ABSTRACT

CARLEY, DANESHA SETH. Potential Use of Hyper-spectral and Multi-spectral Remote Sensing Imagery to Enhance Management of Peanut (*Arachis hypogaea* L.). (Under the direction of David Jordan.)

Experiments were conducted during 2003 and 2004 to determine if peanut yield and market quality factors differed when paraquat was applied 24 to 28 days after emergence or when 2,4-DB was applied in mid August to peanut seeded during the early, mid-, and late May and during early June. In other experiments conducted from 2003-2004, peanut was planted with or without aldicarb in the seed furrow to control tobacco thrips (*Frankliniella fusca* Hinds) followed by paraquat. In a final set of experiments conducted during 2005, treatments consisted of seeding with or without aldicarb followed by no paraquat or paraquat applied 24 to 28 days after emergence. Peanut yield and percentages of extra large kernels, total sound mature kernels, and farmer stock fancy pods were affected by planting date and pesticide treatment independently. Pod yield was higher in one of two years when peanut was planted in early and mid-May compared with late May and June. In the other year peanut yield was higher when seeded in mid-May compared to planting in early or late May or early June. In three of nine experiments pod yield was reduced when aldicarb was not applied and tobacco thrips were not controlled. In five experiments pod mesocarp color was used to determine if damage from tobacco thrips or paraquat delayed pod development and maturity. No differences in percentages of pods considered ready for digging were noted even though significant tobacco thrips damage and injury from paraquat was observed early in the season. Several differences in canopy reflectance were noted when hyperspectral imaging was used within 1 week of digging and inverting vines but they were not associated with pod maturity.

Experiments were conducted in North Carolina from 2003-2005 to determine if reflectance of the peanut canopy could be used as an indicator of pod maturity. The cultivars VA 98R and NC-

V 11 were planted beginning in early-May through early-June during each year and reflectance was measured in mid- to late September and was compared with the total percentage of pods with brown and black mesocarp color. In other experiments, the cultivars Gregory and NC 12C were dug weekly from mid-September through mid-October. Reflectance was determined at two dates spaced approximately 2 weeks apart for the cultivar Gregory. Experiments were also conducted to determine if differences of reflectance characteristics existed between the cultivars Gregory and Georgia Green and between the cultivars VA 98R and Perry seeded in single and twin row planting patterns were compared. Pod yield was affected by planting date with optimum yield occurring when peanut was planted in mid-May. Although pod yield differed among experiments, percentages of extra large kernels (%ELK) and total sound mature kernels (%TSMK) increased as digging was delayed. Pod yield of the cultivars Georgia Green and Gregory was similar in four of six experiments; yield of Georgia Green exceeded that of Gregory in two experiments. Planting peanut in twin rows resulted in higher yields than planting in single rows regardless of year or cultivar. Reflectance characteristics differed in only 1 of 3 years for the cultivar VA 98R and there were no differences for the cultivar NC-V 11 even though the percentage of mature pods ranged from 15 to 69% when assessed in mid- to late-September. Differences in reflectance characteristics were noted when the cultivars Gregory and Georgia Green were compared but not between the cultivars VA 98R and Perry. Reflectance characteristics of peanut did not differ when row pattern plantings were compared.

Experiments were conducted during 2004 and 2005 to develop spectral signatures of peanut with visual symptoms of nitrogen (N) deficiency, injury from a combination of low pH and Zinc (Zn) toxicity, drought stress, early leaf spot (*Cercospora arachidicola* Hori) and web blotch (*Phoma arachidicola* Marasas *et al.*) lesions, and following application of acifluorfen, bentazon, clethodim, imazapic, paraquat, and 2,4-DB. Differences in spectral reflectance characteristics were observed. However, it was difficult to distinguish the herbicide treated plants from the diseased plants, and the nutrient- and drought-stressed plants due to the similarities in spectral characteristics.

During 2003-2005 bi-weekly fungicide applications were made beginning in early July through mid-September and resulted in less canopy defoliation than only two sprays applied in July or no fungicide applications. In many instances, bi-weekly applications increased pod yield. When peanut canopy defoliation exceeded approximately 50%, digging 6 to 12 days prior to projected optimum maturity resulted in higher yields than digging at optimum maturity. However, response to early digging was variable when defoliation at the early digging date was less than approximately 50%.

POTENTIAL USE OF HYPER-SPECTRAL AND MULTI-SPECTRAL REMOTE SENSING IMAGERY TO ENAHNCE MANAGEMENT OF PEANUT (*ARACHIS HYPOGAEA* L.)

by

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DEDICATION

This work is dedicated to my parents

Craig and Linda Seth.

All my life you've believed in me and

challenged me to shine.

BIOGRAPHY

Danésha Seth Carley was born at home in Berea, W.V. to Linda and Craig Seth on May 30, 1976. She grew up in the beautiful foothills of West Virginia on a small farm, and spent much of her childhood barefoot and in the woods informally studying ecology. After graduating from Earlham College (Richmond, I.N.) with a B. A. degree in Biology, she went on to work briefly at an outdoor education center. Having had a taste of the "real world", she decided to seek a Master of Science in Entomology and Plant Pathology at The University of Tennessee. After graduating in 2001, she married her lovely husband and they moved together to Raleigh, N.C. Danésha began her doctoral program in August 2002. By December, she had declared a co-major in Plant Pathology and Crop Science. After finishing her doctoral degree in May, she looks forward to being FINISHED with school for a very long time.

Her plans for the future include starting a new job, and traveling to China to pick her new daughter. She hopes to stay in the Raleigh area, raise a family, and continue to love learning about and working with plants.

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First I have to thank my advisor, David Jordan. It is blatantly obvious that I would not have completed this with out his unyielding hard work.

I would also like to thank all the members of my family who have always believed that I am smarter than I feel and stronger than I know. A special thanks to my hero, my Mom, who listened to me cry on the phone every few days, but never once gave me any room to give up. Ever. Thank you all for your support, the patience to listen to me talk about it, and the love and strength to get me through my program and Tod's surgery. Thank you all. I love you.

I would like to thank my husband and partner, Tod, for his encouragement and patience with my many, many years of education. I love you and your troublesome big heart.

I would be remiss in not thanking the many wonderful friends I've had to help me along the way. First, my very best friend, Uncle Phil. Thank you for keeping me going by never failing to make me laugh, for cooking good food, and for being a fantastic guy.

Thank you Jennifer, for listening to me on the phone, sending care packages, and for reminding me that there is life after a Ph.D. program. Thanks also to Nikki for everything a best girl friend has to offer (but especially the moral support, coffee breaks, and walks around the lake).

And of course, thank you to my committee members Rick Brandenburg, Mike Burton, Cecil Dharmsari and Turner Sutton, who have allowed me to come this far. I appreciate your willingness to help me become a better and more thoughtful scientist.

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GENERAL REVIEW

Electromagnetic radiation is electromagnetic energy or radiation in transit that can be detected only when it interacts with matter (Avery and Berlin, 1992). The electromagnetic spectrum is the entire range of radiation measured in wavelengths. Of particular interest to agricultural remote sensing are the visible light portions of the spectrum from violet at 400 nanometers (nm) to 700 nm (red), and infrared. Near infrared (NIR) light (700 - 1500 nm) is closest in wavelength to visible light and far infrared waves (5600 - 10000 nm) are thermal, and are closer to the microwave region of the electromagnetic spectrum. In between NIR and FIR is the middle IR ranging from 1500 - 5600 nm. Research from a number of agricultural studies indicates that reflectance in certain crops is significantly influenced at certain wavelengths by a variety of environmental factors. Some of these include stress due to weeds, water, and nutrient deficiencies or excess (Brien *et al*., 2004; Kokaly, 2001; Koger *et al*., 2004a; Kroger *et al*., 2004b; Malthus and Madeira, 1993; Shaw, 2005). For example, plant leaves with higher nitrogen content have stronger spectral reflectance in certain blue (450-500 nm) and NIR wavebands (700-940 nm) (Serrano *et al*., 2000). Taylor *et al*. (1998) demonstrated that spectral measurements in the red (650-700 nm), green (500-550 nm), and NIR ranges could be used to estimate forage yield in bermudagrass [*Cynodon dactylon* (L.) Pers.]. In an effort to maximize N application in winter wheat (*Triticum aestivum* L.) Flowers *et al*. (2001) studied the relationship of tiller density to spectral indices and individual NIR, green, red, and blue bands, and reported that tiller density was consistently positively correlated with the NIR region. In studies of sorghum [*Sorghum bicolor* (L.) Moench], Zhao et al. (2005) reported that nitrogen-deficit stress mainly increased leaf reflectance at 555 nm and 715 nm and caused a red-edge shift to shorter wavelength. Similar research conducted in corn, found that the ratio of light reflectance between 550 and 600 nm to light reflectance between 800 and 900 nm also provided sensitive detection of N stress (Blackmer *et al*., 1996).

Other research has focused on crops infested with fungal pathogens, where the red, green and NIR bands were used to help characterize biophysical features of diseased and healthy plants (Apan *et al*., 2004; Thenkabail *et al*., 2000). Malthus and Madeira (1993) found the blue, red, and NIR regions particularly helpful when studying the spectral leaf reflectance properties of field bean (*Vicia faba* L.) suffering from chocolate spot (*Botrytis fabae* Sard.). Nutter (1989) found the red shoulder at 800 nm to be of particular interest when studying leaf spot diseases in peanut (*Arachis hypogea* L.).

The red-edge region (690-750 nm) has been tested as an index of plant stress responses to soil-oxygen depletion by Smith *et al*. (2004). This encompasses an area between the wavelengths that characterizes the boundary between strong absorption of red light by chlorophyll and the high scattered radiation in the leaf mesophyll. Fluorescence occurs when red and far-red light is emitted from green plants in response to excess stimulation by photosynthetically active radiation (PAR). Changes in chlorophyll function often precede changes in chlorophyll content so that it is possible to measure changes in the red-edge reflectance before chlorosis is visually observed in the leaves (Smith *et al*., 2004).

Since about 1945, non-photographic image-forming systems have been used to detect radiation that was either emitted or absorbed from a remote area (Shay, 1970). The spectral characteristics of objects and agricultural crops have been studied extensively in both the visible and the IR portions of the spectrum (Nilsson, 1995). Based on these spectral properties, researchers have been using remote sensing since the 1970s for a variety of important applications in plant pathology. Today, spectral imaging has potential to provide spatially and temporally based remote imaging to aid in precision agriculture and integrated pest management systems. When plants are affected by biotic and abiotic disorders such as pest infestations (Apan *et al*., 2004; Malthus and Madeira, 1993; Guan and Nutter, 2001; Nutter *et al*., 1990), water stress (Aldakheel and Danson, 1997), nitrogen status (Zhao *et al*. 2004), and nutrient deficiencies (Adams *et al*., 2000) their reflectance is altered. This has been used by plant pathologists and entomologists in a variety of crops to help anticipate and identify disease and insect problems in the field (Bounam, 1992; Johnson *et al*., 1996; Knipling, 1970; Lorenzen and Jensen, 1989).

Accurate and precise assessments of diseases, both underground and foliar, are crucial for agronomists, practitioners, and advisors to make timely cost-effective disease management decisions. Traditional methods include visual observations and ratings, and destructive leaf-area measurements. Many of the visual responses to disease (leaf curling, wilting, chlorosis or necrosis, etc.) are difficult to visually quantify with accuracy and speed, and remote sensing instruments can measure the quantity and quality or electromagnetic radiation in the crop in a nondestructive manner. One excellent example is from a study by Wilson *et al*. (1998) where spectral reflectance of elm tree (Ulmus ***americana*** **L.**) foliage was measured with a spectroradiometer to examine reflectance characteristics associated with various stages of Dutch elm disease [*Ophiostoma ulmi* (Buism.) Nannf.]. Early on-set of the disease resulted in a rapid increase in green and red reflectance and a decrease in NIR reflectance. Late symptoms included a decrease in green and NIR reflectance and an increase in short wave infrared reflectance.

Guan and Nutter (2001) used canopy reflectance to quantify the relationship between defoliation, leaf area index, canopy reflectance, and yield in **alfalfa ( ).** Significant relationships between canopy reflectance, percent defoliation, leaf area index, and yield at 810 nm were reported. In fact, the researchers found that the percentage reflectance measurements were related to crop yield and leaf area index than visual defoliation assessments, and that the percent reflectance was effectively used to quantitatively (and non-destructively) estimate yield. Nutter and Littrell (1996) examined peanut defoliation caused by late leaf spot [*Cercosporidium personatum* (Berk. & M. A. Curtis)]. Although their data only covered one spectral band (800 nm), they found significant reflective differences between the healthy green foliage and the diseased foliage. Aquino *et al*. (1992) found that canopy reflectance, also at the 800 nm band in peanuts affected by *C. personatum*, decreased as disease severity and defoliation increased throughout the season.

Malthus and Madeira (1993) studied changes reflectance spectra in field beans infected with chocolate spot. In the visible region, blue and red areas were positively correlated with lesion area and disease incidence. Green reflectance was negatively correlated with percent infection, indicating decreased reflectance as the infection spread. The highest reflectance correlation, however, was found in the NIR region, where reflectance was lower with increased infection. The greatest effect on leaf reflectance was a decline in the height of the red shoulder at about 800 nm, which was attributed to a collapse in the leaf’s cellular structure. Similar results were reported in studies on citrus leaves infected with sooty mold (*Cladosporium* sp.) (Knipling, 1970), and cereal mildew (*Erysiphe graminis* f. sp. *tritici*) on barley (Lorenzen and Jensen, 1989).

The development of multispectral photography and remote sensing techniques has provided an added dimension to remote sensing techniques in crop and land use studies. An effective tool is that of “automatic recognition” of land use categories and crop means through the use of computer analysis of spectral reflectance data. One method is to use spectral reflectance characteristics (also known as spectral signatures) of crops as a reference to develop classification systems of the remotely sensed data.

Spectral signatures are developed through remotely sensed data that can then used to classify informational features in an image into meaningful categories or classes. Spectral signatures, being unique to each material or instance, can be used for differentiating various materials present in an image, depending on its spatial extent and contrast. For example, vegetation has a remarkably high reflection in the near infrared region and a low reflection in the visible red region, so it is possible to distinguish vegetation areas from bare ground. Agricultural scientists can further use spectral signatures to distinguish between a number of damaging agents such as pathogens, insects, sunscald, frost injury, mineral deficiency, drought, and flooding (Nilsson, 1995).

Spectral signatures can also be used to survey healthy areas of vegetation, especially since the spectral signature for green plants is very characteristic. The chlorophyll in a growing plant absorbs visible and especially red light to be used in photosynthesis, whereas near infrared light is reflected very effectively as it is not used by the plant (Trottrup and Rasmussen, 2004). Therefore the reflection from vegetation in the near infrared and in the visual ranges of the spectrum varies considerably. The degree of difference reveals how large a part of the area is covered with growing green leaves (leaf area index). These characteristics are used by scientists to study agricultural land use (or losses) through the satellite imagery (de Jong and van der Meer, 2004). For example, the areas of 600 - 700 nm and 700 - 900 nm are used to distinguish between bare ground and vegetation. Vegetation gives a strong reflection in the 700 - 900 nm range, whereas it gives a weak reflection in the 600 - 700 range. Because the spectral signature of vegetation is so characteristic the distinction between bare ground and green vegetation, it is easy to distinguish one from the other. The difference between the reflection in the visible and the near infrared ranges can also be used to determine the photosynthetic potential and the growth of the plants. One common measure is the normalized difference vegetation index (NDVI), that is usually calculated as: NDVI = (near infrared – red)/(near infrared + red) (Nilsson, 1995). The NDVI, a number between –1 and +1, quantifies the relative difference between the near infrared reflectance ‘peak’ and red reflectance ‘dip’ in the spectral signature.

Leaf nitrogen (N) carries a unique spectral signature and remote sensing can be used to help detect specific leaf N content (Bouman 1992; Curran *et al*., 1992; Kokaly, 2001; Nilsson, 1995). Serrano *et al*. (2000) focused on relationships between reflectance-based NDVI and aboveground biomass, leaf area index, and canopy chlorophyll content in wheat growing under different N supplies. Using spectral signatures, researchers were able to determine that N fertilization promoted significant increases in plant growth and, to a lesser extent, in radiation use efficiency. Another study in sugar beet used univariate correlation analyses between spectral reflectance and the variables N, C:N ratio and biomass to determine spectral signature models for leaf quality and spectral signature models to enhance precision management programs already in place (Beeri *et al*., 2005). Senay *et al*. (2002) used spectral signatures based on spectral class differences (related to leaf N, soil water content, soil organic matter, and plant biomass) to distinguish corn (*Zea mays* L.) from soybean [Glycine max (L.) Merr.] crops. This research established that the maximum distinction between corn and soybean was achieved in the near-infrared bands when the crops were mature, while the visible bands were more useful when soybean was senescing.

Changes in leaf spectral signature have successfully been used to identify broad areas of vineyards infested with the grape phylloxera [Daktulosphaira vitifoliae (Fitch)] (Johnson *et al*., 1996). This was achieved by relating the level of phylloxera incidence to the incidence of vine vigor using NDVI values extracted from remotely sensed imagery. Significant correlations have also been found between NDVI and canopy leaf area index and leaf area per vine. Consequently, significant correlations between image-derived NDVI values and subsequent grape (*Vitis vinifera* L.)yield are possible (Baldy *et al*., 1996).

Di Bella *et al*. (2004) used spectral signatures to develop real-time monitoring of pasture biomass production in France. Satellite images were used to provide the spectral signature corresponding to pasture lands, which was then related to pasture growth variables. The best relationships were obtained between a middle infrared-based vegetation index calculated from the reflectance bands of the satellite, and the leaf area index calculated from spectral signatures. Aparicio *et al*. (2000) reported that LAI was the crop growth trait that most closely correlated with spectral reflectance indices for the assessment of crop growth and yield.

The more scientists can learn about spectral signatures, the faster diagnosis and possibly treatments can be completed and implemented. Growers and researchers will have more time to respond to abiotic and biotic problems and possibly prevent them before they become a problem. Spectral signatures, derived from remote sensing, can help researchers enhance current disease management programs and develop more efficient surveillance and monitoring capabilities that are quicker and cheaper than current scouting techniques. This will allow for more efficient information dissemination, and prediction. More research is necessary before this technology can be made economically feasible and accessible to the general public. However, the ground work has been laid and researchers are discovering more and more uses for remotely sensed image applications in agriculture.

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CHAPTER I

Peanut (*Arachis hypogea* L.) Response to Interactions Among Planting Date and Pest Management Practices

Danésha S. Carley, David L. Jordan, Cecil L. Dharmasri, Turner B. Sutton, Rick L. Brandenburg, and Michael G. Burton

Abstract

Experiments were conducted during 2003 and 2004 to determine if peanut yield and market quality grade factors differed when paraquat was applied 24 to 28 days after emergence or when 2,4-DB was applied in mid-August to peanut seeded during the early, mid-, and late May and during early June. In other experiments conducted from 2003-2004, peanut was planted with or without aldicarb in the seed furrow to control tobacco thrips (*Frankliniella fusca* Hinds) followed by paraquat. Paraquat was applied 24 to 28 days after emergence or 2,4-DB was applied in mid-August. In a final set of experiments conducted during 2005, treatments consisted of seeding with or without aldicarb followed by no paraquat or paraquat applied 24 to 28 days after emergence. Peanut yield and percentages of extra large kernels, total sound mature kernels, and farmer stock fancy pods were affected by planting date and pesticide treatment independently. Pod yield was higher in 1 of 2 years when peanut was planted in early and mid-May compared with late May and June. In the other year peanut yield was higher when seeded in mid-May compared to early or late May or early June. Applying paraquat did not affect yield compared with non-treated peanut regardless of planting date. Pod yield was reduced in three of nine experiments pod yield when aldicarb was not applied and tobacco thrips

were not controlled. In five experiments pod mesocarp color was used to determine if damage from tobacco thrips or paraquat delayed pod development and maturity. No differences in percentages of pods considered ready for digging were found even though significant tobacco thrips damage and injury from paraquat were observed early in the season. Several differences in canopy reflectance were noted when hyperspectral imaging was used within 1 week prior to digging and inverting vines but were not associated with pod maturity.

Key Words: Aldicarb, hull scrape method, hyperspectral reflectance, paraquat, pod maturation, tobacco thrips

Introduction

Peanut grown in the Virginia-Carolina production region generally require 140 to 160 days to reach optimum maturity and is generally seeded in early or mid-May to allow time for pods to reach maximum maturity (Sholar *et al.*, 1995). Delaying peanut planting until late May or June can result in substantial yield loss and lower market grades (Mozingo *et al*., 1991). Additionally, stresses from biotic and abiotic sources can delay development of peanut, and in some cases these stresses can lead to lower yield (Gascho and Davis, 1995; Shew *et al*., 1995; Wilcut *et al*., 1995). However, the indeterminate growth habit of peanut often allows compensation from early season stress, and if given sufficient recovery time, peanut yield and market grade factors may not be compromised (Mozingo *et al*., 1991).

Paraquat (1,1'-dimethyl-4,4'-bipyridinium) is registered for use within 28 days after peanut emergence to control small annual broadleaf weeds and grasses (Ahrens, 1994).

However, applications later than this are discouraged due to the potential for canopy injury with less time for plant recovery (Johnson *et al*., 1993). In many instances weather patterns in North Carolina during late September and October can slow the maturation process, delay pod development, and reduce yield and quality (Wu *et al*., 1996). It is suspected that peanut planted later in the season may be at greater risk of negative impacts of paraquat damage on yield due to delays in maturation if applied to peanut planted later in the season with insufficient time for recovery. Interactions of delayed planting and injury associated with paraquat have not been evaluated for Virginia market type cultivars in the Virginia-Carolina production region.

Damage from tobacco thrips can reduce yield of Virginia market type peanut grown in the Virginia-Carolina region (Brandenburg *et al*., 1998). Growers often apply aldicarb {O-[(methylamino)carbonyl]oxime} in the seed furrow to control tobacco thrips (Brandenburg, 2006; Johnson *et al*., 1999). However, changes in federal farm legislation have caused peanut growers and their advisors to look closely at production costs. While aldicarb controls tobacco thrips in most instances, the benefits of applying aldicarb with respect to yield and quality are being reconsidered. Additionally, concern about effects of tobacco thrips damage combined with injury from paraquat has been expressed, and determining interactions among these variables is important in formulating appropriate management strategies for weeds and tobacco thrips in peanut.

Digging peanut when pods are at optimum reproductive development or maturation increases pod yield and improves market grades (Jordan, 2006a; Jordan *et al*., 1998; Sholar *et al*., 1995). Although several techniques can be used to determine maturation of pods, the hull scrape method involving assessment of mesocarp color is used by most growers and their advisors in North Carolina and the southeastern United States (Sholar *et al*., 1995). This approach involves removing approximately 150 harvestable pods from each field and exposing the mesocarp using glass beads in water at high pressure or a standard pressure washer to remove the exocarp (Johnson *et al*., 1993; Williams and Drexler, 1981). A darker mesocarp is correlated with increasing pod development. This approach is time consuming, and basing the digging decision for the entire field on a relatively small sample is worrisome. Additionally, it is important to track pod development over time, and Cooperative Extension agents recommend that growers monitor pod development using this technique two or three times prior to digging (Jordan *et al*., 2005). An easier and less time consuming approach would be attractive to peanut growers and their advisors.

Previous research has shown that reflectance measurements can be used to monitor stress and other changes in the physiology and development of crops (Nilsson, 1995; Bravo *et al*., 2003). Reflectance is influenced at certain wavelengths by the presence of weeds in corn (*Zea mays* L.) (Goel *et al*., 2003). Koger *et al*. (2003) used multispectral imaging to specifically discriminate late-season grass infestations in soybean [*Glycine max* (L.) Merr.]. Masoni *et al*. (1996) used spectral properties from barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), and sunflower (*Helianthus annuus* L.) leaves to detect iron, sulfur, magnesium, and manganese deficiencies.

Reflectance ratios and indices to study nitrogen (N) stress in crops have been constructed (Osborne *et al*., 2004; Wang *et* al., 2005; Zhao *et al*., 2003). Different wavelengths were found to have high correlation with N content, and spectral band combinations rather than individual bands have shown better predictive value for optimum rates of N applied at the pretassel stage in corn (Sripada *et al*., 2005). Osborne *et al*. (2002) found that the red and green regions of the spectrum were best for predicting N concentration in corn leaves, while grain yield was estimated using reflectance in the near infrared (NIR) region. Reflectance studies on grain sorghum [*Sorghum bicolor* (L.) Moench] followed changes in red-edge characteristics (the point of maximum slope on the reflectance of vegetation spectrum between red and near-infrared wavelengths) found that N deficit stress generally increased leaf reflectance at 555 nm and 715 nm wavelengths and caused shift in the red-edge to shorter wavelengths (Zhao *et al*., 2005). Reflectance varies with leaf disease in some crops (Apan *et al*., 2004; Moshou *et al*., 2004; Nilsson, 1995; Pozdnyakova, *et al*., 2002). Malthus and Madeira (1993) were able to correlate specific wavelengths with increased incidence of chocolate spot (*Botrytis fabae* Sard.) infection in field bean (*Vicia faba* L). Newton *et al.* (2004) reported that reflectance measurements could be used to aid in accurate estimate of disease and yield response to fungicide in barley. However, cultivar and developmental stage had a large influence on measurements.

Nutter (1989) used one single bandwidth at 800 nm wavelength band to assess peanut leaves affected by late leaf spot [*Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton]. Reflectance from canopies provided a quick and nondestructive method of measuring disease intensity and the amount of green leaf area contributing to pod yield. Nutter and Littrell (1996) suggested that reflectance measurements of a healthy peanut canopy are more closely related to pod yield than assessments based on percent defoliation caused by leaf spot diseases**.** Nutter *et al.* (1990) used a handheld multispectral radiometer to compare visual and spectral assessments of foliar diseases as a means of measuring fungicide efficacy in peanut. In all but one case, they were able to determine that percent reflectance increased linearly as disease incidence and severity decreased. Reflectance measurements were correlated more closely with pod yield than the traditional visual assessments leading the researchers to suggest that reflectance measurements from peanut canopies can provide more accurate means to evaluate fungicide efficacy in peanuts. However, the use of hyperspectral and multispectral imaging to determine reflectance and correlate reflectance with pod maturity has not been investigated in peanut.

Research was conducted to determine the effect of planting date and pesticide applications on pod maturation, pod yield, and market quality factors and to determine if canopy reflectance using hyperspectral and multispectral techniques was associated with pod maturation.

Materials and Methods

Interactions of planting date and herbicides. This experiment was conducted in North Carolina during 2003 and 2004 at the Peanut Belt Research Station located near Lewiston-Woodville, NC on a Norfolk loamy sand soil (fine-loamy, siliceous, thermic, Typic Paleudults) under non-irrigated conditions. Plot size was two rows spaced 91 cm apart by 12 m. Seeds were placed 5 to 8 cm deep depending on soil moisture and granular aldicarb (Temik, Bayer Crop Science, Research Triangle Park, NC) at 7.8 kg ai/ha was applied in the seed furrow prior to seed drop. The in-row plant population was 13 plants/m.

Treatments consisted of planting the Virginia market type cultivar VA 98R on May 5, May 15, and May 25 during both years and June 4, 2003 or June 6, 2004. Within each planting date, a non-herbicide control, paraquat (Gramoxone MAX, Syngenta Crop Protection, Greensboro, NC) at 0.14 kg ai/ha applied 24 to 28 days after peanut emergence, and 2,4-DB [(2,4-dichlorophenoxybutyric acid) Butyrac 200, Agri Star, Ankeny, IA] at 0.28 kg ai/ha applied August 15, 2003 or August 18, 2004 were included. Paraquat and 2,4-DB were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L/ha using regular flat fan nozzles (Spraying Systems Co., Wheaton, IL). A non-ionic surfactant at 0.125% (v/v) was applied with paraquat. Adjuvant was not applied with 2,4-DB. All other production and pest management practices were held constant across the experiment and were based on NC Cooperative Extension Service recommendations (Brandenburg, 2006; Jordan, 2006a 2006b; Shew, 2006).

Peanut pods were dug and vines inverted for each planting date based on pod mesocarp color for the no-herbicide control (Johnson *et al*., 1993; Jordan *et al*., 2005; Williams and Drexler, 1981). Peanut was combined 4 to 7 days after digging and dried to a final moisture of 8%. Percentages of extra large kernels (%ELK), total sound mature kernels (%TSMK), and fancy pods (%FP) were determined using NC Cooperative grading criteria (USDA, 2005).

The experimental design was a split plot with planting date serving as the whole plot unit and herbicide treatment serving as subplot units. There were four replicates. Data for pod yield, %ELK, %TSMK, and %FP were subjected to analyses of variance for each year using appropriate error terms for fixed and random effects (Carmer *et al*., 1989).

Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Interactions of aldicarb and herbicides. This experiment was conducted in North Carolina during 2003 at Lewiston-Woodville; during 2004 in two separate fields at Lewiston-Woodville, and in two separate fields at the Upper Coastal Plain Research Station located near Rocky Mount during 2004. The experiment was also conducted during 2005 at Lewiston-Woodville, Rocky Mount, and in grower's fields located near Faison and Whiteville. The peanut cultivar NC-V 11 was established in raised beds as described previously at in-row plant populations of 13 plants/m. Plot size was 2 rows (91-cm spacing) by 12 m. Soil at Rocky Mount was a Goldsboro sandy loam (fine-loamy, siliceous, thermic Aquic Paleudalts). Soil at Faison was Autryville fine sandy loam (fine-loamy, siliceous, thermic, Typic Paleudults) and the soil at Whiteville was Norfolk loamy sand (fine-loamy, siliceous, thermic, Typic Paleudults).

Treatments during 2003 and 2004 consisted of a factorial arrangement of treatments including two levels of aldicarb and two levels of herbicide. Aldicarb rates were 0 and 7.8 kg/ha. Herbicide treatments were paraquat and 2,4-DB applied as described previously. A no-herbicide control was not included in this experiment. All other production and pest management practices were employed as described previously.

Within 1 week prior to peanut inversion, approximately 100 pods were removed from each plot and were subjected to mesocarp color determination (Jordan *et al*., 2005; Williams and Drexler, 1981). Pods were placed into five categories including white, yellow, orange, brown, and black mesocarp color designations. Because of the subjective nature of defining colors using this procedure, pods in the brown and black categories were combined, and this fraction was considered to be pods in the development stage ready for digging.

During 2003 and 2004, canopy reflectance in the form of radiant energy was taken under clear skies and as close to solar noon as possible using a portable spectroradiometer (ASD “FieldSpec Pro”, Analytical Spectral Devices, Inc., Bolder, CO) within 3 days of determining pod mesocarp color. The spectroradiometer was optimized using a standardized white reference panel (Analytical Spectral Devices, Inc., Bolder, CO) before measurements were taken and every 15 to 20 minutes during data collection. Reflectance measurements were collected using a 23° field-of-view optic, and the sensor was held 80 cm above the canopy. Twenty hyperspectral reflectance measurements were taken per plot and combined to get an average reading for each band width from 350 to 2500 nanometers (nm) for each plot. Bandwidths were combined into eleven bandwidth groupings based on their location in the spectrum (350-399, 400-449, 470-500, 500-590, 590-700, 700-760, 800, 950-999, 1000-1049, 1550-1750, and 2000-2400 nm – Table 1.1) for analysis. Because broad bands (from 10 to 70 nm in width) in the visible (400-760) and near-infrared (NIR) (800-1049) regions of the spectrum have been demonstrated to be optimum for estimating crop biophysical information (Thenkabail *et al*., 2000), bands within this region were used for this analysis, as were bands in the mid infrared (MIR) (1550-1750) and far infrared (UMIR) (2000-2400). Portions of the spectrum coincide with water absorption bands [mid-infrared (1350-1450 nm) and far-infrared (1800-1950 nm)], which obscure reflectance measurements, and were therefore not used for this analysis (Hatfield and Pinter, 1993). However, the normalized difference vegetation index (NDVI) was calculated using NDVI = (near infrared – red)/(near infrared + red).

The NDVI, a number between –1 and +1, quantifies the relative difference between the near infrared reflectance ‘peak’ and red reflectance ‘dip’ in the spectral signature (Nilsson, 1995).

The experimental design was a randomized complete block with four replications. Data for pod yield, %ELK, %TSMK, and %FP were subjected to analyses of variance for each year using appropriate error terms for fixed and random effects (Carmer *et al*., 1989). Data for reflectance were subject to analyses of variance for each year using appropriate error terms for fixed and random effects using SAS Systems Software (v 8.2, Cary, NC). Means of significant main effects and interactions were separated using Fisher’s Protected LSD test at $p \leq 0.05$.

A qualitative measure of tobacco thrips damage and visual injury was made at each location in all experiments. Plants were noticeably stunted from feeding by tobacco thrips when aldicarb was not applied. Foliar damage from paraquat was typical for this herbicide and was transient (Wilcut *et al*., 1995).

Results and Discussion

Interactions of planting date and herbicides. Interactions of the year X planting date X herbicide and planting date X herbicide were not significant for pod yield (Table 1.2). Additionally, main effects of planting date and herbicide treatments were not significant for pod yield. While the interaction of year X herbicide was not significant, the interaction of year X planting date was significant. Pod yield was lower when peanut was planted May 5 or 25 or in early June compared with yield of peanut planted May 15 in 2003 (Table 1.3). In contrast, yield during 2004 was higher when peanut was planted

May 5 or 15 compared with the later plantings. The optimum planting period for peanut in North Carolina is during early to mid May (Jordan, 2006a). Concern over tomato spotted wilt has resulted in recommendations to plant peanut between May 10 and 20 (Hurt *et al*., 2003). Visual symptoms of tomato spotted wilt were not apparent in these experiments during either year, and these data indicate that planting on May 15 provided the high yields during both years even in the absence of tomato spotted wilt.

The interaction of year X planting date X herbicide was not significant for %ELK (Table 1.2). However, the year X planting date interaction was significant (Table 1.2). Percent ELK was lower when peanut was planted May 5 or 15 compared with planting later in the 2003 season (Table 1.3). In contrast, the highest %ELK during 2004 was observed for the early planting date. Interaction of year X herbicide was not significant for %ELK, however, the interaction of planting date X herbicide was significant (Table 1.2). Although %ELK did not differ among herbicide treatments during 2004, applying paraquat or 2,4-DB resulted in a decrease in %ELK during 2003 (Table 1.4). Previous research (Knauft *et al*., 1990) suggests that paraquat can reduce %ELK compared with non-treated peanut. Paraquat also increased the proportion of other kernels, which may indicate that the herbicide affected yield and grade by delaying maturity. Other research has also reported this trend (Knauft *et al*., 1990). Baughman *et al*. (2002) reported that 2,4-DB did not affect yield of runner and Virginia market type peanut. This research did not find any effect on yield but %ELK and %TSMK were reduced in one of the two years.

While the interaction of year X planting date X herbicide was not significant for %TSMK, the year X planting date interaction was significant (Table 1.2). Lower

%TSMK was noted for peanut planted May 15 compared with planting earlier than this date or when planting May 25 or June 4 during 2003 (Table 1.3). In 2004, higher %TSMK was noted when peanut was planted May 25 or June 6 compared to planting May 5 or 15.

Interaction of the year X planting date X herbicide and of planting date X herbicide were not significant for %FP (Table 1.2). Year X herbicide was also not significant for %FP, however, %FP was affected by the interaction of planting date X herbicide (Table 1.2). During 2003, %FP was highest for the May 25 planting date. However, the highest %FP was noted for the May 5 planting date during 2004 (Table 1.3).

Interactions of aldicarb and herbicide. The interaction of environment X aldicarb X herbicide was not significant for percentage of mature pods (%MP), pod yield, %ELK, %TSMK, and %FP in the experiments conducted during 2003 and 2004 (Table 1.5). Aldicarb X herbicide and environment X herbicide were also not significant in these experiments. However, the interaction of environment X aldicarb was significant for %TSMK (Table 1.5). In four of the five experiments there was no difference in %TSMK when comparing aldicarb-treated peanut with peanut not treated with aldicarb (Table 1.6). However, %TSMK was lower at Lewiston-Woodville in one experiment during 2004 when aldicarb was applied.

Means for %MP, pod yield, %ELK, %TSMK, and %FP pooled over environments are presented in Table 1.7. While none of the interactions were significant for experiments during 2003 and 2004 for %FP, the herbicide and aldicarb main effects were significant for %FP (Table 1.5). Percent FP was higher when peanut was treated with aldicarb and 2,4-DB (Table 1.7). However, damage from tobacco thrips and injury from paraquat caused a decrease in %FP (Table 1.7). Growing conditions in these environments were considered ideal for peanut growth and development and pod maturation, and even though early season damage was present, peanut recovered and transient effects on foliage did not translate negatively on pod yield, pod maturity, or market grade characteristics. Other research (Brecke *et al*., 1996) indicated that peanut can recover from early season stress with reproductive growth and yield unaffected.

In the 2005 experiments, the interaction of location X aldicarb X paraquat was not significant for pod yield, %ELK, or %TSMK (Table 1.8). However, this interaction was significant for %FP. In contrast to weather conditions during 2003 and 2004, extended periods of dry weather were noted at these locations during 2005 (data not presented). In contrast to results from experiments conducted during 2003 and 2004, the interaction of environment X aldicarb was significant for pod yield and %ELK in 2005 (Table 1.8). Applying aldicarb increased pod yield at Lewiston-Woodville, Faison, and Whiteville compared with the no-aldicarb treatment (Table 1.9). Paraquat did not affect %ELK, %TSMK, or %FP nor did paraquat interact with aldicarb in experiments during 2005 (Table 1.8). Additionally, the %ELK was higher when aldicarb was applied at these locations. There was no difference in pod yield or %ELK when comparing aldicarb treatments at Rocky Mount.

The main effect of herbicide treatment was significant for pod yield (Table 1.8). When pooled over environments and aldicarb treatments, pod yield of peanut treated with paraquat was 4480 kg/ha compared with yield of 4950 kg/ha when paraquat was not applied (data not presented).

When comparing within environments, the interaction of aldicarb X paraquat was significant for %FP at Faison (Table 1.10). At this location, the highest %FP was in the treatment with aldicarb, but no paraquat, while the lowest %FP occurred when both aldicarb and paraquat were not applied or when both pesticides were not applied (Table 1.11).

Although damage from tobacco thrips feeding and paraquat applications were not more severe during 2005 than the previous two years, weather conditions most likely contributed to the relatively poor ability of peanut to recover from tobacco thrips damage. Ability of peanuts to recover from early season thrips damage is often associated with weather conditions later in the season (Marois and Wright, 2003). It was suspected that the combination of damage for tobacco thrips feeding and foliar injury from paraquat would result in greater overall damage and limit recovery. However, these results suggest that damage from tobacco thrips is more deleterious than injury from paraquat, and that the combination of both does not exceed that of tobacco thrips in absence of aldicarb when paraquat is not applied. Johnson *et al*. (1993) reported that paraquat can reduce peanut yield. However, results from our study indicate that visible injury from early season paraquat damage does not always translate into a reduction in yield.

Hyperspectral imaging. The interaction of environment X aldicarb X herbicide was significant for band widths 680-700, 700-750, 800, 950-999, and 1000-1049 (Table 1.12). The interaction of environment X herbicide was also significant for bands ranging from 500-1049. While it is not know what relationship these spectral bands have to peanut herbicide, research has been conducted on specific band widths that relate to some of the significant bands in this study. Milton *et al*. (1991) found that soybean plants deficient in phosphorous (P) displayed a higher reflectance in the green (500-590) portions of the spectrum, while Osborne *et al*. (2004) reported that P concentration in corn was more closely correlated with the NIR portions of the spectrum. Zhao *et al*. (2005) studied nitrogen deficiency in sorghum, and reported that the reflectance bands in the green and near infrared regions, while related to leaf chlorophyll and N concentrations, were a good predictor of N content in the crop. Malthus and Madeira (1992) used spectral reflectance to follow observable leaf damage in field bean infected by chocolate spot. They reported no changes in spectral reflectance were evident before visual symptoms were observed. While there were obvious significant interactions in the course of this research, it is not evident what was causing the change in spectral reflectance.

In summary, results from our experiments indicate that peanut response to paraquat and 2,4-DB most likely will not differ when peanut are planted on different dates and when growing conditions promote rapid recovery from early season injury. Although peanut yield was not affected by damage from tobacco thrips in absence of aldicarb when growing conditions favored rapid recovery, pod yield and %ELK were lower when tobacco thrips damage was prominent and growing conditions did not favor rapid recovery. Differences in reflectance coupled with no differences in percentages of mature pods suggest that reflectance has limited utility in predicting pod maturity.

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Table 1.1. Corresponding wavelength characterization for hyperspectral bandwidths used to compare canopy reflectance within one week prior to digging peanut.

Band width (nm)	Spectrum characterization[a]
350-399	Ultraviolet
400-449	Violet
470-499	Blue
500-590	Green
590-680	Yellow/Orange
680-700	Red
700-760	Red-Edge
800-1099	Near Infrared (NIR)
1550-1750	Mid Infrared (MIR)
2000-2400	Upper Mid Infrared UMIR

[a] Spectrum characterization adapted from Avery and Berlin (1992).

Table 1.2. Analyses of variance for pod yield, percent extra large kernels (%ELK), percent total sound mature kernels (%TSMK), and percent fancy pods (%FP) as influenced by planting date and herbicide treatment during 2003 and 2004.

Treatment factors	Pod yield	%ELK	%TSMK	%FP
	p-value			
Year	0.0001	0.0424	0.0001	0.0002
Planting date	0.4792	0.9001	0.2613	0.7501
Herbicide	0.3018	0.6559	0.0402	0.3265
Year X Planting date	0.0001	0.0001	0.0234	0.0001
Year X Herbicide	0.4720	0.0506	0.1148	0.0947
Planting date X Herbicide	0.7939	0.0419	0.0606	0.0299
Year X Planting date X Herbicide	0.2461	0.5917	0.8155	0.1490
Coefficient of variation (%)	11.5	6.8	3.0	4.4

Table 1.3. Interaction of year and planting date for pod yield, percent extra large kernels (%ELK), percent total sound mature kernels (%TSMK), and percent fancy pods (%FP).[a]

Planting date	Pod yield		%ELK		%TSMK		%FP	
	2003	2004	2003	2004	2003	2004	2003	2004
	kg/ha		%					
May 5	3160 b	6260 a	42 b	45 a	71 a	73 c	83 b	81 a
May 15	3960 a	6200 a	40 c	42 b	69 b	75 b	82 b	77 b
May 25	3260 b	5540 b	46 a	36 c	71 a	77 a	86 a	73 c
June 4 or 6 [b]	3550 b	4870 c	45 a	41 b	71 a	77 a	83 b	74 c

[a]Means within a year for each parameter followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Data were pooled over herbicide treatments.

[b]June 4, 2003 or June 6, 2004.

Table 1.4. Influence of year and herbicide treatment on pod yield and percentages of extra large kernels (%ELK), percentages of total sound mature kernels (%TSMK), and fancy pods (%FP).[a]

		%ELK[c]			
Herbicide	Pod yield[b]	2003	2004	%TSMK[b]	%FP[b]
	kg/ha	%			
Non-treated	4460 a	45 a	41 a	74 a	80 a
Paraquat	4630 a	41 b	41 a	73 ab	78 a
2,4-DB	4710 a	42 b	41 a	72 b	81 a

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

[b]Data were pooled over years and planting dates.

[c]Data were pooled over planting dates.

Table 1.5. Analyses of variance for percent of mature pods (%MP), pod yield, percent extra large kernels (%ELK), percent total sound mature kernels (%TSMK), and percent fancy pods (%FP) for experiments during 2003 and 2004.

Treatment factors	%MP	Pod yield	%ELK	%TSMK	%FP
	p-value				
Environment	0.0003	0.0001	0.0001	0.0001	0.0001
Aldicarb	0.5427	0.2330	0.8241	0.3597	0.0119
Herbicide	0.6132	0.4635	0.6893	0.8999	0.0313
Environment X Aldicarb	0.7397	0.3620	0.4263	0.0135	0.5631
Environment X Herbicide	0.5171	0.4753	0.7481	0.7431	0.9125
Aldicarb X Herbicide	0.3264	0.7290	0.6253	0.5204	0.3667
Environment X Aldicarb X Herbicide	0.1705	0.5725	0.5237	0.2000	0.7573
Coefficient of variation (%)	13.3	11.5	9.8	3.3	4.7

Table 1.6. Influence of environment X aldicarb on percent total sound mature kernels (%TSMK) for experiments during 2003 and 2004.[a]

Location	Year	Field	Aldicarb rate (kg/ha)	
			0	7.8
Lewiston-Woodville	2003	G3	76	75
Lewiston-Woodville	2004	F1	80	77*
Lewiston-Woodville	2004	G2	70	71
Rocky Mount	2004	C11	74	72
Rocky Mount	2004	C12	72	74

[a] * indicates significance at $p \leq 0.05$. Data are pooled over paraquat treatments.

Table 1.7. Influence of aldicarb and paraquat on percent of mature pods (%MP), pod yield, percent extra large kernels (%ELK), percent total sound mature kernels (%TSMK), and percent fancy pods (%FP) for experiments during 2003 and 2004.[a]

Insecticide[b]	Herbicide[c]	%MP	Pod yield	%ELK	%TSMK	%FP
		%	kg/ha		%	
None	Paraquat	70 a	4540 a	51 a	74 a	81 b
None	2,4-DB	66 a	4230 a	50 a	75 a	82 b
Aldicarb	Paraquat	65 a	4180 a	51 a	74 a	82 b
Aldicarb	2,4-DB	67 a	4190 a	51 a	74 a	85 a

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

[b]Aldicarb applied at 7.8 kg/ha in the seed furrow prior to seed drop.

[c]Paraquat applied at 0.14 kg/ha 24 to 28 days after peanut emergence. 2,4-DB applied at 0.28 kg/ha on approximately August 15.

Table 1.8. Analyses of variance for pod yield, percent extra large kernels (%ELK), percent total sound mature kernels (%TSMK), and percent fancy pods (%FP) for experiments during 2005.

Treatment factors	Pod yield	%ELK	%TSMK	%FP
	p-value			
Location	0.0040	0.0001	0.0686	0.0001
Aldicarb	0.0001	0.0008	0.2569	0.4181
Paraquat	0.0004	0.1600	0.3572	0.1809
Location X Aldicarb	0.0151	0.0036	0.2587	0.8106
Location X Paraquat	0.4524	0.0744	0.1069	0.1980
Aldicarb X Paraquat	0.2586	0.7890	0.6773	0.5030
Location X Aldicarb X Paraquat	0.6660	0.1615	0.1180	0.0089
Coefficient of variation (%)	9.8	7.6	3.1	5.3

Table 1.9. Influence of aldicarb on pod yield and percent extra large kernels (%ELK) for experiment during 2005.[a]

Location	Pod yield		%ELK	
	No aldicarb	Aldicarb[b]	No aldicarb	Aldicarb[b]
	kg/ha		%	
Lewiston-Woodville	5010	5560*	55	57*
Rocky Mount	3390	3890	58	58
Faison	4050	5400*	30	42*
Whiteville	4990	5320*	48	50*

[a] * indicates significance at $p \leq 0.05$ within a location. Data were pooled over paraquat treatments.

Table 1.10. Analysis of variance by location for percent fancy pods (%FP) as influenced by aldicarb and paraquat from experiments during 2005.[a]

Treatment factor	%FP Faison	Lewiston-Woodville	Rocky Mount	Whiteville
	p-value			
Aldicarb	0.2907	0.6120	0.6958	0.5603
Paraquat	0.0737	0.2293	0.3016	0.4786
Aldicarb X Paraquat	0.0027	0.1994	0.7796	0.8447
Coefficient of variation (%)	5.1	6.0	4.9	4.7

Table 1.11. Influence of aldicarb and paraquat of percent fancy pods (%FP) from experiments during 2005.[a]

		%FP			
Insecticide[b]	Herbicide[c]	Lewiston-Woodville	Rocky Mount	Faison	Whiteville
		%			
None	None	90 a	87 a	55 c	79 a
None	Paraquat	83 a	89 a	61 b	77 a
Aldicarb	None	88 a	86 a	66 a	80 a
Aldicarb	Paraquat	88 a	89 a	57 c	79 a

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

[b]Aldicarb applied at 7.8 kg/ha in the seed furrow prior to seed drop.

[c]Paraquat applied at 0.14 kg/ha 24 to 28 days after peanut emergence.

Table 1.12. Analyses of variance for hyperspectral bands as influenced by environments, aldicarb, and herbicide treatment for experiments during 2003 and 2004.[a]

Treatment factors	Bandwidths (nm)												
	350-399	400-450	470-500	500-590	590-680	680-700	700-760	800	950-999	1000-1049	MIR	UMIR	NDVI
	p-value												
Environment (Env)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Aldicarb	0.2694	0.3926	0.4405	0.3743	0.3383	0.5329	0.4868	0.6600	0.4239	0.3692	0.4239	0.2941	0.3649
Herbicide	0.4416	0.4995	0.4161	0.4835	0.4511	0.4757	0.4607	0.5023	0.4365	0.4572	0.3260	0.4519	0.4911
Env X Aldicarb	0.5644	0.6367	0.5205	0.7364	0.7098	0.4602	0.4804	0.3505	0.3260	0.3733	0.4209	0.6810	0.8451
Env X Herbicide	0.0661	0.0603	0.0577	0.0049	0.0057	0.0005	0.0005	0.0008	0.0008	0.0008	0.0719	0.0897	0.1221
Aldicarb X Herbicide	0.0654	0.0734	0.1062	0.3987	0.3983	0.7428	0.7064	0.8236	0.6564	0.6454	0.9826	0.0717	0.0654
Env X Aldicarb X Herbicide	0.4696	0.5333	0.4123	0.1388	0.1222	0.0270	0.0265	0.0269	0.0242	0.0242	0.0589	0.1222	0.1805
Coefficient of variation (%)	4.2	14.4	3.4	9.3	25.7	3.2	13.1	9.7	11.4	5.1	14.2	4.8	3.6

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

CHAPTER II

Using Peanut (*Arachis hypogea* L.) Planting and Digging Date to Determine Potential for Reflectance in Determining Pod Maturation

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Abstract

Determining when to dig peanut is complicated because of the plant's indeterminate growth habit. Pod mesocarp color is often used an indicator of pod maturation. However, this process is time consuming and is usually based on a relatively small sub-sample of pods from peanut fields. Research was conducted in North Carolina from 2003-2005 to determine if reflectance of the peanut canopy could be used as an indicator of pod maturation. The cultivars VA 98R and NC-V 11 were planted beginning in early May through early June during each year and reflectance was measured in mid- to late September and was compared with the percentage of pods in the brown and black mesocarp color. The cultivars Gregory and NC 12C were dug weekly beginning in mid-September through mid-October. Reflectance was determined at two dates spaced approximately 2 weeks apart for the cultivar Gregory. Experiments were also conducted to determine differences in reflectance of the cultivars Gregory and Georgia Green and to determine if reflectance differed when compared to the cultivars VA 98R and Perry seeded in single and twin row planting patterns (two rows spaced 18 cm apart on 96 cm rows). Pod yield was recorded in all experiments and percentages of mature pods and pertinent market grade factors were recorded in most experiments. Pod yield was affected by planting date with optimum yield occurring when peanut was planted in mid-May. Although pod yield differed among experiments, percentages of extra large kernels (%ELK) and total sound mature kernels (%TSMK) increased as digging was delayed. Pod yield of the cultivars Georgia Green and Gregory was similar in four of six experiments; yield of Georgia Green exceeded that of Gregory in two experiments. Planting peanut in twin rows resulted in higher yields than planting in single rows regardless of year or cultivar. Reflectance differed in only 1 of 3 years for the cultivar VA 98R and did not differ in any years for the cultivar NC-V 11 even though the percentage of mature pods ranged from 15 to 69% when assessed in mid- to late September. Differences in reflectance were noted between the cultivars Gregory and Georgia Green but not the cultivars VA 98R and Perry. Reflectance did not differ between row patterns.

Key Words: Hyperspectral imaging, pod maturity, digging date, planting date.

Introduction

Peanut grown in the Virginia-Carolina production region generally require as many as 160 days to reach optimum maturity. Peanut is generally seeded in early or mid- May to allow time for pods to reach maximum maturity (Jordan, 2006a). Additionally, stresses from biotic and abiotic sources can delay development of peanut, and in some cases these stresses can lead to lower yield (Aquino *et al*., 1992; Funderburk *et al*., 1998; Marinelli *et al*., 1998). Digging too early can reduce yield by 15% and crop value by 21% (Wright and Porter, 1991), although cultivar selection can influence yield as much as or more than digging date alone (Mozingo *et al*., 1991). Patee *et al*. (1980) reported that with some cultivars yield increased with later harvest dates for some cultivars, while yield of other cultivars reached a peak and then yield began to decline for that same harvest date. Shear and Miller (1959) found that Jumbo Runner peanut, growing under ideal conditions, required a minimum of 148 days to reach optimum maturity, and the earliest digging date for optimum maturity was October 15. Jordan *et al*. (1998) evaluated six Virginia-type peanut cultivars at four different digging dates (spaced approximately 7 days apart). They reported that as digging date increased, so did pod yield and gross return in some but not all the cultivars. The authors stressed that it is important to evaluate maturity for each individual cultivar when determining when to dig peanut. Yield is not the only factor when considering when to dig. At physiological maturity, seed size does not affect germination or vigor, but seed size and mass influences peanut seed quality (Spears, 2000). Furthermore, germination and vigor from seeds with similar size and mass were greatly influenced by maturity stage. As peanut yield and quality are affected by harvest and digging date, planting and digging date experiments with more recently released cultivars have not been conducted with Virginia-market types.

Peanut plant vigor and yield are negatively impacted in plants with obvious tomato spotted wilt virus (TSW) symptoms. Infected plants often produce fewer, smaller pods with lower oil content (Culbreath *et al*., 1992**,** Pappu *et al*. 1999). Current NC Cooperative Extension Service recommendations suggest that peanut should be planted in mid- May to minimize risk of TSW (Brandenburg, 2006), since the most susceptible growth stage of peanut to TSW inoculation has been reported to be 2 to 3 days after seedling emergence (Mandel *et al*., 2001). While thrips injury alone may not reduce yield, thrips injury and TSW incidence may be economically important when combined with another factor, such as postemergence herbicide injury. Determining peanut response to planting date is increasingly important because of higher incidence of TSW and the role delayed planting has in managing this disease (Hurt *et al*., 2005). Additionally, seeding peanut in twin row planting patterns (rows spaced 18 to 22 cm apart on 91 to 96 cm centers) often results in less TSW than seeding in single rows spaced 91 to 96 cm apart (Hurt *et al.*, 2005).

Peanut is an indeterminate crop, meaning once it begins blooming and setting kernels, it continues to grow vegetatively until the plant dies. Therefore, it is important to determine the best time to dig the crop to produce the highest yield. Digging peanut when pods are at optimum maturity increases yield and improves market grades (Jordan, 2006a, Sholar *et al*., 1995). Although several techniques can be used, determining the mesocarp color of pods is used by most growers and their advisors in North Carolina and throughout the southeastern United Sates (Jordan, 2006a). This approach involves removing approximately 150 harvestable pods from each field and exposing the mesocarp (Williams and Drexler, 1981). A darker mesocarp is correlated with an increase in pod development. This approach is time consuming, and basing the digging decision on a relatively small sample is worrisome. Additionally, it is important to track pod development over time, and Cooperative Extension agents recommend that growers monitor pod development using this technique two or three times prior to digging (Jordan *et al*., 2005). An easier and less time consuming approach would be attractive to peanut growers and their advisors.

Heat unit accumulation can be used as a measure of peanut pod maturation (Bell and Wright, 1998). Heat unit accumulations often expressed in growing-degree days (GDDs) have been used in a variety of crops to help predict maturity, monitor crop progress, and predict phenology of crops (Baskervi and Emin, 1969; McMaster and Wilhelm, 1997) such as such as date of full bloom for olive tree (*Olea europaea* L.) (Alcala and Barranco, 1992), flowering of sunflower (*Helianthus annuus* L.) (Leon *et al*., 2001), harvest estimates for highbush blueberry (*Vaccinium corymbosum* L.) (Carlson and Hasndcock, 1991), and germination of sorghum [*Sorghum bicolor*

(L.) Moench] genotypes (Lawlor *et al*., 1990). Schwarte *et al*. (2005) investigated GDDs in winter wheat (*Triticum aestivum* L.) to identify planting dates that allowed maximum dry matter production and nitrogen (N) capture in order to maximize yield in fall plantings. They found that GDDs could be used to predict dry matter production and N accumulation, which was directly related to increased grain yield. Research using GDDs to follow the growth and development of cotton (*Gossipium hirsutum* L.) established that a growing season cooler on average by only 1 °C will delay maturity considerably (Roussopoulos *et al*., 1998). Viator *et al*. (2005) demonstrated that daily weather data, including maximum, minimum, and average air temperature, maximum and average soil temperature, and average soil moisture, is most effective in establishing an accurate degree day baseline in cotton. Awal and Ikeda (2002) studied the effects of heat unit accumulations in soil temperature on seedling emergence, and plant development in peanut. Using soil temperature, they established that seedling emergence increased by about 1.4 calendar-days for every 1 °C rise in soil temperature, while air temperature had a greater impact on the aerial parts of the plant. The GDDs required to reach key reproductive stages including maturity can vary considerably among genotypes and between seasons (Bell *et al*., 1994). Furthermore, heat unit accumulations are poorly correlated with optimal yield when soil moisture is limited (Idso *et al*., 1978). While this approach can be a good indicator of when to begin careful assessment of peanut pod maturity, it is not an adequate indicator by itself.

Nutter and Littrell (1996) suggested that reflectance measurements of healthy peanut canopy measurements have a better relationship with pod yield than assessments based on percent defoliation caused by leaf spot diseases. Nutter *et al.* (1990) used a handheld multispectral radiometer to compare visual and spectral assessments of foliar diseases as a means of measuring fungicide efficacy in peanut. In all but one case, they were able to determine that percent reflectance increased linearly as disease incidence and severity decreased. Reflectance measurements were correlated more closely with pod yield than the traditional visual assessments leading the researchers to suggest that reflectance measurements from peanut canopies can provide more accurate means to evaluate fungicide efficacy in peanuts. In other studies using reflectance to study agricultural crops (Osborne *et al*., 2004; Zhao *et al*., 2003), different wavelengths were found to have high correlation with nitrogen content. Osborne *et al*. (2002) found that reflectance was higher in certain blue and near-infrared wavelengths when foliage was N deficient corn and that reflectance is significantly influenced by the presence of weeds, the N rates, and their interaction. Reflectance studies on grain sorghum followed changes in red-edge characteristics found that N deficit stress generally increased leaf reflectance at 555 and 715 nm wavelengths and caused shift in the red-edge to shorter wavelengths (Zhao *et al*., 2005). Reflectance varies with leaf disease in some crops (Moshou *et al*., 2004; Pozdnyakova, *et al*., 2002). Malthus and Madeira (1993) were able to correlate specific wavelengths with increased incidence of chocolate spot in field bean (*Vicia faba* L.). Newton *et al.* (2004) reported that reflectance measurements could be used to aid in accurate estimate of disease and yield response to fungicide in barley (*Hordeum vulgare* L.). However, cultivar and developmental stage had a large influence on measurements. Nutter (1989) used one single bandwidth at 800 nm wavelength band to assess peanut leaves affected by late leaf spot [*Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton]. This research provided support for the hypothesis that reflectance from canopies could provide a quick and nondestructive method of measuring disease intensity and the amount of green leaf area contributing to pod yield. The possibility of using hyperspectral and multispectral imaging to determine reflectance and correlate reflectance with pod maturity has not been determined in peanut.

The objective of this research was to determine the influence of planting date, digging date, planting pattern, and cultivar on peanut yield and to determine if reflectance can be used as an indicator of pod maturity.

Materials and Methods

Influence of digging date on peanut yield and market grade parameters. The experiment was conducted from 2003-2005 at the Peanut Belt Research Station located near Lewiston-Woodville NC on the Norfolk sandy loam soil (fine-loamy, siliceous, thermic, Typic Paleudults). The peanut cultivar Gregory was established in raised beds spaced 91 cm apart in conventionally-tilled fields. The experiment was conduced in one field during 2003, in three separate fields during 2004, and in one field during 2005. A final in-row plant populations of 13 plants/m was obtained. Seeds were placed 5 to 8 cm deep depending on soil moisture and aldicarb {O-[(methylamino)carbonyl]oxime} (Temik, Bayer Crop Science, Research Triangle Park, NC) at 5.6 kg ai/ha was applied in the seed furrow at planting as a granular formulation prior to seed drop. Production and pest management practices were held constant across the experiment and were based on NC Cooperative Extension Service recommendations (Brandenburg, 2006; Jordan, 2006a, 2006b; Shew, 2006). The cultivar NC 12C was established in the same tillage system and plant population during 1998 and 2005. Plot size was 2 rows (91-cm spacing) by 12 m.

Treatments consisted of digging peanut on approximately weekly intervals beginning in early to mid-September through mid- to late October (Table 2.1 and 2.2). Experiments with the cultivar NC 12C were dug on 5 dates while the cultivar Gregory had 6 digging dates. The experimental design was a randomized complete block with four replications.

The number of days between peanut emergence and digging (DAE) for each planting date were recorded to determine heat unit accumulations (HUA) using a 13 °C minimum and 35 °C maximum (Tables 2.1 and 2.2). Growing degree units were calculated by determining the average of the daily high and low temperatures and subtracting 13 and adding these values through the period between emergence and digging. Peanut were combined 4 to 7 days after digging and final yield converted to 8% moisture. A 1-kg sample from each plot was removed to determine percentages of extra large kernels (%ELK), total sound mature kernels (%TSMK), and fancy pods (%FP) were determined using Cooperative grading criteria (USDA, 2005).

Data for pod yield and market grade parameters were subjected to analysis of variance. Data for pod yield and market grade parameters were also subjected to regression procedures for linear, quadratic, and cubic functions based on result from the analyses of variance. Mean separation was determined for pod yield (NC 12C) and market grade factors (Gregory and NC 12C) when pooled over years or experiments. Correlation indices between pod yield, %MP, market grade factors, days after peanut emergence to digging, and heat unit accumulation were constructed according to Pearson's coefficient correlation (SAS Statistical Software, Cary, NC, 2006) , where the sample covariance is divided by the product of the sample standard deviations of X and Y. The range of the correlation coefficient is from -1 to +1, and is a description of the linear relationship between X and Y.

Influence of planting date on peanut yield and market grade parameters. The experiment was conducted from 2003 through 2005 at the Peanut Belt Research Station located near Lewiston-Woodville, NC on Norfolk loamy sand soil described previously. Peanut was planted in conventional raised beds and was not irrigated. Plot size, tillage system, and production and pest management practices were implemented as described previously.

Treatments consisted of planting the Virginia market type cultivar VA 98R on four dates beginning in early May through early June. Planting dates during 2003 and 2004 were May 5, May 15, and May 25. Planting dates during 2005 were May 2, May 18, and May 27. The early June planting during 2003, 2004, and 2005 was June 4, June 6, and June 6, respectively. In a separate experiment, the cultivar NC-V 11 was planted May 16 or June 4 during 2003, May 5 or June 6 during 2004, and May 2, May 18, May 27, and June 6 during 2005. The experimental design was a randomized complete block with planting dates replicated four times.

Within 1 wk prior to peanut inversion, approximately 100 pods were removed from each plot and were subjected to mesocarp color determination (Jordan *et al*., 2005; Williams and Drexler, 1981). Pods were placed into five categories including white, yellow, orange, brown, and black mesocarp color designations. Because of the subjective nature of defining colors using this procedure, pods in the brown and black categories were combined, and this fraction was considered to be pods in the development stage ready for digging or percentage of mature pods (%MP). Peanut for each date was dug based on prediction of when approximately 65% of pods would be in the combination of brown and black mesocarp color categories for Virginia market type peanut (Jordan *et al*., 2005). Pod yield, %ELK, %TSMK, and %FP were determined as described previously. Data for DAE and HUA for each planting date and cultivar are presented in Tables 2.3 and 2.4.

Data for %MP, pod yield, %ELK, %TSMK, and %FP were subjected to analyses of variance for each year using appropriate error terms for fixed and random effects (Carmer *et al*., 1989). Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Influence of cultivar and digging date on peanut yield. The experiment was conducted during 2003 and 2004 at the Upper Coastal Plain Experiment Station located near Rocky Mount and during 2003, 2004 (two separate fields), and 2005 at the Peanut Belt Research Station located near Lewiston-Woodville, NC. Soil at Rocky Mount was a Goldsboro sandy loam (fine-loamy, siliceous, thermic Aquic Paleudalts). Soil at Lewiston-Woodville was Norfolk sandy loam soil described previously. The cultivars Georgia Green and Gregory were planted in early May on raised seedbeds in conventionally tilled fields to establish a final in-row plant population of 13 plants/m. Establishing these densities required approximately 100 and 160 kg/ha seed for Georgia Green and Gregory, respectively.

Treatments consisted of digging both cultivars approximately September 20 and again during the first week of October. Pods were allowed to air dry for 4 to 7 days prior to combining. Final pod yield was adjusted to 8% moisture. The experimental design was a randomized complete block with treatments replicated four times. Data for pod yield were subjected to analysis of variance for a six (experiment) X two (cultivar) X two (digging date) factorial arrangement of treatments. Data for significant main effects and interactions were separated using Fisher’s protected LSD test at $p \leq 0.05$.

Influence of cultivar and planting pattern on peanut yield. The experiment was conducted from 2003 through 2005 at the Peanut Belt Research Station located near Lewiston-Woodville, NC on Norfolk sandy loam soil described previously. The cultivars VA 98R and Perry were planted in early May on raised seedbeds in conventionally tilled fields. Production and pest management practices other than cultivar and planting pattern were similar for both cultivars and were based on Cooperative Extension recommendations as described previously. Production and pest management practices other than cultivar and digging date were similar for both cultivars and were based on NC Cooperative Extension Service recommendations as described previously. When planted the same day under similar conditions, the number of days required for these cultivars to reach optimum maturity as many as 16 days (Jordan *et al*., 2005).

Treatments consisted of the cultivars VA 98R and Perry planted in single and twin row planting patterns. The single row planting pattern consisted of seeding peanut in rows spaced 91 cm apart at seeding rates designed to achieve a final plant in-row plant population of 13 plants/m. The twin row planting pattern consisted of seeding peanut in rows spaced 18 cm apart on a 91 cm spacing. Final in-row plant population for the combination of both twin rows was 15 plants/m.

Each cultivar for both planting patterns was dug based on pod mesocarp color by assessing 100 pods from each plot in mid-September as described previously. A prediction of when approximately 65% of pods would be in the combined brown and black mesocarp color categories was used to initiate digging for each cultivar (Jordan *et al*., 2005). The cultivar VA 98R was dug 7 to 14 days earlier than the cultivar Perry (data not shown). Peanut for both planting patterns were dug on the dame day. Pods were allowed to air dry for 4 to 7 days prior to combining and final pod yield was adjusted to 8% moisture.

The experimental design was a randomized complete block with treatments replicated four times. Data for pod yield and were subjected to analysis of variance for a three (year) X two (cultivar) X two (planting pattern) factorial treatment arrangement. Data for significant main effects and interactions were separated using Fisher's protected LSD test at $p \leq 0.05$.

Utility of reflectance as a measure of pod maturity. Reflectance was determined using the following procedure during 2004 in the two experiments evaluating the response of the cultivar Gregory to digging date, in all experiments where VA 98R and NC-V 11 were planted on different dates, in two experiments during 2004 when Gregory and Georgia Green were compared, and during 2003 and 2004 when VA 98R and Perry planted in single and twin row planting patterns were compared. Canopy reflectance in the form of radiant energy was taken as close to solar noon as possible using a portable spectroradiometer (ASD "FieldSpec Pro", Analytical Spectral Devices, Inc., Bolder, CO). The spectroradiometer was optimized using a standardized white reference panel (Analytical Spectral Devices, Inc., Bolder, CO) before measurements were taken and every 15 to 20 minutes during data collection. Hyperspectral measurements were collected using a 23° field-of-view optic, and the sensor was held 80 cm above the canopy. Twenty hyperspectral reflectance measurements were taken per plot and combined to get an average reading for each band width from 350 to 2500 nanometers (nm) for each plot. Bandwidths were combined into nine bandwidth groupings based on their location in the spectrum (350-399, 400-449, 470-500, 500-590, 590-700, 700-760, 800, 950-999, 1000-1049, 1550-1750, and 2000-2400 nm) for analysis (Table 2.5). Because broad bands (from 10 to 70 nm in width) in the visible (400-760) and near-infrared (NIR) (800-1049) regions of the spectrum have been demonstrated to be optimum for estimating crop biophysical information (Thenkabail *et al*., 2000), bands within this region were used for this analysis, as were bands in the mid infrared (MIR) (1550-1750) and far infrared (UMIR) (2000-2400). Portions of the spectrum coincide with water absorption bands [mid-infrared (1350-1450 nm) and far-infrared (1800-1950 nm)], which obscure reflectance measurements, and were not used for this analysis (Hatfield and Pinter, 1993). However, the normalized difference vegetation index (NDVI) was calculated using NDVI = near infrared – red/near infrared + red. The NDVI, a number between –1 and +1, quantifies the relative difference between the near infrared reflectance 'peak' and red reflectance 'dip' in the spectral signature (Nilsson, 1995).

Reflectance was recorded in mid-September within 3 days of determining pod mesocarp color when planting dates for cultivars VA 98R and NC-V 11. Reflectance was determined with in 3 days of digging the cultivar VA 98R in the experiment with VA 98R in single and twin row planting patterns were compared. In experiments comparing the response Gregory or Gregory and Georgia Green to digging date, canopy reflectance was determined in mid-September and again in early October. Data for bandwidth categories described previously were subjected to analysis of variance (SAS Systems Software, Cary, NC).

Results and Discussion

Influence of digging date on peanut yield and market grade parameters. The interaction of experiment X digging date was significant for pod yield for the cultivar Gregory but not for %ELK, %TSMK, or %FP (Table 2.6). Previous research has shown that pod yield can vary considerably with respect to digging date depending upon cultivar and edaphic and environmental conditions (Jordan *et al*., 1998; Mozingo *et al*., 1991; Sholar *et al*., 1995). However, market grade factors such as %ELK, %TSMK, and %FP often increase consistently when digging is delayed and pods are allowed to increase maturation (Spears, 2000).

Cubic functions predicted pod yield versus days after peanut emergence (DAE) during 2003 in Field B4 and during 2004 in Fields A2 and F1 (Figure 2.1). However, response over digging date differed considerably when fields were compared. Pod yield increased during 2003 to a maximum approximately 154 DAE and then declined with yields at the first and last digging dates being similar. Pod yield increased to an optimum at approximately 131 days after emergence but then declined to the lowest yield at the final digging date in Field G2 during 2004. In contrast to responses in these fields, yield in Field A2 during 2004 was similar during the first two digging dates but decreased in a linear fashion thereafter. A linear decrease in yield was found in Field F1 after the first digging date during 2004. Surprisingly, peanut did not respond to digging date during 2005 (Mozingo *et al*., 1991).

When pooled over digging dates, %ELK and %TSMK increased to a maximum when dug in late September and early October, respectively (Table 2.7). In contrast, %FP was constant over the first five digging dates with a decrease noted on the last digging date (Table 2.7). This response is consistent with other studies which found at %ELK and %TSMK often increase as digging is delayed even though yield response over digging dates may be inconsistent (Jordan *et al*., 1998). Additionally, farmer stock %FP often decreases as digging is delayed (Knauft *et al*., 1990; Sholar *et al*., 1995).

Pearson correlations among HUA, DAE, pod yield, and market grade factors were constructed for each experiment (Table 2.8). Significant negative correlations were obtained for HUA and DAE in experiments conducted during 2004 but not during 2003 and 2005. While correlations of yield vs. %ELK and yield vs. %TSMK were positive, a negative correlation of yield vs. %FP was noted in four of five experiments. The correlation of %ELK vs. %TSMK was highly correlated in all experiments. No consistent trends were noted when other correlations associated with market grades and HUA or DAE were evaluated.

Pearson correlations between pod reflectance and pod yield, market grade factors, HUA, and DAE were constructed for the cultivar Gregory (Table 2.9). While there were no negative correlations, five correlations proved significant. These positive correlations included: yield and JumboL, Yield and Jumbob, %ELK and FancyL, %TSMK and FancyL, and HUA and Jumboa.

The interaction of year X digging date was not significant for pod yield and market grade factors for the cultivar NC 12C (Table 2.10). When pooled over years, pod yield and %TSMK increased to a maximum in late September (Table 2.11). The highest %ELK was found at the last two digging dates. In contrast, %FP remained relatively constant over digging dates during 1998 (Table 2.10). However, during 2005 %FP increased to a maximum on the third digging date and decreased thereafter.

With the exception of the correlation of %ELK vs. %FP, all correlations were significant during 1998 (Table 2.12). In contrast, only the correlations between yield and %ELK and %TSMK and %ELK with DAE, HUA, and %TSMK were noted during 2005.

Influence of planting date on peanut yield and market grade parameters. The interaction of year X planting was significant for %MP, pod yield, and %ELK in the experiment with the cultivar VA 98R (Table 2.13). Although this interaction was not significant for %TSMK, the main effect of planting date was significant. In contrast, the main effect of planting date and the interaction of year X planting date was not significant for %FP (Table 2.13).

Differences in %MP for all planting dates were found during all years for the cultivar VA 98R when %MP was determined for all planting dates in mid-September (Table 2.13). The highest %MP was observed when peanut was planted May 5 during 2003 compared with %MP planting May 25 or June 4. No differences in %MP were noted when the %MP for the May 5 and 15 plantings during each year were compared. The %MP was lower when peanut was planted June 4 or 6 during 2004 and 2005, respectively.

When mesocarp color was used to determine when to dig, pod yield of VA 98R was highest during 2003 when peanut was planted May 15 with the lowest yield noted for the May 5 or May 25 planting date (Table 2.14). During 2004, the highest yield was obtained when peanut was planted May 15. However, the lowest yield was obtained when peanut was planted in early June. No difference in pod yield was found during 2005 when peanut was planted May 5, 25, or May

25. However, yield did not differ when yield was compared for the last three planting dates. In a study conducted in Lewiston-Woodville, NC on the influence of prohexadione calcium on pod yield in peanut, Beam *et al*. (2002) reported that yield was higher as digging date was delayed, as long as environmental conditions were favorable. Mozingo *et al*. (1991) determined that Virginia-type cultivars planted in favorable conditions yielded higher when planted May 1 rather than in late-April. Conversely, Linker and Coble (1990) suggested that the ideal time to plant peanut in North Carolina was April 20 to May 10. When planting dates were compared, no differences in %ELK, and %TSMK were found during 2003, 2004 and 2005 (Table 2.15). Differences in %FP were found in 2005, but not during 2003 and 2004. The %FP was lower when peanut was planted June 6, 2005.

Days after emergence (DAE) to digging date for peanut planted at different dates varied among years, especially when 2003 and 2004 were compared with 2005 (Table 2.3). These results reflect warmer temperatures, especially in May and June, during 2004 compared with those during 2003 and 2005 (data not shown).   Heat unit accumulation over the four digging dates varied by 62, 304, and 104 growing degree units (13 °C base and 35 °C ceiling) during 2003, 2004, and 2005, respectively (Table 2.3). Although some differences in DAE to digging for planting dates were noted, a consistent trend was not observed when comparing planting dates across years (Table 2.4).

The percentage of MP was higher for the cultivar NC-V 11 when peanut was dug either May 5 or May 16 compared with planting in early June (Table 2.15). However, in contrast to results with VA 98R, there was no difference in pod yield, %ELK, %TSMK, and %FP when comparing pod yield was compared among planting dates (Tables 2.16 and 2.17). Heat unit accumulations differed by 79, 441, and 197 growing degree units during 2003, 2004, and 2005, respectively (Table 2.4).

Collectively, these data indicate that while pod yield can differ among planting dates, especially for the cultivar VA 98R, there were few differences in %ELK, %TSMK, and %FP were found. These data also indicate that digging peanut based on pod mesocarp color continues to be effective in optimizing quality factors. Sanders and Bett (1993) used the hull scrape method to research the best time to dig peanuts based on maturity and overall quality. In their study, peanuts harvested early had less flavor and a bitter taste. In 10 experiments conducted in North Carolina, digging date of peanut was found to influence pod yield of Virginia-type peanut. Peanut response to digging was variable, and delays in digging reduced pod yield and gross value (Jordan *et al*., 1998). In research conducted in North Carolina on peanut cultivar response to planting pattern and digging date (Lanier *et al*., 2004), delayed digging at two locations resulted in lower pod yield for cultivars NC-V 11 and VA 98R. Mozingo *et al*. (1991) reported similar results for delayed digging in the cultivar VA 98R.

Influence of cultivar and planting pattern on peanut yield. Interactions of year X planting pattern X cultivar and planting date X cultivar were not significant for pod yield (Table 2.18). However, year X cultivar and the main effect of planting pattern were significant for this parameter. When pooled over planting patterns, no difference in yield was noted during 2003 when yield of VA 98R and Perry were compared (Table 2.19). In contrast, differences in yield were noted during 2004 and 2005 when comparing cultivars. In contrast to the variation in response to cultivar, planting in the twin row planting pattern increased yield from 4760 kg/ha to 5140 kg/ha when compared to planting in single rows (Table 2.19). Planting peanut in twin row planting patterns often increase pod yields over planting in single row patterns (Lanier *et al*., 2004). While response can vary by cultivar, results from our experiments indicate that the cultivars Perry and VA 98R will respond similarly to planting pattern. In previous research conducted in North Carolina, the cultivars NC-V 11, NC 12C, VA 98R, and Perry were compared in single row and standard twin row planting patterns (Lanier *et al*., 2004). When peanut was dug at optimum maturity, pod yield was higher in standard twin row planting patterns than when grown in single row planting patterns in some but not all experiments. Additionally, Mozingo *et al*. (2000) reported an increase in yield when cultivar VA 98R was planted in twin row verses single row patterns.

Influence of cultivar and digging date on peanut yield. The interaction of year X cultivar X digging date was significant for pod yield (Table 2.20). When analyzed by experiment, the main effects of cultivar and digging dates and the interaction of these factors were significant during 2004 at Lewiston-Woodville (Table 2.21). Cultivar and digging date did not affect pod yield in the remaining experiments. Previous research (Jordan *et al*., 2000, 2005) suggests that maturity and pod yield of the cultivars Gregory and Georgia Green are often similar when grown under optimum conditions. The interaction of cultivar X digging date was most likely associated with incidence of late leaf spot at Lewiston-Woodville during 2004 compared with disease during 2003 and 2005. Although the incidence and severity of late leaf spot was not quantified, significant defoliation was noted, and previous research suggests that Gregory is more susceptible than Georgia Green to late leaf spot (Shew, 2006). Pod yield was lower in Field G2 and F1 when Gregory was planted and peanut was dug in early October rather than September 20 (Table 2.22). In contrast, yield remained high at the later digging date in the other experiments where late leaf spot was presented, and this most likely reduced yield due to pod shed as a result of higher incidence of late leaf spot for Gregory.

Utility of reflectance as a measure of pod maturity. Significant differences in reflectance were found when digging dates for the cultivar Gregory were compared in two fields during 2004 (Table 2.23). When reflectance for the cultivar Gregory was compared between digging dates in Fields G2 and F1 during 2004, reflectance was higher for all bandwidth categories when peanut was evaluated during early October compared with reflectance in mid-September (Table 2.23).

Reflectance was significant for several bandwidth categories when planting dates were compared for VA 98R during 2004 but not during 2003 and 2005 (Table 2.23). Although some variation was noted when comparing planting dates for the cultivar VA 98R, higher reflectance values were noted when peanut was planted later at bandwidth categories of 700-760, 880, 950-999, and 1000-1049 (Table 2.24). Although differences in reflectance were found for the cultivar VA 98R (Table 2.25), the magnitude of difference was much higher than was found for the cultivar NC-V 11 (Table 2.26). The %MP differed in all years when comparing planting dates for both cultivars were compared (Tables 2.13 and 2.14). These data suggest that reflectance most likely will have limited utility in predicting pod maturation.

Significant differences were found when reflectance for the cultivars Gregory and Georgia Green at Lewiston-Woodville during 2003 and in Field F1 during 2004 were compared (Table 2.27). Reflectance was higher for bandwidth categories of 680-700, 800, 950-999, and 1000-1049 during both years (Table 2.28). In contrast, the magnitude of reflectance was higher during both years for the 500-590 bandwidth category. In contrast to differences in reflectance when Gregory and Georgia Green were compared, reflectance of the cultivars VA 98R and Perry did not differ (Table 2.29). The cultivars Gregory, Perry, and VA 98R are Virginia market types while the cultivar Georgia Green is a runner market type. These data indicate that there is a possible difference in reflectance between a Virginia and runner market type but not when comparing two Virginia market type cultivars. Additional research is needed to determine the extent in which reflectance differs among cultivars and for cultivars within the same market type category. No differences in reflectance were noted when planting patterns were compared (Table 2.29).

In summary, results from these experiments indicate that considerable variation in yield response to digging date over a range of edaphic and environmental conditions. However, market grade characteristics held constant in many instances when growing conditions and treatment factors were compared. Planting date affected peanut yield and market grade characteristics for the cultivar VA 98R but not for NC-V 11. Planting VA 98R in mid-May provided the most consistent yield over the three years of study. Pod yield of Gregory and Georgia Green was similar when disease was controlled, and while differences in yield were noted when the cultivars Perry and VA 98R were compared; both cultivars responded positively to twin row planting. While some differences in reflectance were noted in these experiments, this technique did not appear to be a good indicator of predicting pod maturation.

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Table 2.1. Heat unit accumulation and days from peanut emergence to digging in five experiments when the cultivar Gregory was dug at six dates during September and October for experiments conducted from 2003 to 2005.[a]

Digging date	Days from emergence to digging					Heat unit accumulation				
	Field B4 2003	Field G2 2004	Field F1 2004	Field A2 2004	Field F2 2005	Field B4 2003	Field G2 2004	Field F1 2004	Field A2 2004	Field F2 2005
Sep. 13-14	134	122	130	130	121	2413	2519	2738	2738	2512
Sep. 17-23	141	127	135	134	129	2565	2601	2788	2803	2739
Sep. 24-28	147	135	143	141	136	2648	2872	2949	2971	2822
Oct. 1-6	154	142	151	148	143	2670	2900	3003	3010	2901
Oct. 8-14	160	148	157	155	157	2747	2914	3037	3039	3032
Oct. 18-21	166	155	163	161	162	2764	2923	3039	3043	3090

[a]Heat units calculated as the average of the high and low temperatures for each day with a base of 13 °C and ceiling of 35 °C.

Table 2.2. Heat unit accumulation and days from peanut emergence to digging in two experiments when the cultivar NC 12C was dug at five dates during September and October for experiments in 1998 and 2005.[a]

Digging date	Days from emergence to digging		Heat unit accumulation	
	1998	2005	1998	2005
Sep. 13-17	131	121	2555	2512
Sep. 21-23	137	129	2689	2739
Sep. 28-30	143	136	2848	2822
Oct. 4-6	151	143	2968	2902
Oct. 14	159	157	3147	3032

[a]Heat units calculated as the average of the high and low temperatures for each day with a base of 13 °C and ceiling of 35 °C.

Table 2.3. Heat unit accumulation and days from peanut emergence to digging for experiments conducted from 2003 through 2005 when the cultivar VA 98R was planted on four dates from early May through early June.[a]

Planting date	Days from emergence to digging			Heat unit accumulation		
	2003	2004	2005	2003	2004	2005
May 2-5	141	133	144	2688	2678	2752
May 15-18	141	128	139	2673	2572	2742
May 25-27	132	128	131	2626	2398	2679
June 4 or 6	130	133	130	2569	2374	2648

[a]Heat units calculated as the average of the high and low temperatures for each day with a base of 13 °C and ceiling of 35 °C.

Table 2.4. Heat unit accumulation and days from peanut emergence to digging for experiments conducted from 2003 through 2005 when the cultivar NC-V 11 was planted on four dates from early May through early June.[a]

Planting date	Days from emergence to digging			Heat unit accumulation		
	2003	2004	2005	2003	2004	2005
May 4-6	-	142	137	-	2919	2752
May 15-16	138	-	123	2608	-	2615
May 25	-	-	136	-	-	2810
June 1-4	134	128	128	2529	2478	2613

[a]Heat units calculated as the average of the high and low temperatures for each day with a base of 13 °C and ceiling of 35 °C.

Table 2.5. Corresponding wavelength characterization for hyperspectral bandwidths used to compare canopy reflectance within one week prior to digging peanut.

Bandwidth (nm)	Spectrum characterization[a]
350-399	Ultraviolet
400-449	Violet
470-499	Blue
500-590	Green
590-680	Yellow/Orange
680-700	Red
700-760	Red-Edge
800-1099	Near Infrared (NIR)
1550-1750	Mid Infrared (MIR)
2000-2400	Upper Mid Infrared (UMIR)

[a] Spectrum characterization adapted from Avery and Berlin (1992).

Table 2.6. Analyses of variance for pod yield, percentage of extra large kernels (%ELK), percentage of total sound mature kernels (%TSMK), and percentage of fancy pods (%FP) when the cultivar Gregory was dug on six different dates during 2003-2005.

Treatment factors	Pod yield	%ELK	%TSMK	%FP
	p-value			
Experiment	0.0002	0.0001	0.0001	0.0154
Digging date	0.0001	0.0002	0.0001	0.0012
Experiment X Digging date	0.0001	0.5150	0.3397	0.7637
Coefficient of variation (%)	13.8	8.0	4.4	7.1

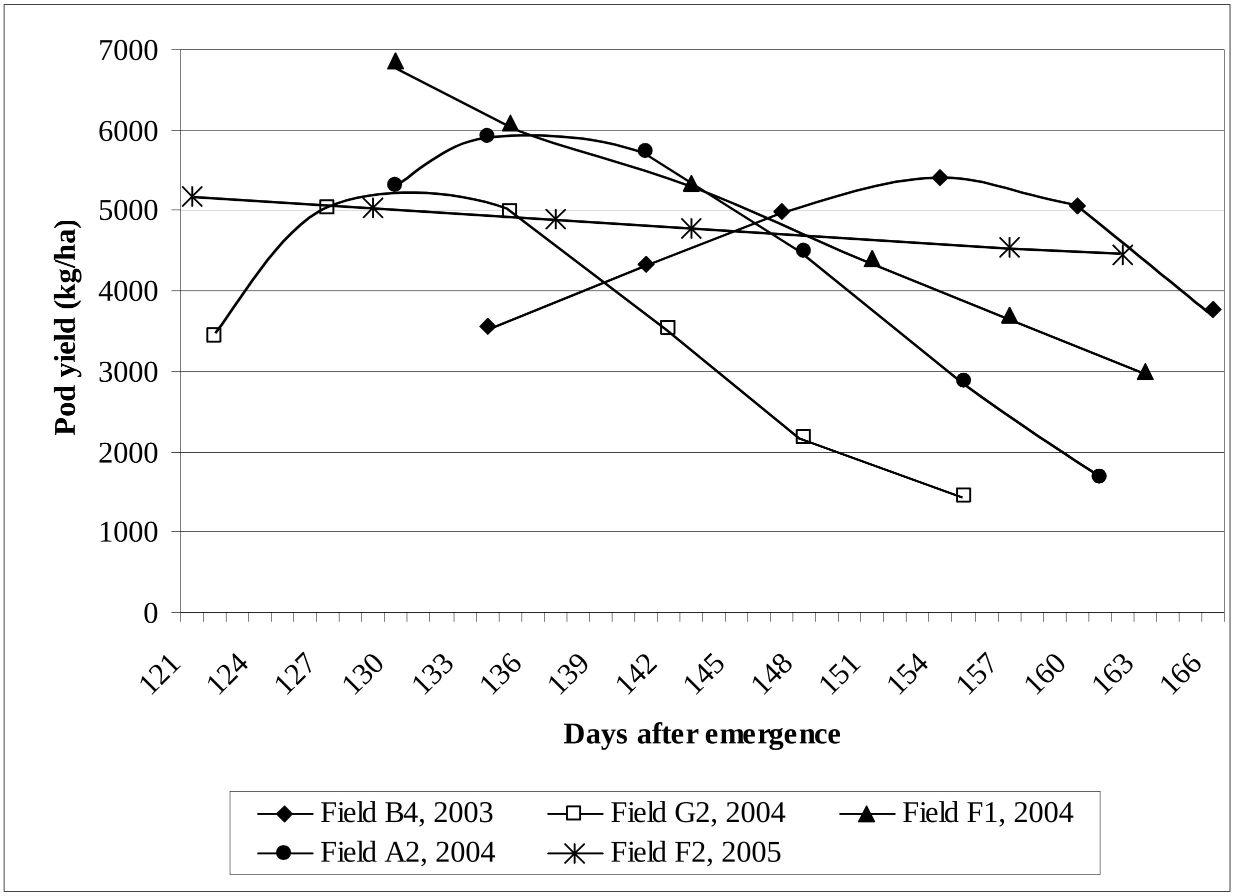

Figure 2.1. Influence of days after emergence for peanut digging on peanut pod yield for the cultivar Gregory.

Field B4, 2003 $Y = 34106x - 240.8x^2 + 0.563x^3 - 1594965$, $R^2 = 0.78$ ($p = 0.0041$)

Field G2, 2004 $Y = -116.9x + 22064$, $R^2 = 0.081$ ($p = 0.0001$)

Field F1, 2004 $Y = 22471x - 149.5^2 + 0.328x^3 - 1110496$, $R^2 = 0.91$ ($p = 0.0425$)

Field A2, 2004 $Y = -14024x + 100.1x^2 - 0.24x^3 + 653539$, $R^2 = 0.78$ ($p = 0.0156$)

Field F2, 2005, NS for linear ($p = 0.1518$), quadratic ($p = 0.6380$), or cubic functions ($p = 0.8624$)

Table 2.7. The influence of digging date on percentage of extra large kernels (%ELK), percentage of total sound mature kernels (%TSMK), and percentage of fancy pods (%FP) for the cultivar Gregory for experiments conducted in 2003, 2004, and 2005.[a]

Digging date	%ELK	%TSMK	%FP
	%		
Sep. 13-14	52 c	67 c	91 a
Sep. 17-23	54 b	69 b	90 a
Sep. 24-28	57 ab	70 b	88 a
Oct. 1-6	59 a	73 a	87 a
Oct. 8-14	58 a	73 a	87 a
Oct. 18-21	56 ab	73 a	82 b

[a]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$. Data were pooled over 5 experiments during 2003-2005.

Table 2.8. Significance of correlations among pod yield, market grade factors, days after peanut emergence, and heat correlation units for the cultivar Gregory in five experiments conducted during 2003-2005.

	Field B4, 2003		Field G2, 2004		Field F1, 2004		Field A2, 2004		Field F2, 2005	
Correlations[a,b]	p-value	r^2	p-value	r^2	p-value	rR^2	p-value	r^2	p-value	r^2
Yield vs. DAE	0.3437	0.42	0.0005	-0.66	0.0001	-0.90	0.0001	-0.87	0.1518	-0.30
Yield vs. HUA	0.0878	0.36	0.0326	-0.44	0.0001	-0.81	0.0003	-0.68	0.1264	-0.32
Yield vs. %ELK	0.4033	0.18	0.4808	0.16	0.4029	0.18	0.8333	-0.05	0.1775	0.29
Yield vs. %TSMK	0.6383	0.10	0.8832	-0.03	0.4176	-0.18	0.0163	-0.52	0.4531	0.16
Yield vs. %FP	0.6883	0.09	0.0003	0.70	0.0437	0.42	0.0088	0.56	0.0001	0.72
%ELK vs. DAE	0.0011	0.63	0.2438	0.25	0.8510	0.04	0.2295	0.27	0.2919	0.22
%ELK vs. HUA	0.0009	0.64	0.0185	0.49	0.6764	0.09	0.0653	0.41	0.1640	0.29
%ELK vs. TSMK	0.0001	0.74	0.0011	0.64	0.0001	0.72	0.0009	0.67	0.0001	0.95
%ELK vs. %FP	0.3048	-0.22	0.0249	0.48	0.0834	0.37	0.3484	0.22	0.5423	0.13
%TSMK vs. DAE	0.0001	0.80	0.1628	0.30	0.1190	0.33	0.0014	0.65	0.0117	0.51
%TSMK vs. HUA	0.0002	0.69	0.0584	0.40	0.1063	0.35	0.0010	0.66	0.0042	0.56
%TSMK vs. %FP	0.0087	-0.52	0.7680	-0.07	0.2031	0.28	0.0764	-0.40	0.9144	0.02
%FP vs. DAE	0.0019	-0.60	0.0298	-0.46	0.0577	-0.40	0.0067	-0.57	0.1657	-0.29
%FP vs. HUA	0.0135	-0.50	0.3949	-0.19	0.0618	-0.40	0.0310	-0.47	0.0971	-0.35

[a]Abbreviations: DAE, days after peanut emergence; HUA, heat unit accumulation; %ELK, percentage extra large kernels; %TSMK, percentage total sound mature kernels; %FP, percentage fancy pods.

[b]Pearson correlation coefficient was calculated as a measure of similarity between each pair of factors.

Table 2.9. Significance of correlations between pod reflectance and pod yield, market grade factors, heat correlation units, and days after peanut emergence in the cultivar Gregory in experiments conducted during 2003 and 2004.

Correlations[a,b]	p-value	r^2	Correlations[a,b]	p-value	r^2
Yield vs. JumboL	0.0049	0.29	%FP vs. JumboL	0.8351	0.02
Yield vs. Jumboa	0.7852	0.03	%FP vs. Jumboa	0.6092	-0.06
Yield vs. Jumbob	0.0013	0.34	%FP vs. Jumbob	0.8568	0.02
Yield vs. FancyL	0.9756	-0.01	%FP vs. FancyL	0.6170	-0.05
Yield vs. Fancya	0.0855	0.18	%FP vs. Fancya	0.9998	0.00
Yield vs. Fancyb	0.2275	0.13	%FP vs. Fancyb	0.8742	-0.02
%ELK vs. JumboL	0.9884	0.01	HUA vs. JumboL	0.3075	0.11
%ELK vs. Jumboa	0.0626	0.20	HUA vs. Jumboa	0.0015	0.33
%ELK vs. Jumbob	0.6910	-0.04	HUA vs. Jumbob	0.7659	0.03
%ELK vs. FancyL	0.0350	0.23	HUA vs. FancyL	0.0286	0.23
%ELK vs. Fancya	0.3216	0.11	HUA vs. Fancya	0.5170	0.21
%ELK vs. Fancyb	0.1718	0.15	HUA vs. Fancyb	0.1612	0.15
%TSMK vs. JumboL	0.8772	-0.02	DAE vs. JumboL	0.6818	0.04
%TSMK vs. Jumboa	0.4797	0.08	DAE vs. Jumboa	0.5299	0.07
%TSMK vs. Jumbob	0.3931	-0.09	DAE vs. Jumbob	0.6775	0.04
%TSMK vs. FancyL	0.0160	0.26	DAE vs. FancyL	0.5365	0.07
%TSMK vs. Fancya	0.9519	0.01	DAE vs. Fancya	0.4139	-0.09
%TSMK vs. Fancyb	0.1819	0.14	DAE vs. Fancyb	0.7497	0.03

[a]Abbreviations: DAE, days after peanut emergence; HUA, heat unit accumulation; %ELK, percentage extra large kernels; %TSMK, percentage total sound mature kernels; %FP, percentage fancy pods.

[b]Pearson correlation coefficient was calculated as a measure of similarity between each pair of factors.

Table 2.10. Analyses of variance for pod yield, percentage of extra large kernels (%ELK), percentage of total sound mature kernels (%TSMK), and percentage of fancy pods (%FP) when the cultivar NC 12C was dug on five different dates during 1998 and 2005.

Treatment factors	Pod yield kg/ha	%ELK	%TSMK	%FP
	p-value			
Year	0.0001	0.0001	0.0001	0.0001
Digging date	0.0005	0.0001	0.0003	0.0007
Year X Digging date	0.4821	0.3590	0.6012	0.0001
Coefficient of variation (%)	10.3	4.7	3.0	4.2

Table 2.11. The influence of digging date on percentage of extra large kernels (%ELK), percentage of total sound mature kernels (%TSMK), and percentage of fancy pods (%FP) for the cultivar NC 12C.[a]

Digging date	Pod yield	%ELK	%TSMK	%FP	
				1998	2005
	kg/ha	%			
Sep.13	4800 c	50 d	74 c	87 a	69 c
Sep. 21	4920 bc	56 c	75 b	81 b	72 c
Sep. 28	5870 a	62 b	77 ab	87 a	85 a
Oct. 4	5990 a	65 a	79 a	84 ab	79 b
Oct. 14	5450 ab	64 ab	79 a	84 ab	69 c

[a]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$. Data for pod yield, %ELK, %TSMK, and %FP are pooled over experiments during 1998 and 2005.

Table 2.12. Significance of correlations among pod yield, market grade factors, days after peanut emergence, and heat unit accumulations for the cultivar NC 12C in two experiments conducted during 1998 and 2005.

	1998		2005		Pooled	
Correlations[a,b]	p-value	r^2	p-value	r^2	p-value	r^2
Yield vs. DAE	0.0056	0.60	0.1887	0.31	NS	NS
Yield vs. HUA	0.0035	0.62	0.1701	0.32	NS	NS
Yield vs. %ELK	0.0001	0.81	0.0010	0.68	NS	NS
Yield vs. %TSMK	0.0001	0.79	0.0023	0.64	NS	NS
Yield vs. %FP	0.0325	0.48	0.5868	0.13	0.0052	0.43
%ELK vs. DAE	0.0001	0.87	0.0005	0.71	NS	NS
%ELK vs. HUA	0.0001	0.87	0.0001	0.76	NS	NS
%ELK vs. %TSMK	0.0001	0.88	0.0001	0.78	NS	NS
%ELK vs. %FP	0.0678	0.42	0.7136	-0.09	0.0143	0.39
%TSMK vs. DAE	0.0001	0.76	0.0304	0.49	NS	NS
%TSMK vs. HUA	0.0003	0.73	0.0181	0.52	NS	NS
%TSMK vs. %FP	0.0389	0.47	0.8459	-0.05	0.0049	0.44
%FP vs. DAE	0.4143	0.19	0.0003	-0.73	0.0455	-0.32
%FP vs. HUA	0.7623	0.07	0.0025	-0.64	0.0052	-0.43

[a]Abbreviations: DAE, days after peanut emergence; HUA, heat unit accumulation; %ELK, percentage extra large kernels; %TSMK, percentage total sound mature kernels; %FP, percentage fancy pods.

[b] Pearson correlation coefficient was calculated as a measure of similarity between each pair of factors.

Table 2.13. Analysis of variance for percentage of mature pods (%MP), pod yield, and percentages of extra large kernels (%ELK), total sound mature kernels (%TSMK), and fancy pods (%FP) for the cultivar VA 98R .

Treatment factors	%MP	Pod yield	%ELK	%TSMK	%FP
	p-value				
Year	0.8492	0.0001	0.0038	0.0001	0.0001
Planting date	0.0001	0.0001	0.2825	0.3474	0.0627
Year X Planting date	0.0087	0.0001	0.0099	0.7477	0.1059
Coefficient of variation (%)	13.4	6.9	7.9	3.2	4.2

Table 2.14. Interaction of year and planting date for percentage of mature pods and pod yield for the cultivar VA 98R for experiments conducted during 2003, 2004, and 2005.[a]

Planting date	Percentage of mature pods[b]			Pod yield		
	2003	2004	2005	2003	2004	2005
	%			kg/ha		
May 2-5	67 a	68 a	60 a	2980 c	5800 b	5520 a
May 15-18	55 ab	67 a	52 a	4090 a	6600 a	5020 ab
May 25-27	41 bc	40 b	51 a	3110 c	5680 b	5250 ab
June 4 or 6	22 c	22 c	38 b	3530 b	4520 c	4570 b

[a]Means within a year for each parameter followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$.

[b]Pod mesocarp color determined in mid-September for all planting dates.

Table 2.15. Interaction of year and planting date for percentages of extra large kernels (%ELK), percentage of total sound mature kernels (%TSMK), and percentage of fancy pods (%FP) for the cultivar VA 98R for experiments conducted during 2003, 2004, and 2005.[a]

Planting date	%ELK			%TSMK			%FP		
	2003	2004	2005	2003	2004	2005	2003	2004	2005
	%								
May 2-5	44 a	46 a	46 a	70 a	74 a	70 a	87 a	78 a	74 ab
May 15-18	46 a	44 a	45 a	70 a	77 a	70 a	84 a	76 a	73 ab
May 25-27	46 a	34 b	47 a	71 a	77 a	70 a	86 a	72 a	76 a
June 4 or 6	46 a	41 a	43 a	72 a	77 a	70 a	83 a	75 a	70 b

[a]Means within a year for each parameter followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$.

Table 2.16. Interaction of year and planting date for percentage of mature pods and pod yield for the cultivar NC-V 11 for experiments conducted during 2003, 2004, and 2005.[a]

Planting date	Percentage of mature pods[b]			Pod yield		
	2003	2004	2005	2003	2004	2005
	%			kg/ha		
May 5	-	69 a	69 a	-	4230 a	4580 a
May 16	37 a	-	59 a	3080 a	-	4990 a
May 25	-	-	40 b	-	-	4100 a
June 4 or 6	26 b	15 b	17 c	3420 a	3710 a	4010 a

[a]Means within a year for each parameter followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$.

[b]Pod mesocarp color determined in mid-September for all planting dates.

Table 2.17. Interaction of year and planting date for percentages of extra large kernels (%ELK), percentage of total sound mature kernels (%TSMK), and percentage of fancy pods (%FP) for the cultivar NC-V 11 for experiments conducted during 2003 to 2005.[a]

Planting date	%ELK		%TSMK		%FP	
	2003	2005	2003	2005	2003	2005
	%					
May 5	-	51 a	-	71 a	-	77 a
May 15	37 a	37 a	70 a	67 a	74 a	76 a
May 25	-	46 a	-	70 a	-	71 a
June 4 or 6	37 a	45 a	72 a	70 a	70 a	74 a

[a]Means within a year for each parameter followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$. Market grades were not determined during 2004.

Table 2.18. Analysis of variance for pod yield when the cultivars Perry and VA 98R were planted in single and twin row planting patterns.

Treatment factors	Pod yield
	p-value
Year	0.0040
Planting pattern	0.0120
Cultivar	0.0948
Year X Planting pattern	0.2967
Year X Cultivar	0.0001
Planting pattern X Cultivar	0.1962
Year X Planting pattern X Cultivar	0.4725
Coefficient of variation (%)	10.0

Table 2.19. Influence of planting pattern and cultivar on peanut yield.[a]

	Treatment factor			
	Cultivar[a]		Planting pattern[b]	
Year	VA 98R	Perry	Single row	Twin row
	kg/ha			
2003	4760	5210	-	-
2004	4790	3980*	-	-
2005	4950	6040*	-	-
Pooled	-	-	4760	5140*

[a]* indicates significance at $p \leq 0.05$ within a year. Data were pooled over planting patterns.

[b]* indicates significance at $p \leq 0.05$. Data were pooled over years and cultivars.

Table 2.20. Analysis of variance for pod yield for the cultivars Gregory and Georgia Green dug at two dates spaced approximately two weeks apart.

Treatment factors	Pod yield
	p-value
Year	0.0001
Cultivar	0.2814
Digging date	0.0001
Year X Cultivar	0.0070
Year X Digging date	0.0057
Year X Cultivar X Digging date	0.0001
Coefficient of variation (%)	11.8

Table 2.21. Analysis of variance for pod yield for the cultivars Gregory and Georgia Green dug at two dates spaced approximately two weeks apart in six experiments conducted 2003, 2004, and 2005.

	Lewiston-Woodville				Rocky Mount	
Treatment factors	2003	Field G2, 2004	Field F1, 2004	2005	2003	2004
	p-value					
Cultivar	0.9325	0.0437	0.0343	0.2381	0.1550	0.5965
Digging date	0.1909	0.0001	0.0147	0.8315	0.3946	0.0810
Cultivar X Digging date	0.1608	0.0014	0.0024	0.1914	0.6888	0.8613
Coefficient of variation (%)	11.1	6.9	17.4	11.5	11.4	8.5

Table 2.22. Peanut pod yield as influenced by cultivar and digging date from six experiments conducted during 2003, 2004, and 2005.[a]

Cultivar	Approximate digging date	Lewiston-Woodville				Rocky Mount	
		2003	Field G2, 2004	Field F1, 2004	2005	2003	2004
		kg/ha					
Gregory	Sep. 20	3560 a	3970 a	5160 a	4930 a	3410 a	5920 a
Gregory	Oct. 5	3580 a	2620 c	2480 b	5270 a	3670 a	5410 a
Georgia Green	Sep. 20	3850 a	3710 ab	4530 a	4970 a	3190 a	6020 a
Georgia Green	Oct. 5	3260 a	3440 b	4960 a	4510 a	3280 a	5580 a

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

Table 2.23. Analyses of variance for reflectance recorded on the same day when the cultivar Gregory was dug in late September or early October or when the cultivars VA 98R or NC-V 11 were planted on different dates.

Bandwidth categories (nm)	Digging date experiments with the cultivar Gregory		Planting date experiments					
			NC-V11			VA 98R		
	Field G2	Field F1	2003	2004	2005	2003	2004	2005
	p-value							
350-399	0.2274	0.7790	0.6401	0.5641	0.6183	0.7921	0.8460	0.8534
400-450	0.8149	0.8540	0.0377	0.5282	0.0073	0.2520	0.951	0.4006
470-500	0.8024	0.7060	0.0687	0.4476	0.0192	0.8689	0.9359	0.9607
500-590	0.4877	0.6963	0.3438	0.4331	0.1775	0.5307	0.9979	0.6903
590-680	0.3542	0.2170	0.0473	0.4620	0.2683	0.4309	0.6033	0.7821
680-700	0.2636	0.2400	0.7665	0.7018	0.7109	0.6936	0.0205	0.6735
700-760	0.0497	0.0060	0.8724	0.8529	0.8812	0.6679	0.0173	0.6213
800	0.0345	0.0059	0.9829	0.8627	0.8329	0.6553	0.0200	0.5053
950-999	0.0154	0.0127	0.4640	0.9179	0.5262	0.4645	0.0484	0.6931
1000-1049	0.0186	0.0141	0.5293	0.9940	0.6601	0.7423	0.0753	0.6845
MIR	0.0128	0.0099	0.7445	0.4473	0.8740	0.7711	0.2000	0.0764
UMIR	0.0305	0.0772	0.5579	0.9203	0.7375	0.8702	0.2360	0.7021
NDVI	0.9390	0.9024	0.6422	0.0221	0.9878	0.3624	0.9270	0.7915

Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

Table 2.24. Differences in magnitude of reflectance in mid-September compared with early October for the cultivar Gregory in two experiments during 2004.[a]

	Bandwidth category (nm)							
	Field G2, 2004				Field F1, 2004			
Date	700-760	800	950-999	1000-1049	700-760	800	950-999	1000-1049
	relative units							
Mid-September	17.4	18.5	18.9	20.1	8.0	8.3	9.5	11.1
Early October	20.8*	22.4*	23.2*	24.3*	10.6*	11.7*	13.6*	15.8*

[a]* indicates significance when comparing means within a bandwidth category for a field at $p \leq 0.05$.

Table 2.25. Difference in magnitude of reflectance at specific bandwidths when the peanut cultivar VA 98R was planted on four dates from early May through early June during 2004.[a]

	Bandwidth category (nm)				
Planting date	680-700	700-760	800	950-999	1000-1049
	relative units				
May 5	15.2 c	15.2 d	16.6 c	17.8 c	18.8 b
May 15	17.6 a	19.2 c	20.4 b	20.9 b	22.6 a
May 25	14.5 c	22.5 a	23.9a	24.0 a	24.8 a
June 4	16.3 b	22.0 b	23.2 a	23.0 ab	24.5 a

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

Table 2.26. Difference in magnitude of reflectance at specific bandwidths when the peanut cultivar NC-V 11 was planted in mid- and late May during 2003 and from early May through early June during 2005.[a]

	Reflectance in the bandwidth category of 400-450 nm	
Planting date	2003	2005
	relative units	
May 5	-	6.4 b
May 15	7.2 a	5.0 c
May 25	-	7.0 a
June 4	4.3 b	5.7 b

[a]Means within a bandwidth for each year followed by the same letter are not significantly different according to Fisher's Protected LSD Test at $p \leq 0.05$.

Table 2.27. Analyses of variance for reflectance on the same day in mid- to late September when comparing the peanut cultivars Gregory and Georgia Green for experiments conducted during 2003 and 2004.[a]

Bandwidth category (nm)	Reflectance for cultivars Gregory and Georgia Green	
	2003	2004
	p-value	
350-399	0.5080	0.5680
400-450	0.5884	0.5843
470-500	0.4811	0.7223
500-590	0.0277	0.0415
590-680	0.2848	0.0045
680-700	0.0001	0.0001
700-760	0.8221	0.0784
800	0.0051	0.0001
950-999	0.0007	0.0019
1000-1049	0.9463	0.0033
MIR	0.3316	0.2317
UMIR	0.1218	0.0830
NDVI	0.0306	0.0080

[a]Abbreviations: MIR, mid infrared; UMIR, far infrared; NDVI, normalized difference vegetation index.

Table 2.28. Difference in magnitude of reflectance at specific bandwidths when comparing the peanut cultivars Gregory and Georgia Green in experiments conducted during 2003 and 2004.[a,b]

	Reflectance			
	2003		2004	
Bandwidth category (nm)	Gregory	Georgia Green	Gregory	Georgia Green
	relative units			
500-590	14.7	8.8*	3.0	2.3*
590-680	7.1	5.4	3.1	2.2*
680-700	28.8	24.0*	24.7	18.0*
800	29.9	25.0*	26.1	19.2*
950-999	25.7	23.8*	26.1	20.1*
1000-1049	25.4	24.8	27.8	21.3*
NDVI	0.43	0.25*	0.38	0.13*

[a]* indicates significance within a bandwidth when comparing reflectance of cultivars at $p \leq 0.05$.

[b]Abbreviations: NDVI, normalized difference vegetation index.

Table 2.29. Analyses of variance for reflectance on the same day in mid- to late September when comparing the peanut cultivars VA 98R and Perry planted in single or twin row planting patterns.[a]

	Bandwidth categories (nm)											
Treatment factor	300-350	400-450	470-500	500-590	680-700	700-760	800	950-999	1000-1049	MIR	UMIR	NDVI
	p-value											
Year	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Cultivar	0.7091	0.4641	0.2232	0.1406	0.1867	0.3848	0.3455	0.2367	0.3333	0.8851	0.0785	0.1413
Planting pattern	0.0827	0.3316	0.5220	0.7696	0.7168	0.5065	0.4034	0.6576	0.5868	0.3663	0.4878	0.9123
Year X Cultivar	0.7652	0.6977	0.5265	0.2547	0.0860	0.7348	0.7122	0.1311	0.2115	0.1506	0.1351	0.0517
Year X Planting pattern	0.8509	0.1432	0.1992	0.3758	0.9926	0.2310	0.1793	0.6704	0.7448	0.0992	0.1685	0.8139
Cultivar X Planting pattern	0.2258	0.4924	0.7358	0.9958	0.0206	0.7445	0.7090	0.5968	0.6169	0.3242	0.2959	0.2747
Year X Cultivar X Planting pattern	0.9885	0.6903	0.6805	0.9387	0.0275	0.8773	0.8809	0.9916	0.9476	0.1513	0.0785	0.2189
Coefficient of variation (%)	19.4	17.5	20.6	19.4	37.6	22.9	21.3	17.7	18.7	17.5	21.3	19.9

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

CHAPTER III

Signatures Developed from Hyperspectral Imaging of Peanut (*Arachis hypogea* L.) Experiencing Abiotic and Biotic Stress

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Abstract

Hyperspectral imaging can be used to define a variety of abiotic and biotic stresses associated with crop production and management. This study was conducted during 2004 and 2005 to develop spectral signatures of peanut with visual symptoms of nitrogen (N) deficiency, injury from a combination of low pH and Zinc (Zn) toxicity, drought stress, early leaf spot (*Cercospora arachidicola* Hori) and web blotch (*Phoma arachidicola* Marasas *et al.*) lesions, and following application of herbicides. Single leaf measurements using an artificial light source were used to develop spectra ranging from 350 to 2500 nm. In the N deficiency trails, significant differences were observed in the visible range (470-700 nm). However, differences between treatments were also significant for the near infrared (NIR), mid infrared (MIR), upper mid infrared (UMIR), and normalized difference vegetation index (NDVI). Much of the time, asymptomatic plants (from the inoculated treatment) displayed higher wavelengths than inoculated plants with no N deficient symptoms from the noninocuolated treatment. Drought affected reflectance at all bandwidths except the NDVI nm range ($p = 0.0565$). Reflectance for the healthy leaves was lower than the drought-affected leaves in each portion of the spectrum. Additionally, Zn toxicity affected all bandwidths except the

350-399 range. Chlorotic plants had lower reflectance compared to control plants for each bandwidth category. Unlike N deficient plants, however, reflectance was suppressed across all Zn deficient treatments. Reflectance differed when leaf spot lesions were present compared with healthy leaves. However, fewer differences among bandwidth categories were noted in the case of leaves with foliar diseases than in the nutrient or drought studies. Significant differences in bandwidth were from 590-680 nm, 700-2400 nm, and the NDVI category. While many of the differences in reflectance were noted in the infrared portions of the spectrum for the leaves with symptoms of foliar diseases, differences in reflectance in plants displaying tomato spotted wilt (TSW) were mainly in the visible portion. Herbicide treatments, which included the application of acifluorfen, bentazon, clethodim, imazapic, paraquat, or 2,4-DB were followed with reflectance measurements at 3 and 24 hours, 3 and 6 days after application. The interaction of timing of application X herbicide was significant at bands 470-500, 500-590, 800, and UMIR, for 3 and 24 hours after treatment, and 470-500, 500-590, 680-700, 800, and UMIR after 3 and 6 days after treatment. Reflectance differed when herbicides were compared at each timing after application. Results suggest that differentiation among herbicide affects and nutrient- and drought-stress plants using this technology is difficult due to the similarities in spectral characteristics.

Key Words: disease management, drought stress, herbicide damage, multispectral imaging, NDVI, nitrogen deficiency, soil pH, weed management, Zn toxicity

Introduction

Peanut (*Arachis hypogea* L.) is an economically important crop in North Carolina and the southern region of the United States (NCDA, 2006). Managing peanut and making decisions to implement production and pest management practices can be challenging. While the possibility of using remote sensing technology with hyperspectral or multispectral imaging to follow crop stress has been addressed in some crops, research with peanut is limited.

Research from a number of agricultural studies indicates that reflectance in certain crops is influenced at certain wavelengths by a variety of environmental factors. Some of these include stress due to weeds, water, and nutrient deficiencies or excesses (Brien *et al*., 2004; Kokaly, 2001; Koger *et al*., 2004a; 2004b; Malthus and Madeira, 1993; Shaw, 2005). For example, plant leaves with higher N content have greater spectral reflectance in certain blue (450-500 nm) and near infrared (NIR) wavebands (700-940 nm) (Serrano *et al*., 2000). Taylor *et al*. (1998) demonstrated that spectral measurements in the red (650-700 nm), green (500-550 nm), and NIR ranges could be used to estimate forage yield in bermudagrass [*Cynodon dactylon* (L.) Pers.]. Other research has focused on crops infested with fungal pathogens, where the red, green and NIR bands were used to help characterize biophysical features of diseased and healthy plants (Apan *et al*., 2004; Thenkabail *et al*., 2000).

Chlorophyll concentration, which has been demonstrated to be an indicator of nutritional stress, photosynthetic capacity, and senescence can be detected using red-shoulder (800 nm) or red-edge (690-750 nm) reflectance (Baranoski and Rokne, 2005). This region characterizes the boundary between dominance by the strong absorption of red light by chlorophyll and the high scattered radiation in the leaf mesophyll.

Fluorescence occurs when red and far-red light is emitted from green plants in response to excess stimulation by photosynthetically active radiation. Changes in chlorophyll function often precede changes in chlorophyll content so that it is possible to observe changes in the red-edge reflectance before chlorosis may be visually observed in the leaves (Smith *et al*., 2004). The red-edge region has also been tested as an index of plant stress (Smith *et al*., 2004). Nutter and Littrell (1996) examined peanut late leaf spot defoliation caused by *Cercosporidium personatum* (Berk. & M. A. Curtis), using the red-shoulder region of the spectrum. They reported significant reflective differences between the healthy green foliage and the diseased foliage. Aquino *et al*. (1992) found that canopy reflectance, also at the 800 nm band in peanuts affected by *C. personatum* decreased as disease severity and defoliation increased throughout the season.

Spectral reflectance has been used to examine specific changes of leaf reflectance due to nutrient deficiencies. Masoni *et al*. (1996) used spectral properties from barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), and sunflower (*Helianthus annuus* L.) leaves to detect iron (Fe), sulfur (S), magnesium (Mg), and manganese (Mn) deficiencies. Graeff *et al*. (2001) reported that the wavelength ranges of 380-390 nm, 430-780 nm, 516-780 nm, and 540-600 nm provided good prediction of N, phosphorus (P), Mg, and Fe status of corn (*Zea mays* L.) because reflectance changed when levels of the nutrients were low. Spectral measurements were also useful for establishing critical levels for Mn, zinc (Zn), Fe, and copper (Cu) under controlled conditions. However, they are reported that Fe and Zn deficiencies were not discriminated very well.

Nitrogen content has been studied frequently with respect to spectral properties. Bands also in the green region of the visible spectrum have also been reported to be relatively important in determining turf quality in selected turf grass species under drought stress

(Jiang and Carrow, 2005). In studies of sorghum [*Sorghum bicolor* (L.) Moench], Zhao et al. (2005) reported that nitrogen-deficit stress mainly increased leaf reflectance at 555 nm and 715 nm and caused a red-edge shift to shorter wavelength. Similar research conducted in corn, found that the ratio of light reflectance between 550 and 600 nm to light reflectance between 800 and 900 nm also provided sensitive detection of N stress (Blackmer *et al*., 1996). In an effort to maximize N application in winter wheat (*Triticum aestivum* L.), Flowers *et al*. (2001) investigated the relationship of tiller density to spectral indices and individual NIR, green, red, and blue bands, and reported that tiller density was consistently positively correlated with the NIR region. Osborne *et al*., (2004) reported that the green waveband and normalized difference greenness vegetation index had the greatest ability to estimate grain yield in the presence of varying N and/or drought stresses. Spectral measures sensitive specifically to water stress have been developed and are capable of separating drought stressed leaves from N stressed and control leaves (Penuelas *et al*., 1993, 1994).

In studies in soybean [*Glycine max* (L.) Merr.], herbicide or herbicide rate had a significant effect on normalized differential vegetation indices (NDVI) values derived from a multispectral ground-based radiometer in four of six site-years (Thelen *et al*., 2004). In addition, Nelson and Renner (2001) reported an increase in the red to far-red light reflectance ratio in soybean treated with lactofen {ethyl *O*-[5-(2-chloro-α,α,α-trifluoro-*p*-tolyloxy)-2-nitrobenzoyl]-DL-lactate} when compared with glyphosate [*N*-(phosphonomethyl)glycine] and bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] treatments.

Reflectance has also been shown to vary with leaf disease in some crops (Moshou *et al*., 2004; Pozdnyakova, *et al*., 2002; Sconyers *et al*., 2005). Malthus and Madeira (1993) were able to correlate specific wavelengths with increased incidence of chocolate spot (*Botrytis fabae* Sard.) infection in field bean (*Vicia faba* L) Newton *et al.* (2004) reported that reflectance measurements could be used to aid in accurate estimate of disease and yield response to fungicide in barley (*Hordeum vulgare* L.). However, cultivar and developmental stage had a large influence on measurements. Nutter *et al.* (1990) used a handheld multispectral radiometer to compare visual and spectral assessments of foliar diseases as a means of measuring fungicide efficacy in peanut. In all but one case, they were able to determine that percent reflectance increased linearly as disease incidence and severity decreased. Reflectance measurements were correlated more closely with pod yield than the traditional visual assessments leading the researchers to suggest that reflectance measurements from peanut canopies can provide more accurate means to evaluate fungicide efficacy in peanuts.

Certain nutrients reveal a unique spectral signature and remote sensing can be used to help detect these deficiencies (Bouman 1992; Curran *et al*., 1992; Kokaly, 2001; Nilsson, 1995). Serrano *et al*. (2000) determined that N fertilization promoted significant increases in plant growth and, to a lesser extent, in radiation use efficiency. To successfully implement remote sensing technology, signatures for a variety of stresses are necessary along with accurate ground checking to define signatures and accompanying abiotic or biotic stress. The objective of this research was conducted to develop signatures for a variety of stresses associated with peanut.

Materials and Methods

Procedures common to all experiments. Leaf reflectance in the form of radiant energy was taken as close to solar noon as possible, with a cloudless sky, using a portable spectroradiometer (ASD "FieldSpec Pro", Analytical Spectral Devices, Inc., Bolder, CO), and an ASD Leaf Clip (Analytical Spectral Devices, Inc., Bolder, CO). Leaf measurements were taken using an internal light source, found within the leaf clip. Five individual leaves per plot were measured nondestructively, for five consecutive readings, for a total of fifty reflectance measurements per plot. Individual bandwidths from 350 to 2500 nanometers (nm) were averaged for each leaf reading, and those readings were then averaged to get five individual readings at each bandwidth for an individual plot. Then, bandwidths were combined into eleven bandwidth groupings based on their location in the spectrum (350-399, 400-449, 470-500, 500-590, 590-700, 700-760, 800, 950-999, 1000-1049, 1550-1750, and 2000-2400 nm) for analysis (Table 3.1). Because broad bands (from 10 to 70 nm in width) in the visible (400-760) and near-infrared (NIR) (800-1049) regions of the spectrum have been demonstrated to be optimum for estimating crop biophysical information (Thenkabail, *et al*., 2000) bands within this region were used for analysis, as were bands in the mid infrared (MIR) (1550-1750) and upper middle infrared (UMIR) (2000-2400). Portions of the spectrum coincide with water absorption bands [mid-infrared (1350-1450 nm) and far-infrared (1800-1950 nm)], which obscure reflectance measurements, and were not used for this analysis (Hatfield and Pinter, 1993).

Bandwidths were subjected to statistical analyses based on the bandwidth groupings. The only spectral index used was the normalized difference vegetation index (NDVI), which was calculated using NDVI = near infrared – red/near infrared + red. The NDVI, a number between –1 and +1, quantifies the relative difference between the near infrared reflectance 'peak' and red reflectance 'dip' in the spectral signature. Pooled data were subjected to analysis of variance (SAS Systems Software, Cary, NC).

Reflectance of nitrogen deficient peanut. This experiment was conducted in during 2005 near in commercial fields Faison and Whiteville and at the Upper Coastal Plain Experiment Station located near Rocky Mount. Soil at Rocky Mount was a Goldsboro sandy loam (fine-loamy, siliceous, thermic Aquic Paleudalts). Soil at Faison was Autryville fine sandy loam (fine-loamy, siliceous, thermic, Typic Paleudults) and the soil at Whiteville was Norfolk loamy sand (fine-loamy, siliceous, thermic, Typic Paleudults). Plot size was two rows spaced 91 cm apart by 12 m. Seeds were placed 5 to 8 cm deep depending on soil moisture and granular aldicarb (Temik, Bayer Crop Science, Research Triangle Park, NC) at 7.8 kg ai/ha was applied in the seed furrow prior to seed drop. The in-row plant population was 13 plants/m. Peanut was not planted in these fields during previous years.

Treatments consisted of no inoculant or *Bradyrhizobia* sp. (Lift, Nitragin Corp., Brookfield, WI) as an in-furrow spray at 1.1 L/ha applied immediately after seed drop but before row drill closure. This rate of product delivers 2.2 X 10^{12} viable cells/ha at this row spacing. The cultivar NC-V 11 was planted at Faison and Whiteville; the cultivar VA 98R was planted at Rocky Mount. Foliage of peanut not receiving inoculant was yellow and nodules were not present on roots of plants. Reflectance was measured in early August at all locations. Production and pest management practices were held constant across the experiment and were based on NC Cooperative Extension Service recommendations (Brandenburg, 2006; Jordan, 2006a 2006b; Shew, 2006).

For trials conducted at Whiteville and Fasion, peanut pods were dug and vines inverted for each planting date based on pod mesocarp color (Johnson *et al*., 1993; Jordan *et al*., 2005; Williams and Drexler, 1981). Peanut was combined 4 to 7 days after digging and dried to a final moisture of 8%. Yield was not recorded at Rocky Mount.

Reflectance of peanut with Zn toxicity. The experiment was conducted at the Peanut Belt Research Station located near Lewiston-Woodville and at Rocky Mount, NC. Soils at Lewiston-Woodville and Rocky Mount were Norfolk sandy loams (fine-loamy, siliceous, thermic, Typic Paleudults). A specific regiment of treatments was not established in this experiment. However, peanut with visual symptoms of Zn toxicity were used to develop reflectance data because peanut in certain areas of the field exhibited symptoms of severe Zn toxicity. In both fields, buildings with galvanized metal roofing had been present in the past, and Zn washed from the roof by rain caused the concentration of Zn in the soil to increase to toxic levels. Peanut in close proximity without visual symptoms were used as controls. The cultivar in both fields was NC-V 11. Tissue and soil samples from areas with toxicity symptoms were taken and analyzed according to NCDA&CS specifications (NCAGR, 2004).

Reflectance of peanut growing under drought stress. The experiment was conducted in North Carolina at the Peanut Belt Research Station located near Lewiston-Woodville in two separate fields during 2005. Soil was Norfolk sandy loam as described previously. Similar to the experiments which evaluated nutrient deficiencies, a specific regiment of treatments was not established. However, peanut with visual symptoms of drought stress, such as wilted leaves, in a field with portions of peanut under irrigation were used to develop reflectance data. Peanut in close proximity without visual symptoms of drought stress grown under irrigation were used as controls. The cultivar in both fields was NC-V 11.

Reflectance of diseased leaves. The experiment was conducted at the Peanut Belt Research Station located near Lewiston-Woodville,NC in four fields during 2004. Soil was Norfolk sandy loam as described previously. Similar to experiments which evaluated nutrient and drought stressed peanut, a specific regiment of treatments was not established. However, peanut leaves with visible lesions caused by early leaf spot or web blotch were used to assess reflectance compared to leaves without visible lesions. In a separate experiment conducted during 2004 and 2005, reflectance of peanut expressing visible symptoms of TSW was compared with healthy plants without visual symptoms of TSW. Tap-root samples were not taken, so plants considered healthy could still have potentially been a carrier of TSW.

Reflectance following herbicide applications. This experiment was conducted at the Peanut Belt Research Station located near Lewiston-Woodville, NC in two separate fields during 2005. Soil was the same Norfolk sandy loam as described previously. Plot size was two rows spaced 91 cm apart by 6 m. The peanut cultivar Gregory was seeded in conventionally prepared seedbeds to establish an in-row density of 13 plants/m.

Treatments consisted of postemergence application of acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid} at 0.44 kg ai/ha, bentazon at 1.12 kg ai/ha, clethodim {(*E*,*E*)-(±)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} at 0.14 kg ai/ha, imazapic {(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl)]-5-methyl-3-pyridinecarboxylic acid} at 70 g ai/ha, paraquat (0.14 kg ai/ha), and 2,4-DB [2,4-(dichlorophenoxy)butanoic acid] at 0.28 kg ai/ha applied to peanut with a diameter of 30 cm in late June. A nonionic surfactant (Induce, Helena Chemical Corp., Memphis, TN) at 0.25% (v/v) was applied with acifluorfen, bentazon, imazapic, and paraquat. A crop oil concentrate (Agri-Dex, Helena Chemical Corp., Memphis, TN) at 1.0% (v/v) was applied with clethodim. Adjuvant was not applied with 2,4-DB. Herbicides were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L/ha using regular flat fan nozzles (Spraying Systems Co., Wheaton, IL). Reflectance was recorded 3 and 24 hours, and 3 and 6 days after treatment using an ASD Leaf Clip assembly attached to the spectroradiometer (ASD "FieldSpec Pro", Analytical Spectral Devices, Inc., Bolder, CO).

Statistical analyses. The experimental design was randomized complete block in all experiments. Data for bands (350-399, 400-449, 470-500, 500-590, 590-700, 700-760, 800, 950-999, 1000-1049, 1550-1750, and 2000-2400 nm, and NDVI – Table 3.1) were subjected to analysis of variance (SAS systems software, Cary, NC). Unless otherwise noted, data were pooled over experiment or location. Means were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Results and Discussion

Reflectance of nitrogen deficient peanut. There was no significant interaction between location and treatment ($p = 0.1964$). However differences were noted between the inoculated and noninoculated peanut (Table 3.2). Not surprisingly, differences were noted in the visible range (470-700 nm). Additionally, differences in reflectance between treatments were also significant for the NIR, MIR, UMIR, and NDVI. Much of the time, the asymptomatic plants (from the inoculated treatment) displayed higher wavelengths than the plants from the noninocuolated treatment (Table 3.3). However, in part of the NIR range, chlorotic leaves displayed a higher reflectance. The interaction of the solar radiation with plant leaves depends on their physical and biochemical characteristics, and the internal structure of the leaf plays a role in determining reflectance across the visible and NIR parts of the spectrum (Jackquemoud and Baret, 1990). Because N plays an important role in the building blocks of chlorophyll-proteins specific to photosystem II, a lack of N with in the plant would result in a reduction in photosynthetic capacity within individual leaves.

Yield increased when peanut was inoculated compared to yield of non-inoculated peanut. When data were pooled over locations, yield increased from 3140 kg/ha without inoculation to 4450 kg/ha with inoculation ($p = 0.0020$). Other research (Lanier *et al*., 2004) has shown the benefits of inoculating peanut in fields where peanut had not been planted previously.

Reflectance of peanut with Zn toxicity. The interaction of treatment X location was not significant (0.3702) for reflectance. Significant treatment differences were noted for all the bandwidths except the 350-399 range ($p = 0.1794$) when pooled over locations (Table 3.2). Unlike N deficient plants, however, reflectance was suppressed across Zn toxic treatment. Most interesting was that even in the yellow/orange range of the spectrum (680-700 nm), reflectance for the Zn toxic plants was dramatically lower (Table 3.4). Tissue analysis confirmed that plants at Lewiston-Woodville were suffering from Zn toxicity (Zn = 193 ppm), however, the control plots also had elevated levels of Zn (Zn = 121 ppm). In addition to plants expressing Zn toxicity at Lewiston-Woodville, plants were also suffering deficiencies for N, P, and S (1.58%, 0.10%, and 0.11%, respectively). Control plants also had high levels of Zn in the tissue, although they were not showing any chlorosis at the time reflectance was recorded. Control samples in Lewiston-Woodville were also low in potassium (K) (1.38%). Furthermore, while the NCDA&CS recommendations (NCDA, 2006) state that the pH range optimum for peanut production ranges from 5.8 to 6.0, soil samples taken from this field showed pH ranging from 4.7 to 5.0. Low pH can cause reduced nutrient uptake, and increased aluminum levels (Al) within the rooting zone. Ultimately the result is poor growth, reduced yields and quality, and decreased N fixation. Samples of tissue from Lewiston-Woodville did show a N deficiency in the Zn toxicity treatments, so it is difficult to separate Zn toxicity from N deficiency in this case. However, when the N deficient leaf reflectance and the Zn toxicity leaf reflectance were compared, the one consistency is that reflectance remains significantly lower in the bands from 350-680 nm for leaves that were chlorotic. Additionally, the NDVI was significant for both the N deficient and the Zn toxicity tests but not in the trial comparing drought-stressed plants. Adams *et al*. (2000) also found NDVI to be sensitive to nutrient deficiency in soybean. Research has shown that while select reflectance ratios and bandwidths can be used to identify stressed plants, the type of stress could not always be identified (Narayanan and Pflum, 1999).

Reflectance of peanut growing under drought stress. The interaction of treatment X location was not significant ($p = 0.4211$) for peanut under drought stress. The main effect of treatment was significant at all bandwidths except the NDVI nm range ($p = 0.0565$) (Table 3.2). In this case, reflectance of healthy leaves was higher than the drought-affected leaves in each portion of the spectrum studied (Table 3.3). This finding was consistent with findings from a study of leaf dehydration in spinach (*Spinacia oleracea* L.) (Aldakheel and Danson, 1997). Research on spinach leaves showed an increase in reflectance, over the course of 48 hour, throughout the 400-2500 nm region, but mostly between 1300-2500 nm. Conroy *et al*. (1986) researched drought-stressed Monterey pine (*Pinus radiate* D. Don) seedlings and reported that electron flow subsequent to photosystem II was negatively affected by drought stress, causing photosynthetic dysfunction in the individual leaves as well as cell disruption. Aldakheel and Danson (1997) hypothesized that the increase in reflectance of the dehydrating leaves may be attributed to a change in the compound effect of the internal structure of the cell.

The change in the spongy mesophyll structure influences the whole spectrum but the maximum impact is in the NIR where chlorophyll and water are minimal, allowing for less absorption of energy, and higher reflectance.

Reflectance of diseased leaves. The interaction of trial X treatment was not significant for leaf reflectance ($p = 0.0933$). While reflectance differed depending on the presence of lesions, there were fewer significant bandwidths in the case of leaves with foliar diseases than in the nutrient or drought studies. With the exception of 590-680 nm, all of the significant bandwidth categories were in the infrared range of the spectrum and ranged from 700-2400 nm (Table 3.5). The NDVI was also significant when comparing diseased and non-diseased leaves. Mean separation of control leaves and diseased leaves showed that in the IR regions of the spectrum, reflectance was consistent for diseased leaves across the upper portions of the spectrum. For bandwidths from 700-2400 nm, there were no differences between diseased leaves and the healthy control (Table 3.6). However, in the visible yellow/orange portion of the spectrum (590-680) differences between the control and the single lesion leaf spot and multiple lesions of leaf spot were not different from one another. Reflectance of leaves displaying web blotch, or web blotch and early leaf spot were different from the no-disease control and early leaf spot alone treatments. This change in the yellow/orange portion of the spectrum due to either early leaf spot or web blotch could be due to a change in the chlorophyll content in the leaves infested with web blotch. Malthus and Madeira (1993) reported that the greatest effect on reflectance in bean leaf suffering from chocolate spot was a decline in the height of the red shoulder at about 800 nm, which was attributed to a collapse in the leaf's cellular structure. Also, leaves with web blotch had a greater percentage of the leaf that was diseased which may have an affect on the spectral properties.

Leaves of plants showing obvious signs of TSW present an interesting contrast to the trial with the foliar diseases. While much of the differences in reflectance were noted in the infrared portions of the spectrum for the leaves with foliar diseases, reflectance differences in plants displaying TSW were primarily in the visible portion of the spectrum (Table 3.5 and Table 3.6). In this study, differences occurred from 350-700 nm, as well as UMIR and NDVI. In contrast, UMIR and NDVI were significant in the foliar disease study. This is in stark contrast to the plants with TSW, where all the visible range was significant. The mean separation showed that the diseased plants displayed a lower reflectance than the control plants in each case (Table 3.7).

Reflectance following herbicide applications. After 3 and 24 hours the interaction of herbicide X timing after application was significant at bands 470-500, 500-590, 800, and UMIR (Tables 3.8 and 3.10, respectively). When recorded three hours after application, reflectance differed when 2,4-DB was applied for bands 470-500, 500-590, and 800 nm (Table 3. 9). In the UMIR region, paraquat and bentazon displayed the highest reflectance (Table 3.9). Paraquat affects the membrane integrity of sensitive plants, and higher reflectance in the infrared range following application of paraquat may have resulted from membrane damage and adverse effects on cellular integrity (Grey and Wehtje, 2005).

After 24 hours, reflectance was higher following application of acifluorfen, imazapic, and 2,4-DB in the 470-500 nm range (Table 3.11). At 500-590 nm, reflectance was different following application of paraquat, imazapic, and acifluorfen to the control and following application of bentazon, clethodim, and 2,4-DB (Table 3.11). In the infrared range, paraquat had the highest reflectance. In the UMIR range, only acifluorfen was higher than the other treatments. Throughout the 24 hour period, reflectance following clethodim application and the non-treated control was similar. Peanut is able to metabolize clethodim rapidly into non-phototoxic metabolites which prevents injury with no effects on cellular function and most likely would result in no difference in reflectance (Teuton *et al*., 2004). It was not surprising that reflectance following application of paraquat differed because visible damage to leaves was expressed within several hours after application (Grey and Wehtje, 2005) (data not shown).

When reflectance was determined 3 and 6 days after application, the interaction of herbicide X timing after application was significant at bandwidth categories of 470-500, 500-590, 680-700, 800 and UMIR (Table 3.12). The main effect of herbicide was significant for 700-760 nm and UMIR. When recorded 3 days after application, reflectance differed for bands 470-500, 500-590, and 680-700 when 2,4-DB was applied (Table 3.13). At 500-590, imazapic did not differ from 2,4-DB, and at 680-700 nm, acifluorfen and imazapic did not differ from 2,4-DB. Reflectance from leaves following application of clethodim was not different from the control. At 800 nm, reflectance following application of acifluorfen and imazapic was different from the reflectance of other herbicides. However, reflectance following application of bentazon, clethodim, and 2,4-DB did not differ from the non-treated control. In the UMIR region, leaf reflectance was highest in plants following the application of bentazon and imazapic (Table 3.13). Visually, the plants treated with bentazon were somewhat chlorotic, and this likely affected reflectance in the leaves, much as the plants in the N deficient and Zn toxic studies were, although reflectance was not lower in the leaves following applications of herbicide.

After 6 days, reflectance was highest following the application of bentazon, and imazapic 2,4-DB in the 470-500 nm range (Table 3.14). Following application of acifluorfen and 2,4-DB treatments reflectance was highest at 500-590 nm. At 680-700 nm, reflectance was highest after applications of 2,4-DB. Reflectance Following application of acifluorfen, bentazon, clethodim, and paraquat did not differ from the non-treated control. Reflectance of leaves following application of bentazon and imazapic was highest at 800 nm, and reflectance of leaves following application of 2,4-DB was highest at UMIR range (Table 3.15). By day 3, the new leaves were not showing visible symptoms of acifluorfen, clethodim, imazapic, and paraquat damage (data not shown), so it is not surprising that the leaf reflectance was beginning to stabilize. However, bentazon-treated plants were still slightly chlorotic, and the new leaves on the 2,4-DB treated plants were similar in appearance to the drought-stressed plants observed in other experiments. Again, due to spectral properties of stressed plants, it is likely that reflectance was affected by the herbicide treatment, but it is difficult to distinguish the herbicide treated plants from the nutrient- and drought-stressed plants due to the similarities in spectral properties.

While there were some significant differences throughout each of these studies, it was difficult to define individual spectral signatures. As is the case in a number of other studies (Kobayashi *et al*., 2001; Nilsson, 1995; Sripada *et al*., 2005; Thenkabail *et al*., 2000), there is considerable overlap between changes in reflectance and the factors that are attributed to the change. Furthermore, as with many field experiments, there are always compounding factors to take into account, as was discussed in the Zn toxicity trial. Baranoski and Rokne (2005) reported that the relative accuracy of spectral reflectance depends on the biological characteristics of the specimen at hand.

Relationships between foliar diseases and reflectance have been inconsistent results (Hatfield and Pinter, 1993). This inconsistency may be due to technique, the disease, crop canopy, and the lack of standardized methods for assessing the effect of the disease on the crop. In theses studies, as well as other studies (Aldakheel and Danson, 1997; Malthus and Madeira, 1993), only single leaves were examined. Therefore, since energy interacts with individual leaves differently than solar energy does at the canopy level, extrapolation to canopy conditions is difficult.

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Table 3.1. Corresponding wavelength characterization for hyperspectral bandwidths used to compare canopy reflectance.

Bandwidth (nm)	Spectrum characterization[a]
350-399	Ultraviolet
400-449	Violet
470-499	Blue
500-590	Green
590-680	Yellow/Orange
680-700	Red
700-760	Red-Edge
800-1099	Near Infrared (NIR)
1550-1750	Mid Infrared (MIR)
2000-2400	Upper Mid Infrared (UMIR)

[a]Spectrum characterization adapted from Avery and Berlin, 1992.

Table 3.2. Analyses of variance for reflectance for peanut growing under Nitrogen (N) deficient conditions, excess Zinc (Zn) conditions, and drought conditions for experiments conducted during 2004.[a,b]

	Stress condition		
Bandwidth grouping	N deficient	Drought	Zn toxicity
nm	p-value		
350-399	0.2222	0.0070	0.1794
400-450	0.0943	0.0042	0.0126
470-500	0.0144	0.0038	0.0416
500-590	0.0160	0.0003	0.0144
590-680	0.0359	0.0005	0.0160
680-700	0.0054	0.0007	0.0260
700-760	0.0113	0.0019	0.0113
800	0.0103	0.0018	0.0103
950-999	0.0101	0.0012	0.0077
1000-1049	0.0077	0.0039	0.0082
MIR	0.0432	0.0013	0.0109
UMIR	0.0013	0.0054	0.0041
NDVI	0.0008	0.0565	0.0017

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]Data were pooled over location.

Table 3.3. Differences in magnitude of reflectance for peanut growing under Nitrogen (N) deficient conditions and drought conditions for experiments conducted during 2004.[a,b]

	Reflectance			
Bandwidth category	N deficient		Drought	
nm	relative units			
	Asymptomatic	Chlorotic	Asymptomatic	Wilted
400-450	8.9	9.2	3.0	4.5*
470-500	4.0	2.2*	5.5	7.2*
500-590	8.3	6.7*	6.3	8.2*
590-680	5.0	3.1*	4.2	6.3*
680-700	28.4	27.3*	27.2	31.5*
700-760	43.6	42.0*	45.5	51.5*
800	44.3	42.6*	46.6	53.3*
950-999	46.5	47.9*	46.5	53.6*
1000-1049	8.9	9.3*	48.0	53.7*
MIR	31.8	28.1*	27.2	30.0*
UMIR	4.2	2.6*	4.1	4.7*
NDVI	0.87	0.94*	0.10	0.11

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]* indicates significance when comparing means within a bandwidth category for a field at $p \leq 0.05$. Data were pooled over location.

Table 3.4. Differences in magnitude of reflectance for peanut growing under excess Zinc (Zn) conditions for experiments conducted during 2004.[a,b]

	Reflectance	
	Excess Zn conditions	
Bandwidth groups	Asymptomatic	Chlorotic
nm	relative units	
350-399	4.9	4.2*
400-450	5.1	3.6*
470-500	6.6	3.9*
500-590	23.2	8.3*
590-680	14.6	5.3*
680-700	67.8	32.8*
700-760	84.2	53.0*
800	86.7	54.7*
950-999	88.6	54.6*
1000-1049	93.1	56.4*
MIR	10.8	8.7*
UMIR	22.3	12.3*
NDVI	0.94	0.70*

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]* indicates significance when comparing means within a bandwidth category for a field at $p \leq 0.05$.

Table 3.5. Analyses of variance for reflectance for peanut with leaf spot and/or web blotch disease, and tomato spotted wilt (TSW) for experiments conducted in 2004, and 2004 and 2005, respectively.[a,b]

	Leaf condition	
Bandwidth groups	Early leaf spot/web blotch	TSW
nm	p-value	
350-399	0.4229	0.0034
400-450	0.3290	0.0075
470-500	0.4088	0.0057
500-590	0.0509	0.0016
590-680	0.0071	0.0010
680-700	0.5988	0.0032
700-760	0.0001	0.5173
800	0.0001	0.4878
950-999	0.0001	0.6292
1000-1049	0.0014	0.1663
MIR	0.0036	0.0982
UMIR	0.0012	0.0147
NDVI	0.0044	0.0023

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]Data were pooled over experiments.

Table 3.6. Differences in magnitude of reflectance for peanut leaves with a single leaf spot lesion, multiple leaf spot lesions, web blotch, or leaf spot lesions and web blotch for experiments conducted during 2004.[a,b]

	Leaf condition				
Bandwidth category	Control	Single lesion	Multiple lesions	Web blotch	Early leaf spot/web blotch
nm	relative units				
590-680	9.1 a	7.6 ab	7.6 ab	5.5 c	6.4 bc
700-760	49.3 a	32.6 b	32.6 b	25.3 c	30.2 bc
800	50.6 a	33.7 b	33.7 b	29.5 b	32.8 b
950-999	49.3 a	35.8 b	35.8 b	37.7 b	37.5 b
1000-1049	51.2 a	40.0 b	40.0 b	43.4 b	42.2 b
MIR	51.4 a	34.4 b	34.4 b	32.9 b	34.7 b
UMIR	57.7 a	34.9 b	34.9 b	35.4 b	36.1 b
NDVI	0.35 a	0.23 b	0.22 b	0.17 c	0.21 b

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]Means within a row followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$. Data were pooled over three experiments

Table 3.7. Differences in magnitude of reflectance for peanut displaying tomato spotted wilt (TSW) symptoms for experiments conducted in 2004 and 2005.[a,b]

	Reflectance	
Bandwidth groups	Control	TSW
nm	relative units	
350-399	7.2	3.2 *
400-450	6.9	2.7 *
470-500	9.1	4.0 *
500-590	10.0	4.0 *
590-680	8.0	3.0 *
680-700	7.2	2.7 *
UMIR	11.3	7.5 *
NDVI	0.20	0.10 *

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]* indicates significance when comparing means within a bandwidth category for a field at $p \leq 0.05$. Data were pooled over four experiments.

Table 3.8. Analyses of variance for reflectance on peanut treated with acifluorfen, bentazon, clethodim imazapic, or paraquat, or 2,4-DB at 3 hours after application for experiments during 2005.[a, b]

	Bandwidth categories (nm)											
Treatment factor	300-350	400-450	470-500	500-590	680-700	700-760	800	950-999	1000-1049	MIR	UMIR	NDVI
	p-value											
Herbicide	0.2291	0.2114	0.0001	0.0091	0.0614	0.0144	0.0161	0.7653	0.7791	0.0072	0.0384	0.0075
Timing after application	0.0001	0.0010	0.0001	0.0001	0.0001	0.0001	0.0241	0.0001	0.0001	0.0001	0.0001	0.0001
Timing after application X Herbicide	0.2736	0.2601	0.0001	0.0001	0.0463	0.1726	0.0022	0.3483	0.1603	0.1030	0.0001	0.4133
Coefficient of variation (%)	39.7	42.5	37.8	33.2	29.8	27.4	30.2	31.8	44.8	21.0	13.2	10.4

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]Data were pooled over experiments.

Table 3.9. Differences in magnitude of reflectance for peanut leaves treated with acifluorfen, bentazon, clethodim imazapic, paraquat, or 2,4-DB at 3 hours after application for experiments during 2005.[a,b]

	Reflectance			
	Bandwidth category (nm)			
Herbicide	470-500	500-590	800	UMIR
	relative units			
Non-treated control	2.1 b	15.1 b	6.8 d	49.5 c
Acifluorfen	2.0 b	12.4 b	11.0 bc	49.0 c
Bentazon	2.0 b	14.8 b	13.6 b	51.7 ab
Clethodim	2.2 b	14.2 b	6.3 d	49.0 c
Imazapic	2.2 b	14.9 b	6.0 d	50.2 bc
Paraquat	2.3 b	14.1 b	10.8 c	53.1 a
2,4-DB	5.9 a	24.4 a	24.2 a	43.5 d

[a]Abbreviations: UMIR, upper mid infrared.

[b]Means within a bandwidth category followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$. Data were pooled over experiments.

Table 3.10. Analyses of variance for reflectance on peanut treated with acifluorfen, bentazon, clethodim imazapic, paraquat, or 2,4-DB at 24 hours after application for experiments during 2005.[a, b]

Treatment factor	Bandwidth categories (nm)											
	300-350	400-450	470-500	500-590	680-700	700-760	800	950-999	1000-1049	MIR	UMIR	NDVI
	p-value											
Herbicide	0.1520	0.2511	0.0065	0.0080	0.0792	0.0886	0.0245	0.0451	0.0129	0.0022	0.0066	0.3541
Timing after application	0.0001	0.0001	0.0001	0.0001	0.0001	0.0020	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Timing after application X Herbicide	0.2257	0.2164	0.0001	0.0001	0.0623	0.1295	0.0301	0.1923	0.3971	0.3960	0.0001	0.0524
Coefficient of variation (%)	21.0	16.3	15.2	18.6	14.5	17.2	13.4	26.8	22.1	27.8	26.5	18.0

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]Data were pooled over experiments.

Table 3.11. Differences in magnitude of reflectance for peanut leaves treated with acifluorfen, bentazon, clethodim imazapic, paraquat, or 2,4-DB at 24 hours after application for experiments during 2005.[a,b]

	Reflectance			
	Bandwidth category (nm)			
Herbicide	470-500	500-590	800	UMIR
	relative units			
Non-treated control	1.4 b	10.3 bc	36.2 b	45.8 c
Acifluorfen	2.4 a	13.2 a	35.3 b	56.7 a
Bentazon	1.4 b	9.5 d	36.3 b	53.0 b
Clethodim	1.4 b	10.4 bc	36.3 b	46.3 c
Imazapic	2.0 a	12.4 a	36.6 ab	51.5 b
Paraquat	1.7 b	12.7 a	38.1 a	50.9 b
2,4-DB	1.9 ab	11.2 b	33.4 c	37.0 d

[a]Abbreviations: UMIR, upper mid infrared.

[b]Means within a row followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$. Data were pooled over experiments.

Table 3.12. Analyses of variance for reflectance on peanut treated with acifluorfen, bentazon, clethodim imazapic, paraquat, or 2,4-DB at 3 days after application for experiments during 2005.[a, b]

	Bandwidth categories (nm)											
Treatment factor	300-350	400-450	470-500	500-590	680-700	700-760	800	950-999	1000-1049	MIR	UMIR	NDVI
	p-value											
Herbicide	0. 3216	0.3385	0.0022	0.0001	0.0127	0.0441	0.0058	0.5293	0.2547	0.0051	0.0402	0.2258
Timing after application	0.0001	0.0010	0.0001	0.0001	0.0011	0.0001	0.0003	0.0001	0.0001	0.0001	0.0024	0.0001
Timing after application X Herbicide	0.0941	0.2115	0.0001	0.0001	0.0208	0.1941	0.0100	0.7091	0.2310	0.0001	0.5220	0.0641
Coefficient of variation (%)	18.0	17.3	17.6	19.2	22.5	26.9	19.7	12.7	23.5	14.7	15.6	11.1

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]Data were pooled over experiments.

Table 3.13. Differences in magnitude of reflectance for peanut leaves treated with 2,4-DB, acifluorfen, bentazon, clethodim imazapic, or paraquat at 3 days after application for experiments during 2005.[a,b]

	Reflectance				
	Bandwidth category (nm)				
Herbicide	470-500	500-590	680-700	800	UMIR
	relative units				
Non-treated control	1.1 c	9.7 c	22.2 c	32.0 bc	46.8 cd
Acifluorfen	3.1 b	11.9 b	31.8 a	34.9 a	55.1 bc
Bentazon	2.6 b	8.3 d	18.8 d	29.7 c	62.5 a
Clethodim	1.5 c	9.4 c	24.0 c	33.4 a	45.0 d
Imazapic	3.0 b	12.7 ab	33.4 a	32.8 ab	58.8 ab
Paraquat	2.7 b	11.6 b	28.3 b	30.4 bc	49.9 c
2,4-DB	4.3 a	13.4 a	32.1 a	29.6 c	51.8 c

[a]Abbreviations: UMIR, upper mid infrared.

[b]Means within a row followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$. Data were pooled over experiment.

Table 3.14. Analyses of variance for reflectance on peanut treated with acifluorfen, bentazon, clethodim imazapic, or paraquat, or 2,4-DB at 6 days after application for experiments during 2005.[a, b]

	Bandwidth categories (nm)											
Treatment factor	300-350	400-450	470-500	500-590	680-700	700-760	800	950-999	1000-1049	MIR	UMIR	NDVI
	p-value											
Herbicide	0.0873	0.4527	0.0001	0.0020	0.0148	0.7140	0.0013	0.2306	0.3111	0.1921	0.0056	0.0830
Timing after application	0.0011	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001
Timing after application X Herbicide	0.2355	0.2489	0.0001	0.0309	0.0011	0.2500	0.0065	0.1543	0.6124	0.0725	0.0240	0.2251
Coefficient of variation (%)	13.2	19.2	26.1	17.4	24.7	24.3	11.1	16.4	19.7	22.6	15.2	28.5

[a]Abbreviations: MIR, mid infrared; UMIR, upper mid infrared; NDVI, normalized difference vegetation index.

[b]Data were pooled over experiments.

Table 3.15. Differences in magnitude of reflectance for peanut leaves treated with acifluorfen, bentazon, clethodim imazapic, paraquat, or 2,4-DB at 6 days after application for experiments during 2005.[a,b]

	Reflectance				
	Bandwidth category (nm)				
Herbicide	470-500	500-590	680-700	800	UMIR
	relative units				
Control	1.7 b	10.6 b	26.7 c	34.3 b	46.8 c
Acifluorfen	2.0 b	12.3 a	27.1 c	33.1 bc	52.9 b
Bentazon	2.1 ab	9.2 c	28.2 c	35.7 ab	47.2 c
Clethodim	1.5 b	10.7 b	26.6 c	32.0 c	46.1 c
Imazapic	2.4 a	11.0 b	30.4 b	36.2 a	50.2 b
Paraquat	1.8 b	10.5 b	27.0 c	32.9 bc	50.6 b
2,4-DB	2.3 a	12.6 a	32.4 a	30.6 c	53.7 a

[a]Abbreviations: UMIR, upper mid infrared.

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

CHAPTER IV

Influence of Digging Date and Fungicide Program on Canopy Defoliation and Pod Yield of Peanut (*Arachis hypogaea* L.)

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Abstract

Applying fungicides bi-weekly beginning in early July through mid-September during 2003, 2004, and 2005 resulted in less canopy defoliation than applying only two sprays in July or not applying fungicide and in many instances increased pod yield. When peanut canopy defoliation exceeded approximately 50%, digging 6 to 12 days prior to projected optimum maturity resulted in higher yields than digging at optimum maturity. However, response to early digging was variable when defoliation at the early digging date was less than approximately 50%.

Key words: Disease management, pod maturation, pod shed, hull scrape method.

Introduction

Management of foliar and soil-borne disease is critical in optimizing yield and quality of peanut (*Arachis hypogaea* L.). Peanut growers in the United States utilize a range of tactics to control disease including host-plant resistance and application of fungicides (Sherwood *et al*., 1995). Cylindrocladium black rot [*Cylindrocladium crotalaria* (Loos) Bell and Sobers], early leafspot (*Cercospora arachidicola* Hori), late leafspot [*Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton], Sclerotinia blight (caused by *Sclerotinia minor* Jagger), southern stem rot (*Sclerotium rolfsii* Sacc.), tomato spotted wilt, and web blotch (*Phoma arachidicola* Marasas *et al.*) are among the most prevalent diseases in peanut in North Carolina (Shew, 2006). Fungicides are effective in controlling most diseases but do not control Cylindrocladium black rot or tomato spotted wilt.

The decision to dig peanut and invert vines can have a tremendous impact on pod yield and market grade characteristics (Jordan *et al*., 1998; Mozingo *et al*., 1991; Sholar *et al*., 1995). Although response can be variable and is dependant upon multiple factors, digging peanut as much as 1 wk prior to or 1 wk following optimum maturity can result in substantial reductions in pod yield (Jordan *et al*., 1998). Peanut is indeterminate in growth habit, and determining when the highest percentage 7of peanut pods are at optimum maturity is challenging. Edaphic and environmental conditions combined with other management constraints at the farm level contribute to grower anxiety over when to dig peanut. Health of vines associated with disease development and contributions to pod shed are also considered when determining when to dig peanut (Sholar *et al*., 1995).

The hull scrape method has proven effective in helping growers predict optimum maturity (Williams and Drexler, 1981). However, this technique was developed primarily for runner market types in the southeastern United States, and utilization of the profile chart developed for this technique in other regions of the United States and for other market types that are more prone to pod shed is limited. More recently, a peanut maturity profile chart was developed for Virginia market type peanut grown in the Virginia-Carolina production region (Jordan *et al*., 2005). In addition to providing estimates of optimum digging date based on mesocarp color, this new chart provides recommendations on how to consider the role of disease incidence, freeze potential, and practicality of heat unit accumulation in the digging process (Jordan *et al*., 2005).

Yield loss from foliar diseases are associated with defoliation of the peanut canopy and subsequent shedding of pods (Sherwood *et al*., 1995). Fungicides are critical in minimizing disease and maintaining sufficient foliage to allow continued pod development and maturation and minimize pod shed. In spite of intensive fungicide programs, some fields may experience significant defoliation in September and October. Defoliation from foliar diseases can be a particular problem in wet years, when growers may be unable to make timely fungicide applications or fungicides may be washed from leaves after heavy rains. Consequently, growers must balance the decision of whether to delay digging in an effort to optimize maturity with concerns that defoliation will result in pod shed if peanut remains in the field. Although considerable research has been conducted to determine the relationships among digging date, pod yield, and market grade when disease is controlled, research addressing interactions of digging date and canopy defoliation is limited (Nutter and Shokes, 1995).

Altering fungicide spray programs has been used to determine relationships between canopy defoliation and pod yield of runner market type peanut (Bowen *et al*., 1997). Backman and Crawford (1984) found that for every 1% increase in canopy defoliation within 2 to 3 weeks of optimum digging resulted in a loss of yield of approximately 57 kg/ha when optimum yield was approximately 4400 kg/ha. Other research (Aquino *et al*., 1992; Nutter *et al*., 1990, 1996; Pixley *et al*., 1990) suggested that canopy reflectance at 800 nm is a more accurate predictor of yield loss than using visual estimates of canopy defoliation. However, the level of canopy defoliation at which yield loss from pod shedding would offset expected yield gains from digging at optimum maturity was not addressed in these studies.

Determining when digging peanut prior to optimum maturity due to disease offsets pod loss due to defoliation of the canopy is a critical question for growers. Therefore, the objectives of this research were to determine relationships among canopy defoliation, yield, and crop maturity in peanut, and to determine whether should be dug prior to optimum pod maturity when high levels of defoliation are present.

Materials and Methods

Experiments were conducted during 2003, 2004, and 2005 at the Peanut Belt Research Station located near Lewiston-Woodville, NC and at the Upper Costal Plain Research Station located near Rocky Mount, NC. Soil at Lewiston is a Norfolk sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults); soil at Rocky Mount was a Goldsboro fine, sandy loam (fine-loamy, siliceous, subactive, thermic Aquic Paleudults). Plot size was two rows (91-cm spacing) by 9 m in length. Peanut was seeded in conventionally prepared seedbeds at a rate designed to achieve a final in-row plant population of 13 plant/m. Two non-treated rows separated each plot. Locations, years, cultivars, fields, and planting and digging dates are presented in Table 4.1.

Experiments were conducted in two fields each at Lewiston-Woodville and Rocky Mount during 2003. Treatments consisted on three fungicide programs that included no fungicide, two fungicide applications in July, and bi-weekly applications beginning in early July and continuing through early September. In 2004 and 2005, seven experiments, five at Lewiston-Woodville and two at Rocky Mount, consisted of the three fungicide programs listed previously with two digging dates. Digging dates included digging at optimum maturity based on pod mesocarp color for the bi-weekly fungicide program and digging 6 to 12 days prior to optimum maturity (Williams and Drexler, 1982). Two additional experiments conducted during 2004 included no fungicide treatments with digging dates at optimum pod maturity based on mesocarp color determination in peanut receiving bi-weekly sprays and digging dates 9 to 12 days prior to optimum maturity. Additionally, peanut receiving bi-weekly sprays were dug at optimum maturity. In 2005 at Lewiston-Woodville, the experiment was expanded to include three digging dates spaced approximately 1 wk apart, and the final digging date was at optimum maturity based on pod mesocarp color.

Fungicides were applied bi-weekly beginning in early to late-July and were continued through early to mid-September. During 2003, the bi-weekly fungicide spray program consisted of propiconazole {1-[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl-methyl]-1*H*-1,2,4 triazole} plus trifloxystrobin {benzeneacetic acid, α-(methoxyimino)-2-[[[(*E*)-[1-[3-(trifluoromethyl)phenyl]ethylidene]amino]oxy]methyl]-, methylester (*E*,*E*)} (120 + 120 g ai/ha) applied in early July. Chlorothalonil (tetrachloroisophthalonitrile) (1,260 g ai/ha) was applied at this timing during 2004 and 2005. Tebuconazole {α-[2-(4-chlorophenyl)ethyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol} (220 g ai/ha) was applied for three consecutive sprays during 2003 and as two consecutive sprays during 2004. The fourth fungicide spray in 2004 and 2005 consisted of pyraclostrobin {carbamic acid, [2-[[[1-(4-chlorophenyl)-1*H*-pyrazol-3yl]oxy]methyl]phenyl]methoxy-, methyl ester} (160g ai/ha). In all experiments, chlorothalonil (1,260 g/ha) was applied in early September. Additionally, treatments during 2005 in the experiment including three digging dates included chlorothalonil (830 g/ha) plus pyraclosrobin (106 g/ha) applied in late September following the no-fungicide control, two early season sprays, and bi-weekly sprays. Treatments were applied in 187 L/ha aqueous solution at 159 kPa using a CO_2–pressurized backpack sprayer equipped with hollow-cone spray nozzles (TXVS-8 Conejet hollow-cone spray tips, Spraying Systems Company, Wheaton, IL).

In all experiments, treatments were replicated four times and were arranged in a randomized complete block design. The percentage of canopy defoliation of peanut vines was estimated visually within 2 days prior to digging and vine inversion using a scale of 0 (no defoliation) to 100 (complete defoliation). Canopy defoliation was caused by the combined effect of early leaf spot, late leaf spot, and web blotch. Early leaf spot was the predominant disease during 2003, and web blotch and late leaf spot were present during both 2004 and 2005. Although southern stem rot may have contributed to response to fungicides, no attempt was made to quantify this disease. Additionally, fields at Lewiston-Woodville were fumigated with metam sodium to minimize Cylindrocladium black rot. Although tomato spotted wilt was present at these locations, fungicide does not affect tomato spotted wilt virus.

Peanut plants were dug in late September or October and vines allowed to air dry for 4 to 7 days prior to combining. Pod yield was adjusted to 8% moisture. Market grades, including percentages of sound mature kernels (%SMK), sound splits (%SS), total sound mature kernels (%TSMK), other kernels (%OK), extra large kernels (%ELK), and fancy pods (%FP) were determined in the experiment with three digging dates during 2005 using Cooperative Grading Service criteria (USDA, 1998).

Data for peanut canopy defoliation within 2 days prior to digging, pod yield, and market grade characteristics (experiment in 2005 with three digging dates) were subjected to analysis of variance appropriate for the factorial arrangement of and treatments (experiments, fungicide programs, digging dates). In an additional analysis, data from all experiments were pooled into a single data set to compare defoliation between digging dates within the same fungicide program. Means of significant main effects and interactions were separated using Fisher's Protected LSD at $p \leq 0.05$. Regression procedures were used to determine linear relationships percent of maximum yield 6-12 days prior to optimum maturity or at optimum maturity versus percent canopy defoliation 6-12 days before optimum maturity. Percent of maximum pod yield at optimum maturity versus defoliation 6-12 days before optimum maturity also was determined. Percent of maximum yield was calculated based on the highest yield of peanut following bi-weekly sprays fungicide sprays considered as 100% of maximum yield. Slopes for linear relationships were compared when pooled over experiments using Fisher's Protected LSD at $p \leq 0.05$.

Results and Discussion

The interaction of field by fungicide program was significant for peanut canopy defoliation and peanut pod yield in 2003. Defoliation at digging was 90% or greater in three of four experiments when fungicides were not applied, and in two of these trials yield loss was noted for this treatment compared with peanut treated bi-weekly with fungicides (Table 4.2). In two of these experiments defoliation was at least 87% when two early season applications of fungicide were made, and in both experiments yield was reduced compared with peanut receiving bi-weekly fungicide applications. At two locations, no yield differences were noted regardless of fungicide program. These experiments were conducted at Rocky Mount, and defoliation in these experiments tended to be lower than defoliation noted for the experiments with yield differences among fungicide programs.

The interaction of experiment X fungicide program X digging date was significant for peanut canopy defoliation in the experiments with two digging dates (Table 4.3). When analyzed by experiment, the interaction of fungicide program X digging date was significant for Fields G2 and C1B during 2004 and in Field F2 during 2005 at Lewiston-Woodville. Main effects of these treatment factors were significant in Fields A2 and F2 (Lewiston-Woodville) and C11 and C15 at Rocky Mount while the interaction of digging date X fungicide program was not significant (data not shown). The main effect of digging date was not significant at Lewiston-Woodville in 2005 in Field F2 or in Field C15 at Rocky Mount.

Applying fungicides bi-weekly resulted in 8% or less defoliation in Fields G2, C1B, and F2 at Lewiston-Woodville (Table 4.4). Canopy defoliation increased in these experiments during the 6 to 12 days between initial evaluations at early digging and evaluations taken at optimum maturity (Table 4.4). The interaction of fungicide program X digging date occurred in part this increase was not observed in the treatments where fungicides were applied bi-weekly. This response also occurred because canopy defoliation did not differ when fungicides were not applied or when two early season fungicide applications were made. However, when peanut was dug at optimum maturity for peanut treated bi-weekly with fungicides, differences in defoliation were observed when comparing the three fungicide programs. This was also the case in Field A2 at Lewiston-Woodville during 2004 and 2005 and at Rocky Mount in both fields during 2004 (Table 4.5). Defoliation at the optimum digging date was higher in Fields A2 (Lewiston-Woodville) and C11 (Rocky Mount) than when fungicides were applied bi-weekly (Table 4.6).

Although the interaction of fungicide program X digging date was not significant for peanut pod yield, interactions of experiment X digging date and experiment X fungicide program were significant. Delaying digging resulted in a reduction in peanut yield in 2 of 7 experiments but did not affect yield in the remaining five experiments (Table 4.7). Although delaying digging can increase pod yield when disease is controlled, delaying digging decreased yield in some experiments. In three of seven experiments, differences in pod yield were noted all fungicide programs (Table 4.7). In three additional experiments, differences in yield following bi-weekly sprays were noted when compared with no fungicides or two bi-weekly sprays. However, there were no differences in yield in the no fungicide treatment compared to the two early sprays. In one experiment, no differences in yield were noted among two early sprays and bi-weekly sprays, although yield of peanut following both of these fungicide programs exceeded that of peanut without fungicide.

In two experiments conducted during 2004 without the entire complement of fungicide programs and digging dates, the interaction of experiment X fungicide/digging date combination was not significant for peanut canopy defoliation and pod yield (data not shown). The main effect of treatment (fungicide and digging date combination) was significant. Canopy defoliation was 78 and 73% when fungicides were not applied and peanut was dug 9 to 12 days before optimum maturity and at optimum maturity, respectively (Table 4.8). However, canopy defoliation was only 6% when fungicides were applied, and protection offered by fungicides resulted in the highest pod yield when compared to no fungicides regardless of digging date (Table 4.8). Pod yield decreased to the lowest value when fungicide was not applied and peanut was dug at the time fungicide-treated peanut was dug (optimum maturity). However, digging earlier than optimum maturity increased yield when fungicide was not applied (Table 4.8).

In the experiment with three digging dates, the interaction of digging date X fungicide program was significant for canopy defoliation and pod yield. Because the interaction was significant, a separate analysis was performed that included fungicide sprays applied in late September. The highest canopy defoliation was observed when fungicides were not applied and digging occurred on October 15 (Table 4.9). Using mesocarp color determination, the optimum digging date was estimated as October 15. Fifty-eight percent canopy defoliation was observed on October 15 when only two fungicide treatments were applied in July. Defoliation in these treatments was lower when peanut was dug 11 or 22 days prior to the optimum digging date. No significant defoliation was observed when fungicides were applied bi-weekly. As expected, the highest yield was observed when fungicides were applied bi-weekly and peanut was dug at the optimum timing. Surprisingly, lower yield was noted when chlorothalonil plus pyraclostrobin was applied following the bi-weekly applications. When fungicides were not applied or when two early sprays were included, there was no difference in pod yield regardless of digging date even though defoliation ranged from 8 to 79% or 4 to 58% for these respective fungicide programs. The salvage treatments had no effect on yield for these fungicide programs (Table 4.9).

No interactions were noted among digging dates and fungicide programs for market grade characteristics (data not presented). However, the main effect of digging date was significant for %SMK and %ELK was significant (Table 4.10). Fungicides did not affect market grade characteristics in these experiments (data not shown). Delaying digging from September 23 until October 6 or 15 resulted in an increase in %SMK and %ELK and a decrease in %SS regardless of fungicide program (Table 4.10). Delaying digging until optimum maturity often increases %SMK and %ELK (Mozingo *et al*., 1991; Sholar *et al*., 1995).

The key objective if this research was to determine what level of defoliation justifies digging peanut prior to optimum maturity (based on pod mesocarp color) when significant canopy defoliation is present. This objective was addressed using two approaches. First, data from all experiments for treatments not receiving fungicides with digging dates that included digging peanut at optimum maturity or digging peanut 6 to 12 days before optimum maturity were compared. Additionally, a similar data set was created using only treatments receiving two early fungicide sprays. These data sets allow determination of the impact of delayed digging on canopy defoliation and changes in yield that otherwise might be otherwise be concealed in the factorial analysis.

The interaction of experiment X digging date was significant for canopy defoliation when comparing data without fungicides or when peanut received only two early fungicide sprays. Defoliation increased as digging was delayed in 5 of 10 experiments when fungicides were not applied, and a reduction in yield was noted when digging was delayed and data from each experiment were compared (Table 4.11). However, the interaction of experiment by digging date was not significant for pod yield, and when pooled over experiments, delaying digging until optimum maturity, resulted in decrease in yield by 430 kg/ha (Table 4.11). Although the interaction of experiment by digging date was significant for canopy defoliation, when pooled over experiments, the decrease in yield of 430 kg/ha reflected an increase in defoliation from 53% (digging prior to optimum maturity) to 76% (digging at optimum maturity) when fungicide was not applied.

When comparing defoliation and yield between digging dates within the fungicide program, including two early sprays only, the main effect of digging date and the interaction of experiment by digging date were significant. In 4 of 8 experiments, delaying digging until the optimum digging date resulted in an increase in canopy defoliation (Table 4.12). With respect to pod yield, while the interaction of experiment by digging date was significant, the main effect of digging date was not significant. When analyzed by experiment, yield increased in one experiment when digging was delayed, and although not significant when analyzed by experiment, in five experiments yield decreased numerically when digging was delayed while in three experiments yield increased (Table 4.12). When pooled over experiments, the increase in defoliation of 31% (digging prior to optimum maturity) to 54% (digging at optimum maturity) resulted in a numerical decrease in yield of 170 kg/ha (Table 4.12).

The second approach to addressing what level of defoliation justifies digging peanut prior to optimum maturity (based on pod mesocarp color) when significant canopy defoliation is present used regression procedures. In the experiment with two digging dates and three fungicide programs (7 experiments), significant linear relationships were observed for percent of optimum yield versus defoliation 6-12 days before optimum pod maturity or defoliation at optimum maturity in 5 of 7 and 7 of 7 experiments, respectively (Table 4.13). These relationships were also significant when pooling over the 7 experiments (Table 4.13). Additionally, the relationship of percent of pod yield when peanut was dug 6-12 days before optimum maturity versus defoliation at this timing was significant in 4 of 7 experiments, and this relationship was also significant when pooling over experiments (Table 4.13). However, no differences in slopes ($p = 0.2784$) for these comparisons were noted when slopes from each experiment were considered replications (Table 4.13).

Results from analyses within fungicide programs with varying levels of canopy defoliation demonstrate the complexity of determining whether early digging is advisable. However, when evaluating the role of digging date when fungicides are not applied, there was a positive benefit to digging prior to optimum maturity. While maturation may have continued when digging was delayed, these data suggest that when defoliation exceeds 50% and increases to higher levels as digging is delayed, pod loss through pod shed overshadows benefits of increased pod maturation. In contrast, when defoliation was at a lower level, as was demonstrated with early digging when two fungicide sprays were made (31%), there appeared to be no benefit in digging early, and in fact, digging early reduced yield in one experiment. These data suggest pod yield of peanut dug with less than 50% canopy defoliation prior to optimum pod maturity may be inconsistent. The inconsistency most likely reflects the difficult balance between pod shed and increased pod maturation that results in higher yield and improved market grades.

Collectively, these data indicate that digging prior to the anticipated optimum digging date, based on pod mesocarp color of relatively disease-free peanut, is advisable in some instances, especially when defoliation exceeds 50% but not when defoliation is less than this amount. The current NC Cooperative Extension Service recommendations for Virginia market types cultivars are that growers not consider early digging until defoliation exceeds 50% (Jordan *et al*., 2005). Additionally, further research is needed to quantify incidence of other diseases with respect to benefits of digging peanut prior to optimum pod maturity.

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Table 4.1. Location, year, cultivar, field, and planting and digging dates from seven experiments conducted in North Carolina during 2003-2005.[a]

Location	Year	Cultivar	Field	Planting date	Digging dates
Lewiston-Woodville	2003	NC-V 11	D7B	May 12	Oct. 6
Lewiston-Woodville	2003	NC-V 11	B3	May 8	Oct. 6
Rocky Mount	2003	NC-V 11	C11	May 15	Oct. 9
Rocky Mount	2003	NC 12C	C15	May 15	Oct. 9
Lewiston-Woodville	2004	NC-V 11	G2	May 10	Oct. 1 and 7
Lewiston-Woodville	2004	NC-V 11	A2	May 5	Sep. 15 and 24
Lewiston-Woodville	2004	NC 12C	C1B	May 8	Sep. 13 and 24
Rocky Mount	2004	VA 98R	C11	May 14	Sep. 16 and 24
Rocky Mount	2004	VA 98R	C12	May 14	Sep. 18 and 24
Lewiston-Woodville	2004	Gregory	C2B	May 4	Sep. 13 and 22
Lewiston-Woodville	2004	NC 12C	A2	May 5	Sep. 13 and 25
Lewiston-Woodville	2005	NC-V 11	F2	May 2	Sep. 23 and 29
Lewiston-Woodville	2005	VA 98R	F2	May 2	Sep. 28 and Oct. 4
Lewiston-Woodville	2005	Gregory	G6	May 6	Sep. 23 and Oct. 6 and 15

Table 4.2. Peanut canopy defoliation and peanut pod yield as influenced by fungicide program during 2003.[a]

Fungicide programs	Canopy defoliation at digging				Peanut pod yield			
	D7B[b]	B3	C11[b]	C15[b]	D7B	B3	C11	C12
	——— % ———				——— kg/ha ———			
No fungicide	93 a	100 a	56 a	90 a	1590 b	2120 b	2860 a	2850 a
Two early sprays[c]	87 a	97 a	15 b	69 b	1730 b	2820 b	3320 a	2830 a
Bi-weekly sprays[d]	22 b	3 b	2 c	14 c	2700 a	4060 a	3260 a	2920 a

[a]Means for each field followed by the same letter are not significant accorded to Fisher's Protected LSD at $p \leq 0.05$.

[b]Fields D7B and B4 were located at Lewiston-Woodville. Fields C11 and C15 were located at Rocky Mount.

[c]Consisted of two fungicide applications in July.

[d]Consisted of five fungicide applications beginning in early July through early September.

Table 4.3. Analyses of variance for defoliation at digging in the experiments including three fungicide programs and two digging dates.

Treatment factor	Defoliation at digging	Pod yield
	p-value	
Experiment	0.0001	0.0001
Fungicide	0.2606	0.0013
Digging date	0.0001	0.0013
Experiment X Fungicide	0.0318	0.0026
Experiment X Digging date	0.0001	0.0053
Fungicide X Digging date	0.0001	0.7526
Experiment X Fungicide X Digging date	0.0242	0.5535
Coefficient of variation (%)	29.9	15.8

Table 4.4. Interaction of fungicide program and digging date on peanut canopy defoliation at Lewiston-Woodville.[a]

Fungicide programs	Field G2[b]		Field C1B[c]		Field F2[d]	
	Sep. 22	Oct. 6	Sep. 23	Oct. 4	Sep. 23	Sep. 30
	%					
No fungicide	44 c	88 a	45 c	75 a	23 c	63 a
Two early sprays[e]	24 d	74 b	40 c	60 b	15 cd	44 b
Bi-weekly sprays[f]	0 e	5 e	3 d	8 d	1 d	5 cd

[a]Means for each field followed by the same letter are not significant accorded to Fisher's Protected LSD at $p \leq 0.05$.

[b]Conducted during 2004 with the cultivar NC-V 11.

[c]Conducted during 2004 with the cultivar NC 12C.

[d]Conducted during 2005 with the cultivar VA 98R.

[e]Consisted of two fungicide applications in July.

[f]Consisted of five fungicide applications beginning in early July through early September.

Table 4.5. Influence of fungicide program on peanut canopy defoliation at digging.[a]

	Lewiston-Woodville[b]		Rocky Mount[c]	
Fungicide programs	Field A2 (2004)	Field F2 (2005)	Field C11	Field C15
	%			
No fungicide	78 a	64 a	64 a	58 a
Two early sprays[d]	62 b	34 b	38 b	42 b
Bi-weekly sprays[e]	17 c	1 c	2 c	0 c

[a]Means for each field followed by the same letter are not significant accorded to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over digging dates.

[b]Conducted with the cultivar NC-V 11.

[c]Conducted with the cultivar VA 98R during 2004.

[d]Consisted of two fungicide applications in July.

[e]Consisted of five fungicide applications beginning in early July through early September.

Table 4.6. Influence of digging date on peanut canopy defoliation.[a]

Fungicide programs	Lewiston-Woodville[b]		Rocky Mount[c]	
	Field A2 (2004)	Field F2 (2005)	Field C11	Field C15
	%			
Dig 6 to 11 days before optimum maturity	40 b	31 a	28 b	33 a
Dug at optimum maturity	65 a	35 a	42 a	34 a

[a]Means for each field followed by the same letter are not significant accorded to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over fungicide programs.

[b]Conducted with the cultivar NC-V 11.

[c]Conducted with the cultivar VA 98R during 2004.

Table 4.7. Influence of digging date and fungicide program on peanut pod yield from seven experiments conducted in North Carolina during 2004-2005.[a]

Location	Year	Cultivar	Field	Digging date[b] 6-11 d BOM[d]	Digging date[b] Optimum maturity	Fungicide program[c] None	Fungicide program[c] Two early sprays	Fungicide program[c] Bi-weekly sprays
				kg/ha				
Lewiston-Woodville	2004	NC-V 11	G2	3910 a	4110 a	2880 c	3860 b	5290 a
Lewiston-Woodville	2004	NC-V 11	A2	2560 a	1750 b	1470 c	2180 b	2810 a
Lewiston-Woodville	2004	NC 12C	C1B	4090 a	3940 a	3890 b	3760 b	4400 a
Rocky Mount	2004	VA 98R	C11	3160 a	3110 a	2310 c	3030 b	4060 a
Rocky Mount	2004	VA 98R	C15	3080 a	2820 a	2480 b	2720 b	3660 a
Lewiston-Woodville	2005	NC-V 11	F2	4740 a	4710 a	4300 b	4760 a	5120 a
Lewiston-Woodville	2005	VA 98R	F2	3970 a	3090 b	2930 b	3390 b	4280 a

[a]Means for each year, cultivar, and field combination followed by the same letter are not significant accorded to Fisher's Protected LSD at $p \leq 0.05$

[b]Data are pooled over fungicide programs.

[c]Data are pooled over digging dates.

[d]Days before optimum digging based on peanut exposed to bi-weekly fungicide treatments using pod mesocarp color to determine pod maturity.

Table 4.8. Peanut canopy defoliation and pod yield as influenced by fungicide program and digging date for experiments conducted in Lewiston-Woodville during 2004.[a]

Fungicide programs	Days before optimum pod maturity	Canopy defoliation at digging	Peanut pod yield
		%	kg/ha
No fungicide	9 to 12	72 b	1860 b
No fungicide	0	78 a	1510 c
Bi-weekly sprays[d]	0	6 c	3360 a

[a]Means for peanut canopy defoliation and pod yield followed by the same letter are not significant accorded to Fisher's Protected LSD at $p \leq 0.05$. Data are from two fields at Lewiston-Woodville during 2004 (Fields C2B and A2). Cultivars were Gregory and NC 12C in Fields C2B and A2, respectively.

Table 4.9. Influence of digging data and fungicide program on peanut canopy defoliation and peanut pod yield for experiments conducted in Lewiston-Woodville during 2005.[a]

Fungicide program	Digging date[b]	Defoliation at digging	Pod yield
		%	kg/ha
No fungicide	Sep. 23	8 cd	1940 e
No fungicide	Oct. 6	46 b	2160 b-e
No fungicide	Oct. 15	79 a	2240 b-e
Salvage spray[c]	Oct. 15	60 b	2300 b-e
Two early sprays	Sep. 23	4 cd	2280 b-e
Two early sprays	Oct. 6	15 cd	2010 de
Two early sprays	Oct. 15	58 b	2270 b-e
Two early sprays and salvage spray	Oct. 15	19 c	2350 b-e
Bi-weekly sprays	Sep. 23	0 d	2120 cde
Bi-weekly sprays	Oct. 6	0 d	2410 bcd
Bi-weekly sprays	Oct. 15	0 d	3010 a
Bi-weekly sprays and salvage spray	Oct. 15	1 d	2510 bc

[a]Means within a column followed by the same letter are not significant accorded to Fisher's Protected LSD at $p \leq 0.05$.

[b]Optimum digging date based on pod mesocarp color was determined to be October 15.

[c]Salvage spray consisted on propiconazole plus trifloxystrobin applied in late September.

Table 4.10. Influence of digging date on:, percentage sound mature kernels (%SMK) percentage of sound splits (%SS) percentage of total sound mature kernels (%TSMK) percentage of other kernels (%OK) percentage of extra large kernels (%ELK) percentage of fancy pods (%FP) for experiments conducted Lewiston-Woodville during 2005.[a]

Digging date[b]	%SMK	%SS	%TSMK	%OK	%ELK	%FP
	———	———	——— %	———	———	———
Sep. 23	61 b	3 a	64 a	2 a	45 b	82 a
Oct. 6	65 a	1 b	66 a	2 a	51 a	79 a
Oct. 15	64 a	1 b	65 a	2 a	51 a	81 a

[a]Means within a column followed by the same letter are not significant accorded to Fisher's Protected LSD at $p \leq 0.05$. Data are pooled over fungicide programs of no fungicide. Two fungicide sprays in July, and bi-weekly fungicide sprays beginning in early July through early September.

[b]Optimum digging date based on pod mesocarp color was determined to be October 15.

Table 4.11. Relationship between early digging, peanut canopy defoliation, and peanut yield when fungicides were not applied.[a]

				Defoliation for the no-fungicide control[a]		Yield for the no-fungicide control[b]	
				Digging date		Digging date	
Experiment	Year	Cultivar	Field	6-12 d BOM[b]	Optimum maturity	6-12 d BOM	Optimum maturity
				———%———		———kg/ha———	
Lewiston-Woodville	2004	NC-V 11	G2	44	88*	2880	2880
Lewiston-Woodville	2004	NC-V 11	A2	69	88	1650	1290
Lewiston-Woodville	2004	NC 12C	C1B	51	78*	2450	2180
Rocky Mt	2004	VA 98R	C11	55	60	2720	2250
Rocky Mt	2004	VA 98R	C15	45	75*	4090	3690
Lewiston-Woodville	2005	NC-V 11	F2	55	70	4150	4450
Lewiston-Woodville	2005	VA 98R	F2	23	63*	3280	2890
Lewiston-Woodville	2004	Gregory	C2B	78	73	2440	1180*
Lewiston-Woodville	2004	NC 12C	A2	73	79	1290	660
Lewiston-Woodville	2005	Gregory	G6	46	79*	2420	2510
Pooled	-	-	-	53	76[c]	2770	2340*

[a]* indicates at $p \leq 0.05$significance when comparing digging dates when fungicides were not applied.

[b]Days before optimum digging based on peanut exposed to bi-weekly fungicide treatments using pod mesocarp color to determine pod maturity.

[c]The interaction of experiment for treatment was significant at $p \leq 0.05$ for peanut canopy defoliation. This interaction was not significant for pod yield.

Table 4.12. Relationship between early digging, peanut canopy defoliation, and peanut yield when two early season applications of fungicide were included for experiments conducted in North Carolina during 2004 and 2005.[a]

				Defoliation for the no-fungicide control[a]		Yield for the no-fungicide control[b]	
				Digging date		Digging date	
Experiment	Year	Cultivar	Field	6-12 d BOM[b]	Optimum maturity	6-12 d BOM	Optimum maturity
				%		kg/ha	
Lewiston-Woodville	2004	NC-V 11	G2	24	74*	3900	3810
Lewiston-Woodville	2004	NC-V 11	A2	48	76*	2770	1600
Lewiston-Woodville	2004	NC 12C	C1B	29	46	2760	3310
Rocky Mt	2004	VA 98R	C11	43	41	2770	2660
Rocky Mt	2004	VA 98R	C15	40	60*	3830	3690
Lewiston-Woodville	2005	NC-V 11	F2	37	33	4740	4780
Lewiston-Woodville	2005	VA 98R	F2	15	44	3960	2830
Lewiston-Woodville	2005	Gregory	G6	15	58*	2250	2880*
Pooled	-	-	-	31	54[c]	3370	3200[c]

[a]* indicates at $p \leq 0.05$significance when comparing digging dates when two early applications of fungicide were included.

[b]Days before optimum digging based on peanut exposed to bi-weekly fungicide treatments using pod mesocarp color to determine pod maturity.

[c]The interaction of experiment for treatment was significant at $p \leq 0.05$ for peanut canopy defoliation and pod yield.

Table 4.13. Linear relationships of percent of maximum yield versus peanut canopy defoliation as influenced by digging date for experiments conducted in North Carolina during 2004 and 2005.

				Linear regression equation, p-value, and coefficient of variation		
Location	Year	Cultivar	Field	Yield at optimum pod maturity vs. defoliation 6-12 d before optimum pod maturity	Yield at optimum pod maturity vs. defoliation at optimum pod maturity	Yield 6-12 d before optimum pod maturity vs. defoliation 6-12 d before optimum pod maturity
Lewiston-Woodville	2004	NC-V 11	G2	Y=-1.40X+93, p=0.0002, r^2=0.77	Y=-0.56+103, p=0.0001, r^2=0.90	Y=-0.81+88, p=0.0001, r^2=0.89
Lewiston-Woodville	2004	NC-V 11	A2	Y=-0.55X+72, p=0.0055, r^2=0.55	Y=-0.63X+94, p=0.0018, r^2=0.64	Y=-0.58X+102, p=0.0063, r^2=0.54
Rocky Mt	2004	VA 98R	C11	Y=-0.93X+93, p=0.0081, r^2=0.52	Y=-0.57X+96, p=0.0092, r^2=0.51	Y=-0.58X+90, p=0.0921, r^2=0.26
Rocky Mt	2004	VA 98R	C12	Y=-0.49X+93, p=0.0009, r^2=0.68	Y=-0.46X+91, p=0.0033, r^2=0.60	Y=-0.47X+97, p=0.0184, r^2=0.44
Lewiston-Woodville	2004	NC 12C	C2B	Y=-0.38X+99, p=0.0416, r^2=0.35	Y=-0.26X+101, p=0.0342, r^2=0.38	Y=-0.15X+97, p=0.2841, r^2=0.11
Lewiston-Woodville	2005	NC-V 11	F2	Y=-0.29X+97, p=0.0978, r^2=0.34	Y=-0.32X+102, p=0.0132, r^2=0.48	Y=-0.18X+98, p=0.2717, r^2=0.17
Lewiston-Woodville	2005	VA 98R	F2	Y=-0.78X+71, p=0.1101, r^2=0.24	Y=-0.48X+84, p=0.0077, r^2=0.52	Y=-0.93X+97, p=0.0157, r^2=0.46
Pooled	-	-	-	Y=-0.44+94, p=0.0001, r^2=0.28	Y=-0.49+85, p=0.0001, r^2=0.26	Y=-0.49+96, p=0.0001, r^2=0.49
Slopes using experiments as replication (p = 0.2784)				-0.53	-0.69	-0.51