DEVELOPMENT OF PRECISION AGRICULTURAL TECHNIQUES AND APPROACHES FOR ENHANCING GROWER DECISIONS FOR PEANUT (*ARACHIS HYPOGAEA* L.) TO INCREASE PRODUCTIVITY AND QUALITY AT THE FARM AND FIELD LEVEL

by

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(Under the Direction of Scott Monfort)

ABSTRACT

Precision agriculture has the ability to provide knowledge to enhance grower decisions in peanut (*Arachis hypogaea* L.) and when used correctly, can contribute to increased profits and efficiency. Five primary objectives were created to contribute to this. A methodology was successfully developed to irradiate peanut seed to simulate non-uniform poor stand in the field. Additionally, a model was created to accurately identify plant material using aerial imagery collected from an unmanned aerial system in a field two to three weeks after planting. With the coupling of an economical threshold, this model can decrease bias in replant decisions. Thirdly, to identify effects of geographical location and planting date on yield, a survey was conducted that collected information regarding production methods and yield of peanuts in Georgia. Next, a method was explored to predict crop quality, as a measure of peanut grade, two weeks from harvest. Aerial images were collected of fields before harvest and were used to evaluate vegetation indices (VIs) for correlations to crop quality and yield. Results indicated that VIs could be beneficial to industry in predicting the quality of peanuts being harvested. Lastly, plant growth regulators also have the potential to increase yield and profits, however the high cost of these chemicals is a limiting factor in its use in peanuts. A trial was conducted to investigate physiological changes in the plant when prohexadione calcium is applied. Results showed differences in fluorescence and pigment content in plants treated with prohexadione calcium when compared to the non-treated check. The precision agricultural techniques explored in this dissertation have the ability to increase productivity and quality in peanut production at the farm and field level.

INDEX WORDS: Precision agriculture, *Arachis hypogaea* L., grower, replant decisions, unmanned aerial systems, aerial images, vegetation index, crop quality, grade, yield, industry, plant growth regulator, prohexadione calcium, physiology, fluorescence, pigment content

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DEDICATION

To my husband who has supported and encouraged me through the entire journey.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Cultivated peanut (*Arachis hypogaea* L.) is an important oil and food crop because of its high levels of oil, protein, and fiber (Savage and Keenan, 1994). Peanut can be used for a variety of products. In the United States some of the main uses are peanut flour, peanut oil, roasted peanuts, and peanut butter, with the latter being the most common use (Soyatech, 2015). Not only can peanut seed be used for human consumption in many ways, but the vegetation can be used as a nutritious animal feed and peanut hulls can be used as poultry bedding making it popular throughout the world (Naab et al., 2004; Nutsugah et al., 2007, Snyder et al., 1958).

Peanut Production Areas

Currently, the United States is the world's fifth largest producer of peanuts after China, India, Nigeria, and Sudan, respectively. These five combine to produce about 70% of the world's total peanut production (FAO, 2021). Total U.S. peanut production in 2020 measured 6.1 billion pounds. This is an increase from 2.5 million metric tons the previous year (USDA NASS, 2021a). In the U.S., peanuts are grown commercially in 13 states; however, in 2019, six states were responsible for 92% of the nation's total production with Georgia ranking number one with nearly 50% of the total production (National Peanut Board, 2020).

Peanut production in Georgia is a $2 billion industry. The average yield in 2020 of peanuts in Georgia was 4,595 kilograms per hectare down from 4,574 kilograms per hectare in 2019. This is the leading average in the United States. Production in Georgia has continuously been on the rise with an increase of over 900,000 metric tons over the last 15 years, from 726,000 in 2006 to 1,488,000 in 2020 (USDA NASS, 2021b). In 2019, the peanut farmgate value for Georgia was almost $660 million (UGA CAED, 2020).

In Georgia, peanuts were grown in 76 out of 159 counties across the state on approximately 300,000 hectares in 2020. Ten counties accounted for nearly 50% of Georgia's peanut production. Bulloch County, located on the South Carolina border, was the only county of the ten that was not located in the south-western corner of the state (UGA CAED. 2020). This is a good example of the diversity of the peanut growing area in the state of Georgia.

Peanut Production

There are many factors that influence yield in peanuts. Some of these include cultivar, planting date, irrigation, crop rotation, diseases, and pests. Growers must make difficult decisions to try to reduce the risk of diseases while trying to maximize yield and profit. Some factors can have a negative impact on yield on their own, but the largest negative impact on yield comes from interactions between multiple factors.

Crop Rotation

The rotation history of the field is a major factor in yield potential of a peanut crop. Crop rotation has been demonstrated to affect pest development and crop yield. Planting a diversity of crops with different pests in rotation can minimize pests, in turn increasing yield (Hague and Overstreet, 2002; Jordan et al., 2008; Rodriguez-Kabana et al., 1987, Rodriguez-Kabana and Touchton, 1984). Cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) are the two rotation crops used with peanut. In irrigated fields, one year out of peanut, in either of these rotation crops, increases yield by over 1000 kg/ha and two years increases yield by over 2300 kg/ha

(Lamb, et al., 2004). Peanut rotated with cotton for two years has been reported to provide some control of peanut root knot nematode (*Meloidogyne arenaria*) which causes substantial yield losses in severely infected fields (Starr et al., 2002). Peanuts can also utilize residual phosphorus and potassium that is applied for previous crops (Jordan et al., 2008). Sorenson and Butts (2014) proved through an eight-year study that as years between peanut crops increased yield increased. The same study also showed that total sound mature kernels increased as years between peanut increased as well.

Cultivar

There are four market-types of peanut grown in the United States: runner, virginia, spanish, and valencia. The runner market-type, the type most widely grown throughout Georgia, Alabama, and Florida since the introduction of the Florunner cultivar in the 1970's, is mostly used to produce peanut butter and candies. Runners account for nearly 80 percent of the total peanut production in the United States. This is because their uniform kernel size makes them ideal for even roasted creating a consistent tasting peanut butter. The virginia-type is primarily used for in shell roasting and account for nearly 15 percent of total U.S. peanut production. The other two types, spanish and valencia, account for the other 5 percent of peanuts grown in the United States (American Peanut Council, 2017).

Historical cultivars were overcome with diseases. This required many costly inputs, such as pesticides, to produce a high yielding and good quality peanut crop. To try to reduce the cost of inputs, advancements have been made in peanut breeding to develop disease resistant cultivars (Branch and Fletcher, 2017). One of the most widely used cultivars, Georgia-06G (Branch, 2007), is a high-yielding, large-seeded runner-type peanut with a high level of resistance to Tomato spotted wilt, caused by Tomato spotted wilt virus (genus *Tospovirus*; family

Bunyaviridae) (TSWV) that was released in 2006. Although, this cultivar is susceptible to early leaf spot caused by *Passalora arachidicola* (Hori) U. Braun [syn.*Cercospora arachidicola* (Hori)], late leaf spot caused by *Nothopassalora personata* (Berk. & M.A. Curtis) U. Braun, C. Nakash., Videira & Crous [syn. *Cercosporidicum personatum* (Berk. & Curt.) Deighton], and southern stem rot (SSR), caused by the soil-borne fungus, *Sclerotium rolfsii* Sacc. Georgia-09B (Branch, 2010) is a high-yielding, high-oleic runner-type cultivar that was released in 2009. This cultivar also has a high resistance to TSWV and is susceptible to leaf spot and SSR. Another high-yielding runner-type cultivar is Georgia-12Y (Branch, 2012). This cultivar has resistance to both TSWV and SSR and was released in 2012. Georgia-12Y is a later maturing cultivar; therefore, it is only recommended for planting dates before May 15th (Monfort, 2020). This cultivar is also susceptible to limb rot (*Rhizoctonia solani* Kuhn) but has moderate resistant to early and late leaf spot (Branch, 2013).

Planting Date

Another variable that can affect yield that growers must consider is planting date. Some of the earliest planting date trials showed that non-irrigated peanut in the southeastern United States had increased yield with earlier planting dates (Sturkie and Buchanan, 1973). This trial was conducted, however, before the introduction of TSWV to the area. Tillman et al. (2007) found that TSWV incidence decreased with later planting dates. Planting dates in June had the smallest incidence of TSWV, but pod yields tended to be greater with planting dates in May. They concluded that planting the most resistant TSWV cultivar, under irrigation, in mid-May maximized yield. This is probably due to the fact that peak thrips populations are typically observed the later part of April (Brown et al., 1996, 2005; Mckeown et al., 2001). It has also been found that later planting dates increase the incidence of leaf spot (Fulmer, 2017).

Seeding Rate

Seeding rate can influence disease susceptibility, specifically diseases such as TSWV. Since the introduction of TSWV to the southeast, one of the main ways to combat the disease has been by seeding rate. Research has demonstrated that greater planting populations within the row can reduce the yield loss to disease (Branch et al., 2003; Culbreath et al., 2003; Culbreath and Srinivasan, 2011; Monfort et al., 2020). It was observed that increasing the number of plants did not reduce the number of infected plants but reduced the percentage of infected plants (Culbreath et al., 2013). Greater plant population may also allow for compensation of yield loss from diseased plants by healthy plants. With this knowledge the recommended planting density is 13.1 plants/m (Culbreath and Srinivasan, 2011). In order to obtain this planting density, growers utilize a seeding rate of 19.7 seed/m. This can be very costly to the grower (Culbreath et al., 2013). Cultivars like Georgia-06G are larger seeded and have a high level of resistance to TSWV. A seeding rate of 14-15 seed/m did not increase the incidence of TSWV, thus reducing seed costs by not increasing seeding rates (Culbreath et al., 2013). Unfortunately, opposite of TSWV, the risk of SSR increases with increased planting density (Sconyers et al., 2005). This increase in SSR is due to rapid disease spread in high density plant stands.

Row Pattern

Most growers plant their fields in either single row or twin row configuration. Generally, in single row plantings, rows are planted with 91 cm spacing in raised 1.8 m wide beds and in twin row plantings four rows are planted with 91 cm between outer rows and 20 cm between twins on 1.8 m wide beds (Cox and Reid, 1965). Twin rows reduce the risk of TSWV resulting in increased yield when compared to single rows (Baldwin et al., 2001; Culbreath et al., 2008, Sconyers et al., 2007, Tilman et al., 2006, Tubbs et al., 2013). Single rows have also demonstrated a three times greater incidence of SSR than twin rows (Sorensen, et al., 2004). Similar to increased seeding rate, this is likely due to plants in single rows being spaced closer together rapidly spreading the disease.

Tillage

Tillage method is another decision growers must make. Conventional production methods include primary and secondary tillage that prepares a flat or slightly raised bed that includes no residual crop material (ASAE, 1990). Conservation tillage was implemented in production practices to reduce fuel, labor, and soil erosion (Gebhardt et al., 1985). Conservation tillage systems may include no tillage, mulch tillage, and strip tillage. These systems consist of planting in essentially an unprepared bed, or a bed with undisturbed crop residue left on the soil surface or planting in a narrow strip or band which disturbs less than 30% of crop residue (ASAE, 1990).

Tillage method has been reported to have great effects on disease incidence throughout the peanut season. Conservation tillage practices have been associated with lower thrip pressure, reduced thrips feeding damage, and less overall TSWV (Brown et al., 1996; Cantonwine et al., 2006; Johnson et al., 2001; Minton et al., 1991; Monfort et al., 2007). It is thought that the plant residues left in the field during conservation tillage interfere with dispersing thrips that use bare ground cues to locate and land on host plants (Culbreath et al., 2003; Culbreath and Srinivasan, 2011). Conservation tillage has also been reported to slow the onset of the leaf spot epidemic (Monfort et al., 2004; Sorensen et al., 2010). However, the risk of SSR and limb rot, can be greater with conservation tillage (Cantonwine et al., 2006; Monfort et al., 2004; Sorensen et al., 2010).

Irrigation

Research has proven that water is a major limiting factor in crop production around the world. Water is also a limiting factor of yield potential in peanut production. Research has demonstrated that peanut responds positively to irrigation (Isleib et al., 2014). Ketring and Wheless (1989) found that water and temperature can affect the development of peanut. Research proves that withholding water at certain stages in development can affect growth and pod development. For instance, withholding water at early stages of growth will slow growth, prolonging maturity (Kvien, 1995). On the other hand, withholding water during pod maturity will lead to faster maturation of the pods and plant (Dreyer et al., 1981). Water stress leads to greater soil temperature which can hinder yield and quality and lead to pest problems (Sanders et al., 1985; Cole et al., 1985). One of these pest that can be influenced by drought conditions is *Aspergillus flavus*. *A. flavus* is a soil borne fungi that can produce aflatoxin. Aflatoxin is one of the most potent carcinogens found in food (Dichter, 1984). This mycotoxin, if found in peanuts, will significantly lower the grade and price of the peanuts (USDA FSA, 2017).

Decision Aid Tools

Decision aid tools and models have become increasingly popular in agronomic crops to aid growers in making decisions to maximize yield and profit. Peanut is no exception to this. These decision tools can range from methods to predict disease pressure to methods to determine maturity of the crop to irrigation scheduling tools.

One of the decision aids used in the Southeast is a risk index for diseases. The original index was developed in Georgia in 1996 and consisted of six factors that contributed to the overall level of risk. These factors were: cultivar, planting date, plant population, volunteer peanut population, county the field is in, and at-plant insecticide (Brown, 1996). The risk values associated with each category were based upon research available up until that point and were developed to help peanut growers make informed management decisions (Olantinwo et al., 2008). Early on-farm trials demonstrated a positive linear relationship between risk points and severity of TSWV, but R^2 values only ranged from 0.20 to 0.44 (Brown et al., 2005). It was determined, based on surveys of Georgia county agents in peanut producing areas, that the 5-year (1995-1999) average increase in peanut yield from using the risk index was 200 kg/ha. The original risk index has been expanded over the last decade to include risk indices for leaf spot and southern stem rot along with TSWV. This expanded index is now known as Peanut Rx (Williams, 2013). Peanut Rx considers ten production practices that impact the severity of these diseases. They are cultivar, planting date, plant population, at-plant insecticide, row pattern, tillage method, the use of Classic® herbicide, years between peanut crops in the field, field disease history, and irrigation (Monfort et al., 2020). The most current form of the decision tool is known as Peanut Rx 2.0. This version was constructed to include both Peanut Rx and the Thrips and TSWV Risk Forecasting Tools (TTRF). TTRF was developed by North Carolina State University for use in cultivated tobacco (*Nicotiana tabacum*). Peanut Rx 2.0 explained 26% of the variability compared to 4% using Peanut Rx alone (Williams, 2013). Research and extension efforts have resulted in an efficient decision tool that utilizes genetic resistance and production practices to maximize yield and profit (Culbreath et al., 2003).

Determining maturity is a difficulty every grower must face. Not only can incorrectly assessing maturity cause economic losses to an individual grower, but it can cause economic losses to the peanut industry (Rowland et al., 2006). Peanut maturity can affect many factors such as yield, crop quality (grade), and even flavor of the seed (Fincher et al., 1980). Growers can also incur a loss due to crops being over mature. These crops can lose between 8% and 40% of pods during digging due to maturity issues (Young et al., 1982; Lamb et al., 2004). There have been methods that growers use to determine the maturity of their crop throughout the past decades. Some of these include days after planting, internal hull color (Shellout Method), Langley's Index, oil color, methanolic extraction, kernel density, seed/hull maturity index (SHMI), arginine maturity index (AMI), physiological maturity index (PMI), the pod maturity profile (PMP), and growing degree days (Sanders et al., 1980; Rowland et al., 2006).

The original method to determine maturity was based on days after planting. Data on maturity evaluations in 1973 indicated that the optimum yield period occurred between 146-153 days after planting (Pearson et al., 1973). Much research was conducted over the next few years to improve upon this method of maturity determination. One of the oldest methods, still used today is the pod maturity profile developed by Williams and Drexler (1981). This method, known today as the hull scrape or pod blast method, determines maturity of the pod based on characteristics of pod mesocarp after partial removal of the exocarp. The pods are then placed into maturity classes based on the color of the mesocarp (Williams and Drexler, 1981). Many attempts to expand on this method have been made over the last several decades. One of the most recent successful attempts incorporated degree day models into the hull scrape method (Rowland, 2006). Research found that by incorporating Maturity Index 1 with the degree day model first proposed by Mills in 1964 a model could be developed that could successfully be used to predict peanut maturity in the southeastern U.S. The Maturity Index 1 was calculated as the percentage of black and brown pods. The degree day model utilized maximum and minimum air temperatures with a lower threshold of 13° C and an upper threshold of 24° C (Rowland et al., 2006). This model was later incorporated into a website the grower can use called the Peanut

Field Agronomic Resource Manager, PeanutFARM, to make informed maturity decisions (www.peanutfarm.org).

Irrigation scheduling can be a major challenge for growers because water requirements vary according to the stage of development of the peanut. Primarily yield reduction occurs when water is withheld during midseason fruiting (Kvien, 1995). To help growers with these decisions the expert model Irrigator Pro, developed at the USDA-ARS National Peanut Research Laboratory, was developed for irrigation scheduling (Davidson et al., 1991). Irrigator Pro considers weather, soil type, previous rainfall or irrigation, irrigation capacity, yield potential, soil temperature in the top 5 cm of the soil, cultivar, planting date (crop growth stage), canopy coverage, pegging date, previous crop, current date, crop conditions, and growing region (Davidson Jr. et al., 1998). This decision tool can help growers make a more informed, economical decision about irrigation.

Management tools that incorporate many of these decision tools have also been created. One of these attempts is the FARM management tool created by Wells (2002) that was used to reduce inputs. This decision tool incorporated Irrigator Pro (Butts et al., 2020), HERB (Wilkerson et al., 1991) and Herbicide Application Decision Support System (HADSS) (Sturgill et al., 2000), a herbicide scheduling tool, and AU-Pnut (Jacobi et al., 1995), a fungicide scheduling tool, to manage peanut crops. When compared to conventional management strategies FARM averaged $99 less per hectare and used 1.4 less irrigation events. There was no statistical yield difference observed between the two management methods showing that FARM could be used to manage a peanut field with less inputs (Wells, 2002).

Models

The use of models in peanut production is not exclusive to growers. Industry and breeding programs have started using models to evaluate yield of peanut crops. One of the most widely used models in peanuts is a crop simulation model, called CSM-CROPGRO Peanut Model, that predicts crop growth, development, and yield as a function of weather conditions, soil conditions, crop management, and cultivar coefficients (Amiri et al., 2015). This model can be found in the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al., 2003). From there the model can be manipulated to be used in many aspects of peanut production. This model has been used to determine the response of different peanut cultivars to different soil moistures (Dangthaisong et al., 2006), quantify yield gaps (Naab et al., 2004), and determine the impact of different irrigation scenarios (Tojo Soler et al., 2013). This type of simulation model could be very beneficial in many areas of peanut production.

Another type of model useful to industry is a yield prediction model. Robson (2007) developed a yield model that has successfully been integrated into the Australian peanut industry. The use of aerial imagery has been beneficial in developing methods to predict pod yield. From aerial IR images, collected two weeks prior to digging, both pixel brightness values and satellite imagery NDVI value were correlated to pod yield. These correlations were able to explain approximately 85% of the yield variability in a field. They attributed this strong correlation to the fact that greater IR values were commonly attributed to larger biomass of the plant and a plant under less stress. Therefore, these plants had the opportunity to yield more (Robson, 2007).

With variability in peanut quality and yield being attributed to such a wide array of production practices and environmental factors, the overall objective was created to develop precision agricultural techniques and approaches to enhance grower decisions for peanut in order to increase productivity and quality at the farm and field level. Sub-objectives included the development of a technique to estimate stand in peanut for replant decisions using an unmanned aerial system, evaluation of vegetation indices for the ability to predict crop quality and yield in peanut using aerial imagery, and the efficacy of prohexadione calcium when tank mixed with fungicides in peanut as well as the effect of prohexadione calcium on peanut physiology.

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CHAPTER II

DEVELOPMENT AND VALIDATION OF A METHODOLOGY TO IRRADIATE PEANUT (*ARACHIS HYPOGAEA* L.) SEED AND INHIBIT GERMINATION FOR ASSESSING STAND ESTABLISHMENT EFFECTS ON YIELD AND GROWTH[1]

[1]Studstill, S. P., Monfort, W. S., Xuelin L., Pilon, C., and Tubbs, R. S. 2021.
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Abstract

Developing small plot trials that simulate natural plant stand loss in peanut (*Arachis hypogaea* L.) is difficult and requires a large amount of time to develop. These types of trials frequently require researchers to manually pull plants from the plot to mimic the spacing and gaps representative of stand losses experienced by growers. To assist in removing the bias of this method a protocol for irradiating peanut seeds was developed. Using a microwave, irradiation treatments were evaluated at different time treatments and wattage levels. An initial test evaluating the full power level of 1350 W was conducted at 0 (control), 30, 60, 90, and 120 seconds. Seeds were then kept in petri dishes with a damp piece of paper in continuous darkness for five days at a constant temperature of 25 °C for germination assessment. On the fifth day, the percentage of germination was determined as a ratio of the number of germinated seeds to the total number of seeds. The period of germination inhibition was determined to be between 60 and 90 seconds. Additionally, treatments above this time period damaged the seed causing the seeds to split. To aid in minimizing damage to seed, power levels of 0% (control), 60% (810 W), 90% (1215 W), and 100% (1350 W) were evaluated at the 90 second exposure time. A power level of 810 W and 1350 W both exhibited 100% inhibition of germination. Since 810 W did not damage the seed or seed coat it is recommended to irradiate peanut seed 810 W for 90 seconds to completely inhibit germination of the seed. Field validation of seed inhibited using this method was done by mixing viable seed with irradiated seed at known ratios (100:0, 90:10, 60:40, and 30:70). Field validation determined that the treatment of 30:70 viable:irradiated seed resulted in significantly lower values of plant density, vigor, and yield than the 100:0 and 90:10 treatments. These results proved that this irradiation method can be used to simulate poor naturally occurring

plant stands. Using this irradiation method research can be conducted on peanut plant stand in an unbiased and timely manner.

Introduction

Research simulating and evaluating yield impacts of stand loss in peanut (*Arachis hypogaea* L.) on a small plot scale can be very difficult to conduct. In order to conduct these trials researchers manually pull plants from the plot to mimic the spacing and gaps observed in a commercial peanut field with stand issues (Sarver et al., 2016). This method, however, results in bias in the trial. The poor stand is not random and naturally occurring (Figure 2.1). To assist in removing the bias of this method a protocol for inhibiting peanut seed germination was explored.

In corn (*Zea mays* L.), these naturally occurring poor plant stands have been achieved by planting a mixture of seed made up of a percentage of glyphosate resistant seeds and non-glyphosate resistant seeds. At the V3 stage plants are sprayed with glyphosate to induce poor stands (Terry et al., 2012). Similarly, in cotton, planting a combination of glufosinate resistant and non-resistant cotton seeds and then spraying the combination with a glufosinate herbicide resulted in naturally occurring poor plant stands (Jost, 2005; Lemon et al., 2004.). However, this is not an option in peanuts since herbicide resistant seeds are not available.

Microwave radiation in agricultural literature has been successful for sterilizing seeds, stimulating seed germination, and inhibiting seed germination. Seeds of mustard (*Sinapis alba* L.), soybean [*Glycine max* (L.) Merr.], peas (*Pisum sativum* L.), and rice (*Oryza sativa* L.) have been successfully sterilized of microorganisms before storage to increase germination rates when planting (Reddy et al.1995; Reddy et al. 1998). This method has also been explored on a commercial scale for wheat (*Triticum aestivum* L.), barley (*Haordeum vulgare* L.), and perennial rye grass (*Lolium perenne* L.) (Rajagopal, 2009).

In common bean seeds (*Phaseolus vulgaris* L.) exposure times of 10, 20, and 30 seconds to magnetron irradiation increased germination (Aladjadjian and Svetleva, 1997). This was also observed with seeds of ornamental perennials (*Gleditschia triacanthos* L. and *Robinia pseudoacacia* L.) in which an exposure time of 30 s to microwave irradiation with a wavelength of 12 cm stimulated germination and growth (Aladjadivan, 2002). Aladjadjiyan (2010) reported that microwave irradiation for 30 s at 450 and 750 W could stimulate germination in lentils (*Lens culinaris*, Med.), but microwave irradiation for 120 s or longer at 450 and 750 W inhibited germination completely. Another study found that when microwaving soil masses of 5 cm depth with weed seeds placed at a depth of 2 cm microwave radiation for 180 s was needed to inhibit 100% germination of the weed seeds (Barker and Craker, 1991). It was determined that time was a limiting factor for this method to be adopted.

Therefore, the main objective of this study was to develop a methodology to irradiate peanut seed using microwave radiation to inhibit germination with minimal damage to the seed coat. A field trial was also developed to validate the irradiation method.

Materials and Methods

Development of irradiation method

This experiment was conducted at the University of Georgia Tifton Campus in 2018. All experiments were conducted using a kitchen type, 2450 MHz microwave oven (Oster, OGWT1603VSE, Sunbeam Products, Inc., Zhongshan China) with capability of producing 135 through 1350 W microwave power. Peanut seeds used for all experiments were Georgia-06G (Branch, 2007). In each trial, the control petri dishes were treated identically to the other treatments, except that they were never exposed to microwave radiation.

For the initial experiment, replicates of 50 seeds were exposed to microwave radiation for 0 s (control), 30 s, 60 s, 90 s, and 120 s. The seeds were then divided into five replications with 10 seeds per replication and placed in petri dishes for a germination test. The peanut seeds were kept in the petri dishes with a damp piece of paper in continuous darkness for five days at a constant temperature of 25 °C. Seeds were assessed every other day and water was applied as needed. On the fifth day the percentage of germination was determined as a ratio of the number of germinated seeds to the total number of seeds. Seeds were considered germinated if the radicle was 5 mm or longer (Ketring and Morgan, 1969). This experiment was conducted three times. The experiment was then repeated three more times omitting the 120 second treatment due to the fact that this time interval significantly damaged the seeds (Figure 2.2). This resulted in six trials total. All seeds used were from the same lot, however, the initial three trials were from a different bag of seed than the last three trials.

A second experiment was conducted to determine what power level (wattage) would be ideal for causing inhibition without causing seed damage using the same microwave described above. Microwave power level treatments consisted of 0% (control), 60% (810 W), 90% (1215 W), and 100% (1350 W) power. Fifty seeds were subjected to each power level treatment for 90 seconds. The seeds were then divided into five replicates of 10 seeds each and placed in petri dishes. A germination test using the same protocol described previously was performed on all seeds. This experiment was conducted a total of six times.

Validation of irradiation method

Three field trials were conducted across 2018 and 2019 to validate the irradiation methodology. The first field trial was planted on 14 May 2018 at the University of Georgia Coastal Plain Experiment Station Plant Sciences Farm in Tifton, Georgia (UGA Plant Science

Farm), the second field trial was planted on 1 May 2019 at the Sunbelt Agricultural Expo Farm in Moultrie, Georgia (Expo), and the final field trial was planted on 22 May 2019 at the Abraham Baldwin Agricultural College JG Woodruff Research Farm in Tifton, Georgia (ABAC). The experimental design for all three field trials was a randomized complete block design with four replications. Plots consisted of four rows spaced 0.91 m apart. In 2018, at the UGA Plant Science Farm, plots were 154 m long. In 2019 at the Expo plots were 60 m long and at ABAC, plots were 106 m long. All tests were planted with the peanut cultivar Georgia-06G at a depth of 5 cm at the University of Georgia's recommended seeding rate of 19.7 plants/m (Monfort et al., 2020). Treatments consisted of a ratio of viable and irradiated seeds (viable:irradiated). The four treatments were: 100:0 (control), 90:10, 60:40, and 30:70. Germination was inhibited by irradiating the appropriate percentage of seed, in groups of 50 as per the original irradiation method, for each treatment using the determined time and wattage from the results obtained in the methodology development trial. Peanuts were maintained using recommendations from the University of Georgia (Monfort et al., 2020).

Stand counts were collected in the field in both years from three randomly selected 3 m sections of the plot that were marked at the time of planting. In 2018, stand counts were collected at 10, 16, 18, and 23 days after planting (DAP). In 2019, at Expo stand counts were collected at 14, 16, 19, and 22 DAP; at ABAC stand counts and were collected at 13, 15, 20, and 23 DAP. A subjective vigor rating was collected for each plot on a 1-5 scale where 1 is a very poor plant and 5 is a healthy plant. The vigor rating was conducted at 23 DAP in 2018, at 22 DAP in 2019 at the Expo, and at 20 DAP in 2019 at ABAC.

In 2018, for the UGA Plant Science test, plants were inverted 151 DAP and harvested 157 DAP. In 2019, for the Expo test, plants were inverted 133 DAP and harvested 139 DAP and for the ABAC test, plants were inverted 148 DAP and harvested 155 DAP. For all three tests, yield was collected for all plots.

Statistical Analysis

Data from both irradiation methods and validation data was analyzed using ANOVA in JMP Pro 15.0.0 (SAS Institute, Cary, NC). For the irradiation methods, data treatments were considered fixed effects and replication was considered random. For analysis of the initial irradiation method, the first three trials were combined, and the second three trials were combined. For the validation data, treatments were considered as fixed effects and data from all three years were combined. Replication was considered a random effect. Appropriate means were separated using Tukey-Kramer honest significant difference test set at 0.05 probability level. Pearson's correlations between stand count, vigor, and yield were performed using Sigma Plot 14.0 (Systat Software Inc., San Jose, CA).

Results and Discussion

Results determined that complete inhibition of germination of peanut seeds can be achieved with an exposure time between 60 and 90 s at a power level of 1350 W (Figure 2.3). On average, seed germination prior to the irradiation treatments was 73%, decreasing as exposure time increased. Gemination percentages varied in individual trials at 30 and 60 s treatments between the two sets of trials (Figure 2.3). This could be due to differences in the vigor of the seeds in the first three trials since seeds came from different bags. However, results converged with 0% germination at 90 s making this the ideal treatment to inhibit germination of peanut seeds. Unlike Aladjadiyan's (2010) results on lentil seeds, germination was not greatly stimulated with less exposure time of microwave irradiation in all trials.

At a wattage level of 1350 W, the seeds and seed coats were damaged in treatments above 60 s (Figure 2.2). Intact seed coats are crucial to ensure proper seeding rate is achieved during planting. Research has proven that the removal of a seed coat results in a broken seed which results in inconsistent seeding rate (Butts, et al., 2007). Therefore, the second experiment was conducted to determine a microwave treatment that would inhibit germination without disrupting the seed coat. Complete inhibition was recorded at 60% (810 W), 90% (1215 W), and 100% (1350 W) wattage levels with an exposure time of 90 s (Figure 2.4). At 60% wattage the seed coat and seeds were unharmed. Therefore, 60% (810 W) wattage for 90 s was determined to be the ideal method for irradiating seeds.

Analysis indicated that year was not significant therefore validation data was combined across years. Results from field trials successfully validated the irradiation method. There were no complications at planting due to the irradiated seed. Stand counts across all trials for treatments of 100:0 and 90:10 were significantly greater than stand counts for 60:40 and 30:70 (Figure 2.5). Stand counts for the 30:70 treatment were the lowest stand counts of the four treatments. Vigor results followed a similar trend to stand counts for the four treatments with a correlation coefficient of 0.78. The treatment 30:70 also had the least vigor while the 90:10 and 100:0 treatments had the greatest vigor (Figure 2.6). Vigor is a subjective rating so even though all seeds that germinated were considered healthy seeds, a plot with less seeds can appear to have a lower vigor. Yield also reflected a similar trend as stand counts and vigor; however, was not correlated to the two. The 30:70 treatment yielded less than the other three treatments (Figure 2.7). The University of Georgia recommends a seeding rate of 19.7 seeds/m to obtain a final plant stand of 13.3 plants/m (Beasley et al., 1997); therefore, a treatment with 30:70 expected germination should result in 5.9 plants/m. Our study, which resulted in a yield reduction at the

30:70 treatment, is similar to other studies showing reductions in yield when stand is less than 8.2 plants/m (Sarver et al., 2016).

Conclusions

In conclusion, a microwave treatment of 90 s at 810 W is recommended to inhibit germination of the peanut seed. The results of this trial show that the irradiation of peanut seeds, when combined with live peanut seeds, can be used to simulate naturally occurring poor plant stand in peanut (Figure 2.8). The fate of the seed in the soil was not recorded. Therefore, future research could determine whether rotting seed in the soil leads to disease complications. This method can be beneficial in research experiments analyzing the effects of poor plant stand. This method to generate a random sub-optimal plant stand can decrease bias and time compared to the manual pulling of plants. Ultimately, the ability to irradiate seeds will aid in delivering high quality, unbiased data to growers regarding plant stand in peanut.

Figures

Figure 2.1. Small plot trial with plants pulled manually to create gaps. Image courtesy of R. Scott Tubbs.

Figure 2.2. Damaged seeds and seed coats of seeds exposed to microwave irradiation of 1350 W at the 120 s.

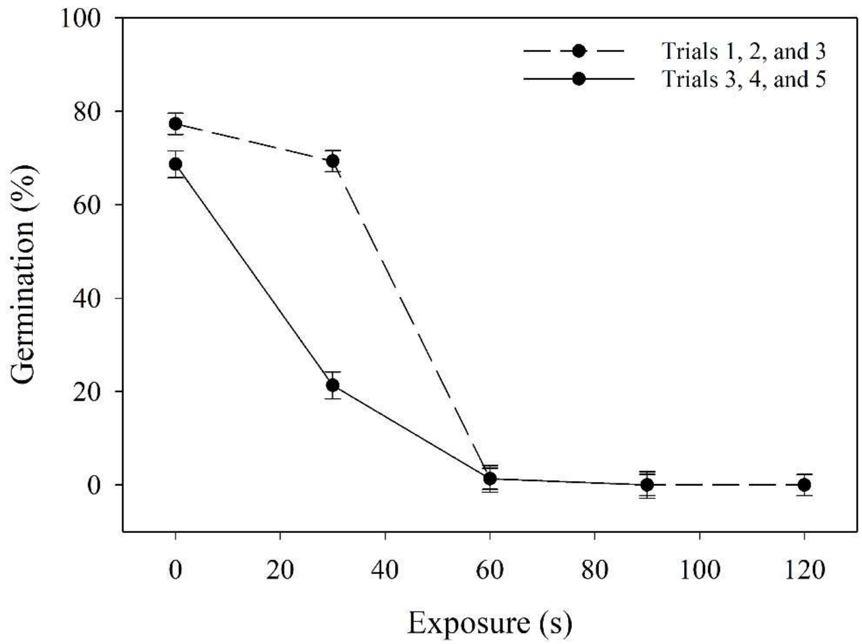

Figure 2.3. Germination (%) of peanut seeds at different exposure times (s) to 1350 W of microwave irradiation for irradiation trials conducted in Tifton, GA.

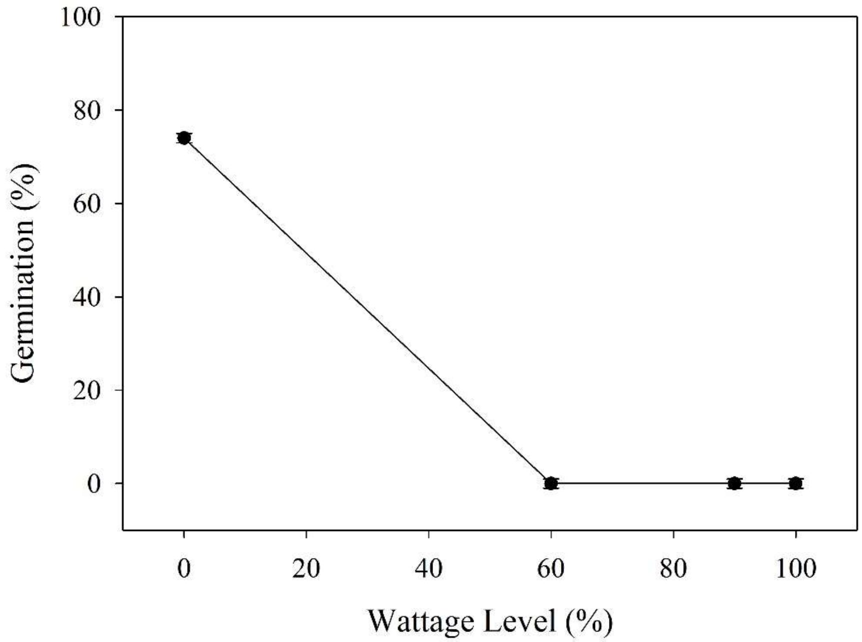

Figure 2.4. Germination (%) of peanut seeds at different wattage levels (%) of 1350 W microwave irradiation for all irradiation trials conducted in Tifton, GA combined.

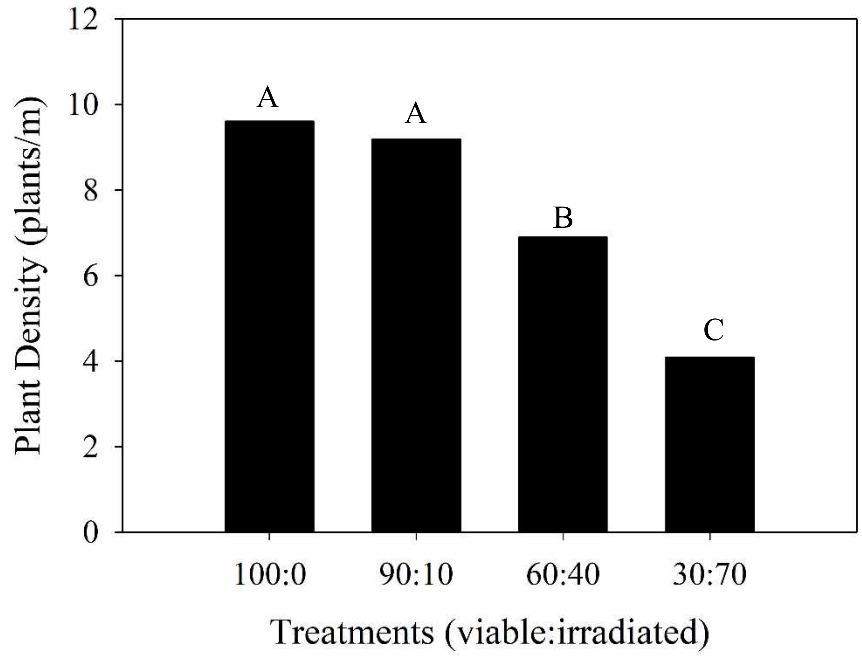

Figure 2.5. Plant density counts conducted 16 days after planting for field validation trials of an irradiation method conducted in Tifton, GA at each treatment combined across years. Bars with the same letter are not significantly different according to Tukey-Kramer HSD test at $p \leq 0.05$.

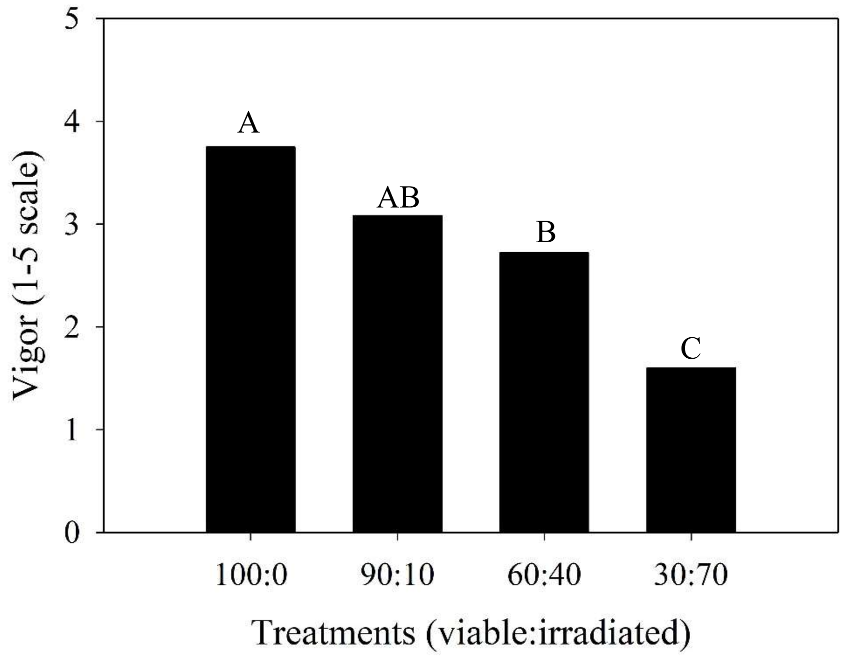

Figure 2.6. Seedling vigor rating (1-5 scale) conducted between 20 and 23 days after planting in field validation trials of an irradiation method conducted in Tifton, GA for each treatment combined across years. Bars with the same letter are not significantly different according to Tukey-Kramer HSD test at $p \leq 0.05$.

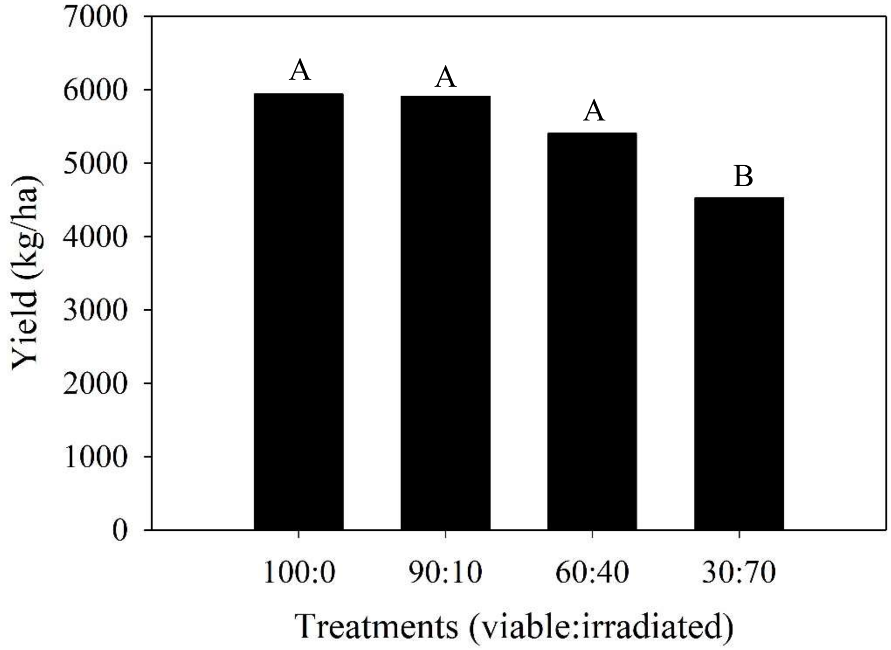

Figure 2.7. Peanut yield (kg/ha) recorded at time of harvest for field validation trials of an irradiation method conducted in Tifton, GA for each treatment combined across years. Bars with the same letter are not significantly different according to Tukey-Kramer HSD test at $p \leq 0.05$.

Figure 2.8. Naturally occurring poor stand in Tifton, GA using seed treated with microwave irradiation of 810 W for 90 seconds.

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CHAPTER III

DEVELOPMENT OF A TECHNIQUE TO ESTIMATE STAND IN PEANUT (*ARACHIS HYPOGAEA* L.) FOR REPLANT DECISIONS USING AN UNMANNED AERIAL SYSTEM

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Abstract

The use of unmanned aerial systems (UASs) in agriculture has greatly increased over the past decade for their use in delivering near-real-time information of crop and soil properties. One area that UASs could be beneficial for peanuts (*Arachis hypogaea* L.) is in a scenario of poor stand establishment where a grower is trying to decide to replant or not. Poor stand in peanuts can be caused by multiple factors including drought and diseases which can lead to a reduction in yield and ultimately a loss of revenue for the grower. Due to lost revenue, it is important to establish a uniform plant stand early in the season. Therefore, the objective of this study was to develop a low-cost technique using a UAS to estimate stand in peanuts for replant decisions. Over 2018 and 2019 three seeding rate field trials were conducted with treatments of 9.8, 13.1, 16.4, and 19.7 (control) seed/m and in 2019 two irradiated seed field trials were conducted with treatments of 100:0 (control), 90:10, 60:40, and 30:70 viable:irradiated seeds. Aerial images were collected for all field trials via UAS multiple times over the first 30 days after planting (DAP). A model was developed in ArcMap 10.5 to estimate percent plant material per plot. Linear regression was conducted to find a relationship between estimated percent plant material and manual stand counts. Results proved that in seeding rate field trials the model could accurately estimate stand. Positive linear trends were observed at 14 DAP in both 2018 and 2019 with R^2 values of 0.696 and 0.724 respectively. Regression results for treatments of 9.8 seed/m and 19.7 seed/m collected at 14 DAP in 2019 showed strong R^2 values of 0.776 and 0.930 respectively. The data from this study suggests that aerial estimation may perform best in either poor stand situations or near perfect stand. Results from the irradiated seed field trial showed that the strongest linear regression was at 14 DAP with an R^2 value of 0.711 in 2019. Regression analysis for the treatments identified failures in the method but still showed that the

method could be useful in ideal stands. This aerial estimation of stand would take bias and potential missed areas from fields out of this crucial decision.

Introduction

One of the most important decisions a grower will have to face is the decision of whether to replant a peanut crop when marginal plant stands are observed after emergence. This decision has to be made very early in the season and can have a huge economic impact on the crop in the end. Poor stands have been reported to reduce yield resulting in reduced profit (Sorensen et al., 2004; Sconyers et al., 2007; Culbreath et al., 2011; Sarver et al., 2016). However, the cost of replanting can outweigh the benefits in some cases (Sternitzke et al., 2000).

Even though very little research has been conducted on replant decisions in peanuts, the case of a poor stand has been extensively researched. Poor stand in peanuts can be caused by a multitude of factors including but not limited to improper planting practices (Tubbs, 2019), soilborne and seedling diseases (Jackson and Bell, 1969; Sullivan, 1984), herbicides (Grey et al., 2001; Grey and Prostko, 2011; Price et al., 2004; Prostko et al., 2011, 2013), and mechanical issues at planting (Tubbs and Sarver, 2013). Improper planting conditions can include factors like inadequate soil temperature and soil moisture. Seed germination can be greatly delayed or reduced in soils that are below 68 °F at the 10 cm depth. Therefore, the soil temperature needs to be 68 °F or greater at the 10 cm depth for three consecutive days without risk of a cold front after planting in order to ensure proper germination and quick emergence (Tubbs, 2019). Germination of seeds is initiated by the uptake of water into the seed so a lack of moisture in the soil will result in a poor stand. Due to this, it is important to ensure that there is adequate soil moisture at the 5 cm depth where the seed will be planted. If the field is irrigated, it is recommended to plant after irrigating the field or after rain in a non-irrigated scenario (Tubbs, 2019).

Seedling diseases, such as *Aspergillus niger*, *Cylindrocladium parasiticum*, *Pythium* spp., and *Rhizoctonia solani*, can also cause stand issues (Jackson and Bell, 1969; Sullivan, 1984).

These diseases infect the plant as it is emerging and kill it resulting in poor stand in areas with lots of seedling diseases. Poor stand establishment can lead to problems with TSWV later in the season, so it is important to have a uniform established stand (Culbreath et al., 2011). Fungicide seed treatments are the best way to combat seedling diseases; however, significant stand loses can be reported even with the use of fungicide seed treatments (Melouk and Backman, 1995; Ruark and Shew, 2010; Tubbs et al., 2013; Turner and Backman, 1991).

Seed quality is another issue that affects germination and emergence in peanuts. Seed quality can be attributed to production practices and environmental factors associated with the production of seed. Sullivan et al. (1974) found that applying gypsum could increase germination by providing adequate Ca levels to the seed. Practices in storage and handling of the seed can also affect germination of the seed. Storing seed in cool, dry areas can maintain germination percentages when compared to hot storage environments (Weaver, 2020). Mechanical shelling can also reduce seedling emergence when compared to seed shelled by hand (Bell 1969) and seed without the testa have lower germination rates (Dey et al., 1999).

Herbicide injury is another reason for poor stands in peanuts. This injury can be a result of residual herbicides from previous crops, from drift, or from incorrectly using an herbicide. Commonly used herbicides that have been proven to negatively affect peanut are flumioxazin (Burke et al., 2002; Grichar et al., 2004; Price et al., 2004), diclosulam (Grey et al., 2001; Murphree et al., 2003), and glyphosate (Lassiter et al., 2008; Robinson, 2005). Even though these products are not labeled for peanut Grey and Prostko (2010) observed that it was not uncommon for them to be mistakenly applied to peanut. In the case of glyphosate, Lassiter et al. (2008) determined that injury to peanut stands greater than 48% benefited from replanting.

Growers need to ensure that they are planting the adequate number of seed to obtain final plant stands of at least 13.1 plants/m which is recommended by the University of Georgia (Tubbs, 2019). This starts at the beginning of the season by doing required planter maintenance. Planting speed can play a large role in plant stand. It is reported that there is a decrease in plant stand as planter speed increases (Tubbs and Sarver, 2013). As speed increases, planter efficiency and number of seed dropped in furrow both decrease (Tubbs, 2019). Due to this, it is critical that growers maintain appropriate planting speed to optimize plant stand.

Replant decisions have been studied in crops like corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybeans [*Glycine max* (L.) Merr.] (Nielsen, 2003; Wrather et al., 2008, Vasilas et al., 1990). In all three crops, replanting was beneficial below certain plant populations with uniform distribution in the field. However, it was found in corn that there were nine pieces of information that were needed to calculate the feasibility of replanting. They are the original target plant population, the after-damage plant population, the after-damage stand uniformity, the after-damage plant leaf loss, the original planting date, the expected replanting date, the expected replanting cost, the expected "normal" yield, and the expected market price of corn (Nielsen, 2003). Even though this list is specific to corn, this can also be a beneficial list in replant decisions of peanut.

Considerable research has been conducted to identify the ideal plant stand in peanut and the official recommendation from the University of Georgia is a seeding rate of 19.7 seed/m to obtain a final stand of 13.1 plants/m (Beasley et al., 1997). Research has proved that in some cases, yield potential can be maintained at reduced plant stands – therefore stand issues do not always result in yield reductions (Augusto et al., 2010; Bell et al., 1987; Tewolde et al., 2002). Very little research has been conducted on replanting in peanuts, but two recent studies have investigated this issue (Sarver et al., 2016; Sarver et al., 2017). These studies show that in single rows, replanting is beneficial at stands equal to or below 8.2 plants/m (Sarver et al., 2016). In twin row, planting plant stands less than or equal to 9.8 plants/m benefitted from replanting (Sarver et al., 2017). Results also showed that in a scenario of poor stand, completely replanting the field resulted in a lower yield than a supplemental replanting (Sarver et al., 2017).

With the degree of difficulty in this decision, a decision aid tool could be very useful to growers. Decision aid tools and models are becoming increasingly popular in agronomic crops to aid growers in decisions to maximize yield and profit. Peanut is no exception to this. These decision tools can range from methods to predict disease pressure to methods of determining maturity of the crop to irrigation scheduling tools.

During the process of making a replant decision a grower or crop consultant may survey a small area of the field and not survey the entire field. Therefore, a rash decision could be made that is not beneficial when the whole field is considered. An image obtained of the entire field using an unmanned aerial system (UAS) will give a more complete view of the problem. This method could result in only the poor area being replanted and not the entire field reducing input costs for the grower. There are many factors that need to be considered when making the decision. Therefore, the main objective of this study was to develop a method to estimate percent plant material in the field at two weeks from planting using a UAV.

Materials and Methods

Seeding Rate Field Trial

Three field trials were conducted during 2018 and 2019 for this experiment. The first field trial was planted on 8 May 2018 at the Sunbelt Agricultural Expo in Moultrie, Georgia

(Expo), the second field trial was planted on 1 May 2019 at the Sunbelt Agricultural Expo in Moultrie, Georgia (Expo), and the final field trial was planted on 22 May 2019 at the Abraham Baldwin Agricultural College JG Woodruff research Farm in Tifton, Georgia (ABAC). The experimental design for all three field trials was a randomized complete block design with four replications. Plots consisted of four rows spaced 0.91 m apart. In 2018 and 2019, at the Expo, plots were 60 m long. In 2019, at ABAC, plots were 143 m long. Peanut cultivar AUNPL-17 (Branch, 2007) was planted at a depth of 5 cm. There were four treatments consisting of: 9.8, 13.1, 16.4, and 19.7 (control) seed/m. Peanuts were maintained using recommendations from the University of Georgia (Monfort et al., 2020).

Manual stand counts were collected in the field in both years for three randomly selected 3 m sections of the plot that were marked at the time of planting. In 2019, plant area measurements were also collected at the time of stand counts by recording the representative maximum length (cm) (in direction of furrow) and width (cm) (perpendicular to the furrow) from the top foliage (birsdeye view) of twelve randomly selected plants in each plot. In both years, aerial flights were conducted to calculate aerial stand counts as well. These aerial flights were at a height of 100 m using a UAS consisting of a FireFLY6 Pro (BirdsEyeView Aerobotics, Andover, NH) equipped with a Sony α5100 (Sony Electronics Inc., San Diego, CA). The Sony α5100 has a resolution of 24.3 MP. In 2018, manual stand counts were collected at 9, 14, 16, 23, and 28 DAP with aerial flights at 7, 9, 14, 16, 21, 23, 26, 28, and 30 days after planting (DAP) to conduct aerial stand counts. In 2019, at the Expo manual stand counts, plant area measurements, and aerial flights were completed at 14, 16, 19, and 22 DAP; at ABAC manual stand counts, plant area measurements, and aerial flights were done at 13, 15, 20, and 23 DAP.

Irradiated Seed Field Trial

Two field trials were conducted in 2019 for this experiment. The first field trial was planted on 1 May 2019 at the Expo and the second field trial was planted on 22 May 2019 at ABAC. The experimental design for the two field trials was a randomized complete block design with four replicates of each treatment. Plots consisted of four rows spaced 0.91 m apart. At the Expo plots were 60 m long and the plots at ABAC were 106 m long. All tests were planted in the peanut cultivar Georgia-06G (Branch, 2007) at a depth of 5 cm at the University of Georgia's recommended seeding rate of 19.7 plants/m. Treatments consisting of ratios of viable and irradiated seed (viable:irradiated). The four treatments were: 100:0 (control), 90:10, 60:40, and 30:70. Germination was inhibited by irradiating the appropriate percentage of seed, in batches of 50 seed, for each treatment for 90 s at 810 W using a 2450 MHz microwave oven (Oster, OGWT1603VSE, Sunbeam Products, Inc., Zhongshan China). Peanuts were maintained using recommendations from the University of Georgia (Monfort et al., 2020).

Manual stand counts were collected in the field in both trials for three randomly selected 3 m sections of the plot that were marked at the time of planting. Plant area measurements were also collected at the time of stand counts by recording the length and width (in cm) of the top of twelve plants in each plot, as previously described. Aerial flights were also conducted to calculate aerial stand counts as well. These aerial flights were completed at a height of 100 m using an UAS consisting of a BirdsEyeView FireFLY6 Pro equipped with a Sony α5100. The Sony α5100 has a resolution of 24.3 MP. At the Expo manual stand counts, plant area measurements, and aerial flights were done at 14, 16, 19, and 22 DAP; at ABAC manual stand counts, plant area measurements, and aerial flights were done at 13, 15, 20, and 23 DAP.

The Expo test was inverted at 133 DAP and harvested at 139 DAP and the ABAC test was inverted at 148 DAP and harvested at 155 DAP. For all tests yield was collected for all plots and a composite grade sample was collected for each treatment.

Analyzing Imagery

Images were stitched together using Pix4Dmapper (Pix4D S.A., Switzerland) and were then imported into ArcMap 10.5 (Environmental Systems Research Institute, Inc., Redlands, CA). In ArcMap 10.5 shapefiles were created for each of the plots in the test. A model was created to identify plant material in each plot. This was done by first creating training samples to identify plant material and soil in the image. The model then created a mask to hide the soil and the plant material was identified using maximum likelihood classification. Features of plant material are then converted to polygons to calculate area of plant material. Based on the area of the whole plot and the area of plant material in the plot a percentage of plant material can be calculated for each individual plot.

Statistical Analysis

A model was created in Sigma Plot 14.0 (Systat Software Inc., San Jose, CA) that predicted plant area based on DAP using plant area measurements taken in 2019. Manual plant stand counts were then converted to percentage of the plot covered in plant material using this model. Linear regression and Pearson's correlation was completed using Sigma Plot 14.0 comparing aerial estimations for percent plant material to actual percent plant material.

Results and Discussion

Seeding rate field trial. Compiling all aerial estimations from the seeding rate trial into one graph and plotting them versus the actual percent plant material shows that there is not a strong linear relationship between the two (Figure 3.1). Across all three trials there was a significant linear trend; however, the relationship between aerial estimations and actual plant material was weak. Four distinct groups of data points can be seen in the graph. This weak relationship and the grouping of data points likely contributed to differences in growth between years and collection dates. Due to this, data points for the two years were then graphed individually (Figure 3.2). The grouping of data points is very defined in the graph for 2018 (Figure 3.2a) while the graph for 2019 (Figure 3.2b), does not show as pronounced grouping of data points. Results in the 2018 graph show four distinct groups. Since the data in 2018 belongs to one field trial, this difference is likely due to growth suggesting that breaking the stand data into graphs based on the DAP may yield better linear relationships. This shows that the model is not adequate to calculate plant area when plants are at different growth stages.

When analyzing the data by DAP for each year, correlation coefficients show that in both years the strongest correlation was at 14 DAP with $R = 0.834$ ($P < 0.001$) in 2018 and $R = 0.851$ ($P < 0.001$) in 2019 (Table 3.1). The weakest correlation coefficient in 2018 occurred on the first data collection date at 9 DAP. This is because at 9 DAP plants were still emerging and many had not fully emerged yet. In 2019, after 14 DAP, correlation coefficients decreased as DAP increased. This is likely due to the plants coalescing. This results in foliage overlapping that the model would not be able to see in an image, therefore, it cannot account for it.

To further explore correlations in the seeding rate field trial, regression analysis was run for each of the treatments for the data collection collected at 14 DAP in 2019 (Figure 3.3). The weakest linear relationship was observed at the treatment of 16.4 seed/m (Figure 3.3c) while the strongest linear relationship was at 19.7 seed/m (Figure 3.3d). Regression analysis of the 9.8 seed/m treatment also showed a strong linear relationship (Figure 3.3a). The 13.1 seed/m treatment had a weak linear relationship at $R^2 = 0.267$ (n.s.) but it had the slope closest to 1.0 (Figure 3.3b). Even though it did not have a strong linear relationship it had the most accurate estimations. The treatment with 9.8 seed/m yielded the second most accurate estimations (Figure 3.3a). This could suggest that stand counts in extreme situations – i.e. very poor stands – are most accurate to correlate aerial stand count estimations with actual plant stand counts. This is likely because in a situation of very poor stand plants would likely not be coalesced. However, these treatments would not be consistent with the non-uniform stand issues that would be found in a grower's field.

Irradiated seed field trial. Like results from the seeding rate field trial compiling all data collected for the irradiated seed trial resulted in a very weak linear relationship (Figure 3.4). The grouping of data for this field trial appears to be weaker when compiling all data points. However, two distinct groupings can be seen on the graph just as with the previous field trial. This once again suggests that growth causes differences in linear relationships between aerial estimations of percent plant material and actual plant material in the field.

Data collected in 2019 were once again analyzed by the DAP. For this trial, the strongest correlation was observed at 16 DAP with an R value of 0.843 ($P < 0.001$) (Table 3.2). It is unclear what caused the anomaly that resulted in the weakest relationship between aerial plant material estimations and actual plant material at 14 DAP. As with the seeding rate field trial, after 16 DAP, the correlation decreased as DAP increased showing that data collected between 15 and 19 DAP is the ideal range. In 2019, a strong correlation was still observed at 22 DAP with $R = 0.791$. This is generally the latest point in the season when a grower would need to make a decision on whether or not to replant the field.

The irradiated seed trial was created to mimic more closely the non-uniform stand issues that would occur in a grower's field. Similar to the seeding rate trial, the strongest linear relationship among treatments at 16 DAP was observed at the 100:0 treatment which would be comparable to the 19.7 seed/m treatment in the seeding rate trial (Figure 3.5). The regression analysis for the 100:0 treatment yielded a R^2 value of 0.724 ($P < 0.05$) with the most accurate slope of 3.221 ($P < 0.05$) (Figure 3.5d). Strength of linear relationships and accuracy of the data collected decreased as the ratio of viable:irradiated seed decreased. This suggests that this method would not be accurate in estimating stand counts in non-uniform stand issues.

This failure of the model could be caused by multiple issues. First, non-uniform stand issues could have large spaces with no plants. This results in large areas of soil that could throw off the estimations. The model masks most of the soil in the images; however, color issues throughout the image caused by clouds, shadows, color differences between wet and dry soil, or color differences due to different soil types in a field can cause the model to still process soil as plant material. Next, the same issue could be happening with the identification of plant material. Different colors in the plant material can cause the model to not identify all plant material in the plot. The presence of weeds in plots could also throw off the amount of plant material in a plot. Last of all, the actual stand counts were collected at three randomly selected 10 m sections in each plot. These three sections may not have been representative of the entire plot. Therefore, it could be that actual stand counts are not correlated to the total field estimations. The aerial method has the ability to assess the entire plot resulting in a better estimation for the plot. This is a good example of why a method like this would be beneficial to growers. Growers are not able to easily assess an entire field for stand issues.

Conclusions

It is important to note that this model does not fit across years or collection dates due to plant growth. To implement this method a dynamic model would have to be created that changes with each scenario. However, this method has proven that it can be used in ideal situations before the plants coalesce, 14 to 16 DAP, to estimate percent plant material. Aerial estimation of plant stands in ideal situations could be useful to researchers that need to speed up and automate data collection. More research is needed to fully understand why there are failures in non-uniform plant stand issues. This area is where this method would be the most beneficial to growers. Coupled with the current economics of replanting an aerial estimation could be used to determine if it is beneficial for a grower to replant a field or not. Growers are not able to easily assess an entire field and are likely to go to an area with poor stand and make a replant decision based on that small area. An aerial estimation would be able to identify the stand of the entire field. Other areas of the field with good plant stands may be able to balance out the loss of areas with poor stands. Further research can be used to identify the failures in the method and make it beneficial to growers.

Figures

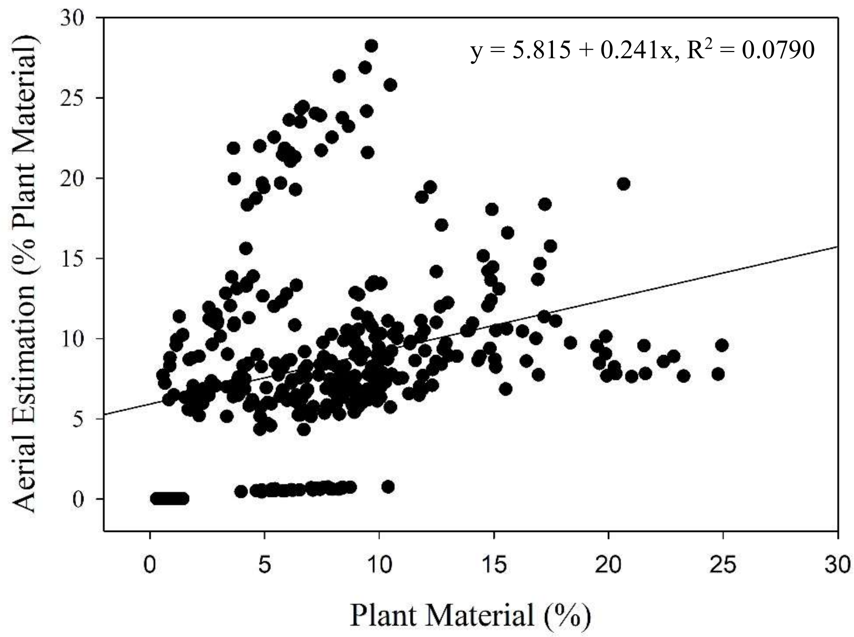
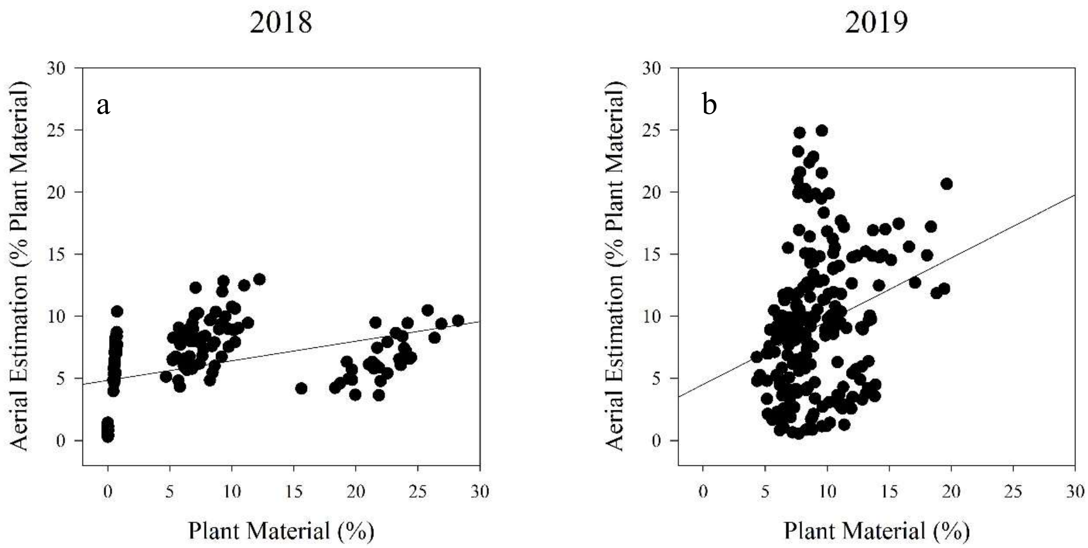


Figure 3.1. Linear trend between plant material (%) and aerial plant material estimations (%) collected using aerial imagery across three seeding rate field trials conducted in Tifton, GA in 2018 and 2019.



y = 4.864 + 0.158x, R^2 = 0.161

y = 4.528 + 0.509x, R^2 = 0.0717

Figure 3.2. Linear trend between plant material (%) and aerial plant material estimations (%) in the plot collected using aerial imagery in (a) 2018 and (b) 2019 for seeding rate field trials conducted in Tifton, GA.

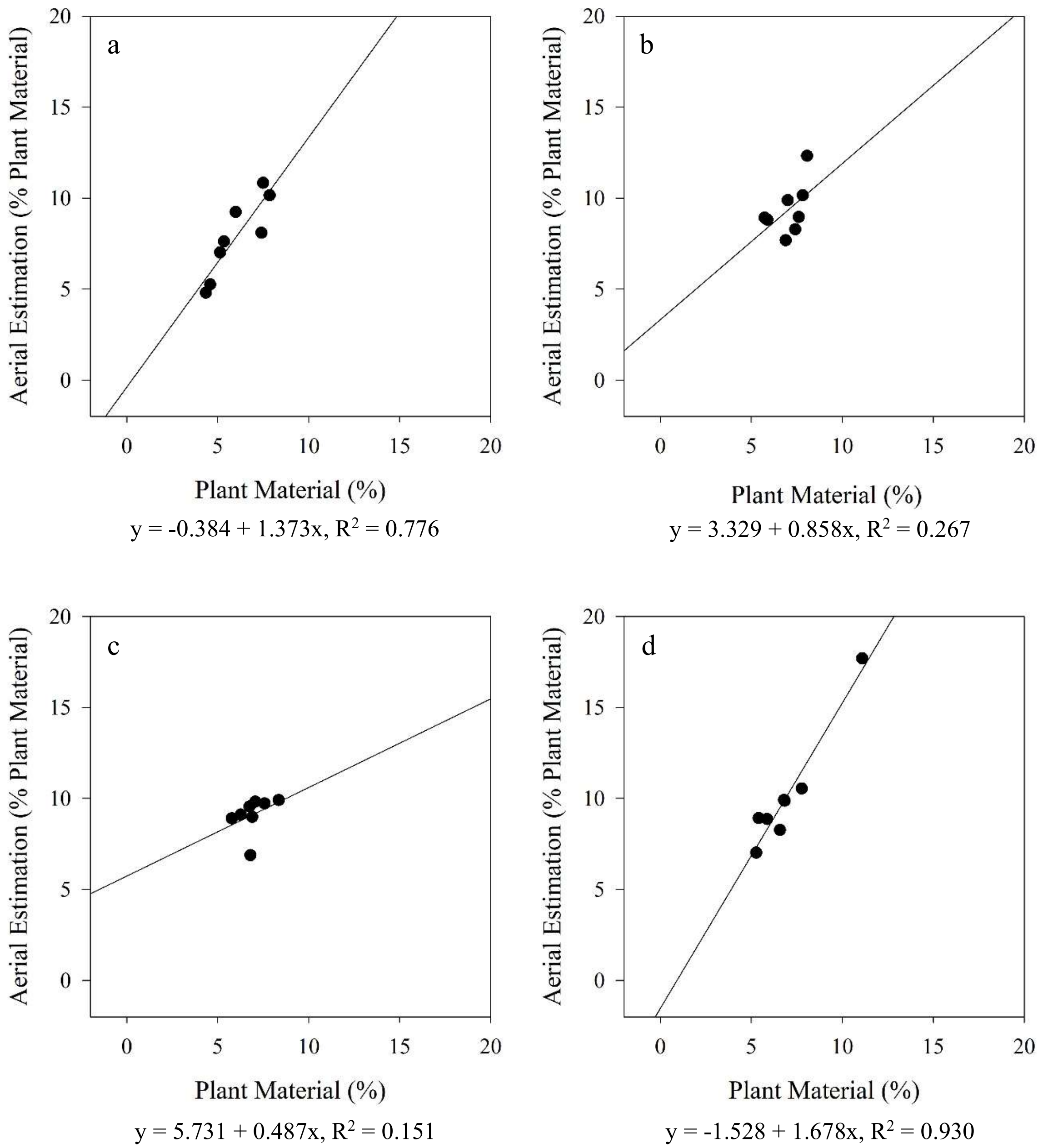


Figure 3.3. Linear trend between plant material (%) and aerial plant material estimations (%) in the plot collected using aerial imagery for treatments (a) 9.8 seed/m, (b) 13.1 seed/m, (c) 16.4 seed/m, and (d) 19.7 seed/m in 2019 seeding rate field trials conducted in Tifton, GA at 14 days after planting.

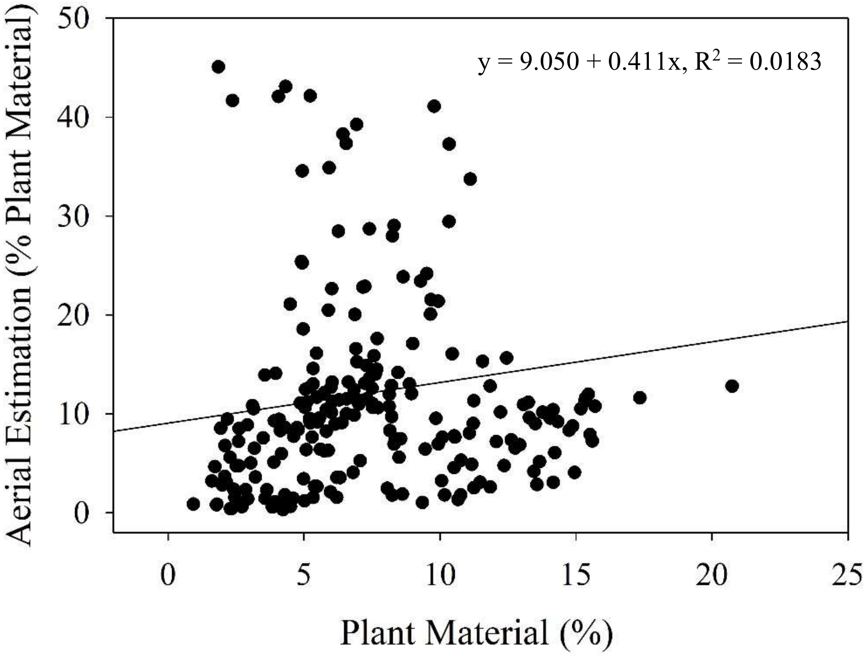


Figure 3.4. Linear trend between plant material (%) and aerial plant material estimations (%) in the plot collected using aerial imagery across two irradiated seed field trials in 2019 conducted in Tifton, GA.

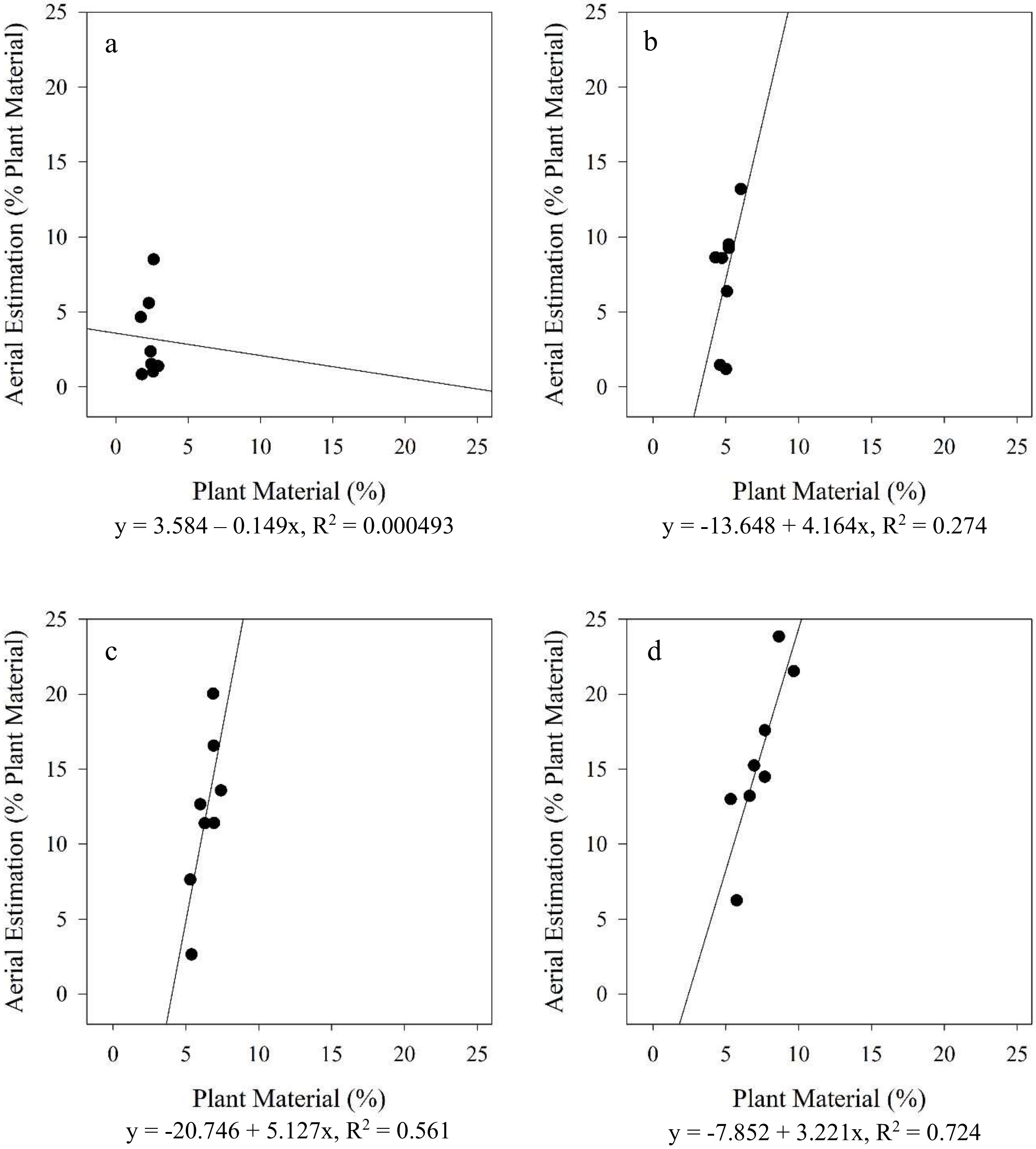


Figure 3.5. Linear trend between plant material (%) and aerial plant material estimations (%) in the plot collected using aerial imagery for the viable:irradiated seed treatments (a) 30:70, (b) 60:40, (c) 90:10, (d) 100:0 at 16 days after planting in irridaed seed field trials in 2019 conducted in Tifton, GA.

Tables

Table 3.1. Pearson correlation coefficients between aerial plant material estimations (%) and actual plant material (%) in the plot for seeding rate field trials conducted in Tifton, GA at all collection dates.

	Correlation Coefficient			
Collection Date[a]	2018		2019	
9	0.159		-	
13	-		0.759	*
14	0.834	*	0.851	*
15	-		0.816	*
16	0.589	*	0.787	*
19	-		0.687	*
20	-		0.686	*
22	-		-0.714	*
23	0.674	*	-	
28	0.747	*	-	

[a]Days after planting
[b]* = $P < 0.01$

Table 3.2. Pearson correlation coefficients between aerial plant material estimations (%) and actual plant material (%) in the plot for irradiated seed field trials conducted in Tifton, GA at all collection dates in 2019.

Collection Date[a]	Correlation Coefficient
13	0.796 *
14	0.238
15	0.825 *
16	0.843 *
19	0.821 *
20	0.698 *
22	0.791 *

[a]Days after planting
[b]* = $P < 0.01$

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CHAPTER IV

A SURVEY OF PEANUT (*ARACHIS HYPOGAEA* L.) PRODUCTION METHODS IN GEORGIA TO DETERMINE PEANUT YIELD POTENTIAL BY GEOGRAPHICAL LOCATION

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Abstract

The use of crop models to predict yield have become increasingly popular in agronomic crops. To implement a crop model for peanut (*Arachis hypogaea* L.) in Georgia, it is imperative to understand the effects of geographical location in the state and planting date on yield. The main objective of this study was to determine yield potential of peanut by geographic location and planting date in Georgia using an agronomic production survey. Survey data consisted of latitude and longitude, planting date, row configuration, irrigation method, cultivar, digging date, yield, and grade for each of the selected fields. Growers were also allowed to leave specific comments about the field allowing for the explanation of low yields and yield anomalies. Data collected showed that over 95% of the fields were planted to Georgia-06G across all three years and 51% of the fields were irrigated. Planting dates ranged from April 5th to June 10th with yields ranging from 785 kg/ha to 7473 kg/ha. Initial results using linear regression did not show a correlation between yield and planting date. However, a visual negative relationship was observed between yield and planting date. Surveys were categorized by river basin based on geographical location in order to better observe geographical effects. Significant differences were observed for row pattern, irrigation, rotation length, and seeding rate based on river basins. Yield showed differences due to river basin effect with the Satilla river basin showing the greatest negative effect on yield and the Flint river basin showing the greatest positive effect. The results from the survey conducted are beneficial for showing differences in yield due to geographical location in Georgia. These results will be useful in building future peanut models that can be implemented across the entire state.

Introduction

In Georgia, peanut (*Arachis hypogaea* L.) was grown in 76 of 159 counties across the state on over 320,000 hectares in 2020. However, ten counties accounted for nearly 50% of Georgia's peanut production. Bulloch County, located on the South Carolina border, was the only county of the ten that was not located in the southwestern corner of the state (UGA CAED, 2020). This information shows the diversity of the peanut growing area in the state of Georgia. There are many production decisions that influence yield in peanut. Some of these include planting date, irrigation, row pattern, cultivar, and crop rotation. Growers must make difficult decisions to try to reduce the risk of diseases such as early leaf spot caused by *Passalora arachidicola* (Hori) U. Braun [syn.*Cercospora arachidicola* (Hori)], late leaf spot caused by *Nothopassalora personata* (Berk. & M.A. Curtis) U. Braun, C. Nakash., Videira & Crous [syn. *Cercosporidicum personatum* (Berk. & Curt.) Deighton] and Tomato spotted wilt, caused by Tomato spotted wilt virus (genus *Tospovirus*; family Bunyaviridae) (TSWV) while trying to maximize yield and profit. While some factors can have a great impact on yield on their own, the highest influence on yield comes from interactions between the combination of multiple factors.

The earliest planting date trials showed that non-irrigated peanut in the southeastern United States had increased yield with earlier planting dates (Sturkie and Buchanan, 1973). This trial was conducted, however, before the introduction of TSWV to the area. Tillman et al. (2007) found that TSWV incidence decreased with later planting dates. Planting dates in June had the smallest incidence of TSWV, but pod yields tended to be greater with planting dates in May. They concluded that planting the most resistant TSWV cultivar, under irrigation, in mid-May maximized yield. This is probably due to the fact that peak thrips populations are typically observed the later part of April (Brown et al., 1996, 2005; Mckeown et al., 2001). It has also been found that later planting dates increase the incidence of leaf spot (Fulmer, 2017).

Water is a major limiting factor in crop production around the world. Research has demonstrated that peanut responds positively to irrigation (Isleib et al., 2014; Lamb, et al., 1997; Rao et al., 1985). Ketring and Wheless (1989) found that water and temperature can affect the development of peanut. Research proves that withholding water at certain stages in development can affect growth and pod development. For instance, withholding water at early stages of growth will slow growth, prolonging maturity (Kvien, 1995). On the other hand, withholding water during pod maturity will lead to faster maturation of the pods and plant (Dreyer et al., 1981). Water stress leads to hotter soil temperature which can hinder yield and quality and lead to pest problems (Sanders et al., 1985; Cole et al., 1985). One of these pests that can be influenced by drought conditions is *Aspergillus flavus*. *A. flavus* is a soil borne fungi that can produce aflatoxin. Aflatoxin is one of the most potent carcinogens found in food (Dichter, 1984). This mycotoxin, if found in peanuts, will significantly lower the grade and price of the peanuts (USDA FSA, 2017).

Growers plant their fields in either single row or twin rows. Generally, in single row plantings, two rows are planted with 91 cm spacing on raised 1.8 m wide beds and in twin row plantings four rows are planted with 91 cm between outer rows and 20 cm between adjacent twins on 1.8 m wide beds (Cox and Reid, 1965). Twin rows reduce the incidence of TSWV often resulting in increased yield when compared to single rows (Baldwin et al., 2001; Culbreath et al., 2008, Sconyers et al., 2007, Tilman et al., 2006, Tubbs et al., 2013). Single rows have also demonstrated incidence of southern stem rot (SSR), caused by the soil-borne fungus, *Sclerotium rolfsii* Sacc., that is three times greater than in twin rows (Sorensen, et al., 2004). This is likely due to plants in single rows being spaced closer together rapidly spreading the disease to adjacent plants.

The rotation history of the field is a major factor in yield potential of a peanut crop. Crop rotation has been exhibited to affect pest development and crop yield. Planting a diversity of crops in rotation that are hosts to different pests can minimize pest populations, in turn increasing yield (Hague and Overstreet, 2002; Jordan et al., 2008; Rodriguez-Kabana et al., 1987, Rodriguez-Kabana and Touchton, 1984). Cotton (*Gossypium hirsutum* L.) and corn (*Zea mays* L.) are the two rotational crops used with peanut. Peanut rotated with cotton for two years has been reported to provide some control of peanut root knot nematode (*Meloidogyne arenaria*) which causes substantial yield losses in severely infected fields (Starr et al., 2002). Peanuts can also utilize residual phosphorus and potassium that is applied for previous crops (Jordan et al., 2008).

Plant population can influence disease susceptibility, specifically diseases such as TSWV. Since the introduction of TSWV to the Southeast, one of the main ways to combat the disease has been by increasing plant population through seeding rate. Research has demonstrated that greater plant populations within the row can reduce yield loss to disease (Branch et al., 2003; Culbreath et al., 2003; Culbreath and Srinivasan, 2011). It was observed that increasing the number of plants did not reduce the number of infected plants but reduced the percentage of infected plants (Culbreath et al., 2013). Greater plant population may also allow for compensation of yield loss from diseased plants by healthy plants. With this knowledge, the recommended plant density is 13.1 plants/m (Culbreath and Srinivasan, 2011). In order to obtain this plant density, many growers utilize a seeding rate of 19.7 seed/m. This can be very costly to the grower (Culbreath et al., 2013). By using cultivars like Georgia-06G that are larger seeded and have a high level of resistance to TSWV, it was recorded that a seeding rate of 14-15 seed/m would not increase the incidence of TSWV thus lowering seed costs by using reduced seeding rates (Culbreath et al., 2013). Unfortunately, opposite of TSWV, the risk of SSR increases with increased plant density (Sconyers et al., 2005). This increase in SSR is due to rapid disease spread in dense plant stands.

Decision aid tools and models have become increasingly popular in agronomic crops to aid growers in making decisions to maximize yield and profit. These decision tools can range from methods to predict disease pressure to methods to determine maturity of the crop to irrigation scheduling tools. However, to create decision aids for growers in Georgia, it is important to know how production practices vary across the state. Therefore, the objective of this study was to collect information from growers across the state regarding yield and production decisions.

Materials and Methods

Survey questions were developed based on the information that growers' input into Peanut Rx 2.0, a decision aid tool used to predict risk and determine a fungicide program for the growers' situation (Williams, 2013). The survey was then sent to county extension agents in all Georgia counties where peanut is produced. County agents were requested to get two growers to complete the survey for all fields each grower planted to peanut during the 2017 and 2018 growing season.

For the 2017 growing season the survey consisted of the following questions:

1. In what county is the field located?
2. What is the field name?
3. What is the latitude and longitude of the field?

4. What date was the field planted?
5. What cultivar was planted?
6. What was the row pattern?
7. Does this field receive irrigation?
8. Was this field planted using seed saved from the year before?
9. What date was the field dug?
10. What was the grade of the field?
11. Comments about the field (I.e. stand issues, disease, etc.).

For the 2018 growing season the following questions were added to all surveys:

1. What was the tillage method of the field?
2. What was the seeding rate of the field?
3. What is the rotation of the field?
4. What is the soil type of the field?

There were 357 fields submitted for the 2017 growing season, 156 fields submitted for the 2018 growing season, and 36 fields submitted for the 2019 growing season. Linear regression was completed for initial data using Sigma Plot 14.0 (Systat Software Inc., San Jose, CA) comparing yield to planting date using different production methods. Surveys were grouped by river basin based on geographical location (Figure 4.1). Yield data were analyzed using mixed model methodology as implemented in SAS® PROC GLIMMIX (SAS/STAT 15.1, SAS Institute, Cary, NC). Because of the fragmented nature of the survey data resulting in extreme imbalance of 'treatment' combinations we opted for separate analyses of combinations of river basin with management factors such as planting date, row spacing, row pattern and rotation interval. Heterogenous variance issues were addressed by creating homogeneous residual variance groups. The pairwise comparisons were based on simple t-tests.

Results and Discussion

Initial analysis of survey results show that overall yields and planting dates varied greatly (Figure 4.2). Across the three years the first planting date was April 5th and the last planting date was June 10th. The median planting date was May 7th across all three years. There was a wide range in yields ranging from 785 to 7473 kg/ha. The median yield across all three years was 4989 kg/ha. Even though initial survey analysis showed a wide range in yield compared to planting date with a poor R^2 value of 0.0266, there was an observed negative linear trend between yield and planting date. Results showed that 95% of fields were planted to the cultivar Georgia-06G (Figure 4.3a), therefore, for remaining analyses all other cultivars were excluded. Saved seeds only accounted for 21% of fields surveyed across the three years (Figure 4.3b).

Analyses showed that fields varied more on row pattern than cultivar (Figure 4.3c). Twin rows accounted for 66% of all fields reported. Results also showed that there was no significant difference in yield for row configuration across all three years (Figure 4.4). When analyzing yield by row configurations separately there is not a strong relationship observed (Figure 4.5). An R^2 value of 0.0186 was observed for the linear relationship between yield and planting date for a single row planted fields (Figure 4.5a) and an R^2 value of 0.0858 was observed for all twin row planted fields (Figure 4.5b).

Water is the most yield limiting factors in peanut yield (Kvien, 1995). Irrigation method was divided with 51% of the fields being irrigated and 49% being non-irrigated (Figure 4.3d). Irrigation had a significant impact on yield across all three years (Figure 4.6). Irrigated fields produced a higher yield than non-irrigated fields with a difference of 1207 kg/ha. However, the linear relationship between yield and planting date for the separate irrigation methods was not strong (Figure 4.7). Both non-irrigated and irrigated fields had weak linear relationships.

To segregate fields to further explore the effects of production methods, surveys were segregated by a geographical river basin map based on their county (Figure 4.1). However, it is important to mention that the number of surveys that fell into each river basin were not equal so effects for some river basins such as Altamaha and Oconee may not be accurate. Significant differences were observed for yield differences between single row and twin row patterns in some river basins. These differences were calculated by subtracting the mean twin row yield from the mean single row yield for each river basin. Oconee, Satilla, and Suwanee river basins had differences of -2823, -1059, and 710 kg/ha respectively (Table 4.1). It was observed that some river basins had higher single row yields while others had higher yields with a twin row configuration. The Oconee river basin had the highest yield as a single row configuration with an improvement of 2823 kg/ha over twin row. The Satilla river basin and Ochlocknee river basin also had higher yield in single rows with an improvement of 1059 kg/ha and 912 kg/ha respectively over twin row. The Ogeechee, Ocmulgee, and Suwannee river basin all produced higher twin row yields than single rows. The Suwanee river basin had significant improvement in yield with 710 kg/ha when planted to twin row over single row. These results show that the effect of row configuration varies across the state.

Results for individual river basins show that irrigated fields had a significantly higher yield than non-irrigated fields in the Ogeechee, Flint, and Satilla river basins with a yield improvement of 1527, 1148, and 914 kg/ha respectively (Table 4.2). These survey results support findings that show that peanut cultivars respond positively to irrigation (Isleib et al., 2014). The greatest yield improvement when going from non-irrigated to irrigated fields was in the Ogeechee river basin with a yield improvement of 1634 kg/ha. The smallest statistical yield improvement was in the Satilla river basin where non-irrigated fields only lost 440 kg/ha when compared to irrigated fields.

Rotation length proved to have significant effects on yield in some river basins (Figure 4.8). Significant differences were observed in the Flint, Ocmulgee, and Ogeechee river basins.

Fields in the Flint river basin fields that had peanuts every 3rd year yielded less than fields with a 1-year rotation or a 2-year rotation. The Ocmulgee river basin had lower yield in fields that had a 1-year rotation when compared to fields with a 2-year rotation. Fields in the Ogeechee river basin that had 1 year rotation and a 3-year rotation had significantly lower yields than fields with a 2-year rotation length. Although, differences varied across river basins, the most consistent yield advantage was in fields with a 2-year rotation.

Significant differences in yield were observed in the Flint, Oconee, and Ogeechee river basins when analyzing seeding rates (Figure 4.9). The Flint river basin had the most variation in seeding rates compared to all other river basins. A seeding rate of 19.7 seed/m resulted in less yield than seeding rates of 21.3, 22.0, and 24.6 seed/m. The Oconee river basin only had fields planted to 19.7 and 22.0 seed/m. The lower rate of 19.7 seed/m resulted in less yield than the 22.0 seed/m rate. The Ogeechee river basin had smallest yields when planted with seeding rates of 16.4 and 26.2 seed/m compared to seeding rates of 19.7 and 22.0 seed/m. A seeding rate of 19.7 seed/m resulted in the greatest yield in the Ogeechee river.

When looking at the effect of geographical location on yield, there are once again large variations across the state (Figure 4.10). The geographical effects on yield are based on the median yield of all surveys which was 4989 kg/ha. The Satilla river basin produced the greatest negative effect on yield. Yields for fields located in this river basin were 1149 kg/ha lower when compared to the median yield. On the other end of the spectrum, fields in the Flint river yielded 442 kg/ha higher compared to the median yield. Other river basins that yielded higher than the median were Altamaha, Savannah, and Ocmulgee. River basins where yield was below average were Suwanee, Ochlocknee, Ogeechee, and Oconee. Results showed that most of the irrigated fields had yields that were above the median yield (Figure 4.11). Trends for geographical location grouped by irrigation method showed that as planting date increased yield decreased. This was true for all irrigated fields except for Ochlocknee river basin and all non-irrigated fields except for the Altamaha, Oconee, and Suwanee river basins.

Conclusions

Results showed that overall irrigation method and geographical location had the greatest effects on yield. The presence of irrigation resulted in a 20% increase in yield across the state. Geographical location had as much as an 18% decrease or a 4% increase in yield compared to the median yield of all fields. Within each geographical location, row configuration, irrigation method, seeding rate, and crop rotation were proven to be factors in yield potential. The effect of each production method varied by geographical location with row configuration having the greatest impact on yield. Further research using soil series could be beneficia to further evaluate the effect of production methods on yield.

These results are crucial in emphasizing that there are many factors that must go into the creation of a model in peanut. There are many differences that can be associated with production methods and geographical location. Models will need to address these and become dynamic – changing over time and production methods. It is imperative that a model addresses this issue.

Figures

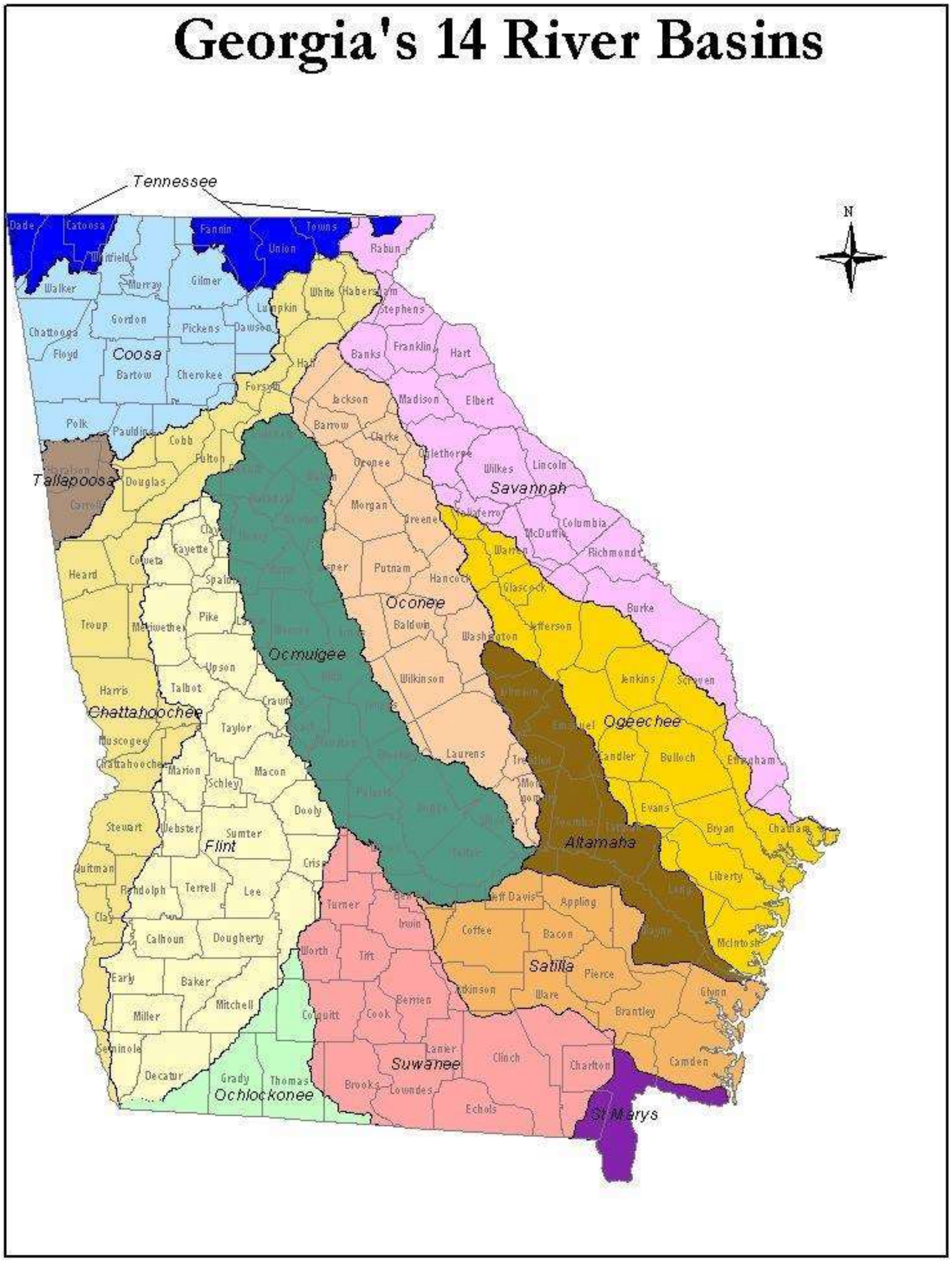

Figure 4.1. Georgia's 14 River Basins (WWALS Watershed Coalition).

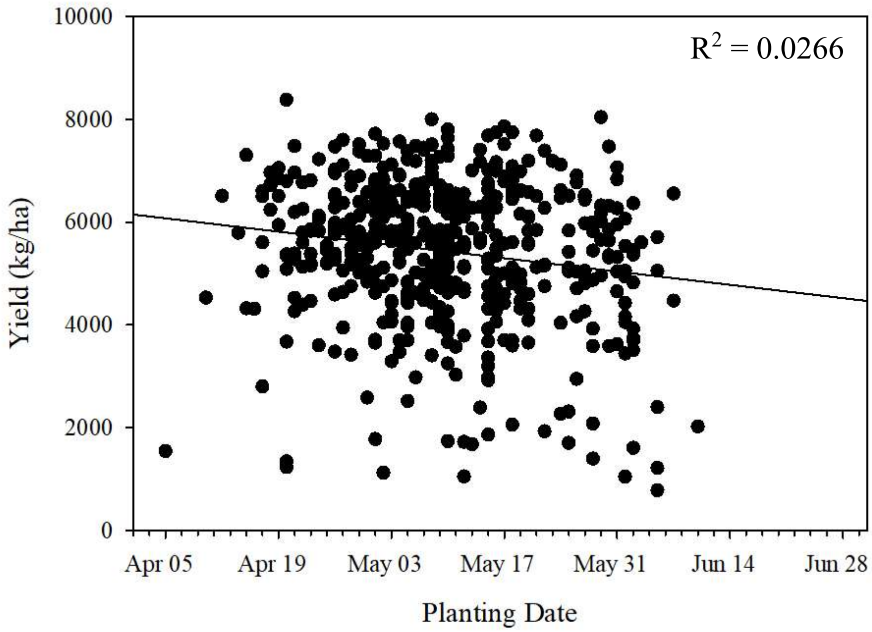

Figure 4.2. Peanut yield (kg/ha) versus planting date across 2017, 2018, and 2019 for all surveys collected in Georgia.

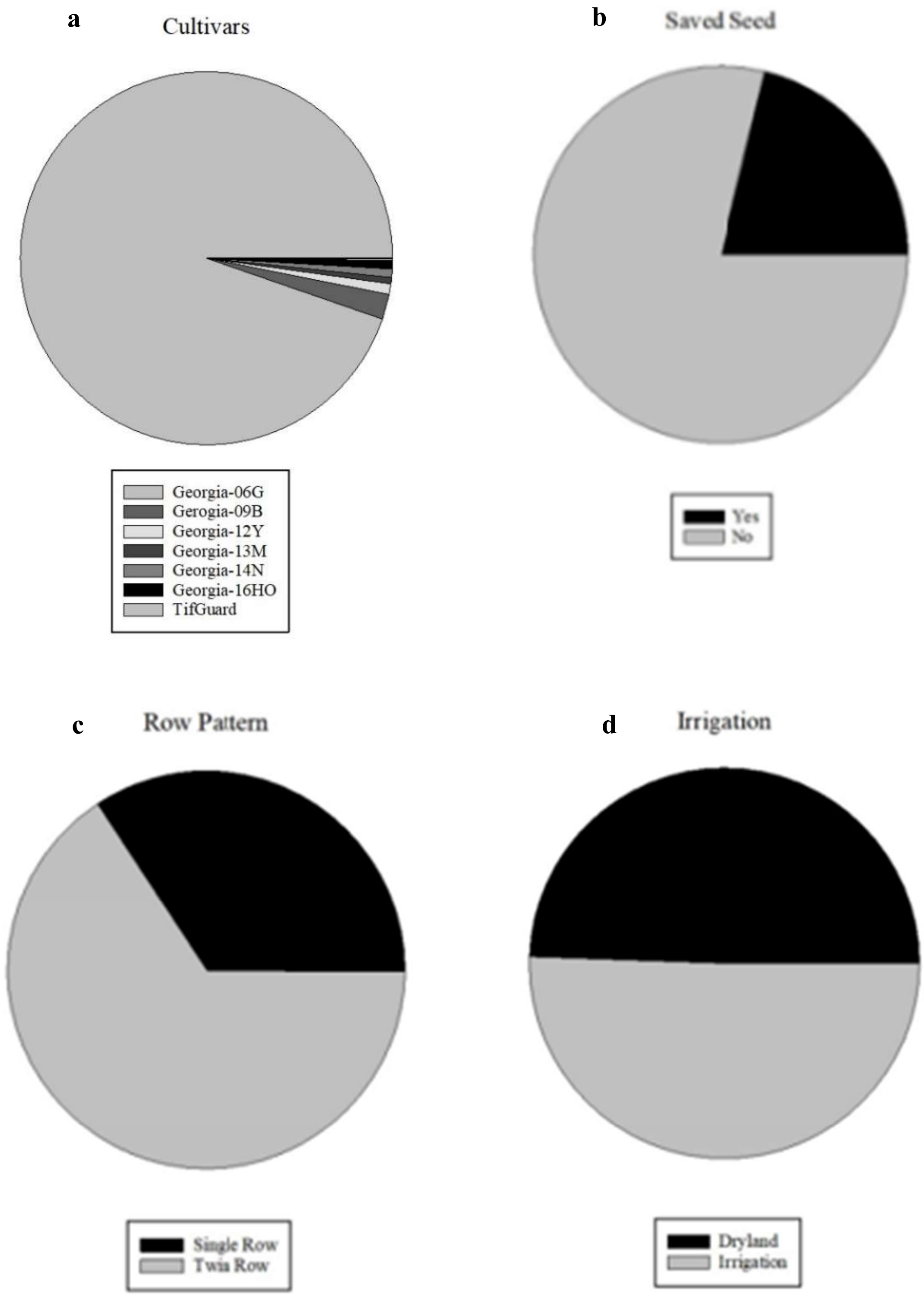

Figure 4.3. Pie charts for (a) cultivars, (b) saved seed, (c) row pattern, and (d) irrigation method across 2017, 2018, and 2019 for all surveys collected in Georgia.

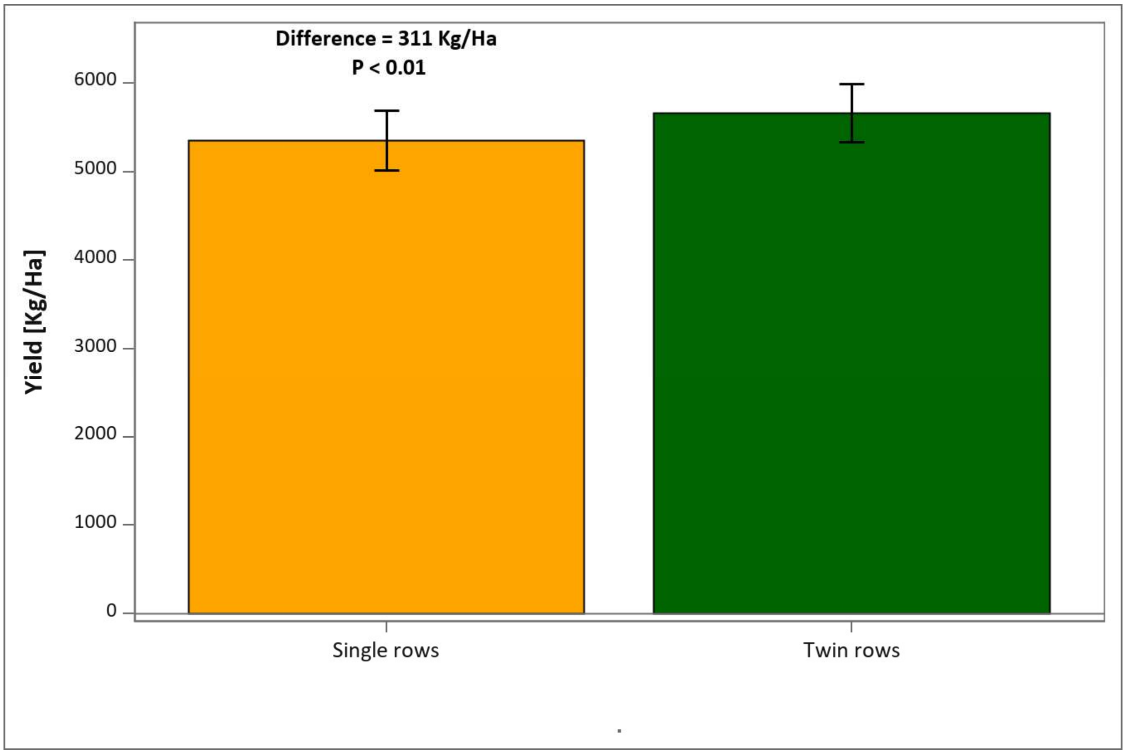

Figure 4.4. Peanut yield (kg/ha) based on row configuration (single rows and twin rows) across 2017, 2018, and 2019 for all surveys collected in Georgia. Error bars represent ± standard error of the mean.

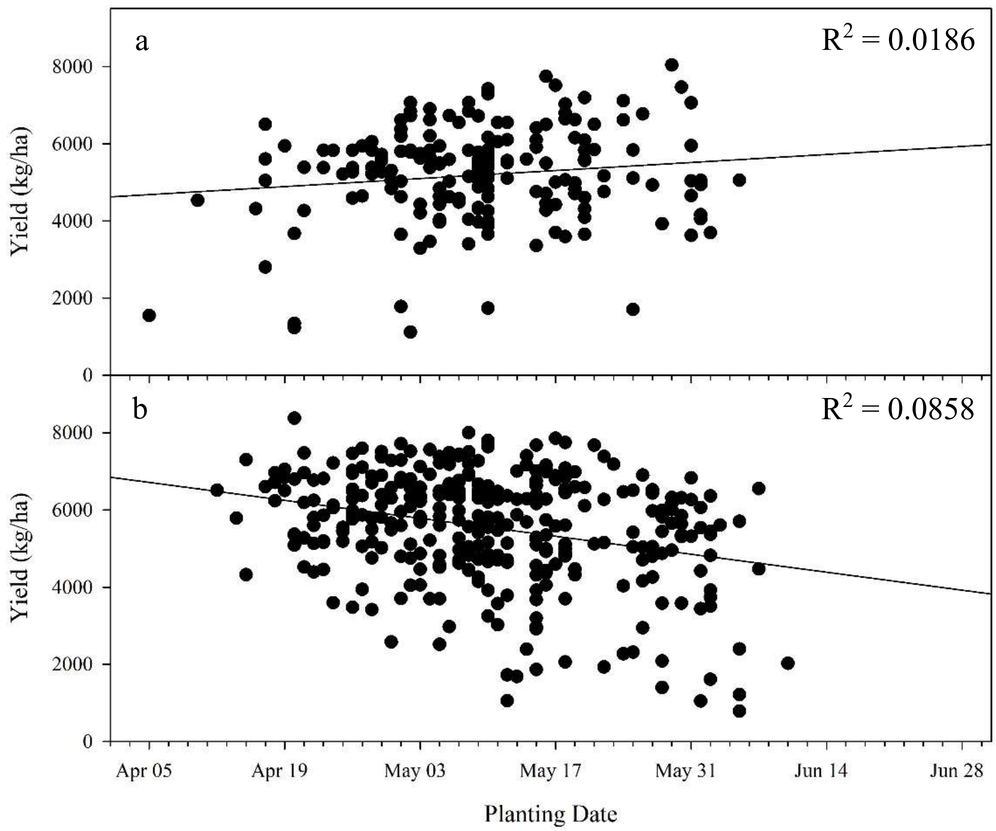

Figure 4.5. Peanut yield (kg/ha) versus planting date for each row configuration ((a) single row and (b) twin row) across 2017, 2018, and 2019 for all surveys collected in Georgia.

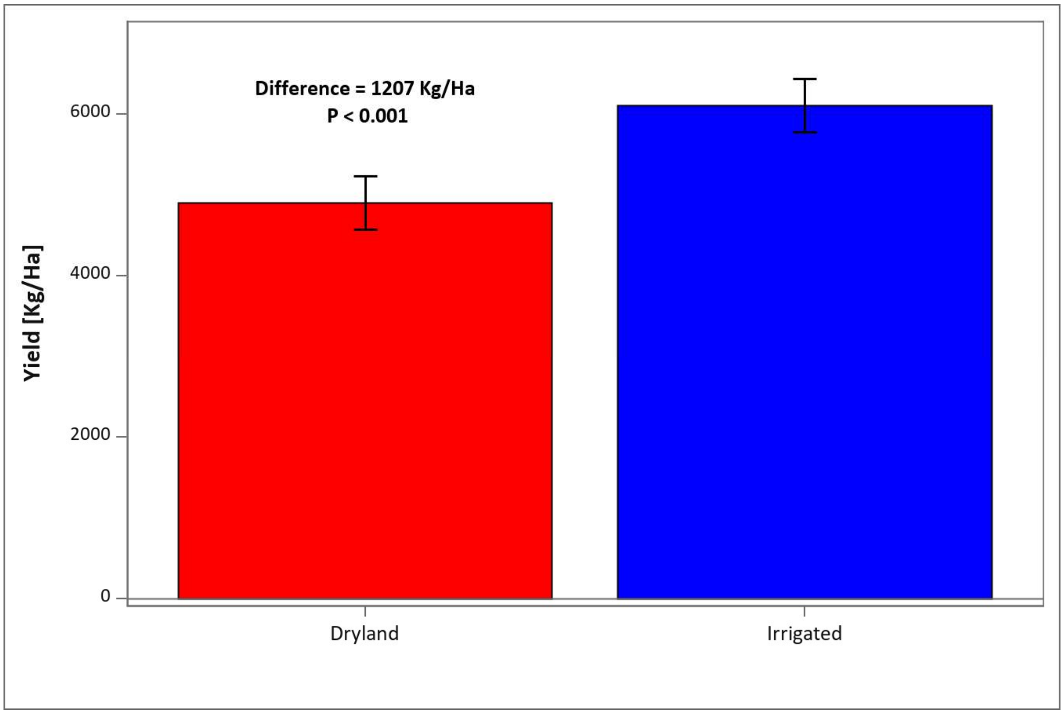

Figure 4.6. Peanut yield (kg/ha) based on irrigation method (non-irrigated and irrigated) across 2017, 2018, and 2019 for all surveys collected in Georgia. Error bars represent ± standard error of the mean.

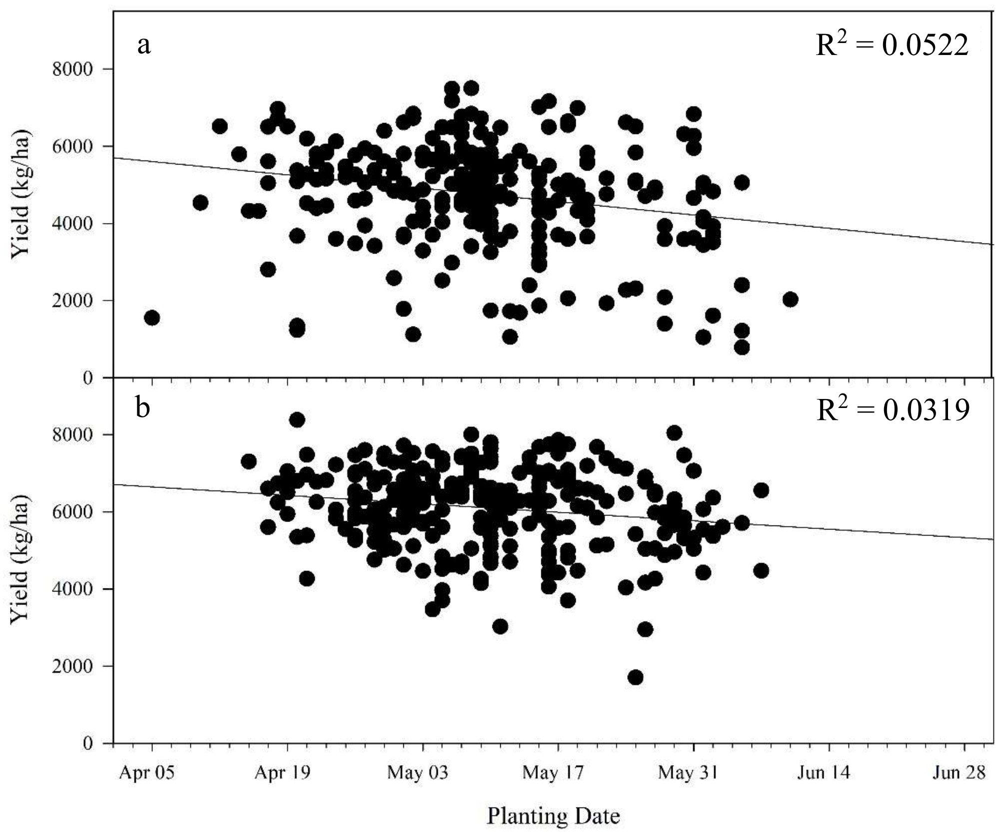

Figure 4.7. Peanut yield (kg/ha) versus planting date for each irrigation method ((a) non-irrigated and (b) irrigated) across 2017, 2018, and 2019 for all surveys collected in Georgia.

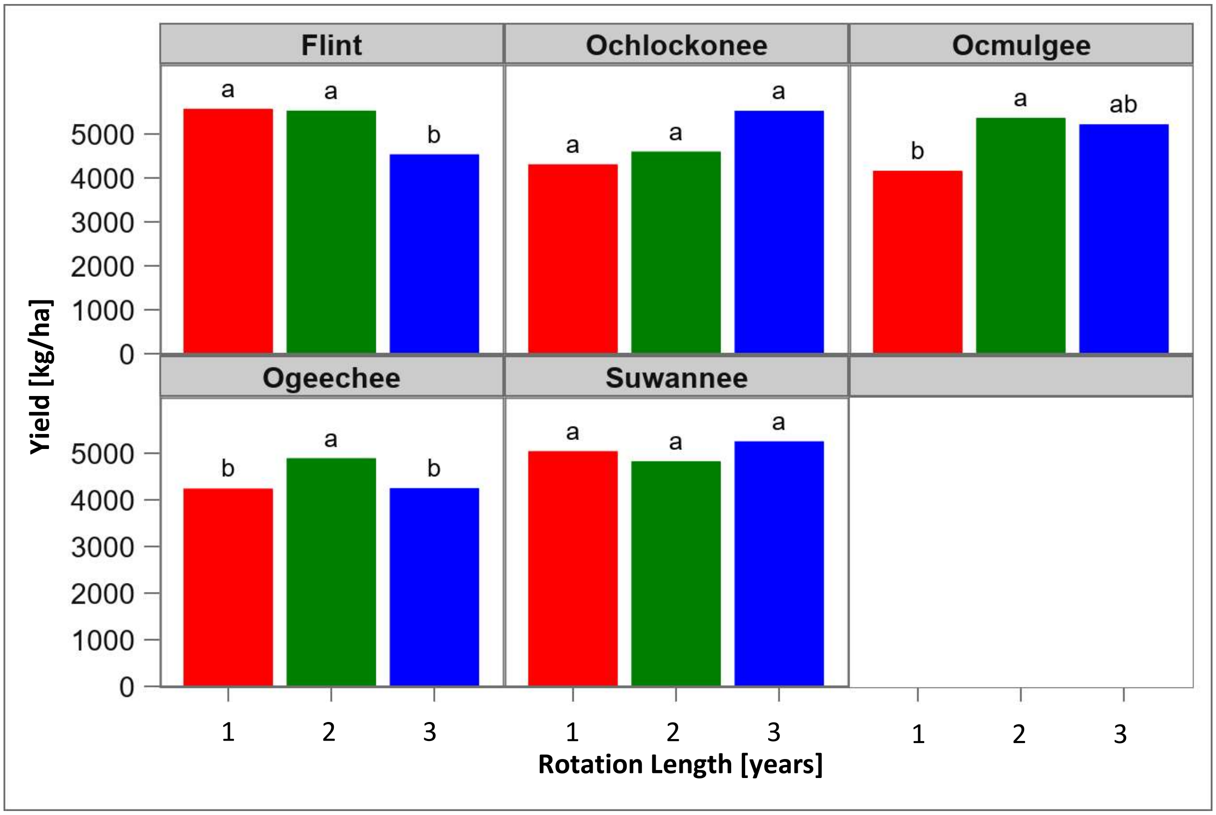

Figure 4.8. Effect of rotation length (years) on peanut yield (kg/ha) for individual river basins of surveys collected across 2017, 2018, and 2019 in Georgia. Bars with the same letter within river basins are not significantly different according to Fisher's Protected LSD test at p ≤ 0.05.

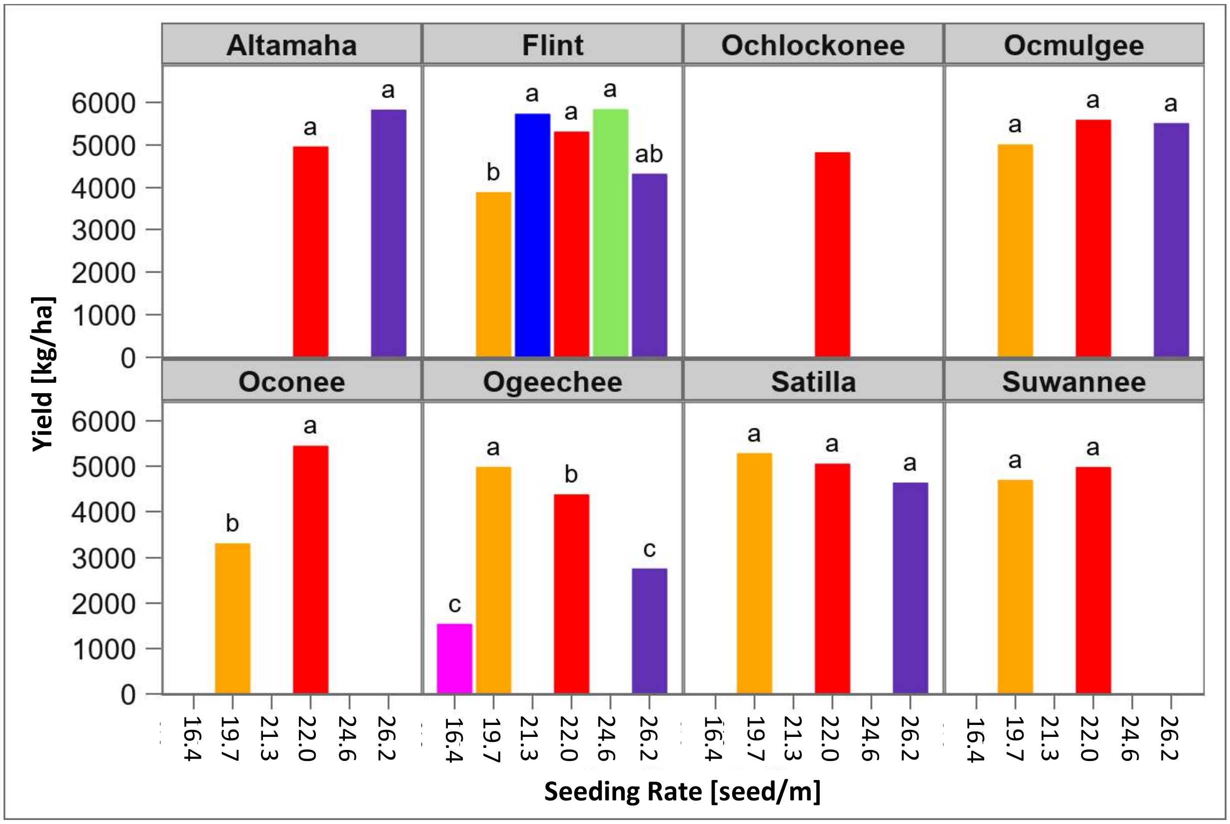

Figure 4.9. Effect of seeding rate (seed/m) on peanut yield (kg/ha) for individual river basins of all surveys collected across 2017, 2018, and 2019 in Georgia. Bars with the same letter within river basins are not significantly different according to Fisher's Protected LSD test at p ≤ 0.05.

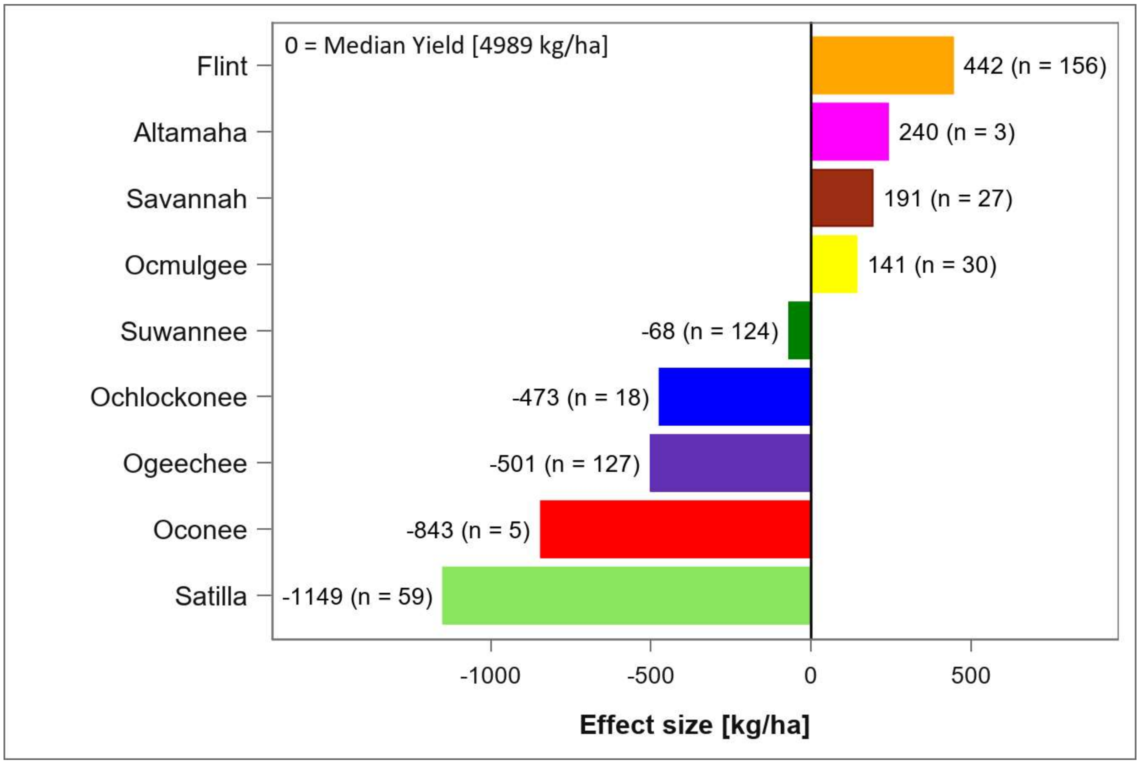

Figure 4.10. Effect river basin had on peanut yield (kg/ha) based on the median yield of 4989 kg/ha of all surveys collected across 2017, 2018, and 2019 in Georgia.

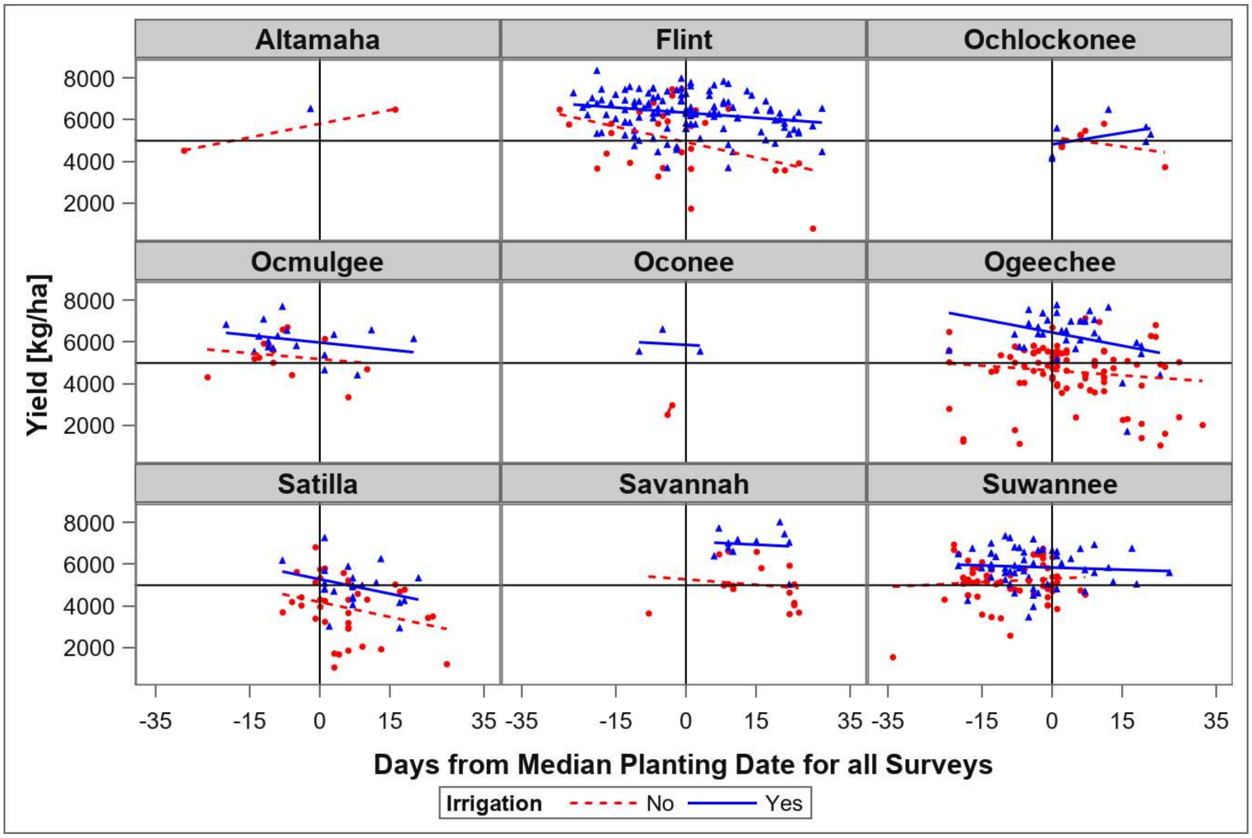

Figure 4.11. Peanut yield vs. planting date, where the vertical line at 0 equals the median planting date (May 7th) from all surveys collected in Georgia across 2017, 2018, and 2019. The horizontal line equals the median yield (4989 kg/ha) from all surveys.

Tables

Table 4.1. Estimated peanut yield by row pattern for all river basins, which had both row patterns present. Data were averaged across all irrigation levels and planting dates for all surveys collected across 2017, 2018, and 2019 in Georgia.

	Single rows		Twin rows		Difference	
River Basin	Yield	SE[a]	Yield	SE	Yield	Prob t[b]
	---------------------- kg/ha	---------------------------				
Ochlockonee	5225	537.5	4313	287.3	-912	0.135
Ocmulgee	4865	268.8	5434	287.3	569	0.149
Oconee	5275	620.7	2452	760.2	-2823	0.004
Ogeechee	4427	129.4	4560	141.2	134	0.485
Satilla	4576	253.4	3517	167.9	-1059	0.001
Suwannee	4390	196.3	5100	111.5	710	0.002

[a]SE = standard error
[b]Differences are significant at Prob t < 0.05.

Table 4.2. Estimated peanut yield by irrigation at the median planting date for all river basins for which there were enough observations. Data were averaged across row pattern for all surveys collected across 2017, 2018, and 2019 in Georgia.

	Non-irrigated		Irrigated		Difference	
River Basin	Yield	SE[a]	Yield	SE	Yield	Prob t[b]
	---------------------- kg/ha ---------------------------					
Flint	4394	185.4	5656	88.8	1262	0.000
Ocmulgee	4620	368.4	5330	264.6	710	0.118
Ogeechee	4129	108.1	5763	187.2	1634	0.000
Satilla	3732	196.1	4709	307.3	978	0.008
Savannah	4703	493.3	6338	750.3	1634	0.069
Suwannee	4771	194.3	5211	145.1	440	0.070

[a]SE = standard error

[b]Differences are significant at Prob t < 0.05.

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CHAPTER V

EVALUATION OF VEGETATION INDICIES FOR THE ABILITY TO PREDICT YIELD AND GRADE IN PEANUT (*ARACHIS HYPOGAEA* L.) USING AERIAL IMAGERY

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Abstract

Growers and industry could greatly benefit from a decision aid tool that estimates crop quality and yield across a field. This information can be used by buying points to prepare for post-harvest storage decisions for peanuts (*Arachis hypogaea* L.). With this idea in mind, an objective was created to evaluate vegetation indices (VI) using aerial imagery to determine correlations to yield (kg/ha) and crop quality parameters such as total sound mature kernels (TSMK), loose shelled kernels (LSK), other kernels (OK), sound splits (SS), and foreign material (FM). Aerial images, consisting of red (R), green (G), and near infrared (NIR) wavelength bands, were collected from three peanut fields in 2018 and 12 fields in 2019. In 2018 all fields were non-irrigated and in 2019 five fields were irrigated and seven fields were non-irrigated. Fields were separated into zones using the NIR image based on previous research in Australia and zones were harvested independently of each other. Yield and crop quality parameters were recorded for each of the 22 zones in 2018 and 46 zones in 2019. Images were then processed in ArcMap 10.5 to create 10 different VIs and mean pixel values for each zone were recorded for each VI. Yield was only significantly correlated to TSMK in 2018; showing that yield is not an indicator of crop quality parameters. A strong negative relationship was observed between TSMK and OK in all years and irrigation methods. There were no significant correlations to yield in 2019, however, green ratio VI and green normalized difference VI (GNDVI) both produced strong positive relationships with yield in 2018. The strongest correlation for TSMK was in 2018 and it was produced by GNDVI. Yield results show that VIs may not be the best method to estimate yield before peanuts are inverted. However, crop quality parameters had strong correlation to VIs. R produced the most significantly consistent correlations to LSK, though, in the 2019 irrigated zones GNDVI produced the strongest correlation for LSK. For OK, SS, and FM, the overall strongest correlation was produced in the 2019 irrigated zones. The strongest correlation for OK was produced by DVI, the strongest correlation for SS was produced by GNDVI, and the

strongest correlation for FM was produced by R. The results suggest that relationships between VIs and crop quality parameters may be better suited under irrigated conditions. This research was beneficial in understanding relationships between yield and crop quality parameters. Using the VIs with strong correlations to yield and crop quality parameters, a model can be created that can estimate peanut yield and quality before the crop has been harvested.

Introduction

In 2020 there were over 320,000 ha of peanut harvested in Georgia (NASS, 2020) making peanuts the fifth largest commodity in the state by area (UGA CAED, 2020). Georgia is the largest producer of peanuts in the United States growing approximately 42% of the nation's total peanuts (USDA NASS, 2021). In 2019, the farmgate value totaled over $650 million (UGA CAED, 2020). The average peanut yield across the state of Georgia is approximately 4600 kg/ha however the range of yields can be quite large (USDA NASS, 2021). This wide range in yields can be attributed to geographical location and environmental conditions as well as production methods such as planting date, irrigation method, and harvest timing.

Harvest timing (when to invert and harvest) is also important in maintaining high yields and quality. Not only can incorrectly assessing maturity cause economic losses to an individual grower, but it can cause economic losses to the peanut industry (Rowland et al., 2006). Peanut maturity can affect many factors such as yield, and crop quality (Fincher et al., 1980). Growers can also incur a loss due to crops being over mature. These crops can lose between 8% and 40% of pods during digging due to maturity issues (Young et al., 1982; Lamb et al., 2004). The original method to determine maturity was based on days after planting. Data on maturity evaluations in 1973 indicated that the optimum yield period occurred between 146-153 days after planting (Pearson et al., 1973). Much research was conducted over the next few years to improve upon this method of maturity determination. One of the oldest methods, still used today is the pod maturity profile or hull scape method developed by Williams and Drexler (1981).

Yield is the ultimate deciding factor in how much revenue a grower makes at the end of the season. However, the grade (overall quality) of the crop affects the revenue received for the crop. Grade is determined by the total of sound mature kernels (TSMK) that are in a sample.

TSMK is determined by sound mature kernels (SMK) plus sound splits (SS) minus any deductions. SMK are undamaged whole kernels while SS are undamaged split kernels or broken kernels. One of the deductions that a grower may face are undamaged kernels not in the shell, known as loose shelled kernels (LSK). Foreign material (FM) is anything that is not an in-shell peanut or loose kernel. This can include dirt, rocks, vines, sticks, insect parts, and hulls. Other kernels (OK) are smaller, less mature kernels and damaged kernels (DK) are kernels that are deemed inedible (American Peanut Council, 2020). All of these factors together create the grade of the crop which is a representation of the overall crop quality. With this knowledge, buying points could greatly benefit from a method that predicts yield and crop quality before the crop arrives at their facilities.

Many models have been developed to aid in grower and industry decisions. Industry and breeding programs have begun to use models to evaluate yield of peanut crops. One of the most widely used models in peanut is a crop simulation model, called CSM-CROPGRO Peanut Model, that predicts crop growth, development, and yield as a function of weather conditions, soil conditions, crop management, and cultivar coefficients (Amiri et al., 2015). This model can be found in the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al., 2003). From there, the model can be manipulated to be used in many aspects of peanut production. This model has been used to determine the response of peanut cultivars to soil moistures (Dangthaisong et al., 2006), quantify yield gaps (Naab et al., 2004), and determine the impact of different irrigation scenarios (Tojo Soler et al., 2013). This type of simulation model could be very beneficial in many areas of peanut production.

Another type of model useful to industry is a yield prediction model. Robson (2007) developed a yield model that has successfully been integrated into the Australian peanut industry. The use of aerial imagery has been beneficial in the creation of methods to predict peanut pod yield. Aerial IR images, collected two weeks prior to inversion, were correlated to pod yield using pixel brightness values. Satellite imagery was also correlated to pod yield using normalized difference vegetation index (NDVI). The aerial imagery correlations using IR were able to explain approximately 85% of the yield variability in a field. This strong correlation was attributed to the fact that greater IR values were commonly attributed to larger biomass of the plant and a plant under less stress. Therefore, these plants had the opportunity to yield more (Robson, 2007).

Therefore, the objective of this study was to examine vegetation indices using green (560 nm) (G), red (670 nm) (R), and near infrared (840 nm) (NIR) bands for their utility to correlate crop reflectance to peanut yield and crop quality parameters. The development of a model that accurately predicts yield and crop quality can be useful to industry in preparing for harvest.

Materials and Methods

In 2018 one grower was selected and in 2019 two growers were selected in Coffee County, Georgia to participate in the trial. In 2018 there were three fields used for analysis and in 2019 there were 14 fields used (Table 5.1). This created a total of 17 fields used across the two years. All fields were planted to the cultivar Georgia-06G (Branch, 2007) and both irrigated and non-irrigated fields were used for the study. However, in 2018 all three fields were non-irrigated. Planting dates for the fields varied from April 23rd to June 11th across the two years. Fields were inverted based on the pod maturity profile or hull scape method developed by Williams and Drexler (1981). Fields in 2018 were inverted between 145 and 149 DAP and in 2019 fields were inverted between 131 and 154 DAP. The difference in maturity was likely due to extremely dry environmental conditions in 2019. Information for each field such as year, field name, planting date, cultivar, irrigation method, flight date (DAP), inversion date (DAP) and number of zones created for each field can be found in Table 5.1.

Aerial images of each field were collected using a plane mounted camera prior to harvest. Flights across the two years ranged from 85 to 132 DAP. This range in flight dates is due to scheduling around weather events and cloud cover. The plane used in this study was a Cessna 206 (Textron Aviation, Inc., Wichita, KS) equipped with a Canon 6d (Canon U.S.A. Inc., Huntington, NY) modified to collected G, R, and NIR bands. Images were collected at a height of 760 m above ground level. This altitude resulted in images with a 10 cm resolution, 70% forward lap, and 70% side lap. Images were then stitched together using Pix4dmapper (Pix4D S.A., Switzerland). The resulting orthomosaic image could then be analyzed by wavelength (G, R, and NIR) as needed for analysis (Figure 5.1).

The orthomosaic of each field were then imported into ArcMap 10.5 (Environmental Systems Research Institute, Inc., Redlands, CA) where the NIR image was used to create zones in the fields. The NIR image was chosen based on research conducted by Robson (2007) that found NIR pixel values correlated the best to peanut pod yield in Australia. The NIR image was subjected to unsupervised classification to separate pixels into three groups – low, medium, and high – to aid in the creation of zones (Figure 5.2). Red denotes a smaller NIR pixel value while green denotes a higher NIR pixel value. Zones were created based on the NIR pixel values as well as the layout of the field and the harvest method. The zones were created in such a way that a grower could easily divide the field and harvest the areas independently. This process resulted in a total of 18 zones from the three fields in 2018 and 46 zones from the 12 fields in 2019. This method resulted in a total of 64 zones for analysis across the two years. Zones were harvested independently of each other to collect the following crop quality parameters: TSMK, SMK, SS, LSK, FM, and OK. Yield was also collected for each zone.

In ArcMap, 10 vegetation indices (VIs) were produced for each field using the orthomosaic images (Table 5.2). The images were then analyzed by zones using zonal statistics to record the mean pixel value for each VI. Pairwise correlations were performed using JMP Pro 15.0.0 (SAS Institute, Cary, NC) for each VIs mean pixel value versus the crop quality parameters and yield to identify relationships.

Results and Discussion

Crop quality parameters and yield are the most important information a grower receives on the crop at harvest. Results for all zones did not show strong correlations between yield and any of the crop quality parameters (Table 5.3). This result showed that not all high yielding areas of the field produced the highest quality peanuts. This could be due to the plant putting more energy into producing a large number of pods instead of the quality of the pods. Results also showed that there was a negative correlation between TSMK and OK. Therefore, as the percentage of mature kernels increases the percentage of small immature kernels (OK) would decrease.

When analyzing the relationship between VIs and yield, the only significant correlation to yield was G with a negative relationship (Table 5.3). This relationship was not very strong suggesting that yield may not be able to be estimated using VIs. This could be due to the fact that VIs are only able the assess the above-ground biomass of the plant which may not be an indicator of below-ground yield.

In examining the relationship of VIs to crop quality parameters NGVI had the strongest relationship to TSMK as well as OK (Table 5.3). Similar to yield, the strongest correlation to LSK was G. The strongest correlation of all the VIs was the relationship between FM and the GDVI.

Even though there are significant correlations in the combined data, the lack of strong correlations between crop quality parameters and VIs across all years and zones showed that a model would not be able to be used across all years and environmental conditions. One of the sources for the lack of strong correlations could be different environmental factors between years. Environmental factors in 2019 consisted of extremely hot and dry conditions which could cause a grower to decide to harvest earlier in 2019 when compared to 2018. This decision could have a direct impact on yield and maturity. Therefore, the low correlations could be related to maturity differences among the fields.

It is important to note that in 2018 environmental factors hindered harvest and the inverted peanuts sat on top of the soil for four weeks before they were harvested. Therefore, the data were further analyzed by year. Data analyzed in 2018, showed that there was a significant correlation between yield and TSMK (Table 5.4). However, this was not a very strong correlation as TSMK only accounted for 50% of the variation in yield. Once again showing that yield and quality of a crop are not the same. Like the combined analysis, there was again a strong correlation between TSMK and OK. There was an additional positive correlation between LSK and FM. This suggests that in 2018, as LKS increased the amount of FM also increased. Conditions that would encourage larger amounts of LSK are hot, dry conditions after inversion.

When the zones for 2018 were analyzed separately from 2019 there were many strong correlations between yield and crop quality parameters. The differences in physiological maturity in 2018 only ranged by five days (Table 5.1). This could be a reason for the improved correlations a result of the closer maturity. The strongest correlation for yield came from the GRatioVI and the GNDVI (Table 5.4). They both resulted in a strong positive correlation that accounted for 68% of the variation in yield. The GNDVI also produced the strongest correlation with TSMK and OK. This VI has been found to be very sensitive to chlorophyll concentration in the plant (Gitelson and Merzlyak, 1998). Since the correlation with TSMK is positive this could suggest that an increase in chlorophyll content in the plant results in an increase in crop quality. The strongest correlation to LSK came from R. Additionally, the were no VIs that were significantly correlated to SS or FM.

Analyses for 2019 were separated by irrigation method because of the possible variation in yield potential between non-irrigated and irrigated fields. Yield was not significantly correlated to other crop quality parameters for either irrigation method (Table 5.5 & 5.6). This, again, proved that yield and quality of the pods are not indicators of each other. For both irrigation methods, TSMK had a significant negative correlation to OK. This correlation is consistent across all scenarios proving that as TSMK increased OK decreased. Like 2018, correlations between other crop quality parameters show that LSK was positively correlated to SS and FM for both irrigation methods. This shows that as LSK increased SS and FM also increased. The crop quality parameters SS and FM were also significantly correlated in both non-irrigated and irrigated zones. These are all parameters that lower the quality of the crop and are often influenced by prolonged harvest periods as brought on by environmental conditions. Therefore, it is reasonable that as one increases, they all increase.

There were many more significantly correlated VIs to crop quality parameters in the irrigated fields than the non-irrigated fields (Table 5.6 & 5.7). There were no VIs that were significantly correlated to yield for either irrigation method showing, once again, that aerial imagery is not a good indication of below-ground yield. For the non-irrigated zones there were no VIs that were significantly correlated to TSMK, OK, or SS. The only significant correlations were for LSK and FM. The strongest significant correlation to LSK for the non-irrigated zones was produced by R while the strongest correlation to FM was produced by the GDVI. Since non-irrigated fields are more prone to hot, dry conditions they are more likely to have more LSK and SS. For the irrigated zones, DVI produced the strongest correlation to TSMK. This VI also yielded a strong significant relationship with OK. DVI has been shown to be sensitive to the amount of vegetation a plant has. This could suggest that peanut plants with greater amounts of vegetation produce higher quality pods. GNDVI produced a very strong relationship with LSK and SS, and R yielded a strong significant relationship with FM.

Conclusions

Results of this study show that the use of VIs to predict yield are not very conclusive. The poor result of this model is likely due to variations between environmental factors and management strategies on yield potential. A model for predicting this attribute would need to be dynamic and consider environmental changes over years, locations, and production methods. It would also be important to assess the maturity of the crop in this prediction model. Therefore, further research is needed to assess maturity of the crop at harvest as it relates to correlations between yield and VIs.

This research also indicated that yield and crop quality parameters are not always correlated. For examples, yield was only significantly correlated to TSMK in 2018. Therefore, yield may not be an indicator of quality in a peanut crop. However, there were significant relationships observed between the crop quality parameters. A strong negative relationship was observed between TSMK and OK in all years and irrigation methods.

Unlike yield, above-ground biomass as assessed by aerial imagery, provided a better indicator for crop quality parameters as observed by the strong correlations to VIs. GNDVI provided the strongest and most consistent correlations with crop quality parameters. Overall, the best correlations came from zones within irrigated fields. These results suggest that crop quality parameters can be more accurately predicted in irrigated fields due to the reduction of environmental stresses. Although there is a need of more research in the use of VIs for aerial estimations, this research did prove there is some utility in using aerial imagery in illustrating the variability of these crop quality parameters in peanut fields.

Figures

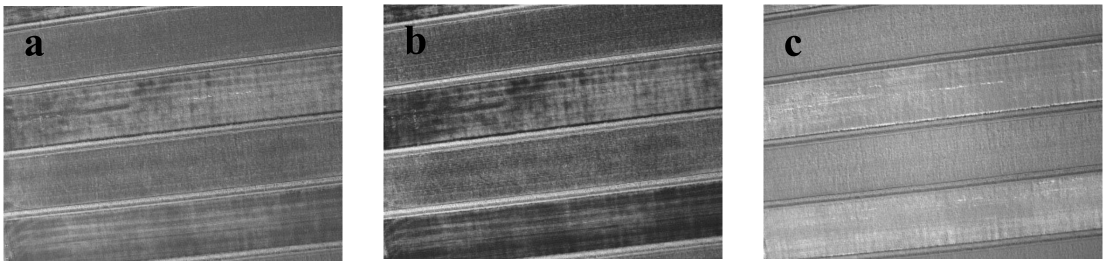

Figure 5.1: Example of green (a), red (b), and near infrared (c) bands derived from whole field orthomosaic images.

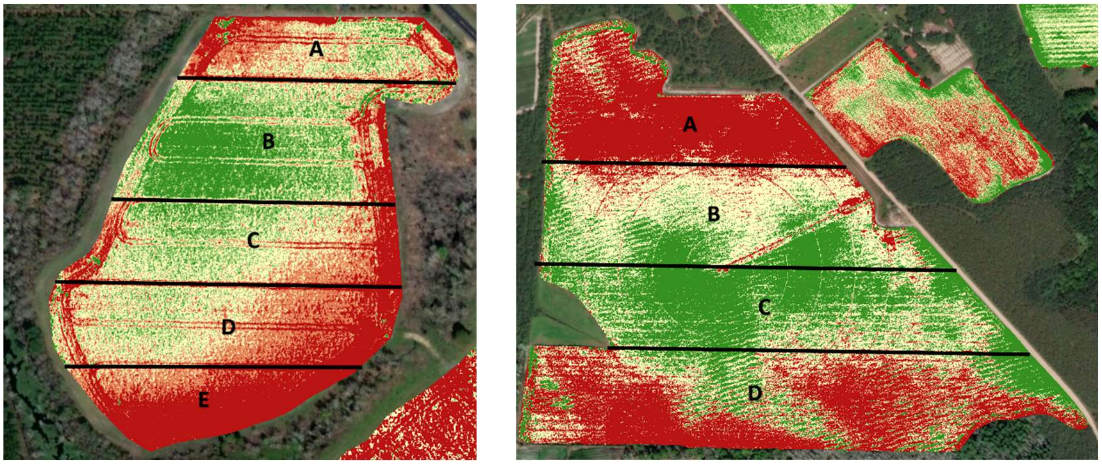

Figure 5.2: Example of zones created from near infrared (NIR) images for peanut harvest in Coffee County, Georgia in 2018 and 2019. Red denotes a smaller NIR pixel value while green denotes a larger NIR pixel value.

Tables

Table 5.1. Year, field name, planting date, cultivar, irrigation method, flight date, inversion date, and number of zones for each on-farm peanut trial conducted in Coffee County, Georgia in 2018 and 2019.

Year	Field Name	Planting Date	Cultivar	Irrigation	Flight Date (DAP[a])	Inversion Date (DAP)	# of Zones
2018	Farm 409	June 5	Georgia-06G	Non-irrigated	132	149	4
2018	Hersey	June 9	Georgia-06G	Non-irrigated	128	146	6
2018	Blaelock	June 11	Georgia-06G	Non-irrigated	125	145	8
2019	Gerald's	April 23	Georgia-06G	Non-irrigated	107	147	5
2019	Burl's	April 24	Georgia-06G	Non-irrigated	106	139	3
2019	Johnny White	April 25	Georgia-06G	Non-irrigated	105	154	3
2019	Marvin's	April 27	Georgia-06G	Non-irrigated	103	152	5
2019	Ms. Lott	April 29	Georgia-06G	Irrigated	101	141	1
2019	Barton 8' Well	April 30	Georgia-06G	Irrigated	100	134	3
2019	Lott Pivot	May 1	Georgia-06G	Irrigated	99	139	3
2019	Highway	May 2	Georgia-06G	Non-irrigated	98	135	2
2019	Bubbas House	May 2	Georgia-06G	Non-irrigated	98	142	3
2019	Guthrie	May 3	Georgia-06G	Irrigated	97	136	5
2019	Pack House	May 3	Georgia-06G	Non-irrigated	97	143	3
2019	Big Field	May 4	Georgia-06G	Irrigated	96	131	4
2019	EH	May 4	Georgia-06G	Non-irrigated	96	135	4
2019	Nugent	May 15	Georgia-06G	Non-irrigated	85	135	2

[a]DAP = days after planting

Table 5.2. Vegetation indices and their formula for aerial imagery.

Vegetation Index[a]	Abbreviation	Formula[b]
Difference VI	DVI	NIR-R
Green Difference VI	GDVI	NIR-G
Green Normalized Difference VI	GNDVI	(NIR-G)/(NIR+G)
Green Ratio VI	GRatioVI	NIR/G
Normalized Difference VI	NDVI	(NIR-R)/(NIR+R)
Normalized Green	NGVI	G/(NIR+R+G)
Normalized Near Infrared	NNIRVI	NIR/(NIR+R+G)
Normalized Red	NRVI	R/(NIR+R+G)
Optimized Soil Adjusted VI	OSAVI	(NIR-R)/(NIR+R+0.16)
Ratio VI	RatioVI	NIR/R

[a]VI = Vegetation Index

[b]G = Green band, R = Red band, NIR = Near infrared band

Table 5.3. Pairwise correlation coefficients for yield, crop quality parameters, and mean pixel value for vegetation indices for all on-farm peanut trials conducted in Coffee County, Georgia across 2018 and 2019.

	Yield	TSMK	LSK	OK	SS	FM
Yield	1					
TSMK	0.24	1				
LSK	0.19	0.36 **	1			
OK	-0.18	-0.77 **	-0.19	1		
SS	-0.04	0.23	0.39 **	-0.12	1	
FM	0.00	-0.20	0.34 **	0.27 *	0.25	1
Mean R	-0.02	0.34 **	-0.15	-0.29 *	-0.10	-0.47 **
Mean G	-0.32 *	-0.23	-0.40 **	0.08	-0.12	-0.19
Mean NIR	-0.13	0.18	-0.21	-0.20	-0.11	-0.45 **
Mean DVI	-0.16	-0.46 **	0.02	0.34 **	0.05	0.35 **
Mean RatioVI	-0.22	-0.38 **	0.05	0.28 *	0.17	0.28 *
Mean NDVI	-0.16	-0.33 **	-0.05	0.25 *	0.09	0.25 *
Mean NRVI	0.24	0.46 **	0.08	-0.33 **	-0.12	-0.34 **
Mean GDVI	0.05	0.43 **	0.10	.0.33 **	-0.04	-0.49 **
Mean GRatioVI	0.03	0.24	0.36 **	-0.18	0.07	-0.18
Mean GNDVI	-0.02	-0.20	-0.19	0.11	-0.21	-0.23
Mean NGVI	-0.21	-0.48 **	-0.13	0.35 **	0.11	0.42 **
Mean NNIRVI	-0.03	0.05	-0.10	-0.0	-0.21	-0.28 *
Mean OSAVI	-0.25	-0.39 **	0.01	0.27 *	0.15	0.26 *

[a]Abbreviations: TSMK = total sound mature kernels; LSK = loose shelled kernels; OK = other kernels; SS = sound splits; FM = foreign material; VI = vegetation index; R = red band; G = green band; NIR = near infrared band; DVI = difference VI; NDVI = normalized difference VI; NRVI = normalized R VI; GDVI = G difference VI; GRatioVI = G ratio VI; GNDVI = G normalized difference VI; NGVI = normalized G VI; NNIRVI = normalized NIR VI; OSAVI = optimized soil adjusted VI
[b]* indicates correlation coefficient is significant at $P < 0.05$, ** indicates correlation coefficient is significant at $P < 0.01$

Table 5.4. Pairwise correlation coefficients for yield, crop quality parameters, and mean pixel value for vegetation indices for all on-farm peanut trials conducted in Coffee County, Georgia in 2018.

	Yield	TSMK	LSK	OK	SS	FM
Yield	1					
TSMK	0.50 *	1				
LSK	0.15	0.43	1			
OK	-0.43	-0.75 **	-0.32	1		
SS	-0.17	0.09	-0.31	-0.18	1	
FM	-0.46	0.19	0.62 **	0.01	-0.18	1
Mean R	-0.43	-0.46	-0.67 **	0.35	0.43	-0.18
Mean G	-0.62 **	-0.66 **	-0.60 **	0.43	0.42	0.43
Mean NIR	-0.59 **	-0.64 **	-0.61 **	0.41	0.44	0.42
Mean DVI	-0.10	-0.12	0.36	-0.04	-0.16	-0.16
Mean RatioVI	-0.18	-0.23	0.10	-0.00	0.07	0.07
Mean NDVI	-0.24	-0.30	0.02	0.03	0.09	0.09
Mean NRVI	0.32	0.37	0.06	0.08	-0.13	-0.13
Mean GDVI	-0.52 **	-0.57 *	-0.65 **	0.34	0.46	0.46
Mean GRatioVI	0.68 **	0.69 **	0.51 *	-0.47 *	-0.30	-0.30
Mean GNDVI	0.68 **	0.70 **	0.50 *	-0.49 *	-0.30	-0.30
Mean NGVI	-0.49 *	-0.54 *	-0.20	0.23	0.19	0.19
Mean NNIRVI	-0.16	-0.21	0.06	-0.05	0.06	0.06
Mean OSAVI	-0.24	-0.30	0.02	0.03	0.09	0.09

[a]Abbreviations: TSMK = total sound mature kernels; LSK = loose shelled kernels; OK = other kernels; SS = sound splits; FM = foreign material; VI = vegetation index; R = red band; G = green band; NIR = near infrared band; DVI = difference VI; NDVI = normalized difference VI; NRVI = normalized R VI; GDVI = G difference VI; GRatioVI = G ratio VI; GNDVI = G normalized difference VI; NGVI = normalized G VI; NNIRVI = normalized NIR VI; OSAVI = optimized soil adjusted VI

[b]* indicates correlation coefficient is significant at $P < 0.05$, ** indicates correlation coefficient is significant at $P < 0.01$

Table 5.5. Pairwise correlation coefficients for yield, crop quality parameters, and mean pixel value for vegetation indices for all on-farm peanut trials conducted on non-irrigated fields in Coffee County, Georgia in 2019.

	Yield	TSMK	LSK	OK	SS	FM
Yield	1					
TSMK	-0.07	1				
LSK	0.26	0.05	1			
OK	0.04	-0.68 **	0.09	1		
SS	-0.16	0.37 *	0.49 **	-0.09	1	
FM	0.29	-0.05	0.71 **	0.12	0.46 *	1
Mean R	-0.12	0.11	-0.51 **	-0.13	-0.21	-0.35
Mean G	-0.22	-0.04	-0.32	-0.13	-0.09	-0.11
Mean NIR	-0.17	0.02	-0.50 **	-0.12	-0.23	-0.33
Mean DVI	0.01	-0.18	0.38 *	0.11	0.12	0.28
Mean RatioVI	-0.14	-0.10	0.25	0.06	0.16	0.17
Mean NDVI	-0.11	-0.07	0.14	-0.02	0.13	0.11
Mean NRVI	0.11	0.07	-0.31	-0.02	-0.22	-0.26
Mean GDVI	-0.06	0.08	-0.48 **	-0.06	-0.29	-0.41 *
Mean GRatioVI	0.00	0.04	-0.45 *	-0.03	-0.31	-0.39 *
Mean GNDVI	0.05	-0.18	-0.23	0.11	-0.29	-0.34 *
Mean NGVI	-0.09	-0.04	0.36	0.01	0.28	0.32
Mean NNIRVI	-0.11	-0.14	-0.06	0.06	-0.15	-0.11
Mean OSAVI	-0.13	-0.09	0.25	0.03	0.16	0.19

[a]Abbreviations: TSMK = total sound mature kernels; LSK = loose shelled kernels; OK = other kernels; SS = sound splits; FM = foreign material; VI = vegetation index; R = red band; G = green band; NIR = near infrared band; DVI = difference VI; NDVI = normalized difference VI; NRVI = normalized R VI; GDVI = G difference VI; GRatioVI = G ratio VI; GNDVI = G normalized difference VI; NGVI = normalized G VI; NNIRVI = normalized NIR VI; OSAVI = optimized soil adjusted VI

[b]* indicates correlation coefficient is significant at $P < 0.05$, ** indicates correlation coefficient is significant at $P < 0.01$

Table 5.6. Pairwise correlation coefficients for yield, crop quality parameters, and mean pixel value for vegetation indices for all on-farm peanut trials conducted on irrigated fields in Coffee County, Georgia in 2019.

	Yield	TSMK	LSK	OK	SS	FM
Yield	1					
TSMK	0.43	1				
LSK	0.02	-0.31	1			
OK	-0.39	-0.91 **	0.36	1		
SS	0.16	-0.30	0.79 **	0.22	1	
FM	-0.05	-0.45	0.59 *	-0.48	0.63 **	1
Mean R	-0.11	0.43	-0.72 **	-0.50 *	-0.87 **	-0.74 **
Mean G	-0.38	-0.12	-0.40	-0.01	-0.35	-0.48
Mean NIR	-0.26	0.21	-0.72 **	-0.32	-0.75 **	-0.71 **
Mean DVI	-0.21	-0.61 *	0.59 *	0.59 *	0.67 **	0.42
Mean RatioVI	-0.27	-0.54 *	0.62 *	0.49	0.66 **	0.39
Mean NDVI	-0.09	-0.24	0.49	0.37	0.40	0.34
Mean NRVI	0.30	0.58 *	-0.61 *	-0.53 *	-0.67 **	-0.39
Mean GDVI	-0.13	0.25	-0.85 **	-0.33	-0.88 **	-0.73 **
Mean GRatioVI	-0.04	-0.41	0.13	0.35	-0.01	0.21
Mean GNDVI	0.09	0.38	-0.89 **	-0.43	-0.89 **	-0.65 **
Mean NGVI	-0.22	-0.52 *	0.79 **	0.52 *	0.82 **	0.54 *
Mean NNIRVI	0.05	-0.17	-0.71 **	0.16	-0.60 *	-0.36
Mean OSAVI	-0.32	-0.57 *	0.52 *	0.51 *	0.58 *	0.31

[a]Abbreviations: TSMK = total sound mature kernels; LSK = loose shelled kernels; OK = other kernels; SS = sound splits; FM = foreign material; VI = vegetation index; R = red band; G = green band; NIR = near infrared band; DVI = difference VI; NDVI = normalized difference VI; NRVI = normalized R VI; GDVI = G difference VI; GRatioVI = G ratio VI; GNDVI = G normalized difference VI; NGVI = normalized G VI; NNIRVI = normalized NIR VI; OSAVI = optimized soil adjusted VI
[b]* indicates correlation coefficient is significant at $P < 0.05$, ** indicates correlation coefficient is significant at $P < 0.01$

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CHAPTER VI

EFFECT OF PROHEXADIONE CALCIUM ON PEANUT (*ARACHIS HYPOGAEA* L.) GROWTH AND PHOTOSYNTHETIC EFFICIENCY

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Abstract

Prohexadione calcium is a plant growth regulator (PGR) used in peanut (*Arachis hypogaeae* L.) to reduce excessive vine growth. The use of this PGR has been proven to reduce main-stem height and increase yields and grade in large on-farm trials. While extensive research has been done on the effect of prohexadione calcium on yield and grade, the effects of prohexadione calcium on peanut physiology has not been studied. Therefore, the objective was to assess the effect of prohexadione on whole plant growth, pigment content, leaf fluorescence, nutrients, and maturity in peanut. This trial was conducted over 2018 and 2019 and consisted of a non-treated control along with a 0.50x rate, 0.75x rate, and 1.0x rate of prohexadione calcium applied twice during the season. The first application was performed when 50% of lateral vines were overlapping and followed by a second application 14 days later. Results showed that main stem heights and internode length were significantly reduced in the 0.75x rate compared to the non-treated control in 2019. Pigment contents and soil plant analytical development (SPAD) chlorophyll meter readings (SCMR) were significantly greater for the 0.75x rate than the non-treated control in later sampling dates in 2019. Fluorescence was decreased in the 0.75x rate when compared to the non-treated control for sampling dates in 2018. The percentage of calcium in the foliage was also significantly increased in the 1.0x rate of prohexadione when compared to the non-treated control. Maturity was also observed to be hastened in prohexadione calcium treatments. Overall, prohexadione calcium application had a positive impact on physiological processes associated with the leaf photosynthetic apparatus as well as on pod maturity in runner-type peanut.

Introduction

Plant growth regulators (PGRs) are compounds, either naturally occurring or synthetic, that have been proven to affect development or metabolic processes of plants (Rademacher, 2015). PGRs are generally “applied directly to a target plant to alter its life processes or its structure to improve quality, increase yields, or facilitate harvest” nutrition (Nickell, 1982). Some of the most common PGRs used in agriculture are auxins – compounds that cause enlargement of cells, gibberellins – compounds that stimulate cell division, cell enlargement, or both, and cytokinins – which are compounds that stimulate cell division in plants. Response to PGRs can vary depending on many factors. The biggest of these factors that determines response is the plant species. However, even one cultivar within a plant species can show varied response to a PGR based on its age at treatment, environmental conditions, physiological stage of development, and nutrition status (Nickell, 1982).

Prohexadione calcium [calcium salt of 3,5-dioxo-4 propionylcyclohexanecarboxylic acid] (Apogee 27.5 WDG, , BASF Corp., 26 David Dr., Research Triangle Park, NC 27709 or Kudos 27.5 WDG, Fine-Americas, 1850 Mt. Diablo Blvd., Walnut Creek, CA 94596), is a PGR widely used in apple (*Malus pumilia*), grain sorghum (*Sorghum bicolor* (L.) Moench), oilseed rape (*Brassica napus* L.), peanuts (*Arachis hypogaea* L.), rice (*Oryza sativa* L.), tomato (*Solanum lycopersicum*), and wheat (*Triticum aestivum* L.) to slow down vegetative growth (Yamaji et al., 1991; Nakayama et al., 1992; Grossman et al., 1994; Lee et al., 1998; Byers and Yoder, 1999). Prohexadione calcium inhibits the biosynthesis of gibberellin by blocking kaurene oxidase. As a result of that inhibition, the level of abscisic acid and cytokines is increased (Grossman et al., 1994).

There are many different forms of the naturally occurring hormone gibberellin – in 1990 there were 84 different forms that had been discovered in various fungi or plants – but all are named GA with a different subscript to distinguish them. GAs have many different roles in plants. Overall, GA is known to stimulate plant growth and development and has been demonstrated to stimulate seed germination, trigger transitions from meristem to shoot growth, juvenile to adult leaf stage, vegetative to flowering, determines sex expression and grain development along with an interaction of different environmental factors including light, temperature and water (Hooley 1994, Swain and Olszewski, 1996). The major site of bioactive GA is stamens that influence male flower production and pedicel growth. In peanuts, GA has been proven to regulate cell elongation. In turn, plants that are GA deficient tend to be dwarfed (Culpepper, et al., 1997; Jordan, et al., 2000).

Prohexadione calcium has been used in virginia market type peanuts for many years to reduce excessive vine growth and with the introduction of runner market type cultivars in recent years with more vine growth, prohexadione calcium has become the focus of extensive research (Studstill et al., 2020). Initial research studies on prohexadione calcium in peanut showed a reduction in main-stem height of 32% over the non-treated control (Mitchem et al, 1996). This reduction in vegetative growth was found to be similar to previously used synthetic growth regulators like daminozole. The study also showed that prohexadione calcium improved yield by 8% and increased the percentage of extra-large kernels without having an impact on the percentage of fancy pods and total sound mature kernels. It was also discovered that prohexadione calcium hastens pod maturity when applied at row closure (Mitchem et al., 1996). Additionally, prohexadione calcium was reported to reduce digging losses by as much as 4%. This is likely due to the lack of excessive vine growth (Beam et al., 2002).

The effect of prohexadione calcium on yield and grade has been vastly studied in peanut. However, the effect of prohexadione calcium on plant growth and photosynthetic efficiency of peanut plants has not been thoroughly investigated. Therefore, the objective of this study was to evaluate the changes in growth and accumulation of photosynthetic pigments in peanut with application of prohexadione calcium.

Materials and Methods

Plant material and experimental layout

A two-year field experiment was conducted during the growing seasons in 2018 and 2019. In 2018, a trial was conducted at the University of Georgia, Coastal Plain Experiment Station, Ponder Farm using the runner market-type peanut cultivar Georgia-12Y (Branch, 2013). The trial was planted on June 6 in four replications to a randomized complete block design. Plots consisted of two rows that were 9.14 m long spaced 0.91 m apart with a two border rows separating plots. In 2019, a field trial was conducted at the Abraham Baldwin Agricultural College, J. G. Woodruff Research Farm using the cultivar Georgia-12Y. The trial was planted on May 21 to a randomized complete block design consisting of 4 replications. Plots were composed of two rows 152.4 m long rows spaced 0.91 m apart. There were also two border rows between each plot. In both trials, peanut was planted at rates to achieve a final in-row plant population of 13.1 to 16.4 plants/m and production management decisions were made based on the University of Georgia's Extension Service recommendations (Monfort et al., 2020).

Prohexadione calcium treatments evaluated in both experiments were the manufacturer's recommended use rate of 140 g/ha (1.0x), and reduced rates of 105 g/ha (0.75x), and 70 g/ha (0.5x). A non-treated control was also included in both experiments. As per label directions, crop oil concentrate, (Agri-Dex, 83% paraffin-based petroleum oil and 17% surfactant, Helena Chemical Co., 5100 Poplar Ave., Memphis, TN 38137) was applied at 2.3 L/ha and 28% urea ammonium nitrate was applied at 1.2 L/ha with prohexadione calcium applications. Prohexadione calcium was applied in 140 to 233 L/ha water. Prohexadione calcium treatments were initiated when at least 50% lateral vines from adjacent rows were touching with a second application performed 14 days later (Table 6.1).

In 2018, plots were inverted on October 30 and harvested on November 19. In 2019, plots were inverted October 17 and harvested October 23. Peanut plants in each plot were dug and inverted based on maturity profile method (pod mesocarp color) (Williams and Drexler, 1981). Plants were allowed to dry in windrows for 3 to 7 days depending on weather and harvested mechanically. Pod yield was assessed at harvest and final pod weight was adjusted to 7% moisture. After harvest grade was assessed and total sound mature kernels (TSMK) was recorded.

Measurements and sampling protocol

Whole plant growth. Whole plants (not including tissues below the cotyledons) from a total of 0.5 m were destructively sampled from the non-treated control and the 0.75x rate treatment for three reps in both years. The first growth analysis was recorded right before the first prohexadione calcium application with the second data collection seven days after application. The third data collection was right before the second prohexadione calcium application and the fourth growth analysis was conducted seven days after application. Plants were placed in a large plastic bag and stored in a cooler for further growth analysis. The number of plants in the 0.5 m length was recorded for each plot. The roots were removed from each plant along with any pods that were developing. Plant height was then recorded from the base of the plant to the terminal for each plant along with the number of internodes. Plants were then stripped of leaves and total leaf area per plant (cm^2) was measured using a LI-3100 tabletop leaf area meter (LI-COR, Lincoln, NE, USA). Plant stems and leaves were then dried and weighed to provide a whole plant dry weight. Values for crop growth rate (CGR), net assimilation rate (NAR), and leaf are index (LAI) were calculated in 2018 using values from the first sampling date and the last sampling date and in 2019 using values from the first sampling date and the third sampling date.

In 2018, at the time of plant collection for growth analysis, samples for pigment content and leaf fluorescence were collected for the non-treated control and the prohexadione calcium - 0.75x rate treatments. Nutrient analyses samples were also collected on the second growth analysis sample date. In 2019, samples for pigment content, leaf fluorescence, and nutrient analyses were collected at the time of all growth analyses sampling dates. In 2019, relative pigment content was also measured in the field at all growth analyses collection dates.

Pigment content. Pigment analysis was conducted by placing four leaf discs (6 mm in diameter) in amber vials containing 5 ml of a 96% ethanol solution. The vials were transferred to the laboratory where they were stored for two weeks at 4 °C. After two weeks the supernatants were used for extraction of pigments. Absorbance was measured at 470, 649, and 665 nm wavelengths using a multi-well plate reader (Synergy HTX, BioTek, Winooski, VT, USA). The contents of chlorophyll *a*, *b*, and carotenoids were determined according to the equations given in Lichtenthaler and Wellburn (1983). The contents of all pigments assessed were expressed as $\mu g\ cm^{-2}$. Soil plant analytical development (SPAD) chlorophyll meter readings (SCMR) were also collected in 2019 on all plots to determine relative chlorophyll content (SPAD-502, Konica Minolta Optics Inc., Japan). This measurement was collected in the field at the time of growth analysis sampling. Measurements were collected from 10 random leaves in the upper canopy of each plot.

Fluorescence measurement. OJIP fluorescence measurements needed to be conducted in a dark-adapted state. Therefore, samples were collected by placing two leaves from each plot in a plastic bag with a damp paper towel. Samples were then placed in a box and acclimated to darkness for 24 hrs when the readings were taken. Readings were collected in the dark using a portable fluorometer (OS5p+; Opti-Sciences Inc., Hudson, NH, USA) with full OJIP capabilities and using protocols and calculations according to Strasser et al. (2004). OJIP fluorescence was used to calculate parameters related to quantum efficiencies, including Φ_{Po} (maximum quantum yield of energy trapping by PSII), Φ_{Eo} (quantum yield of intersystem electron transport), and Φ_{Ro} (quantum yield of PSI end electron acceptor reduction). Further the parameter ΔV_{IP} was also calculated to analyze the PSI reaction center content.

Nutrient analyses. Plant tissue analysis samples were collected for all plots by randomly selecting leaves in the upper canopy of each plot and analyzed for nutrient content at Southeastern Agricultural Laboratories, Inc (Barney, GA, USA). Analyses results consisted of total Nitrogen (%), Phosphorus (%), Potassium (%), Magnesium (%), Calcium (%), Sulfur (%), Boron (ppm), Zinc (ppm), Iron (ppm) and Copper (ppm) in the foliage using nitric/perchloric digestion.

Maturity and peg strength. Peanut plants in each plot were dug and inverted based on maturity profile method (pod mesocarp color) (Williams and Drexler, 1981). At digging, a minimum of five plants were selected from all plots to be used for maturity assessment and peg strength. For peg strength, 10 pods, closest to the mainstem, were removed from each plant before maturity assessment. The pod was placed in a clamp and the peg was removed from the pod using an electronic force gauge (Imada, Inc. Model DS2-11, Northbrook, IL, www.imada.com). Peg strength was recorded in Newtons for the 50 pods and an average peg strength was determined for the whole plot. Those pods were then placed with the original samples and used for maturity assessment. Maturity of the pods was determined using the maturity profile method (pod mesocarp color). Based on mesophyll color, pods were classified as a percentage of pods that were 1 wk from harvest (1WFH), 2 wk from harvest (2WFH), 3 wk from harvest (3WFH), and 4 wk from harvest (4WFH).

Statistical Analyses

Analysis of variance was conducted using JMP Pro 15.0.0 (SAS Institute, Cary, NC). Treatments were considered as fixed effects and data from both years were analyzed separately due to differences between years. Replication was considered a random effect. Appropriate means were separated using Tukey-Kramer HSD set at 0.05 probability level.

Results and Discussion

Whole plant growth was assessed by measuring main-stem height, number of main-stem internodes, internode length, dry stem weight, dry leaf weight, and total dry weight. A significant difference for mainstem height was observed in 2019 for sample dates (SD) 3 and 4 (Table 6.2). At both SDs the non-treated control had significantly greater mainstem heights of 48.20 cm and 52.10 cm in 2018 and 2019, respectively, compared to the 0.75x rate of prohexadione calcium, which produced main stem heights of 36.25 cm and 39.43 cm in 2018 and 2019, respectively. This resulted in a 24.8% and 24.3% reduction in mainstem height. This supports the findings of Studstill et al. (2020) that found the non-treated check in large on-farm trials of peanut had significantly greater main-stem than any rate of prohexadione calcium. A significant difference was also observed for internode length at SD4 in 2019. The internodes in the non-treated control were significantly longer than the internodes of the 0.75x treatments by 23.0%. Physiologically, these findings support original research that showed that prohexadione calcium inhibits the biosynthesis of gibberellin which in turn inhibits cell elongation in the plant (Mitchem *et al*, 1996). The lack of other significant differences across other whole plant growth parameters indicates that prohexadione calcium does not reduce the amount of plant foliage; however, it shortens the plant and produces a more compact growth habit.

Crop growth analysis for both years included CGR, NAR, and LAI (Table 6.3). There were no significant differences between treatments for any year for crop growth analysis. CGR, the amount of dry matter the plant puts on per day in a given area, varied greatly across the two years. There was a 10.7% decrease in 2018 and a 26.0% decrease in 2019 between the untreated control and the 0.75x rate for CGR. This wide range in values is likely due to different amounts of rainfall in both years. For all three of the crop growth parameters values in 2019 were greater than values in 2018 once again indicating that environmental conditions, such as rainfall and irrigation received and disease pressure, in both years varied.

The results of nutrient analysis only show a significant difference between treatments for the percentage of calcium in the foliage of the plant (Table 6.4). This difference was found in 2019 at SD4, 7 days after the second application of prohexadione calcium. The amount of calcium found in the foliage of the non-treated control was 2.01% compared to 2.87% in the 1.0x rate. Since prohexadione calcium is a calcium salt of 3,5-dioxo-4 propionylcyclohexanecarboxylic acid, this could explain the increase of calcium in the foliage.

Values for SCMR showed similar results. Observations collected in the field in 2019 showed significant differences in the relative amount of chlorophyll at the third and fourth sampling dates (Table 6.5). The non-treated control had a significantly lower relative chlorophyll content at than any of the prohexadione calcium treatments. At the last sample date (SD4), the non-treated control plots indicated SCMR values 30.0% lower than those in plots treated with prohexadione calcium at 1.0x rate. A greater value for SCMR suggests a greater chlorophyll content in the leaf. Since there was not an increase in foliage the pigment results suggest that prohexadione calcium contributes to the synthesis of photosynthetic pigments. This supports results that showed that prohexadione calcium increased the accumulation of photosynthetic pigments in rice seedlings (Pal and Thind, 2019).

Results showed that there were no significant differences for pigment content collected in 2018 (Table 6.6). However, in 2019 there was a difference in chlorophyll a, chlorophyll b, and carotenoid content between treatments after SD3. For all three pigments the non-treated control had significantly lower pigment content. For chlorophyll *a* content, there was a 20.8% at SD3 and a 23.5% decrease at SD4 between the 0.75x rate and the untreated control. For chlorophyll *b* content, a significant difference was only observed at SD3. The treatment mean for the non-treated control was significantly lower at 0.40 $\mu g/cm^2$ than the 0.75x rate prohexadione calcium treatment at 2.68 $\mu g/cm^2$. Similar to chlorophyll *a*, carotenoid content was significantly lower in the non-treated control plots than those treated with prohexadione calcium at 0.75x rate at both SD3 and 4. At SD 3 the non-treated control had a carotenoid content of 5.9 $\mu g/cm^2$ compared to 7.2 $\mu g/cm^2$ for the 0.75x rate and at SD4 the non-treated control had a carotenoid content of 4.58 $\mu g/cm^2$ compared to 5.75 $\mu g/cm^2$ for the 0.75x rate.

Significant differences in fluorescence were only observed in 2018 (Table 6.7). For the four parameters selected the non-treated control had a greater value than the 0.75x rate of prohexadione calcium. Significant differences in Φ_{Po} were recorded at SD3. The non-treated control had a greater value of 0.86 than the 0.75x rate which had a value of 0.85. The significant difference for Φ_{Eo}, Φ_{Ro}, and ΔV_{IP} were all observed at SD4, 7 days after the second application. For Φ_{Eo} the value for the non-treated control was 0.74 while the value for the 0.75x rate had a value of 0.72. For Φ_{Ro} the non-treated control produced a treatment mean of 0.49 while the 0.75x produced a value of 0.47. The non-treated control also had a value of 0.57 for ΔV_{IP} while the 0.75x treatment had a value of 0.54. These results suggest that prohexadione calcium may slightly decrease the efficiency of the thylakoid reactions of the photosynthetic process, decreasing the ability of PSII to trap light, reduces the quantum yield of electron transport between PSII and PSI, decreases the reduction of PSI and electron acceptors as well as PSI content. Due to the fact that there was an observed increase in pigment content, this decrease in efficiency of the thylakoid reactions may not affect the photosynthetic process negatively. The plant, therefore, has more pigments with slightly lower efficiency in the thylakoid reactions. This could be the reason that prohexadione calcium does not affect plant growth negatively other than internode length and mainstem height which is expected by inhibiting gibberellin synthesis.

Harvest data collected for maturity showed significant differences in 2018 only (Table 6.8). The significant differences were seen in the categories 3WFH and 4WFH. The 1.0x rate of prohexadione calcium had a significantly greater percentage of pods in the 3WFH class at 58.18% than the 0.75x rate with 32.35%. In the 4WFH class the 0.75x rate had a significantly greater value with 40.57% than the 1.0x rate with 20.86%. These results show that the 1.0x rate of prohexadione calcium hastens pod maturity when compared to the 0.75x rate. However, the 1.0x rate was not significantly different than the non-treated control or the 0.50x rate. Mitchem et al. (1996) found variable effects on pod maturity by year and location when prohexadione calcium was applied. However, peg strength was not affected by the prohexadione calcium treatments. Values across both years ranged from 5.41 N to 7.45 N showing that peg strength did not vary greatly between years or treatments.

Treatment had no effect on peanut pod yield or TSMK in either year. This is similar to results by Studstill et al. (2020), in which the authors found that small-plot trials do not show significant yield differences between prohexadione calcium rates. In 2018, yield means ranged from 3371 kg/ha to 3578 kg/ha. There were also no significant differences for TSMK for any trial with small range in grades from 73.3 to 77.0 over the two years.

Conclusions

It is concluded that while the effect of prohexadione calcium on yield and grade are not observed in small plot trials, the physiological effects can be observed. Prohexadione calcium is known to inhibit the biosynthesis of gibberellin in turn reducing cell elongation. Mainstem heights were decreased by prohexadione calcium treatments. However, biomass did not decrease proving that the foliage is not affected by the PGR. Results also prove that differences in pigment content, fluorescence, and maturity can be seen after applications of prohexadione calcium. While the trial shows that prohexadione calcium treatments increase the pigment content in the plant it also proves that fluorescence is decreased in the plant. The trial also validates that a full rate application of prohexadione calcium hastens maturity compared to a reduced rate. Results indicate that prohexadione calcium can be beneficial in creating a more compact plant structure without compromising the yield and physiological processes in the plant.

Tables

Table 6.1. Year, planting date, prohexadione calcium application timing, inversion dates, and harvest dates used in field trials across 2018 and 2019 in peanut trials conducted in Tifton, GA.

		DAP[a]			
		Prohexadione calcium appl.			
Year	Planting Date	First	Second	Inversion Date	Harvest Date
2018	June 18	71	86	146	166
2019	May 21	78	86	149	155

[a]DAP = days after planting

Table 6.2. Effect of prohexadione calcium on whole plant growth across field trials in 2018 and 2019 in peanut trials conducted in Tifton, GA.

	Mainstem Height (cm)							
	2018				2019			
Treatment	SD1[a]	SD2[b]	SD3[c]	SD4[d]	SD1	SD2	SD3	SD4
Non-treated control	38.96a[a]	39.98a	39.01a	40.56a	37.33a	42.05a	48.20a	52.10a
Prohexadione calcium – 0.75x rate[f]	36.03a	39.08a	38.73a	41.36a	37.95a	38.33a	36.25b	39.43b

	Number of Internodes							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	16.80a	18.97a	15.31a	19.27a	19.75a	18.95a	20.20a	22.18a
Prohexadione calcium – 0.75x rate	18.37a	15.89a	16.92a	15.04a	19.18a	19.00a	18.90a	21.78a

	Internode Length (cm)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	2.41a	2.17a	2.66a	2.18a	1.89a	2.23a	2.38a	2.35a
Prohexadione calcium – 0.75x rate	1.98a	2.57a	2.39a	2.82a	1.98a	2.01a	2.00a	1.81b

	Dry Stem Weight (g)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	125.33a	105.67a	136.33a	134.67a	151.75a	149.50a	153.50a	-
Prohexadione calcium – 0.75x rate	130.33a	86.67a	117.67a	123.00a	161.00a	129.75a	142.50a	-

	Dry Leaf Weight (g)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	112.33a	74.33a	98.33a	102.00a	112.50a	182.50a	201.25a	-
Prohexadione calcium – 0.75x rate	122.00a	63.67a	94.33a	108.33a	126.75a	135.00a	166.00a	-

Table 6.2. cont.

	Total Dry Weight (g)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	237.67a[e]	180.00a	234.67a	236.67a	264.25a	332.00a	354.75a	-
Prohexadione calcium – 0.75x rate	252.33a	150.33a	212.00a	231.33a	287.75a	264.75a	308.50a	-

[a]SD1 = Sample Date 1 – Right before the first application of prohexadione calcium
[b]SD2 = Sample Date 2 – 7 days after the first application of prohexadione calcium
[c]SD3 = Sample Date 3 – Right before the second application of prohexadione calcium
[d]SD2 = Sample Date 4 – 7 days after the second application of prohexadione calcium
[e]Means followed by the same letter in a column are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.
[f]Prohexadione calcium – 0.75x rate =105 g/ha

Table 6.3. Effect of prohexadione calcium on crop growth analysis across field trials in 2018 and 2019 in peanut trials conducted in Tifton, GA.

	CGR[a] ($g/m^2/day$)		NAR[b] ($g/m^2/day$)		LAI[c]	
Treatment	2018	2019	2018	2019	2018	2019
Non-treated control	12.27a[d]	32.46a	4.41a	9.61a	2.86a	3.59a
Prohexadione calcium – 0.75x rate[e]	10.95a	24.00a	4.16a	7.31a	2.68a	3.38a

[a]CGR = Crop growth rate
[b]NAR = Net assimilation rate
[c]LAI = Leaf area index
[d]Means followed by the same letter in a column are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.
[e]Prohexadione calcium – 0.75x rate =105 g/ha

Table 6.4. Effect of prohexadione calcium on nutrient analysis in a 2019 field trial in peanut trials conducted in Tifton, GA.

	Calcium (%)			
Treatment	SD1[a]	SD2[b]	SD3[c]	SD4[d]
Non-treated control	2.54a[e]	2.23a	2.20a	2.01b
Prohexadione calcium – 0.50x rate[f]	2.58a	2.46a	2.42a	2.60ab
Prohexadione calcium – 0.75x rate[g]	2.48a	1.97a	2.67a	2.48ab
Prohexadione calcium – 1.0x rate[h]	2.36a	2.23a	2.28a	2.87a

[a]SD1 = Sample Date 1 – Right before the first application of prohexadione calcium
[b]SD2 = Sample Date 2 – 7 days after the first application of prohexadione calcium
[c]SD3 = Sample Date 3 – Right before the second application of prohexadione calcium
[d]SD2 = Sample Date 4 – 7 days after the second application of prohexadione calcium
[e]Means followed by the same letter in a column are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.
[f]Prohexadione calcium – 0.50x rate =70 g/ha
[g]Prohexadione calcium – 0.75x rate =105 g/ha
[h]Prohexadione calcium – 1.0x rate =140 g/ha

Table 6.5. Effect of prohexadione calcium on relative chlorophyll content in a 2019 field trial in peanut trials conducted in Tifton, GA.

	SCMR[a]			
Treatment	SD1[b]	SD2[c]	SD3[d]	SD4[e]
Non-treated control	49.13a[f]	49.10a	40.52b	44.26b
Prohexadione calcium – 0.50x rate[g]	52.28a	55.73a	47.26a	48.70ab
Prohexadione calcium – 0.75x rate[h]	49.17a	55.58a	47.35a	51.28ab
Prohexadione calcium – 1.0x rate[i]	50.48a	53.38a	47.82a	51.71a

[a]SCMR = Soil plant analytical development (SPAD) chlorophyll meter readings
[b]SD1 = Sample Date 1 – Right before the first application of prohexadione calcium
[c]SD2 = Sample Date 2 – 7 days after the first application of prohexadione calcium
[d]SD3 = Sample Date 3 – Right before the second application of prohexadione calcium
[e]SD2 = Sample Date 4 – 7 days after the second application of prohexadione calcium
[f]Means followed by the same letter in a column are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.
[g]Prohexadione calcium – 0.50x rate =70 g/ha
[h]Prohexadione calcium – 0.75x rate =105 g/ha
[i]Prohexadione calcium – 1.0x rate =140 g/ha

Table 6.6. Effect of prohexadione calcium on pigment content across field trials in 2018 and 2019 in peanut trials conducted in Tifton, GA.

	Chlorophyll *a* (μg/cm^2)							
	2018				2019			
Treatment	SD1[a]	SD2[b]	SD3[c]	SD4[d]	SD1	SD2	SD3	SD4
Non-treated control	-	19.00a[e]	25.10a	26.37a	28.53a	22.33a	20.83b	20.90b
Prohexadione calcium – 0.75x rate[f]	-	19.77a	25.40a	28.37a	27.75a	24.93a	29.13a	27.33a
	Chlorophyll *b* (μg/cm^2)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	5.30a	6.17a	6.67a	6.65a	5.80a	0.40b	0.77a
Prohexadione calcium – 0.75x rate	-	5.57a	6.83a	7.40a	6.28a	8.50a	2.68a	0.77a
	Carotenoids (μg/cm^2)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	4.50a	5.30a	5.60a	5.95a	4.60a	5.85b	4.58b
Prohexadione calcium – 0.75x rate	-	4.43a	5.30a	5.90a	6.03a	4.25a	7.23a	5.75a

[a]SD1 = Sample Date 1 – Right before the first application of prohexadione calcium
[b]SD2 = Sample Date 2 – 7 days after the first application of prohexadione calcium
[c]SD3 = Sample Date 3 – Right before the second application of prohexadione calcium
[d]SD2 = Sample Date 4 – 7 days after the second application of prohexadione calcium
[e]Means followed by the same letter in a column are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.
[f]Prohexadione calcium – 0.75x rate =105 g/ha

Table 6.7. Influence of prohexadione calcium on fluorescence across field trials in 2018 and 2019 in peanut trials conducted in Tifton, GA.

	Φ_{Po}							
	2018				2019			
Treatment	SD1[a]	SD2[b]	SD3[c]	SD4[d]	SD1	SD2	SD3	SD4
Non-treated control	-	0.50a[e]	0.86a	0.87a	0.87a	0.86a	0.86a	0.84a
Prohexadione calcium – 0.75x rate[f]	-	0.48a	0.85b	0.86a	0.86a	0.87a	0.86a	0.83a
	Φ_{Eo}							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	0.26a	0.70a	0.74a	0.71a	0.68a	0.69a	0.71a
Prohexadione calcium – 0.75x rate	-	0.29a	0.70a	0.72b	0.71a	0.69a	0.65a	0.70a
	Φ_{Ro}							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	0.31a	0.44a	0.49a	0.39a	0.35a	0.34a	0.46a
Prohexadione calcium – 0.75x rate	-	0.30a	0.43a	0.47b	0.39a	0.36a	0.38a	0.44a
	ΔV_{IP}							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	0.61a	0.51a	0.57a	0.45a	0.41a	0.39a	0.55a
Prohexadione calcium – 0.75x rate	-	0.65a	0.50a	0.54b	0.46a	0.41a	0.44a	0.53a

[a]SD1 = Sample Date 1 – Right before the first application of prohexadione calcium
[b]SD2 = Sample Date 2 – 7 days after the first application of prohexadione calcium
[c]SD3 = Sample Date 3 – Right before the second application of prohexadione calcium
[d]SD2 = Sample Date 4 – 7 days after the second application of prohexadione calcium
[e]Means followed by the same letter in a column are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.
[f]Prohexadione calcium – 0.75x rate =105 g/ha

Table 6.8. Effect of prohexadione calcium on pod maturity across field trials in 2018 and 2019 in peanut trials conducted in Tifton, GA.

	Maturity (%)[a]							
	2018				2019			
Treatment	1WFH	2WFH	3WFH	4WFH	1WFH	2WFH	3WFH	4WFH
Non-treated control	0.00a[b]	3.76a	46.04ab	38.27ab	0.20a	3.23a	16.24a	30.73a
Prohexadione calcium – 0.50x rate[c]	0.00a	5.80a	41.40ab	38.19ab	0.18a	2.62a	12.77a	30.80a
Prohexadione calcium – 0.75x rate[d]	0.26a	6.29a	32.35b	40.57a	0.20a	3.05a	13.50a	32.42a
Prohexadione calcium – 1.0x rate[e]	1.15a	9.13a	58.18a	20.86b	0.71a	4.41a	16.22a	31.57a

[a]Maturity is calculated as a percentage of pods that fell into a category of 1 week from harvest (1WFH), 2 weeks from harvest (2WFH), 3 weeks from harvest (3WFH), and 4 weeks from harvest (4WFH).

[b]Means followed by the same letter in a column are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.

[c]Prohexadione calcium – 0.50x rate =70 g/ha

[d]Prohexadione calcium – 0.75x rate =105 g/ha

[e]Prohexadione calcium – 1.0x rate =140 g/ha

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CHAPTER VIII

CONCLUSIONS

In conclusion, there are many production practices and environmental factors that can affect peanut crop quality and yield. Growers face difficult decisions all season long starting before planting even begins. Objectives throughout this dissertation have proven that the implementation of precision agriculture is vital to decrease the difficulty and bias associated with these decisions. Not only growers, but also researchers and industry, can benefit from research conducted in this dissertation. Researchers can benefit from the creation of a method to irradiate peanut seeds. This method can be used to look at natural plant stand issues in research without intensive labor and time. The implementation of a method to indicate plant material in the field at 2 weeks from planting that identifies percent plant material in a field can be coupled with an economic threshold to remove bias in replant decisions. Once again researchers can benefit from the information gained from the survey of peanut growers to determine peanut yield potential by geographical location and production methods in Georgia. This information is vital in understand differences associated with the geographical regions in Georgia. The evaluation of indices to assess crop quality and yield in peanuts prior to harvest has the ability to allow industry to prepare for different qualities of peanut that will be harvested throughout the season. The proven efficacy of prohexadione calcium when tank mixed with fungicides applications, in this dissertation, has the ability decrease costs associated with the application of the product making it accessible to more growers. The identified physiological changes in peanut when prohexadione calcium is applied allow researchers to know the effects of the plant growth regulator. All of these findings benefit the grower by leading to an increase in profits when implemented.

APPENDIX A

EFFICACY OF PROHEXADIONE CALCIUM WHEN TANK MIXED WITH FUNGICIDES

IN PEANUT (*ARACHIS HYPOGAEA* L.)

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[1]Studstill, S. P., Monfort, W. S., and Pilon, C. 2021.
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Abstract

Prohexadione calcium, a plant growth regulator, has been proven to be beneficial in runner market type peanuts (*Arachis hypogaea* L.) to decrease vine growth and increase yield. However, its high cost has prevented it from being a staple in peanut production. The objective of this research was to evaluate the efficacy of prohexadione calcium when tank mixed with fungicide applications. Treatments consisted of a prohexadione tank mixed with two fungicide applications, prohexadione calcium followed by two fungicide applications, and a non-treated control (two fungicide applications with no additional prohexadione calcium application). Treatment responses were evaluated based on disease severity ratings, mainstem height, yield, and total sound mature kernels (TSMK). There were no significant differences among treatments for disease severity ratings, mainstem heights, and yield. There was an interaction between cultivar and treatment for TSMK. TSMK was significantly greater in treatments that included prohexadione calcium for the cultivar Gerogia-18RU. The lack of significant differences between treatments for disease severity ratings and yield proves that prohexadione calcium can be tank mixed with fungicide applications to decrease application costs for the plant growth regulator. The increase in TSMK in treatments with prohexadione calcium can also increase profits further justifying the use of prohexadione calcium on peanuts.

Introduction

The use of prohexadione calcium [calcium salt of 3,5-dioxo-4 propionylcyclohexanecarboxylic acid] (Apogee 27.5 WDG, BASF Corp., 26 David Dr., Research Triangle Park, NC 27709 or Kudos 27.5 WDG, Fine-Americas, 1850 Mt. Diablo Blvd., Walnut Creek, CA 94596) is becoming increasingly popular in peanut (*Arachis hypogaea* L.) production. Prohexadione calcium is a plant growth regulator that is used in production to slow vegetative growth and works by inhibiting the biosynthesis of gibberellin, a natural plant hormone that regulates cell elongation by blocking kaurene oxidase. It also increases the level of abscisic acid and cytokines (Grossman et al., 1994).

Managing excessive vine growth in peanut has become a popular research objective for several reasons. Research has demonstrated that peanut plants produce more vegetative growth than needed to achieve maximum pod yield (Mitchem et al., 1996) and this, causes nutrients and photosynthate to be directed toward vegetative growth and maintenance as opposed to reproductive growth (Brown et al., 1973; Henning et al., 1982). Another problem with excessive vine growth is the lack of disease suppression. Under high moisture conditions excessive vine growth can contribute to increased levels of disease (Bauman and Norden, 1971; Henning et al., 1982; Gorbet and Rhoads, 1975). Dense canopies inhibit foliar-applied fungicide contact with lower leaves (Henning et al., 1982). Suppressing vine growth can improve pesticide spray coverage and placement, resulting in improved disease and insect control (Henning et al., 1982; Maloy, 1993; Wu and Santelman, 1977). Excessive vines can become damaged by tractor tires during mid and late season pesticide applications potentially causing an increase in disease and yield losses (Wu and Santelman, 1977). Lastly, excessive vines can decrease digging and harvesting efficiency (Beam et al., 2002).

Prohexadione calcium has increased yields when used in large on-farm trials. This yield increase is attributed to a decrease in plant main stem heights which increases row definition (Studstill, et al., 2020). Digging losses have been reduced by as much as 4% by applying prohexadione calcium regardless of digging date and lifting treatment compared with nontreated peanuts (Beam et al., 2002). However, the cost of prohexadione calcium can be prohibitive to growers at $148/ha for two applications at 140 g/ha (Bullen et al., 2019). This amount does not include the cost of adjuvants or the act of applying the chemical. Tank mixing prohexadione calcium with fungicides would decrease the number of trips across the field. This in turn would minimize wheel-traffic injury to the plants as well as reduce production cost (Powell, 1993).

Tank mixes have been successfully used in peanut production to preserve the utility of fungicides. Culbreath et al. (2002) showed that half rates of the systemic fungicide benomyl and the protectant fungicide chlorothalonil tank mixed provided better early leaf spot, caused by *Passalora arachidicola* (Hori) U. Braun [syn.*Cercospora arachidicola* (Hori)], and late leaf spot, caused by *Nothopassalora personata* (Berk. & M.A. Curtis) U. Braun, C. Nakash., Videira & Crous [syn. *Cercosporidicum personatum* (Berk. & Curt.) Deighton], control than full season applications of either fungicide. Other fungicides that have been successfully tank mixed together include cyproconazole and chlorothalonil for control of late leaf spot and southern stem rot (SSR), caused by the soil-borne fungus, *Sclerotium rolfsii* Sacc. (Culbreath, et al., 1992) and propiconazole and chlorothalonil for control of leaf spot (Culbreath, et al., 1995).

The purpose of this study was to determine the efficacy of prohexadione calcium when tank mixed with timed fungicide applications by evaluating final disease severity of Tomato spotted wilt, caused by Tomato spotted wilt virus (genus *Tospovirus*; family Bunyaviridae) (TSWV) and early and late leaf spot as well as physiological processes in the plants.

Materials and Methods

Plant material and experimental layout

Trials were conducted over three years to test the efficacy of fungicides when applied with prohexadione calcium. The trial was conducted at the University of Georgia, Coastal Plain Experiment Station, Ponder farm (2018), at the Sunbelt Agricultural Expo Farm (2019), and at the J. G. Woodruff Farm at Abraham Baldwin Agricultural College (2020). Cultivars tested were TUFRunner™ '297' (Tillman, 2017) in 2018 and Georgia-18RU (Branch, 2019) in 2019 while both cultivars were evaluated in 2020. All trials were planted in two rows spaced 0.91 m apart with two border rows between each plot. In 2018 and 2020 the plot length was 9.14 m and in 2019 plot length was 57.91 m. Peanut was planted at rates to achieve a final in-row plant population of 13.1 to 16.4 plants/m and production management decisions were made based on the University of Georgia's Extension Service recommendations (Monfort et al., 2020).

Treatments evaluated in all trials were:

1. Non-treated control
2. Prohexadione calcium + fungicide
3. Prohexadione calcium followed by fungicide

Prohexadione calcium was applied at a rate of 105 g/ha (0.75x rate) and as per label directions, 28% urea ammonium nitrate was applied at 1.2 L/ha with the prohexadione calcium. Crop oil concentrate (Agri-Dex, 83% paraffin-based petroleum oil and 17% surfactant, Helena Chemical Co., 5100 Poplar Ave., Memphis, TN 38137) was applied at 2.3 L/ha. Prohexadione calcium was applied in 233 L/ha water. Treatments were initiated twice during the season (Table A.1). The first application was when at least 50% lateral vines from adjacent rows were touching with a second application 14 days later. Fungicides applied during the trials followed the same schedule in all three years (Table A.2). In all trials the first application of prohexadione calcium was applied with chlorothalonil and flutolanil while the second application was applied with benzovindiflupyr and azoxystrobin. Mainstem height measurements, were collected 7 days after the second application of prohexadione calcium.

Peanut plants in each plot were dug and inverted based on maturity profile method (pod mesocarp color) (Williams and Drexler, 1981). Plants were allowed to dry for 3 to 7 days depending on weather and harvested mechanically. Pod yield was assessed at harvest and final pod weight was adjusted to 7% moisture. After harvest grade was assessed and total sound mature kernels (TSMK) was recorded.

Measurements and sampling protocol

Final disease ratings. Before digging, final disease ratings were collected for TSWV and leaf spot severity. TSWV severity was assessed visually by percentage of the plot showing symptoms. Leaf spot severity was assessed visually using the Florida 1-10 leaf spot severity scale where 1 = no disease, 0% defoliation and 10 = 100% defoliation, plants dead, killed by leaf spot (Chiteka et al., 1988).

Whole plant growth. Whole plants (not including tissues below the cotyledons) from a total of 0.5 m were destructively sampled from all treatments. The first growth analysis was recorded the day of the first prohexadione calcium application before it was applied with the second data collection seven days later. The third data collection was the day of the second prohexadione calcium application before it was applied, and the fourth growth analysis was conducted seven days later. They were placed in a large plastic bag and stored in a cooler until growth analysis could be run on each one. The number of plants in the 0.5 m length was recorded for each plot. The roots were removed from each plant along with any pods that were developing. Plant height was then recoded from the base of the plant to the terminal for each plant along with the number of mainstems. Plants were then stripped of leaves and total leaf area per plant (cm^2) was measured using a LI-3100 tabletop leaf area meter (LI-COR, Lincoln, NE, USA). Plant stems and leaves were then dried and weighed to provide a whole plant dry weight. Values for crop growth rate (CGR), net assimilation rate (NAR), and leaf are index (LAI) were calculated using values from the first sampling date and the last sampling date in all three years.

Physiological Measurements

In 2018, at the time of plant collection for growth analysis, pigment content samples and fluorescence samples were collected for all treatments. Nutrient analysis samples were also collected on the second growth analysis sample date. In 2019, pigment content, fluorescence, and nutrient analyses were collected at the time of all growth analyses sampling dates. In 2019, chlorophyll content was also measured in the field at all growth analyses collection dates.

Pigment content. Pigment analysis was conducted by placing four leaf discs (6 mm in diameter) in amber vials containing 5 ml of a 96% ethanol solution. The vials were transferred to the laboratory where they were stored for two weeks at 4°C. After two weeks the supernatants were used for extraction of pigments. Absorbance was measured at 470, 649, and 665 nm wavelengths using a multi-well plate reader (Synergy HTX, BioTek, Winooski, VT, USA). The contents of chlorophyll *a*, *b*, total chlorophyll, and carotenoids were determined according to the equations given in Lichtenthaler and Wellburn (1983). The contents of all pigments assessed were expressed as $\mu g\ cm^{-2}$. Soil plant analytical development (SPAD) chlorophyll meter readings (SCMR) were also collected in 2019 to determine relative chlorophyll content (SPAD-502, Konica Minolta Optics Inc., Japan). This measurement was collected in the field at the time of growth analysis sampling. Measurements were collected from 10 random leaves in the upper canopy of each plot.

Fluorescence measurement. OJIP fluorescence measurements needed to be conducted in a dark-adapted state. Therefore, samples were collected by placing two leaves from each plot in a plastic bag with a damp paper towel. Samples were then placed in a box and acclimated to darkness for 24 hrs when the readings were collected. Readings were collected in the dark using a portable fluorometer (OS5p+; Opti-Sciences Inc., Hudson, NH, USA) with full OJIP capabilities and using protocols and calculations according to Strasser et al. (2004). OJIP fluorescence was used to calculate parameters related to quantum efficiencies including Φ_{Po} (maximum quantum yield of energy trapping by PSII), Φ_{Eo} (quantum yield of intersystem electron transport), and Φ_{Ro} (quantum yield of PSI end electron acceptor reduction). Further the parameter ΔV_{IP} was also calculated to analyze the PSI reaction center content.

Nutrient analyses. Plant tissue analysis samples were collected by randomly selecting leaves in the upper canopy of each plot to send to Southeastern Agricultural Laboratories, Inc (Barney, GA, USA). Analyses consisted of total Nitrogen (%), Phosphorus (%), Potassium (%), Magnesium (%), Calcium (%), Sulfur (%), Boron (ppm), Zinc (ppm), Iron (ppm) and Copper (ppm).

Maturity and peg strength. Peanut plants in each plot were dug and inverted based on maturity profile method (pod mesocarp color) (Williams and Drexler, 1981). In 2018 and 2019, at digging, a minimum of five plants were selected from all plots to be used for maturity assessment and peg strength. For peg strength, 10 pods with their peg were removed as close to the mainstem as possible from 10 plants before maturity assessment. The pod was placed in a clamp and the peg was removed from the pod using an electronic force gauge (Imada, Inc. Model

DS2-11, Northbrook, IL, www.imada.com). Peg strength was recorded in Newtons for the 50 pods and an average peg strength was determined for the whole plot. Those pods were then placed with the original samples and used for maturity assessment. Maturity of the pods was determined using the maturity profile method (pod mesocarp color) (Williams and Drexler, 1981). Based on mesophyll color, pods were classified as a percentage of pods that were 1 wk from harvest (1WFH), 2 wk from harvest (2WFH), 3 wk from harvest (3WFH), and 4 wk from harvest (4WFH).

Statistical Analyses

Analysis of variance was conducted using JMP Pro 15.0.0 (SAS Institute, Cary, NC). Treatments and cultivar were considered fixed effects and data from all three years were analyzed separately due to cultivar differences among years. Replication and replication x cultivar x treatments were considered random effects. Appropriate means were separated using Tukey-Kramer HSD set at 0.05 probability level.

Results and Discussion

Final disease ratings for TSWV and leaf spot did not show large differences in treatments throughout the three years (Table A.4). This could suggest that disease pressure was not significant at the trial locations. There were no significant differences for final TSWV rating in 2018 or 2019. In 2020, there was an interaction between cultivar and treatment for final TSWV disease ratings (Table A.3). Due to this, data for the final TSWV ratings in 2020 could not be combined across cultivars for analysis. There was a significant difference among cultivars for the untreated control (Table A.4). TUFRunner™ '297' had a significantly greater percentage of TSWV than Georgia-18RU with respective means of 4.32% and 2.34%. This is likely due to the amount of TSWV resistance each of the cultivars has been proven to have. Georgia-18RU is known to have "high-resistance" to TSWV while TUFRunner™ '297' is known to only have "some resistance" to TSWV (Anco and Thomas, 2021.). There were no significant differences for final leaf spot severity ratings in any year. This shows that treatments with combinations of prohexadione calcium and fungcides did not influence final TSWV or leaf spot severity ratings. This does not support research stating that less vines can improve fungicide penetration and improve disease control (Henning et al., 1982; Maloy, 1993; Wu and Santelman, 1977). However, this could be due to the fact that disease pressure was not severe in any of the trials which may have contributed to no significant differences in disease severity ratings between treatments. Overall, in all three years final TSWV severity ranged from 2.34% to 8.43% and leaf spot severity ratings ranged from 1.75 to 5.00. These results show that fungicide efficacy is not affected by tank mixing prohexadione calcium with timed fungicide sprays.

Treatment had no effect on peanut pod yield in 2018 or 2019. In 2020 there was no interaction between cultivar and treatment for yield and treatment had no effect on yield (Table A.3). This is similar to results that found that small-plot trials do not show significant yield differences between prohexadione calcium rates (Studstill et al., 2020). Cultivar, however, did have a significant difference on yield. Cultivar means for yield in 2020 were 4330 kg/ha (a) for Gerogia-18RU and 3802 kg/ha (b) for TUFRunner™ '297'. These results are likely due to general yield differences between the two cultivars. Overall, in all three years, yields ranged from 3658 to 6175 kg/ha. There were also no significant differences for TSMK for any trial with small range in grades from 72.0 to 76.0 over the three years. These results further prove that tank mixing prohexadione calcium with timed fungicide sprays does not negatively affect the crop.

Data collected to analyze crop growth analysis in all three years included CGR, NAR, and LAI (Table A.6). There were no significant differences between treatments for any year for crop growth analysis. CGR, the amount of dry matter the plant put on per day in a given area, exhibited a wide range of means throughout the years with the lowest being 20.22 $g/m^2/day$ in 2018 with the cultivar TUFRunner™ '297' and the highest being 76.51 $g/m^2/day$ in 2019 with the cultivar Georgia-18RU. This wide range in values could be due to differences in cultivar growth habits or in environmental conditions each year. In 2020 CGR treatment means ranged from 21.30 to 48.43. Both of these values come from the cultivar TUFRunner™ '297' indicating that the large differences in treatment means throughout the trial are likely due to environmental conditions each year.

Whole plant growth was analyzed using main stem height (cm), number of internodes per mainstem, internode length (cm), dry stem weight (g), dry leaf weight (g), and total dry weight (g). However, the only significant difference observed related to whole plant growth dry leaf weight (g). A significant difference for dry leaf weight was observed at sample date 4 (Table A.7). The untreated control had a significantly lower amount of dry leaf weight than the prohexadione calcium treatment followed by fungicide. This is not the expected results for dry leaf weight. Prohexadione calcium does not alter leaf formation. It inhibits the biosynthesis of gibberellin which, in peanuts, lengthens internodes. Therefore, a reduction in leaf tissue is not an expected result.

Results showed that there were no significant differences in 2018 or 2019 for pigment content collected (Table A.8). Measurements were used to calculate chlorophyll a ($\mu g/cm^2$), chlorophyll b ($\mu g/cm^2$), and carotenoid ($\mu g/cm^2$) content in the treatments. SCMR observations collected in the field in 2019 showed significant differences in the relative amount of chlorophyll at the third growth analysis sampling date (Table A.9). The non-treated control had a significantly lower relative chlorophyll content at 38.95 than the prohexadione calcium treatment followed by fungicide at 47.92. A greater value for SCMR suggests a greater chlorophyll content in the leaf. This result would suggest that the prohexadione calcium treatment followed by fungicide had a significantly greater chlorophyll content that the untreated treatment that received fungicide only. The prohexadione calcium treatment tank mixed with fungicide was not significantly different from either of the two treatments at 43.65. Readings for the other three sampling dates had a narrow range of 44.83 to 53.02.

Results for fluorescence did show significant differences in quantum efficiencies in both years (Table A.10). No significant differences were identified for Φ_{Po} in either year. This suggests that the applications of prohexadione calcium do not affect the ability of the PSII to trap light. In 2019 significant differences can be seen at SD2 and SD4 for Φ_{Eo}. At SD2, 7 days after the first application of prohexadione calcium, the untreated control had a significantly greater quantum yield for Φ_{Eo} than either of the treatments with prohexadione calcium. Similarly, at SD4, 7 days after the second application of prohexadione calcium, the untreated check was significantly greater than the treatment of prohexadione calcium tank mixed with fungicide. These results suggest that after an application of prohexadione calcium the quantum yield of electron transport between PSII and PSI is reduced by the plant growth regulator. Results indicate that in 2018 the non-treated control had a significantly lower quantum yield for Φ_{Ro} than the treatments that included prohexadione calcium at SD3. Similar results were also observed for ΔV_{IP} that indicated the non-treated control had a significantly lower value in 2018 at SD3 than either of the treatments that included prohexadione calcium. These results signify that prohexadione calcium may increase the reduction of the PSI and electron acceptors as well as PSI content.

There were no significant differences for nutrient analysis in either 2018 or 2019 for the nutrients nitrogen (%), sulfur (%), phosphorus (%), and manganese (ppm). There were significant differences for the nutrients potassium (%), magnesium (%), calcium (%), boron (ppm), zinc (ppm), iron (ppm), and copper (ppm) (Table A.11). The percentage of potassium in in the non-treated control in 2019 at SD1 was significantly lower than the treatments with prohexadione calcium. Like potassium, in 2019 at SD1, zinc was significantly greater in the prohexadione calcium treatment followed by fungicide at 227.13 PPM than either the non-treated control with a value of 103.33 or the prohexadione calcium treatment tank mixed with fungicide which had a value of 108.95. Since prohexadione calcium had not been applied to the trial yet this difference was not due to the treatment. However, this result could suggest that the prohexadione calcium or fungicide applied helped to increase the percentage of potassium and the amount of zinc in the foliage since there are not significant differences at SD2 or SD3. In 2019, a significant difference was identified at SD2 for the percentage of magnesium in the foliage. The prohexadione calcium treatment that was tank mixed with fungicide was a greater percentage of magnesium at 0.50% than the non-treated control at 0.43% or the prohexadione treatment followed by fungicide at 0.41%. It is unclear what would contribute to the difference in the foliage. The percentage of calcium in foliage showed significant differences in 2019 at SD2 and SD3. In both cases the non-treated control had significantly lower amounts of calcium in the foliage than the prohexadione calcium treatment tank mixed with fungicide. The non-treated control was also significantly lower than the prohexadione calcium treatments followed by fungicide at SD3. Since prohexadione calcium is a calcium salt of 3,5-dioxo-4 propionylcyclohexanecarboxylic acid this could explain the increase of calcium in the foliage. Significant differences were also identified for boron in the foliage in 2019 at SD2 and SD3. Like calcium, the non-treated control had significantly lower boron values than the prohexadione calcium treatment tank mixed with fungicide at both SD2 and SD3. The non-treated control was also significantly lower than the prohexadione calcium followed by fungicide at SD3. Nutrient analysis data is not available for SD4 in 2019 so it is unclear if these differences would have continued after the second treatment of prohexadione calcium. In 2018 significant differences were only observed for iron and copper. The boron in the non-treated control at SD2 was significantly lower at 89.37 PPM than the prohexadione treatment tank mixed with fungicide at 109.03 PPM. This difference did not continue throughout the year though. Copper at SD 3 in the prohexadione calcium treatment followed by fungicide was significantly greater at 4.27 PPM than the prohexadione calcium treatment tank mixed with fungicide at 3.84 PPM. It is unclear what causes this difference since the values in all the treatments at SD3 appear lower than the values at SD2 or SD4.

Harvest data collected for maturity showed significant differences in both 2018 and 2019 (Table A.12). In 2018 the significant difference was seen in the category correlating to 3WFH. The prohexadione calcium treatment followed by fungicide had a much greater percentage of pods, 17.48%, in the 3WFH class than the non-treated control, 10.29%, or the prohexadione calcium treatment tank mixed with fungicide, 10.36%. In 2019, a significant difference was observed for the 1WFH class. The prohexadione calcium treatment tank mixed with fungicide had a significantly greater percentage at 3.61% than the non-treated control and the prohexadione calcium treatment followed by fungicide, both with values of 0.18%. For peg strength, a significant difference was only recorded in 2019 (Table A.13). The peg strength for the prohexadione calcium treatment followed by fungicide, 7.27 N, was significantly greater than the prohexadione calcium treatment tank mixed with fungicide, 6.08 N, and the non-treated control, 6.46 N, was not significantly different than either of the other treatments. It is unclear what causes these differences in maturity and peg strength since there are prohexadione calcium treatments in both cases that are not significantly different than the non-treated control. These results suggest that there are environmental conditions in these trials that affected maturity and peg strength.

Conclusions

Trials did not show a significant difference in peanut disease severity ratings, peanut pod yield, or grade regardless of treatment. These results prove that farmers can tank mix fungicide with prohexadione calcium applications to decrease costs associated with the plant growth regulator. With a cost of at $148/ha for 2 applications at 140 g/ha growers can justify prohexadione calcium by not having additional application costs included (Bullen et al., 2019). Future research should be done in an area with high disease pressure to validate that tank mixing prohexadione calcium with fungicides does not affect the efficacy of the fungicide. Research using large on-farm trials could also be valuable in showing a significant increase in yield and mainstem heights in the treatments with prohexadione calcium. Future research can be beneficial in further justification of applying prohexadione calcium on peanut.

Future research into how the plant growth regulator affects the plant physiologically will spread further light on the differences happening in the plant. No differences were found between treatments for crop growth parameters or pigment contents. Fluorescence results in this trial suggest that prohexadione calcium decreases the quantum yield of electron transport to intersystem electron acceptors and increases the quantum yield for reduction of PSI and electron acceptors as well as the PSI content. Results also suggest that prohexadione calcium increases the relative chlorophyll in the plant. This increase in chlorophyll as well as increases of the nutrients calcium and boron in foliage could be contributing factors to yield increases seen in prohexadione calcium trials conducted using large on-farm trials. However, further research is required validate these findings.

Tables

Table A.1. Year, planting date, prohexadione calcium timing, digging dates, and harvest dates used in all peanut field experiments in Tifton, GA.

		DAP[a]			
		Prohexadione calcium appl.			
Year	Planting Date	First	Second	Digging Date	Harvest Date
2018	April 27	69	89	145	151
2019	May 1	75	89	141	146
2020	June 2	70	84	153	156

[a]DAP = days after planting

Table A.2. Fungicide schedule used in all peanut field experiments in Tifton, GA across 2018, 2019, and 2020.

DAP[a]	Fungicide Applied
45	Chlorothalonil & Tebuconazole
60	Benzovindiflupyr & Azoxystrobin
75	Chlorothalonil & Flutolanil
90	Benzovindiflupyr & Azoxystrobin
105	Chlorothalonil & Flutolanil
120	Chlorothalonil & Tebuconazole
135	Chlorothalonil

[a]DAP = days after planting

Table A.3. Analysis of variance for peanut crop final disease ratings, pod yield, and TSMK in 2020 in Tifton, GA.

	TSWV (%)[a]		Leaf Spot (1-10)[b]		Yield (kg/ha)		TSMK[c]	
Effect	F	P value	F	P value	F	P Value	F	P Value
Cultivar	3.72	0.0682	0.44	0.5132	9.68	0.0055	0.04	0.8504
Treatment	0.99	0.3895	0.69	0.5119	0.15	0.8639	0.26	0.7770
Cultivar x treatment	4.01	0.0344	0.03	0.9727	1.32	0.2907	2.23	0.1340

[a]TSWV = Tomato spotted wilt virus
[b]Leaf spot severity rating is a visual rating developed by Chiteka *et al.* (1988) where 1 = no disease, 0% defoliation and 10 = 100% defoliation, plants dead, killed by leaf spot.
[c]TSMK = total sound mature kernel

Table A.4. Influence of prohexadione calcium tank mixed with fungicide on final disease ratings in all peanut field experiments in Tifton, GA across 2018, 2019, and 2020.

	TSWV (%)[a]			
	2018	2019	2020	
Treatment	TUFRunner™ ‘297’	Georgia-18RU	TUFRunner™ ‘297’	Georgia-18RU
Non-treated control	6.60	6.71	4.32a[b]	2.34b
Prohexadione calcium + Fungicide	3.37	6.40	2.34	3.04
Prohexadione calcium	8.43	7.17	3.32	2.34
	Leaf Spot (1-10)[c]			
	2018	2019	2020	
Treatment	TUFRunner™ ‘297’	Georgia-18RU	TUFRunner™ ‘297’	Georgia-18RU
Non-treated control	3.63	1.75	5.00	4.80
Prohexadione calcium + Fungicide	3.75	1.75	4.70	4.60
Prohexadione calcium	4.13	2.38	4.70	4.60

[a]TSWV = Tomato spotted wilt virus

[b]Means followed by the same letter are not significantly different according to Fisher’s Protected LSD test at $p \leq 0.05$.

[c]Leaf spot severity rating is a visual rating developed by Chiteka *et al.* (1988) where 1 = no disease, 0% defoliation and 10 = 100% defoliation, plants dead, killed by leaf spot.

Table A.5. Influence of prohexadione calcium tank mixed with fungicide on peanut pod yield and grade in all peanut field experiments in Tifton, GA across 2018, 2019, and 2020.

	Yield (kg/ha)			
	2018	2019	2020	
Treatment	TUFRunner™ '297'	Georgia-18RU	TUFRunner™ '297'	Georgia-18RU
Non-treated control	5770	5246	3782	4481
Prohexadione calcium + Fungicide	5786	5776	3967	4107
Prohexadione calcium	5368	6175	3658	4404
	TSMK[a]			
	2018	2019	2020	
Treatment	TUFRunner™ '297'	Georgia-18RU	TUFRunner™ '297'	Georgia-18RU
Non-treated control	73.5	72.0	75.8	75.8
Prohexadione calcium + Fungicide	74.5	76.0	76.0	75.2
Prohexadione calcium	73.8	76.0	75.0	76.0

[a]TSMK = Total sound mature kernels

Table A.6. Influence of prohexadione calcium tank mixed with fungicide on crop growth analysis in all peanut field experiments in Tifton, GA across 2018, 2019, and 2020.

	CGR[a] ($g/m^2/day$)			
	2018	2019	2020	
Treatment	TUFRunner™ '297'	Georgia-18RU	TUFRunner™ '297'	Georgia-18RU
Non-treated control	24.90	57.45	48.43	30.73
Prohexadione calcium + Fungicide	30.26	59.45	21.30	44.53
Prohexadione calcium	20.22	76.51	36.14	41.97
	NAR[b] ($g/m^2/day$)			
	2018	2019	2020	
Treatment	TUFRunner™ '297'	Georgia-18RU	TUFRunner™ '297'	Georgia-18RU
Non-treated control	6.65	14.65	17.04	11.58
Prohexadione calcium + Fungicide	8.85	15.48	8.67	17.14
Prohexadione calcium	4.70	20.81	15.10	13.58
	LAI[c]			
	2018	2019	2020	
Treatment	TUFRunner™ '297'	Georgia-18RU	TUFRunner™ '297'	Georgia-18RU
Non-treated control	3.92	4.09	2.98	2.71
Prohexadione calcium + Fungicide	3.39	3.96	2.61	2.72
Prohexadione calcium	4.17	3.64	2.47	3.12

[a]CGR = Crop growth rate
[b]NAR = Net assimilation rate
[c]LAI = Leaf area index

Table A.7. Influence of prohexadione calcium tank mixed with fungicide on whole plant growth in all peanut field experiments in Tifton, GA across 2018, 2019, and 2020.

Main Stem Height (cm)																
	2018				2019				2020							
	TUFRunner™ '297'				Georgia-18RU				TUFRunner™ '297'				Georgia-18RU			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	22.1	39.6	34.2	31.4	38.1	37.8	39.4	39.1	29.7	29.9	34.8	36.2	33.9	35.4	37.1	34.3
Prohexadione calcium + Fungicide	27.5	34.8	37.8	36.7	34.9	37.0	38.0	35.0	30.4	31.1	31.1	33.9	30.0	28.0	32.3	33.4
Prohexadione calcium	26.7	34.0	34.8	33.4	39.7	39.8	36.4	34.8	25.6	30.7	33.3	30.6	27.1	33.8	34.2	34.3

Number of Internodes																
	2018				2019				2020							
	TUFRunner™ '297'				Georgia-18RU				TUFRunner™ '297'				Georgia-18RU			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	11.6	14.5	14.1	15.1	16.5	17.5	22.3	23.3	15.3	17.0	15.4	16.1	15.1	15.8	16.5	16.1
Prohexadione calcium + Fungicide	11.6	14.2	16.9	18.0	17.1	17.9	21.2	22.9	14.1	15.8	17.4	17.7	16.4	15.5	15.2	16.3
Prohexadione calcium	13.2	13.4	17.7	16.7	16.9	18.6	21.6	20.9	14.6	15.9	16.9	16.7	12.8	17.2	18.0	17.5

Internode Length (cm)																
	2018				2019				2020							
	TUFRunner™ '297'				Georgia-18RU				TUFRunner™ '297'				Georgia-18RU			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	2.1	2.8	2.6	2.2	2.3	2.2	1.8	1.7	2.0	1.8	2.3	2.3	2.3	2.2	2.3	2.1
Prohexadione calcium + Fungicide	2.5	2.5	2.4	2.1	2.0	2.1	1.8	1.5	2.2	2.0	1.8	1.9	1.8	1.8	2.1	2.1
Prohexadione calcium	2.2	2.7	2.2	2.1	2.4	2.1	1.7	1.7	1.8	2.0	2.0	1.8	2.0	2.0	1.9	2.0

Dry Stem Weight (g)																
	2018				2019				2020							
	TUFRunner™ '297'				Georgia-18RU				TUFRunner™ '297'				Georgia-18RU			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	220	150	133	188	135	189	200	168	99	118	139	165	114	135	163	127
Prohexadione calcium + Fungicide	192	156	130	188	140	195	195	177	127	126	136	118	86	105	112	138
Prohexadione calcium	209	162	121	180	141	173	163	189	82	114	161	133	116	143	161	154

Dry Leaf Weight (g)																
	2018				2019				2020							
	TUFRunner™ '297'				Georgia-18RU				TUFRunner™ '297'				Georgia-18RU			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	175	127	152	157	105	158	140	136b	76	89	90	78	72	96	107	68
Prohexadione calcium + Fungicide	147	121	154	162	138	150	138	152ab	93	86	96	60	72	80	74	83
Prohexadione calcium	193	129	150	141	143	141	123	198a	63	86	104	65	92	91	104	81

Total Dry Weight (g)																
	2018				2019				2020							
	TUFRunner™ '297'				Georgia-18RU				TUFRunner™ '297'				Georgia-18RU			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	395	276	285	346	240	347	341	304	175	207	229	243	195	231	271	196
Prohexadione calcium + Fungicide	339	277	184	349	278	345	333	329	220	212	232	178	156	185	186	220
Prohexadione calcium	401	290	272	321	284	314	286	387	145	200	265	198	202	234	265	235

Table A.8. Influence of prohexadione calcium tank mixed with fungicide on pigment content in 2018 and 2019 in all peanut field experiments in Tifton, GA.

	Chlorophyll A (µg/cm^2)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	20.69	22.23	21.60	21.25	24.48	20.80	22.79	22.85
Prohexadione calcium + Fungicide	20.52	24.18	25.23	21.71	22.11	23.01	25.43	27.26
Prohexadione calcium	22.53	23.48	30.51	22.28	21.13	23.68	25.11	25.73
	Chlorophyll B (µg/cm^2)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	4.79	5.20	5.49	5.62	5.72	4.93	5.55	4.29
Prohexadione calcium + Fungicide	4.41	5.58	5.71	5.70	4.85	5.30	5.90	7.04
Prohexadione calcium	6.31	5.63	7.88	7.21	4.89	5.70	6.03	5.43
	Carotenoids (µg/cm^2)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	4.80	5.09	5.12	4.56	5.36	4.73	5.19	5.20
Prohexadione calcium + Fungicide	5.07	5.34	6.04	4.81	4.98	5.21	5.60	5.46
Prohexadione calcium	4.92	5.21	6.80	4.64	4.76	4.94	5.53	5.46

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.

Table A.9. Influence of prohexadione calcium tank mixed with fungicide on relative chlorophyll content in 2019 in all peanut field experiments in Tifton, GA.

	SCMR[a]			
Treatment	SD1	SD2	SD3	SD4
Non-treated control	53.02	47.07	38.95b[b]	44.83
Prohexadione calcium + Fungicide	52.13	48.27	43.65ab	47.82
Prohexadione calcium	49.97	46.92	47.92a	47.22

[a]SCMR = Soil plant analytical development (SPAD) chlorophyll meter readings

[b]Means followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.

Table A.10. Influence of prohexadione calcium tank mixed with fungicide on fluorescence in 2018 and 2019 in all peanut field experiments in Tifton, GA.

	Φ_{Po}							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	0.83	0.87	0.76	0.87	0.87	0.86	0.86	0.86
Prohexadione calcium + Fungicide	0.83	0.87	0.84	0.87	0.86	0.85	0.86	0.86
Prohexadione calcium	0.84	0.87	0.81	0.86	0.86	0.85	0.85	0.87
	Φ_{Eo}							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	0.60	0.73	0.43	0.66	0.69	0.73a[a]	0.65	0.71a
Prohexadione calcium + Fungicide	0.61	0.73	0.61	0.70	0.68	0.71b	0.66	0.68b
Prohexadione calcium	0.58	0.71	0.58	0.68	0.69	0.70b	0.65	0.71a
	Φ_{Ro}							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	0.37	0.42	0.23b	0.33	0.41	0.46	0.33	0.41
Prohexadione calcium + Fungicide	0.36	0.42	0.37a	0.39	0.40	0.45	0.34	0.37
Prohexadione calcium	0.32	0.38	0.37a	0.38	0.41	0.43	0.35	0.40
	ΔV_{IP}							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	0.45	0.48	0.30b	0.38	0.47	0.53	0.38	0.48
Prohexadione calcium + Fungicide	0.44	0.49	0.45a	0.45	0.47	0.53	0.40	0.43
Prohexadione calcium	0.39	0.43	0.46a	0.38	0.48	0.51	0.42	0.47

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.

Table A.11. Influence of prohexadione calcium tank mixed with fungicide on nutrient analysis in 2018 and 2019 in all peanut field experiments in Tifton, GA.

	Potassium (%)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	2.73	2.22	1.65	1.37b	1.52	1.77	-
Prohexadione calcium + Fungicide	-	2.88	1.99	2.27	2.19a	1.59	1.64	-
Prohexadione calcium	-	2.49	2.10	2.06	1.98a	1.37	1.80	-
	Magnesium (%)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	0.34	0.32	0.24	0.55	0.43b	0.48	-
Prohexadione calcium + Fungicide	-	0.35	0.28	0.30	0.60	0.50a	0.54	-
Prohexadione calcium	-	0.31	0.27	0.24	0.52	0.41b	0.48	-
	Calcium (%)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	0.47	1.85	1.59	2.26	1.92b	2.19b	-
Prohexadione calcium + Fungicide	-	0.44	1.99	2.14	2.44	2.37a	2.83a	-
Prohexadione calcium	-	0.46	1.89	2.00	2.37	2.01b	2.83a	-
	Boron (PPM)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	34.63	23.77	28.60	46.13	48.88b	41.63b	-
Prohexadione calcium + Fungicide	-	37.57	22.80	25.43	47.73	64.40a	55.70a	-
Prohexadione calcium	-	34.60	24.03	27.27	44.75	54.88ab	54.2a	-
	Zinc (PPM)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	37.03	39.00	35.37	103.33b	99.83	75.38	-
Prohexadione calcium + Fungicide	-	64.67	96.07	51.63	108.95b	94.80	83.58	-
Prohexadione calcium	-	43.53	84.53	47.10	227.13a	128.50	80.68	-
	Iron (PPM)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	89.37b	64.80	85.33	108.70	74.63	84.50	-
Prohexadione calcium + Fungicide	-	109.03a	86.17	68.80	120.90	76.73	82.05	-
Prohexadione calcium	-	98.47ab	98.20	66.67	134.25	99.23	86.20	-
	Copper (PPM)							
	2018				2019			
Treatment	SD1	SD2	SD3	SD4	SD1	SD2	SD3	SD4
Non-treated control	-	6.84	4.27ab	6.41	3.58	1.48	2.93	-
Prohexadione calcium + Fungicide	-	6.96	3.84b	6.62	3.46	1.50	2.65	-
Prohexadione calcium	-	6.78	4.27a	6.45	3.21	3.82	3.19	-

[a]Means followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.

Table A.12. Influence of prohexadione calcium tank mixed with fungicide on maturity in 2018 and 2019 in all peanut field experiments in Tifton, GA.

	Maturity (%)[a]							
	2018				2019			
Treatment	1WFH	2WFH	3WFH	4WFH	1WFH	2WFH	3WFH	4WFH
Non-treated control	1.24	1.18	10.29b	27.46	0.18b	3.09	19.42	25.87
Prohexadione calcium + Fungicide	0.21	0.75	10.36b	28.86	3.61a	10.89	19.36	19.98
Prohexadione calcium	0.00	1.18	17.48a	37.16	0.18b	9.38	22.16	20.76

[a]Maturity is calculated as a percentage of pods that fell into a category of 1 week from harvest (1WFH), 2 weeks from harvest (2WFH), 3 weeks from harvest (3WFH), and 4 weeks from harvest (4WFH).

Table A.13. Influence of prohexadione calcium tank mixed with fungicide on peg strength in 2018 and 2019 in all peanut field experiments in Tifton, GA.

	Peg Strength (N)	
Treatments	2018	2019
Non-treated control	8.08	6.46ab
Prohexadione calcium + Fungicide	8.28	6.08b
Prohexadione calcium	7.64	7.27a

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