallock and Garren, 1968). High rates of K_2SO_4 along with MgSO_4 have increased pod rot (Walker and Csinos, 1980).

Although negative side effects of excessive K and Mg can occur, an interaction between K and Ca has been observed (Sullivan et al., 1974). The addition of gypsum (CaSO_4) has resulted in a reduction of pod rot compared to no added Ca fertilization (Garren, 1964). Increased leaching of K and Mg when gypsum is added to the topsoil has been demonstrated by Sumner et al. (1986), O'Brien and Sumner (1988), and Alva et al. (1991). Calcium is likely to replace the Mg and K on exchange sites, then the Mg and K are leached from the pegging zone (Sullivan et al., 1974).

The importance of Ca and the negative consequences of excessive K and even Mg is known; however, the ratio or amount of Mg to cause these problems for peanut production is not fully understood. This purpose of this study is to focus on the effect Mg, with and without gypsum application, has on peanut growth and development. The primary objective of this study is to determine if the competition between Mg and Ca has an impact on soil nutrient concentration, vegetative nutrient concentrations, and seed nutrient concentrations.

Materials and Methods

Greenhouse trails were conducted in 2016 and 2017 on the UGA Coastal Plains Experimental station in Tifton, GA. The experimental design was a randomized complete block design with five replications in 2016 and four replications in 2017. The six treatments were: 1. non-treated check (no added fertilizer); 2. MgSO_4 (28 kg Mg ha^{-1}); 3. MgSO_4 (28 kg Mg ha^{-1}) plus gypsum (330 kg Ca ha^{-1}); 4. MgSO_4 (56 kg Mg ha^{-1}); 5. MgSO_4 (56 kg Mg ha^{-1}) plus gypsum (330 kg Ca ha^{-1}); and 6. gypsum (330 kg Ca ha^{-1}). The 28 kg Mg ha^{-1} and the 330 kg Ca

ha⁻¹ rates correspond with the UGA Extension Service recommendation of Mg and Ca fertilization for peanut (Kissel and Harris, 2008; Harris, 2013).

Plastic pots with tapered sides that had a top diameter of 52 cm, bottom diameter of 35 cm, and a height of 31 cm were used in 2016 and 2017 to grow peanuts. The volume of each pot was 172,002 cm³. Two field soils were mixed together to make a soil considered deficient in (below 250 mg Ca kg⁻¹) but with adequate pH to sustain growth. The first soil was a Loamy, siliceous, semiactive, thermic Aquic Arenic Paleudults and the second soil was a Fine-loamy, kaolinitic, thermic Plinthic Kandiudults (USDA-NRCS, 2017). Both soils were pasteurized for 24 hr at 104°C. After pasteurization, a 50-50 mix was made using a small rotary mixer. A volume of 35,000 cm³ of soil were added to the pots. The bulk density was roughly 1.38 g cm⁻³.

Georgia-06G (Branch, 2007) was planted on 18 July 2016 and 14 February 2017. In 2016, three seeds were planted into the center of the pot. In 2017, eight seeds were 5.1 cm apart and 5.1 cm deep across the diameter of the pot to simulate a peanut row. Both years 1 mL of Optimize[®] Liquid Inoculant for Peanut (Monsanto Company, St. Louis, MO) was added to the soil around each seed. On 17 August 2016, each pot was thinned back to one plant and on 9 March 2017 each pot was thinned back to five plants.

Irrigation was applied by measuring distilled water out into graduated cylinders. The irrigation amounts were based on the weekly water use by peanut (Stansell et al. 1976; Porter, 2017). The gypsum and Mg treatments were applied at first bloom (R1 growth stage [Boote, 1982]), on 22 August 2016 and on 29 March 2017. The gypsum used was roughly 242 g Ca kg⁻¹ and 184 g sulfur (S) kg⁻¹ (Waters Agricultural Laboratories [WAL], Inc., Camilla, GA). The Mg source used was MgSO₄ or commonly known as Epsom salt. The MgSO₄ used was 98 g Mg kg⁻¹ and 129 g S kg⁻¹. Gypsum and MgSO₄ were weighed based on the surface area of the pot (0.17

m²) and hand applied by spreading each fertilizer evenly across the soil surface. Liquid Boron (B) (10%) was applied at 0.56 kg B ha⁻¹ on 23 October 2016 and 10 July 2017, in accordance to UGA's recommendations (Harris, 2013). The B was sprayed with a backpack sprayer.

In 2016, whiteflies (*Bemisia argentifolii*) were a severe problem. Pyriproxyfen (61.8 g ai ha⁻¹) was sprayed on 26 August 2016, 16 September 2016 and 6 October 2016. Spider mites (*Tetranychus urticae*) flared in 2016 and 2017. Therefore, Abamectin (10.8 g ai ha⁻¹) was sprayed on 21 October 2016, 9 November 2016, and 30 June 2017. The few weeds that emerged were hand pulled.

Soil samples were taken at planting and harvest from the top 8 cm. In 2016, initial samples were removed on 18 July 2016 and harvest samples were taken on 8 December 2016. In 2017, initial soil samples were removed 14 February 2017 and harvest samples were taken on 18 July 2017. All the soil samples were sent to the UGA Soil, Plant, and Water Lab for routine soil analysis using Mehlich-I (Kissel and Sonon, 2008; Mehlich, 1953). On 8 December 2016 and 18 July 2017 all pods were pulled from each pot and counted. In 2016, there were not enough pods for each individual pot so the pods were combined over treatments. The pods were shelled and the seeds were sent to the UGA Soil, Plant, and Water Lab in Athens, GA to perform a routine nutrient analysis. There were not enough leaves for analysis, so the entire vegetative biomass was also sent for analysis.

Data collected in 2016 and 2017 included soil Ca, K, and Mg concentrations at planting and harvest; soil pH at planting and harvest; vegetative Ca, K, and Mg concentrations; seed Ca, K, and Mg concentrations; and number of pods per plant. Statistical analyses were conducted using PROC MIXED, PROC PLM, and PROC CORR in SAS University 5.2.7 (SAS Institute Inc., Cary, NC). Data was analyzed by analysis of variance (ANOVA) and differences among

least square means were determined using multiple pairwise t-tests ($P=0.05$, unless otherwise noted) for each year (Table 6.1). Data were not combined over years because of the different number of plants grown in each year.

Results and Discussion

Environmental Conditions

Average air and soil temperatures for the greenhouse in Tifton for both years are presented in Table 6.2. The average soil moistures for 2017 and the amount of irrigation for 2016 and 2017 is included in Table 6.3. The 2016 soil moistures were unavailable due to failure of the equipment used. The irrigation water used had a pH of 6.3, $0.01 \text{ mg Ca kg}^{-1}$, $0.01 \text{ mg K kg}^{-1}$, and $0.01 \text{ mg Mg kg}^{-1}$ concentrations.

The initial soil Ca concentration was 134 mg kg^{-1} in 2016 and 173 mg kg^{-1} in 2017 with a Ca:K ratio of 4:1 in both 2016 and 2017. This is below the minimum recommended Ca concentration of 250 mg kg^{-1} (Harris, 2013). The soil K level was initially 38 mg kg^{-1} in 2016 and 43 mg kg^{-1} in 2017, while the soil Mg concentration was 23 mg kg^{-1} in 2016 and 24 mg kg^{-1} in 2017. This is in the medium concentration level for soil K and the low level for soil Mg, no K fertilizer application is needed for K and Mg fertilizer is applied based on treatment (Kissel and Harris, 2008).

Soil Concentrations

Differences among fertilizer treatments were observed in 2016 and 2017 at harvest (Table 6.4). Soil Ca was the greatest in both years when gypsum was part of the treatment, even when MgSO_4 was also applied. From these results, the addition of gypsum was beneficial in increasing soil Ca, and addition of Mg did not hinder Ca availability. Soil Mg was greatest in both 2016 and 2017 for the 56 kg Mg ha^{-1} rate of MgSO_4 and 28 kg Mg ha^{-1} plus gypsum treatments. The soil

Mg was similar for the 56 kg Mg ha⁻¹ rate of MgSO₄ plus gypsum compared with the non-treated check for both years. In 2016, the 56 kg Mg ha⁻¹ rate of MgSO₄ produced a greater soil K concentration compared to the 56 kg Mg ha⁻¹ plus gypsum, 28 kg Mg ha⁻¹, 28 kg Mg ha⁻¹ plus gypsum, and gypsum treatments. There was a negative correlation between harvest soil Ca and soil Mg in 2016 (Pearson Coefficient= -0.46, P=0.0099). The addition of gypsum likely flushed the exchange sites with Ca causing the Mg to be knocked off exchange sites and be taken up into the pod or leached from the pegging zone. Studies conducted by Sumner et al. (1986), O'Brien and Sumner (1988), and Alva et al. (1991) support this claim by reporting that an increase in leaching of K and Mg occurs with the addition of gypsum to the topsoil. Therefore, Ca seems to inhibit Mg availability, but Mg does not inhibit Ca availability at the rates used in this study.

Examining cation ratios can help determine the level of possible competition among cations (Table 6.5). In 2016 and 2017, the soil Ca:K ratio was increased when gypsum was applied compared to the 56 kg Mg ha⁻¹ and non-treated treatments. When 56 kg Mg ha⁻¹ is applied, the Ca:Mg ratio shows a lower concentration of Ca compared to Mg than compared to an application of 56 kg Mg ha⁻¹ plus gypsum. The soil Ca:K+Mg ratio in 2016 and 2017 showed that with the addition of gypsum, Ca is available in large enough quantities to displace the other cations. The addition of gypsum added more Ca ions to the soil compared to either of the rates of Mg ions. Simply, there were more Ca ions than Mg ions to compete for soil exchange sites.

Vegetative Concentrations

Vegetative Ca was significantly different based on treatment in 2016 (Table 6.6). The addition of MgSO₄ did not reduce the amount of Ca concentration in the vegetative plant compared to when no fertilizer was applied. There was no difference in vegetative Ca in 2017. Also, there were no differences in vegetative K and Mg for 2016 and 2017.

Seed Concentrations

Seed weight and number of pods were not different among treatments for either year. Fertilizer treatment had a significant effect on seed nutrient concentrations for 2017 (Table 6.7). Seed Ca concentration increased where gypsum was applied. A 56 kg Mg ha⁻¹ rate of MgSO₄ plus gypsum had less seed Ca than the 28 kg Mg ha⁻¹ rate of MgSO₄ plus gypsum and the gypsum only treatment, but more seed Ca than treatments without gypsum. There was a positive correlation between harvest soil Ca and seed Ca in 2017 (Pearson Coefficient=0.82, P<0.0001). From these results, the addition of gypsum increased seed Ca even when MgSO₄ was present. The 56 kg Mg ha⁻¹ rate of MgSO₄ supplied extra Mg to compete with the Ca. All seed Ca concentrations in 2017 were above 420 mg Ca kg⁻¹ and according to Cox et al. (1976), seed Ca concentrations above this level result in good germination (89% to 94%). Seed Mg concentration increased with the addition of MgSO₄ compared to the non-treated check and the gypsum only application. A negative correlation occurred between soil Ca at harvest and seed Mg (Pearson Coefficient= -0.52, P=0.009) There were higher Mg concentrations in the seed for the 28 kg Mg ha⁻¹, 56 kg Mg ha⁻¹, and 56 kg Mg ha⁻¹ plus gypsum treatments compared to the non-treated and gypsum only treatments. When the high rate of Mg was used, the concentration of Mg possibly prevented Ca from competing as heavily (lower seed Ca concentrations with 56 kg Mg ha⁻¹ plus gypsum than the other treatments with gypsum) resulting in a higher concentration of Mg in the seed. This was shown with a negative correlation between seed Ca and seed Mg (Pearson Coefficient= -0.42, P=0.0418).

Conclusion

The results of this study show competition between Ca and Mg. When soil Ca concentrations increase, soil Mg concentrations decrease. The addition of gypsum floods soil

exchange sites with Ca, stripping Mg and creating an interaction between Ca and Mg. This Ca and Mg interaction is also seen between seed concentrations when treatments with more seed Mg tend to have less seed Ca and vice versa. When Mg is added but Ca is not, seed Mg can increase while seed Ca remains the same. This indicates that when Mg is added, it competes enough with the Ca already in the soil for availability to enter peanut seeds. The movement from cations in the soil into the seed can be observed with the increases in both soil and seed concentrations for each nutrient. The addition of gypsum increases soil Ca concentration which then produces greater Ca concentration in the seeds. A 56 kg Mg ha⁻¹ rate of MgSO₄ reduces the amount of Ca that enters the seed even when extra Ca is available. The extra Mg competes with the present Ca so less Ca enters the seeds. However, the added Mg does enter the peanut seeds compared to the gypsum only treatment and the non-treated check.

There is an interaction occurring between Ca and Mg in the peanut growing environment. A competition is present on soil exchange sites and the path of entering the peanut seeds. Additional Ca reduces the cation competition, but when Mg is added, especially at a 56 kg Mg ha⁻¹ rate, it can compete with the present Ca to enter the peanut seeds. Overall, K is not the only cation to compete with Ca. Magnesium can impact peanut growth and development.

Table 6.1 Analysis of variance probability values for soil, leaf, pod concentrations, yield, and TSMK for 2016 and 2017.

Sources of Variation	df ^b	Harvest Soil Ca	Harvest Soil K	Harvest Soil Mg	Veg. Ca	Veg. K	Veg. Mg	Seed Ca	Seed K	Seed Mg	Avg. ^c Seed Weight	Avg. Number of Pods
<u>2016</u>												
				values ^a								
Treatments	5	0.0085	0.0929	0.0035	0.0279	ns ^e	ns	n/a ^f	n/a	n/a	ns	ns
<u>2017</u>												
				values ^a								
Treatments	5	0.0001	ns	0.0001	ns	ns	ns	0.0001	0.0054	0.0029	ns	ns

^a p-values were obtained from ANOVA table in output of SAS using PROC MIXED and PROC PLM procedure

^b df = degrees of freedom

^c Veg. = vegetative

^d Avg. = average

^e ns = not significant

^f n/a = not applicable because seeds combined over treatment before analysis (1 rep)

Table 6.2 Air and soil temperature for the greenhouse on the Coastal Plain Research Station, Tifton, GA in 2016 and 2017.

	Average Air Temperature °C ^a		Average Soil Temperature °C ^a	
	<u>2016</u>	<u>2017</u>	<u>2016</u>	<u>2017</u>
February	x	25.1	x	27.5
March	x	26.0	x	28.7
April	x	28.3	x	30.0
May	x	27.7	x	29.1
June	x	28.8	x	29.7
July	n/a	31.0	n/a	32.6
August	27.2	x	26.6	x
September	25.3	x	25.3	x
October	23.7	x	23.7	x
November	19.2	x	19.7	x
December	n/a	x	n/a	x
Season	24.3	27.8	24.2	29.6

^aAverage of daily values for time period listed

Table 6.3 Soil moisture and irrigation amount for the greenhouse in 2016 and 2017.

	<u>Avg. Soil Moisture^a</u>	<u>Irrigation^b</u>	
	—kPa—	—mL—	
	<u>2017</u>	<u>2016</u>	<u>2017</u>
February	131.3	x	4874
March	132.7	x	10260
April	150.0	x	12800
May	156.4	x	11900
June	153.9	x	10400
July	151.6	4000	6000
August	x	10760	x
September	x	10700	x
October	x	6820	x
November	x	5820	x
December	x	1000	x
Season	147.0	39100	56234

^aAverage of daily values for time period listed^bSum of daily values for time period listed

Table 6.4 Soil Ca, K, and Mg as affected by fertilizer treatment in 2016 and 2017 at harvest.

	<u>Ca</u>	<u>2016</u> <u>Mg</u>	<u>K*</u>	<u>Ca</u>	<u>2017</u> <u>Mg</u>	<u>K</u>
	mg kg ⁻¹					
Non-treated	142 bc	22 bc	30 ab	134 b	21 c	33 a
28 kg Mg ha ⁻¹	157 abc	20 bc	27 b	128 b	25 b	26 a
28 kg Mg ha ⁻¹ plus Gypsum	185 a	23 b	27 b	192 a	23 bc	27 a
56 kg Mg ha ⁻¹	136 c	31 a	35 a	132 b	32 a	28 a
56 kg Mg ha ⁻¹ plus Gypsum	172 ab	21 bc	26 b	175 a	21 c	23 a
Gypsum	185 a	17 c	28 b	191 a	16 d	23 a

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-tests at P=0.05 unless otherwise noted *P=0.1.

Table 6.5 Soil Ca:K ratio, soil Ca:Mg ratio, and soil Ca:K+Mg ratio as affected by fertilizer treatment in 2016 and 2017.

	2016			2017		
	<u>Ca:K</u>	<u>Ca:Mg</u>	<u>Ca:K+Mg</u>	<u>Ca:K</u>	<u>Ca:Mg</u>	<u>Ca:K+Mg</u>
Non-treated	4.6:1 bc	6.4:1 bc	2.8:1 bc	4.3:1 b	6.5:1 b	2.5:1 b
28 kg Mg ha ⁻¹	6.0:1 ab	8.8:1 ab	3.4:1 ab	5.0:1 b	5.0:1 b	2.5:1 b
28 kg Mg ha ⁻¹ plus Gypsum	7.2:1 a	8.4:1 abc	3.8:1 ab	7.3:1 a	8.5:1 a	4.0:1 a
56 kg Mg ha ⁻¹	4.2:1 c	4.4:1 c	2.0:1 c	5.0:1 b	4.0:1 b	2.3:1 b
56 kg Mg ha ⁻¹ plus Gypsum	7.0:1 a	9.6:1 ab	4.2:1 a	8.3:1 a	8.3:1 a	4.0:1 a
Gypsum	6.8:1 a	11.0:1 a	4.2:1 a	8.8:1 a	12.5:1 a	5.0:1 a

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-tests at P=0.05.

Table 6.6 Vegetative Ca as affected by fertilizer treatment in 2016.

	—g kg ⁻¹ —
Non-treated	14.2 bc
28 kg Mg ha ⁻¹	14.9 bc
28 kg Mg ha ⁻¹ plus Gypsum	15.0 bc
56 kg Mg ha ⁻¹	12.6 c
56 kg Mg ha ⁻¹ plus Gypsum	15.4 ab
Gypsum	17.7 a

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-tests at P=0.05.

Table 6.7 Seed Ca and Mg as affected by fertilizer treatment in 2017.

	<u>Ca</u>	<u>Mg</u>
	—mg kg ⁻¹ —	
Non-treated	562 c	1646 c
28 kg Mg ha ⁻¹	711 c	1895 a
28 kg Mg ha ⁻¹ plus Gypsum	1405 a	1667 bc
56 kg Mg ha ⁻¹	692 c	1870 a
56 kg Mg ha ⁻¹ plus Gypsum	991 b	1817 ab
Gypsum	1455 a	1603 c

Means within a column followed by the same lowercase letter are not significantly different according to pairwise t-tests at P=0.05.

CHAPTER 7

CONCLUSION

Calcium (Ca) fertilization is an important factor in peanut production. The impact irrigation makes on increased pod Ca concentration can vary from year to year based on the year's rainfall and how the irrigation is scheduled. Calcium source also plays a role in peanut fertility. In a relatively wet year, such as 2017, irrigation with the addition of lime can significantly increase yield. Irrigation in the pegging zone also saw the increase in number of pods and seed size. However, a partially irrigated pegging zone produced greater seed Ca concentration when lime or lime plus gypsum were applied to soils with initial soil Ca concentrations below the minimum recommend concentration. When soil Ca concentrations were above the recommended concentration, Ca sources were not significant for improving yield. Therefore, the results of this research indicate that current Ca fertility recommendations for peanut production are adequate.

The research involving Ca and Magnesium (Mg) fertilization resulted in evidence of competition between Ca and Mg. The addition of Ca decreased soil K and Mg, even when Mg was applied for both the field and greenhouse trials. The Ca and Mg interaction was also observed when seed Mg concentrations increase, seed Ca concentrations decrease and vice versa. Although this competition between the cations was observed, even an application of 56 kg Mg ha⁻¹ did not add enough Mg to cause detrimental problems. Therefore, until higher rates of Mg can be tested, a Ca:Mg or even a Ca:K+Mg ratio are not necessary for the current Ca fertility recommendations for peanut production.

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