ABSTRACT

HARE, ANDREW TREVOR. Influence of Production and Weed Management Practices on Yield of Agronomic Crops in North Carolina. (Under the direction of Dr. David L. Jordan).

Optimum planting date and effective weed management practices are critical production decisions for producing high yields and returns of major agronomic crops in North Carolina. Three experiments were conducted in North Carolina to characterize the effects of planting date and herbicide application timing on weed control, crop yield, estimated economic return, and weed populations the following season.

In one study, under weed-free conditions, research was conducted from 2013-2017 to determine yield potential of corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], peanut (*Arachis hypogaea* L.), and soybean [*Glycine max* (L.) Merr.] planted in reduced tillage systems within the recommended planting window for full-season production versus planting these crops following wheat harvest. Yield of corn, cotton, grain sorghum, peanut, and soybean in full-season production exceeded that of double-cropping cropping with wheat in 5, 5, 2, 4, and 5 years of the study, respectively. Yield of mid-April and Mid-May planted corn exceeded yield of mid-June planted corn in most instances. Yield of cotton, soybean, and peanut planted in early May or late May exceeded yield of mid-June plantings of these crops in most years. Estimated economic returns were generated for five different pricing structures using combinations of the ten-year average and ten-year high summer crop and wheat prices (2008-2017). Regardless the pricing structure, grain sorghum consistently produced the lowest estimated economic returns when not influenced by a high wheat price in most years. Double-cropped wheat and peanut generated economic return similar to or greater than double-cropped wheat and soybean in most years and pricing structures. In most cases, double cropping wheat with corn, cotton, or peanut was economically feasible when prices were

set at \$0.32 kg^{-1}, \$2.33 kg^{-1}, and \$1.02 kg^{-1}, respectively, compared to double cropping wheat and soybean.

In two other experiments, research was conducted during 2016 and 2017 at two locations in North Carolina to determine weed control and yield of corn, cotton, grain sorghum, and soybean in the same experiment and peanut alone in a separate experiment. Various herbicides were applied postemergence (POST) to each crop at 2 or 6 weeks after planting (WAP) only; 2 and 4 WAP; 4 and 6 WAP; and 2, 4, and 6 WAP along with a non-treated check (NTC). Clethodim was applied over the entire test area to remove interference from annual grasses in the peanut experiment only to aid in digging and vine inversion. In absence of herbicides, percent of maximum yield was greater for corn than all other crops regardless of the weed complex. When common ragweed (*Ambrosia artemiisifolia* L.) and Texas millet (*Urochloa texana* L.) were present, grain sorghum yield was greater than yield of cotton and soybean. When Palmer amaranth (*Amaranthus palmeri* S. Wats) and large crabgrass (*Digitaria sanguinalis* L.) were present, grain sorghum and soybean yield was similar and exceeded yield of cotton. In absence of herbicides, peanut yield was 880 and 1110 kg ha^{-1} at Lewiston-Woodville and Rocky Mount, respectively. Applying herbicides 2 WAP only or at least twice maximized yield of corn regardless of weed complex. Maximum cotton and soybean yield was obtained when at least two herbicide applications were made. Grain sorghum yield was optimized when herbicides were applied at least once beginning 2 WAP in presence of common ragweed and Texas millet or at least twice when initiated 2 WAP in presence of Palmer amaranth and large crabgrass. The greatest peanut yields were recorded when herbicides were applied three times (3680 kg ha^{-1} at Lewiston-Woodville and 5030 kg ha^{-1} at Rocky Mount). Corn generated the greatest economic return of the four crops when no herbicide was applied or one application was made 2 WAP regardless of weed complex. When common ragweed and Texas millet were present, estimated economic return was greater in corn than other crops even when multiple herbicide applications were made. Applying herbicides increased the estimated economic return of peanut compared to the NTC. When Palmer amaranth and large crabgrass were present, estimated economic returns for corn and soybean were often similar and exceeded estimated economic return of grain sorghum and cotton. In the year following weed management in these four crops, common ragweed and Palmer amaranth densities in cotton were lower when herbicides were applied the previous season compared with the NTC regardless of previous crop. Applying herbicide 2 and 4, 4 and 6, and 2, 4, and 6 WAP reduced populations similarly. Variation in the effect of crop on weed density the following year was observed. Common ragweed populations following peanut were affected by previous seasons herbicide applications while palmer amaranth populations were not. Although these experiments do not constitute a true time of weed removal or duration of weed interference study, results inform practitioners of the relative importance of timing and duration of weed management for peanut in North Carolina.

Influence of Production and Weed Management Practices on Yield
of Agronomic Crops in North Carolina

by
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DEDICATION

This thesis is dedicated to my parents, Andy and Carolyn Hare. I am thankful for encouragement and support poured out by family and friends along the way.

BIOGRAPHY

Drew Hare was raised in the small town of Edenton, North Carolina. In 2012, he graduated from John A. Holmes High School and launched his college education at North Carolina State University, pursuing a degree in Agricultural business management with minors in economics and crop science. While at N.C. State, he assisted the North Carolina Cotton and Peanut specialists in conducting various research projects involving variety performance, defoliation, plant growth regulators, fertility, herbicide and fungicide applications, planting dates, and harvesting dates. In spring 2016, Drew graduated Cum Laude and began his pursuit towards a Master's of Science degree in Crop Science under the direction of Dr. David Jordan. During the course of his Master's of Science degree, Drew has served as the research Technician for the North Carolina peanut extension Specialist, David Jordan, in maintaining a comprehensive program on peanut production and pest management from planting through harvesting. He has been involved in various peanut field days and extension trainings. Upon graduation, Drew hopes to begin a career in the agricultural industry.

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CHAPTER 1

POTENTIAL FOR AGRONOMIC CROPS IN A DOUBLE CROPPING SYSTEM WITH WHEAT (*Triticum aestivum* L.) IN NORTH CAROLINA

This chapter is written in the style and format for the American Society of Agronomy publication *Agronomy Journal*

ABSTARCT

Wheat (*Triticum aestivum* L.) and soybean [*Glycine max* (L.) Merr.] are generally double-cropped in North Carolina. However, if other commodity prices and projected net returns are higher than soybean, growers might consider a non-traditional double-crop system. Research was conducted in North Carolina from 2013-2017 at Lewiston-Woodville to determine yield potential of corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], peanut (*Arachis hypogaea* L.), and soybean planted in reduced tillage systems within the recommended planting window for full-season production versus planting these crops following wheat harvest. Yield of corn, cotton, grain sorghum, peanut, and soybean in full-season production exceeded that of double-cropping with wheat in 5, 5, 2, 4, and 5 years out of 5 years of the study, respectively. Corn, cotton, and peanut yields varied across years and planting dates. Yield of mid-April and Mid-May planted corn exceeded yield of mid-June planted corn in most instances. Yield of cotton and peanut planted in early May or late May exceeded yield of mid-June plantings of these crops in most years. Estimated economic returns were generated for five different pricing structures using crop and planting date combinations. The analyses used included combinations of the ten-year average (2008-2017) summer crop prices with the ten-year average wheat price, the ten-year average summer crop prices with the ten-year high wheat price, the ten-year high summer crop prices with the ten-year average wheat price, the ten-year high summer crop prices with the ten-year high wheat price, and the ten-year high wheat and average price of soybean verses the ten-year high summer crop and high wheat price. Regardless the pricing structure, grain sorghum consistently produced the lowest estimated economic returns when not influenced by a high wheat price in most years. Double cropped wheat and peanut generated economic return similar to or greater than double-cropped wheat and soybean in most years and pricing structures. In most cases, double-cropping wheat with corn, cotton, or peanut was economically feasible when prices were set at \$0.32 kg^{-1}, \$2.33 kg^{-1}, and \$1.02 kg^{-1}, respectively, compared to double-cropping wheat and soybean.

KEYWORDS: Conservation tillage, cropping system, estimated economic return, planting date.

INTRODUCTION

Cropping systems in the southeastern United States most often include a single crop in a year. However, double-cropping wheat (*Triticum aestivum* L.) and soybean [*Glycine max* (L.) Merr.] is a common practice in the United States (Foote et al., 2014). Multiple cropping systems most likely date back several centuries in more tropical climates (Smith and Varvil, 1982). Lengthened growing seasons over the past half century can be attributed to an increase in daily minimum temperatures resulting in an earlier onset and later end of the frost-free period (McCabe et al., 2015). When the price of corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], or peanut (*Arachis hypogaea* L.) is relatively high, producers often inquire whether the climatic conditions will make the double-cropping of these crops with wheat an economical option in North Carolina. Cereal rye (*Secale cereale* L.) and wheat are among the most popular cover crops used in the United States (Clark, 2007). The USDA reported that approximately 182,100 ha of wheat were grown in North Carolina in 2017 (USDA-NASS, 2018).

An increase in use of herbicide-resistant crops has decreased herbicide use and facilitated adoption of conservation tillage practices (Brookes and Barefoot, 2012; Sosnoskie and Culpepper, 2014). Conservation tillage is regularly used in double cropping systems. Many growers in the southeastern United States use the conservation tillage system known as strip tillage (Balkcom et al., 2018), which consists of isolated bands of varying widths, separated by bands of undisturbed soil (SSSA, 2008). Reduced tillage systems reduce soil and wind erosion, lessen time and labor during field preparations, increase water infiltration, and in some instances reduce disease pressure (Bosch et al., 2008; Cantonwine et al., 2007; Johnson et al., 2001; Price et al., 2007).

Corn. The estimate for planted area of corn was 360,170 ha in North Carolina in 2017, accounting for about 0.99% of the United States total (USDA-NASS, 2018). Recommended planting occurs when soil temperatures at the 5-cm depth have reached 13ºC and weather forecasts show warm temperatures for days to come (Heiniger et al., 2003). Optimum temperatures for planting corn usually occur before 20 March in the Tidewater, 20 March to 25 March in the Coastal Plain, 25 March to 5 April in the Piedmont, and 5 April to 20 April in the mountain regions of North Carolina (Heiniger et al., 2003). Yield penalties usually exist when corn is planted past the optimum date because of the cumulative time and thermal requirements for regionally adapted corn hybrids to reach black layer are not met (Nielsen et al., 2002). Yield penalties also exist when soil temperatures are below optimum, often times as a result of early planting or conservation tillage (Griffith et al., 1973; Kaspar et al., 1987; Swan et al., 1987).

The optimal planting date for corn varies across the United States because of differences in climate and length of growing seasons in the areas the crop is produced (Bruns, 2003). Planting dates in late April produced the highest gross income over 29-site years for early and mid-maturity hybrids in the North Central Midwest (Jeschke and Paszkiewicz, 2008). In Minnesota, planting of full- and short-season hybrids between 21 April and 6 May resulted in yields within 1% of the maximum average, while delayed planting until 30 May resulted in 80%

of the maximum (Coulter, 2010). Bruns and Abbas (2006) found that yields rapidly declined as planting was delayed past 20 April in Mississippi. Wiatrak et al. (2004) documented lower yields when corn was planted later than May but they associated these losses due to greater insect and disease pressure. Corn yields decrease by 63 kg ha^{-1} for everyday that planting is postponed past 15 April in the Piedmont and Coastal Plain areas of North Carolina (Heiniger et al., 2003). Growers in North Carolina are advised to switch from a full-season hybrid to medium season hybrids around 28 April and from medium-season to early-season hybrids around 7 May (Heiniger et al., 2003).

Cotton. Cotton, an important export commodity in the United States, is grown in the southeastern and southwestern regions (Durmaz, 2014). Approximately 152,000 ha of cotton were grown in North Carolina in 2017 accounting for about 3% of the United States total cotton ha (USDA-NASS, 2018). A critical determinant of yield potential for cotton in the midsouthern United States is planting date (Boquet and Clawson, 2009). Recommended planting occurs when the soil at the 5-cm depth approaches 18ºC and future weather forecasts are favorable for crop development (Silvertooth et al., 1999). In Arkansas, the optimal planting window is between 28 April and 9 May (Waddle, 1984). Boquet and Clawson (2009) reported that optimum planting dates in the midsouthern United States occurred between 15 April and 15 May. Suggested planting of cotton in North Carolina occurs after 15 April when soil temperature has reached 18ºC by 1000 h in a 7-cm deep, moist seedbed (Edmisten and Collins, 2018). When temperatures are expected to be below 10ºC within five days of planting, planting is usually delayed, as cotton seedling growth is affected at these low temperatures (Christiansen and Thomas, 1969; Pettigrew, 2002).

In midsouthern United states, yields tend to decline when planting is delayed after 15 May (Boquet and Clawson, 2009; Waddle, 1984). Cathey and Meredith (1988) found that a late planting date resulted in fewer flowers, smaller bolls, and less lint when compared to an earlier planting date. In the past, later-planted cotton was exposed to insect damage for longer periods of time (Hopkins and Culp, 1984), but these threats have been alleviated with the advancement of effective insecticides and *Bacillus thuringiensis* (Bt) cultivars protecting against bollworm [*Helicoverpa zea* (Boddie)], tobacco budworm (*Heliothis virescens* F.), and fall armyworms (*Spodoptera* spp.) (Leonard and Emfinger, 2002). The cause of yield reductions from late planting dates are poorly understood compared with early planting dates (Boquet and Clawson, 2009). Because North Carolina is near the Northern boundary of the cotton growing region, there is a narrow optimal planting window usually favoring-early May (Guthrie, 1991; Nuti et al., 2006). Lower yields from late planting dates are associated with reduced season length and lower heat unit accumulation (Gunthrie, 1991; Krieg, 1985; O'Berry et al., 2008).

Planting before the optimum planting date can result in lower plant populations. Early planting dates of 25 March and 5 April in Louisiana resulted in 20% seed emergence 20 days after planting as a result of low soil and air temperatures and rainfall events (Boquet and Clawson, 2009). When intensive spring rain events occur, soil crusting takes place, limiting emergence of cotton seedlings (Wilkes and Corely, 1968). Soil crusting is of greater concern for early planting dates because of slower emergence as a result of fewer degree hours (Boquet and Clawson, 2009). Slower emergence can also cause weaker seedlings, increasing the likelihood of pathogen infection (Waddle, 1984). Kittock et al. (1987) found that lower than optimum populations did not result in lower yield in all cases, further recognizing that plant compensation and other factors throughout the growing season play a key role in determining yield. Yield responses associated with planting dates have not been consistent because of cultivar adaptation, occurrence of weather events, and insect infestations that also influence yield (Bauer et al., 1998; Gaylor et al., 1983; Hopkins and Culp, 1984; Porter et al., 1996).

Grain Sorghum. Grain sorghum has a wide range of planting dates that can result in optimum yields. The use of grain sorghum as animal feed has increased interest in double cropping this crop with wheat in southeastern United States (Shore, 2015). USDA data states that 8,093 ha of grain sorghum were grown in North Carolina in 2017 accounting for about 0.36% of the United States total grain sorghum ha (USDA-NASS, 2018). When soil and air temperatures are below 15ºC during germination, emergence, and early season growth, stand establishment and early-season vigor of grain sorghum are adversely affected (Yu and Tuinstra, 2001). Risks associated with an early planting of grain sorghum include cool damp soil, spring rainstorms during germination and emergence, late spring frosts, and bird damage to grain prior to harvest (Martin and Vanderlip, 1997). Risks associated with late planting of grain sorghum include lack of soil moisture for germination, excessively hot soil conditions for seedling growth, delayed flowering and grain development, moisture and heat stress during flowering, and developing grain not maturing due to cool weather and late-season frosts (Martin and Vanderlip, 1997).

In Arkansas, Bryant et al. (1986) reported that yield decreased 22% for 19 March, 25% for 20 May, and 49% for 21 June compared to a 19 April planting date. Optimum yields were obtained in Kansas when grain sorghum was planted between 25 May and 5 June (Martin and Vanderlip, 1997). Consistent yields can be obtained when grain sorghum is planted between 10 May and 15 June but high yields are still obtainable in some years when planted as late as 15 July in North Carolina and Virginia (Anonymous, 2011). Quantifying the effect of planting date and hybrid maturity on yield is critical in order to maximize economic return (Conley and

Wiebold, 2003). In Kansas, hybrid maturity only affected yield during extreme planting dates such as April or July (Martin and Vanderlip, 1997).

Peanut. Approximately 48,200 ha of peanut were grown in North Carolina in 2017 accounting for about 6% of the United States total peanut ha (USDA-NASS, 2018). Peanut is seeded in early to mid-May in North Carolina in order to reach its 140-day optimum maturity (Jordan et al., 2005: Jordan, 2018). Recommended planting occurs when soil temperature at a 10 cm depth is 18º C or above at noon for three days with favorable future weather forecast for seed germination (Jordan, 2018). The planting window for Virginia market type peanut cultivars in North Carolina is the entire month of May but there is concern with late May and early June plantings not reaching maturity due to unfavorable weather or stresses during the growing season and harvest (Drake et al., 2014). Cool temperatures in late September and October can prevent late planted peanut from reaching the required number of growing degree days for optimum maturity (Jordan, 2018). A later planting date and increased plant populations have shown to decrease the severity of tomato spotted wilt virus (family *Bunyaviridae*, genus *Tospovirus*), which is vectored by thrips (*Frankliniella* spp.) (Culbreath et al., 2010; Tillman et al., 2006). Mahoney et al. (2018) found varying results with peanut planting dates. They found that late May planted peanut exceeded yield of peanut planted early May in some years, while early May planted peanut exceeded yield of late May planted peanut in others. They also found that yield of early May planted peanut and late May planted peanut was similar in some years. Carley et al. (2008) found that peanut planted in May yielded greater than peanut planted in June. In one year, Moss et al. (2012) noted greater yields for peanut planted in early May compared to peanut planted early June while in another year peanut planted in early June produced greater yields than peanut planted early May.

Planting peanut into conventionally-raised seedbeds may help with faster germination and early growth aided by warmer soil, provide better drainage, and minimize pod losses during digging (Jordan, 2018). However, the shift of peanut toward sandy soils has shown favorable responses to reduced tillage systems (Jordan, 2018). In a survey of peanut growers in North Carolina, adoption of reduced tillage systems increased from 10% to 20% from 1998 to 2014 (Jordan, 2018). Peanut area under conservation tillage increased from 8% in 2004 to 25% in 2014 nationally (USDA, 2017). Balkcom et al. (2018) found that peanut plant population 28 d after planting was reduced when strip tillage was implemented with cover crop compared with strip tillage into desiccated native vegetation. These results could have been due to the cover crop causing poor seed to soil contact at planting. Inconsistent yield responses have been documented for Virginia market type peanut cultivars planted into reduced-tillage systems (Drake et al., 2010; Faircloth et al., 2005, 2008; Jordan and Johnson, 2010; Jordan et al. 2008; Meijer and Jordan, 2010; Tubbs and Gallaher, 2005). Resulting yields from strip-tillage have been documented to be lower than yields of conventionally-tilled peanut, possibly due to pod loss during digging or production on fine textured soils (Jordan et al., 2001; Jordan et al., 2004; Jordan and Johnson, 2010). However, Moss et al. (2012) saw no differences between strip tilled and conventional tilled peanuts in both monocropping and double cropping systems.

Soybean. In 2017, approximately 688,000 ha of soybean were grown in North Carolina accounting for about 2% of the United States total soybean ha (USDA-NASS, 2018). Planting date of soybean has been studied for more than a century and continues to gain attention because of the effects this particular production decision has on seed yield and quality (Cartter and Hartwig, 1963; Egli and Cornelius, 2009; Hu and Wiatrak, 2012; Mooers, 1908). Daytime length and temperature greatly affect photoperiod sensitive crops including soybean (Board and Hall, 1984; Egli and Bruening, 1992). In the midsouthern United States (Arkansas, East Texas, Mississippi, southern Missouri, and West Tennessee), a wide window of options are available for planting date and cultivar selection for soybean extending from late March to early July and from maturity group III to VII (Salmeron et al., 2014). In North Carolina, optimum planting for soybean occurs from 1 May to 10 June but planting typically extends to 1 July (Dunphy, 2017). A maturity group V cultivar would be considered an early season cultivar, a group VI cultivar a mid-season cultivar, and a group VII cultivar would be considered a late season cultivar in most of North Carolina (Stowe and Dunphy, 2017). Regardless of maturity group, grain yields rapidly decline when soybean is planted later than 27 May in the Midwest and Deep South (Egli and Cornelius, 2009). Chen and Wiatrak (2010) recommend that soybeans should be planted early to mid-May in the southeastern Coastal Plain if not double-cropped to lengthen the duration of vegetative, flowering, and pod-set stages and to avoid cooler temperatures during seed-fill. They also found that yields of all maturity groups could be determined by precipitation during pod-set. In addition to planting date, soil moisture affects soybean yield from seed germination to maturity (Helms et al., 1996; Irmak et al., 2002; Mengistu and Heatherly, 2006). It is recommended that soybean be planted in narrow rows (<75 cm) when planted late to increase pod number, resulting from greater light interception and crop growth rate during early productive periods (Board et al., 1992; Board and Harville, 1992; Boerma and Ashley, 1982). It is also recommended that as planting is delayed, soybean seeding rate should be increased (Dunphy, 2017).

Double Cropping Systems. In 2017, 30% of the total soybean area planted was planted following the harvest of another crop in a double-cropping system (USDA-NASS, 2018). The double-cropping of soybean has been studied extensively across the United States. The majority of double-cropped soybean in North Carolina is planted without tillage (Dunphy and Osmond, 2017). Minimum tillage and no-tillage strategies generally result in a decreased soil temperature at planting from solar radiation reflectance and crop residues insulating the soil (Wall and Stobbe, 1983), but this is typically not an issue when double-cropping with wheat because soils have reached or exceeded optimum temperatures by mid-June. Ashlock et al. (1998a, 1998b) recommend maturity groups V and VI soybean cultivars when planting late or double-cropping with wheat in Arkansas. In the southeastern United States, maturity group VII and VIII are recommended for double cropping soybean systems in order to ensure high yield potential (Wiatrak et al., 2009). Salmeron et al. (2014) suggested that maturity group IV soybean were most stable when planted late in the midsouth. They suggest more research should be conducted with newer cultivars and environmental effects such as planting date, plant population, row width, and irrigation to determine proper maturity group selection. Depending upon year, cultivar, and other culture practices, double cropping soybean can result in yields that are 0 to 55% lower than full-season soybean (Beaty and Eldridge, 1980; Caviness and Thomas, 1979). In southeastern Virginia, Thomason et al. (2017) noted greater net returns when double cropping wheat and soybean compared to double cropping wheat and grain sorghum. In the southeast, insect and disease problems can be more challenging when corn is planted later in the spring (Wiatrak et al., 2004). Wiatrak et al. (2004) suggested that selection of higher-yielding corn hybrids from tropical locations rather than germplasm developed for the mid-western United States can result in the potential for corn to be grown in a double cropping system in the southeast due to higher disease resistance. Heiniger et al. (2003) suggested that using early maturing Bt hybrids may help the grower avoid insect damage with later plantings. Later planted corn will be in the vegetative stage during July when heat stress is most prevalent, potentially having less yield reductions than early planted corn experiencing heat stress during reproductive stages. Lewis and Phillips (1976) noted 40% yield reductions of corn double-cropped with wheat compared to when planted in the traditional window between 9 April and 12 May. Camper et al. (1972) noted greater net returns from double-cropped corn following barley compared to double-cropping barley with grain sorghum or soybean. They also found that summer crops could be planted about two weeks earlier when following barley rather than following wheat in a double-cropping system. In terms of cotton, early maturing cultivars may make double cropping with wheat feasible in the United States. In the northern-most cotton growing region of the United States, Smith and Varvil (1982) found that the rapid fruiting cotton cultivar Arkugo 4 double cropped with wheat produced yields 36-52% lower than full-season monocropped cotton. They also found that the full-season cultivar Deltapine 16 produced yields 65% lower when double cropped than when monocropped. In Pakistan, Shah et al. (2017) overcame the yield penalty associated with a late planting of cotton following wheat harvest by transplanting 45-day old seedlings into the harvested stubble. When double-cropping grain sorghum behind wheat, it is important to choose an early to medium maturing hybrid and is recommended to plant on narrow rows (Anonymous, 2011). However, Conley and Wiebold (2003) found no evidence that growers in Missouri should switch to early maturing hybrids when double-cropping wheat and grain sorghum. Double cropping peanut using strip tillage following wheat produced greater net returns than planting peanut early May in 3 of 4 trials in Georgia (Moss et al., 2012).

Relay Intercropping Systems. A relay intercropping system has been suggested as an alternative method of mono-cropping and double cropping cotton and peanut following wheat (Foote et al., 2014; Moss et al., 2012). Previously, in intercropping systems, crops are planted at the same time causing shorter plant species to be shaded out by the taller companion species

(Allen et al., 1976) ultimately resulting in severe yield reductions for the shorter species (Koli, 1975). Controlling light availability for the shorter crop during critical stages of development by spacing planting timings of the two crops in the intercropping system, referred to as relay intercropping, is a strategy growers have used in minimizing yield reductions associated with the competition exhibited by two tandemly growing crops (Misbahulmunir et al., 1989). Relay intercropping can also be used to alleviate some of the yield penalties associated with a late planting of summer crops in a double-cropping with wheat system. In the fall, wheat is planted leaving skip rows for wheel traffic, and the subsequent crop is planted in the spring into the skip rows while the wheat is still living. Insect pests including cotton aphids (*Aphis gossypii* Glover), thrips, leafhopper (*Amrasca biguttula* Ishida), and whiteflies (*Bemicia tabaci* Genn.) have shown suppression when cotton was intercropped with winter cereal grains and legumes or had cover crop residues present (All and Vencill, 2008; All et al., 1993; Jambhrunkar et al., 1998; Olson et al., 2006). Although relay intercropping has many advantages, there are a few management implications. Early season weed and insect management and other technical challenges may be a major drawback for relay intercropping cotton and peanut with wheat due to restricted use of pesticides and limited traffic routes caused by the presence of harvestable wheat (Hood et al., 1991; Moss et al., 2012). Due to the previously mentioned implications as well as reduced initial stand because of wheel routes, Foote et al. (2014) noted a 21% yield reduction of wheat grown in a relay intercropping system compared to a conventional system. They also found cotton lint yield to be similar for monocropped cotton and cotton relay intercropped with wheat. Moss et al. (2012) documented similar peanut yields for relay intercropping and double cropping wheat and peanut using strip tillage in 3 of 4 trials.

Determining the feasibility of double cropping corn, cotton, grain sorghum, peanut, and soybean with wheat will be important in determining whether growers have more options during times of higher crop prices. For example, in some years, prices of corn, cotton, grain sorghum, peanut, and soybean reached \$0.32 kg^{-1}, \$2.33 kg^{-1}, \$0.27 kg^{-1}, \$1.02 kg^{-1}, and \$0.62 kg^{-1}, respectively (Table 1.1). During years of high prices, growers may have an incentive to double-crop with wheat an alternative crop to soybean if yield penalties associated with this later planting date are well documented and minimal. Determining the yield potential of major agronomic crops in North Carolina double-cropped with wheat would provide useful information to growers and contribute new information to the literature as there is limited published data that allow a direct comparison of double cropping for these major agronomic crops in North Carolina. Research was conducted in North Carolina to compare yield of corn, cotton, grain sorghum, peanut, and soybean planted during the typical monocropped window compared to planted mid-June following harvested wheat to compare the effects of planting date on yield and economic returns at different pricing structures for the respective crops.

MATERIALS AND METHODS

Study Information. The experiment was conducted in North Carolina from 2013-2017 at the Peanut Border Belt Research Station near Lewiston-Woodville (36.1353º N, -77.1767º W). Soil was a Goldsboro sandy loam (fine-loamy, siliceous, subactive, thermic Aquic Paleudult) and a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudult). Plot size was four rows (91-cm spacing) by 18 m in length. Alleys between plots were 2.4 m. Corn, cotton, grain sorghum, peanut, and soybean (summer crops) hybrids/cultivars planted each year are provided in Table 1.2.

The experimental design was a split plot with summer crop serving as the whole plot unit and planting date serving as the sub-plot unit. Sub-plots were replicated four or five times. Treatments consisted of three planting dates for each summer crop (Table 1.3). For corn, plantings were approximately mid-April, mid-May, and Mid-June. For cotton, grain sorghum, peanut, and soybean, plantings were approximately early May, late May, and mid-June. Plantings prior to June were sown into desiccated wheat stubble where glyphosate at 1.1 kg ae ha^{-1} (Roundup Ultra MAX, Monsanto Co., St. Louis, MO) was applied approximately two weeks before planting. Plantings of each crop in mid-June were sown into harvested wheat stubble. Seedbeds were established using a strip tillage implement (Kelly Manufacturing Co., Tifton, GA) by strip tilling a 45-cm section of each 91-cm row into either desiccated or harvested wheat stubble.

Management of all crops were based on North Carolina State extension services recommendations and were designed to maximize yields (Edmisten et al. 2018; Heiniger et al. 2003; Jordan et al. 2018; Stowe et al. 2017). Each planting date received the same degree of production management. Crop yield was determined in each year at optimum maturity in most cases. Corn, grain sorghum, peanut and soybean were adjusted to 15.5%, 13%, 8% and 13% moisture, respectively. Daily precipitation and daily minimum temperature data were recorded from 1 April to 1 December in each year (Table 1.4)(Figures 1.1 to 1.5).

Economic Analyses. Economic returns were estimated using modified North Carolina State University enterprise budgets for strip tilled corn, cotton, grain sorghum, peanut, soybean and conventional wheat to accommodate a 400-hectare operation in North Carolina (Washburn, 2019). Base cost for corn, cotton, grain sorghum, Virginia market type peanut, and soybean were set at \$1,019 ha^{-1}, \$1,493 ha^{-1}, \$713 ha^{-1}, \$1,719 ha^{-1}, and \$771 ha^{-1}, respectively. The base cost excluded variable costs associated with yield such as drying, cleaning, hauling, ginning, state checkoff fees, and national assessment fees which were adjusted into total costs accordingly for each crop after yield was determined. Base cost for wheat was set at \$519 ha^{-1} excluding hauling costs, which were added into total cost varying with yield. Five different pricing structures were used to compare estimated economic returns using the ten-year average and the ten-year high summer crop and wheat prices (USDA-NASS, 2018). Crop prices found in table 1.1 were used to compare crop and planting date combinations using an average wheat price and average summer crop price, an average wheat price and a high summer crop price, a high wheat and average summer crop price, a high wheat and high summer crop price, and the ten-year high wheat and average price of soybean verses the ten-year high summer crop and high wheat price. Only mid-June planted summer crops included the additional wheat revenue in the estimated economic return analyses.

Statistical Analyses. Yield of each crop and economic returns were subjected to analysis of variance using the GLIMMIX procedure in SAS (SAS Institute Inc., Cary, NC). In one analysis data for yield were subjected to ANOVA for the 5 (year) × 3 (planting date) structure of the experiment. In this analysis, both year and planting date were considered fixed effects. In a second analysis, data for yield were subjected to ANOVA with year considered a random effect and planting date considered a fixed effect. Replication was considered a random effect in both analyses. Means for crop yield within years and pooled over years were separated using Fisher's Protected LSD test at $p \leq 0.05$. Data for estimated economic returns for the five pricing structures were subjected to ANOVA including 5 years, 5 cropping systems, and 3 planting dates. In this analysis all factors except replication were considered fixed effects. In a separate analysis, year and replication were considered random effects. Means for estimated economic returns across crops in a year or pooled over years were separated using Fisher's Protected LSD test at $p \leq 0.05$. Additionally, Dunnett's test was used to compare differences in estimated economic returns at the five price structures for the crop and planting date combinations with double-cropped wheat and soybean at the $p \leq 0.05$ level of significance.

RESULTS AND DISCUSSION

Crop Yield. The interaction of year × planting date was significant for yield in most cases for each crop ($p \leq 0.05$). Similarly, the main effect of planting date was significant for crop yield when year was considered a random effect. These results indicate that substantial variation in yield and estimated economic return was observed over the five years of the experiment.

Corn. In 2013 and 2016, yields were greatest when corn was planted in mid-April followed by planting in mid-May followed by corn planted mid-June. In 2014, 2015, and 2017 corn planted in mid-May resulted in the greatest yields (Table 1.5). In these respective years, corn planted in mid-April exceeded yield of corn planted in mid-June. When pooled over five years, yields were similar for corn planted mid-April and mid-May, exceeding yields of corn planted mid-June by at least 2,250 kg ha^{-1} (Table 1.5). Bruns and Abbas (2006) documented significant yield losses when corn was planted after late April in the mid-South while Wiatrak et al. (2004) noted a decline in corn yield when planted after late May.

Cotton. In 2014, 2016, and 2017, lint yield was similar for early May and late May plantings and exceeded yield of the mid-June planted cotton following wheat (Table 1.5). In both 2013 and 2015, lint yield was greatest for cotton planted in late May compared with early-May or mid-June plantings. In 2013, the next greatest yield was obtained with the early May planting date. Surprisingly, cotton lint yield from the mid-June planting date exceeded lint yield from the early May planting in 2015. This was likely due to a wet harvest season where losses occurred with earlier planted cotton during the period between harvest and defoliation or limited rainfall in the month of May (Table 1.4). In this case cotton planted in mid-June was not defoliated during the period of excessive rainfall and boll loss was minimal due to inclement weather. The late May and mid-June planted cotton also avoided early season drought stress. This was not the case for cotton planted in May. When averaged over years, lint yield of cotton planted early May and late May was similar and exceeded lint yield of cotton planted mid-June by at least 310 kg ha^{-1} (Table 1.5). Cotton yield in North Carolina has been favorable to early May plantings (Guthrie, 1991; Nuti et al., 2006).

Grain Sorghum. Four different responses were noted when comparing yield of grain sorghum for planting dates within each year (Table 1.5). In 2015 and 2016, yield was similar across all planting dates. In 2013, grain sorghum planted in early May and mid-June yielded greater than yield of grain sorghum planted late May. In 2014, yields were greatest when planted in early May and late May compared to grain sorghum planted mid-June following wheat. In 2017, yield of grain sorghum planted in early May and mid-June were less than yield of grain sorghum planted late May. Conley and Wiebold (2003) also had inconsistent yield results for grain sorghum at different planting dates leading them to conclude that a wide planting date window for grain sorghum exists in Missouri. When averaged over years, yield of grain sorghum was similar when planted early May, late May, and mid-June. In Kansas, Martin and Vanderlip (1997) found optimum yields of grain sorghum resulting from plantings between 25 May and 5 June.

Peanut. Five different responses were noted when comparing yield for planting dates within each year for peanut (Table 1.5). In 2014, 2015, and 2016, mid-June planted peanut following wheat produced lower yields than early and late May planted peanut. Carley et al. (2008) also found that peanut planted in May yielded greater than peanut planted in June. In 2013, planting date did not influence peanut yield. In 2014, yields were similar for early May and late May planted peanut, exceeding yield of mid-June planted peanut. In 2015, peanut yield was greater when planted early May than planted late May, while in 2016 yield of peanut planted late May was greater than peanut planted early May. In 2017, yield of late May planted peanut exceeded yield of early May and mid-June planted peanut. When averaged over years, yield of peanut planted in early May was similar to yield of peanut planted in late May exceeding yield of mid-June planted peanut by at least 1350 kg ha^{-1}. Mahoney et al. (2018) found that late May planted peanut exceeded yield of peanut planted early May in 2013 and 2016, while early May planted peanut exceeded yield of late May planted peanut in 2014. They also found that yield of early May planted peanut and late May planted peanut was similar in 2015. In one year, Moss et al. (2012) noted greater yields for peanut planted in early May compared to peanut planted early June while in another year peanut planted in early June produced greater yields than peanut planted early May.

Soybean. Four different responses were noted when comparing yield for planting dates within each year for soybean (Table 1.5). In 2015 and 2016, yield of early May and late May planted soybean was similar and exceeded yield of mid-June planted soybean. In 2013 and 2017, late May planted soybean generated the greatest yield. In 2013, yield of early May planted soybean was greater than yield of mid-June planted soybean while in 2017 early May planted soybean was similar to yield of mid-June planted soybean. In 2014, yield of early May and late May planted soybean was similar with only yield of late May planted soybean being greater than yield of the mid-June planted soybean. When averaged over years, greatest yield was noted in soybean planted late May followed by yield of soybean planted early May with both exceeding yield of soybean planted mid-June. This is in agreement with findings from Egli and Cornelius (2009) documenting rapid yield reductions when soybean is planted prior to 27 May.

Estimated Economic Returns. The interaction of cropping system × planting date was significant when year was considered either a fixed or random effect for estimated economic return, regardless of pricing structure.

Average Summer Crop and Average Wheat Price. When prices were set at the ten-year average for summer crops and the ten-year average for wheat, maximum and minimum estimated economic returns varied over years (Table 1.6). Planting peanut in late May generated the greatest estimated economic return in 2016 and 2017 netting \$1,076 and \$1,798 ha^{-1}, respectively. These respective returns were \$975 and \$657 ha^{-1} greater than returns generated from soybean planted mid-June following wheat. Peanut planted in early May generated the greatest estimated economic return of \$1395 ha^{-1} in 2015, while cotton planted late May generated the greatest estimated economic return of \$1375 ha^{-1} in 2013. In 2014, an estimated economic return of at least \$427 ha^{-1} was generated from soybean at all planting dates, from cotton planted early May and late May, and from corn planted mid-May. When averaged over years, the greatest estimated economic returns were generated from cotton and peanut planted in late May with returns of \$692 and \$769 ha^{-1}, respectively. Peanut planted in late May was the only crop-planting date combination that generated a greater estimated economic return than soybean planted in mid-June following wheat.

With summer crops and wheat set at the ten-year average, Dunnett's test was used to compare the estimated economic returns generated from non-traditional double cropping systems with the double cropping of wheat and soybean (Table 1.6). The only non-traditional double cropping system that generated a greater estimated economic return than double-cropped soybean with wheat was double-cropped cotton with wheat in 2013.

Average Summer Crop and High Wheat Price. When prices were set at the ten-year average for summer crops and the ten-year high for wheat (Table 1.7), the greatest estimated economic returns were noted in peanut planted early May in 2015 and peanut planted late May in 2016. In 2013, the greatest estimated economic returns were noted from late May and mid-June planted cotton. Mid-June planted cotton and soybean as well as late May planted peanut generated the greatest estimated economic returns in 2017. Peanut and soybean planted mid-June generated the greatest estimated economic returns in 2014. When averaged over years, the greatest estimated economic returns were obtained from mid-June planted cotton and soybean and from late May planted peanut. Soybean planted mid-June following wheat generated greater estimated economic returns than grain sorghum and corn at all planting dates, early May and late May planted cotton and soybean, and early May and mid-June planted peanut.

With the pricing structure consisting of the ten-year average summer crop prices and the ten-year high wheat price, estimated economic returns of the non-traditional double cropping systems was compared with that of the soybean double-cropped with wheat using Dunnett's test (Table 1.7). In this scenario, double-cropped cotton with wheat was the only non-traditional double cropping system that generated a greater estimated economic return than double-cropped soybean with wheat.

High Summer Crop and Average Wheat Price. In 2013, late may planted cotton generated the greatest estimated economic return compared with all other crop-planting date combinations (Table 1.8). In this respective year cotton or peanut planted at any date, corn planted mid-April, and soybean planted late May exceeded the estimated economic return generated from soybean planted mid-June following wheat. Peanut at all planting dates and cotton planted early May and late May generated the greatest estimated economic returns of at least \$1666 ha^{-1} in 2014. Early May planted peanut produced the greatest estimated economic return in 2015, while late-May planted peanut produced the greatest estimated economic return in 2016 and 2017. In 2015, only peanut planted early May and late May generated estimated economic returns greater than soybean planted mid-June following wheat. In 2016, estimated economic returns of cotton and soybean planted early May and late May, corn planted mid-April and mid-May, and peanut at all planting dates exceeded estimated economic return of double cropped wheat and soybean. Peanut at all planting dates and cotton planted early May and late May generated estimated economic returns greater than soybean planted mid-June following wheat in 2017. When averaged over the five years, peanut planted early in May generated the greatest estimated economic return totaling \$3017 ha^{-1}. Peanut at all planting dates and cotton planted early May and late May generated greater estimated economic returns than double cropped wheat and soybean.

Dunnett's test was again used to compare the generated estimated economic returns of the non-traditional double cropping systems with soybean double-cropped with wheat when summer crop prices were set at the ten-year high and wheat price was set at the ten-year average (Table 1.8). In this pricing structure, we noted five non-traditional double cropping scenarios within years that generated greater estimated economic returns than double-cropped soybean with wheat. When averaged over years, one scenario of a non-traditional double cropping system generated a greater estimated economic return than that of double-cropped soybean with wheat. In 2013, double-cropped peanut and double-cropped cotton generated a greater estimated economic return than that of double-cropped soybean with wheat. In 2014, 2016, 2017, as well as when pooled over years, only double-cropped peanut with wheat generated a greater estimated economic return than double-cropped soybean with wheat.

High Summer Crop and High Wheat Price. The higher wheat revenue increased estimated economic returns for the double cropped scenarios using the ten-year high summer crop and the ten-year high wheat prices (Table 1.9). Cotton at all planting dates and peanut planted mid-June generated estimated economic returns greater than soybean planted mid-June following wheat in 2013. Only mid-June planted peanut following wheat generated a greater estimated economic return than soybean planted mid-June following wheat in 2014. In 2015, peanut planted early May and late May generated greater estimated economic returns than mid-June planted soybean following wheat while in 2017, late May and mid-June planted peanut generated greater estimated economic returns than mid-June planted soybean. Peanut at all planting dates and corn planted mid-April and mid-May produced greater estimated economic returns than soybean planted mid-June following wheat in 2016. When averaged across years, late May planted peanut generated the greatest estimated economic return totaling \$3,017 ha^{-1}. Peanut at all planting dates generated greater estimated economic returns than soybean planted mid-June following wheat.

Estimated economic returns of the non-traditional double cropping systems was again compared with double-cropped soybean and wheat using Dunnett's test, when summer crops and wheat prices were set at the ten-year high (Table 1.9). Again, we noted five non-traditional double cropping scenarios within years that generated greater estimated economic returns than double-cropped soybean with wheat. Also, when averaged over years, one scenario of a non-traditional double cropping system generated a greater estimated economic return than that of double-cropped soybean with wheat. In 2013, double-cropped peanut and double-cropped cotton generated a greater estimated economic return than that of double-cropped soybean with wheat. In 2014, 2016, 2017, as well as when pooled over years, only double-cropped peanut with wheat generated a greater estimated economic return than double-cropped soybean with wheat.

High Summer Crop and High Wheat Price Versus Average Soybean Price. Analyzing the crop and planting date combinations using the ten-year high summer crop and wheat prices compared to the ten-year average soybean and ten-year high wheat prices, may be the best predictor of a viable alternative double-cropping system in North Carolina (Table 1.10). In 2013, 2014, 2016, and 2017 estimated economic returns were greater for peanut planted early May, late May, and double cropped with wheat compared to double-cropped wheat and soybean. Early May and late May planted peanut generated greater estimated economic return than double-cropped wheat with soybean in 2015, while estimated economic return of double-cropped wheat and peanut was similar. Grain sorghum planted mid-June following wheat generated greater estimated economic return than double-cropped wheat and soybean in 2013 and 2015. In 2014, 2016, and 2017, estimated economic returns were similar for double-cropped wheat and soybean and double-cropped wheat and grain sorghum. Early May and late May planted cotton as well as double-cropped wheat and cotton generated greater estimated economic returns than double-cropped wheat and soybean in 2013 and 2017. Cotton planted early May in 2014 and cotton planted early May and late May in 2016 generated greater estimated economic returns than double-cropped wheat and soybean. Double-cropped wheat and cotton generated similar estimated economic returns as double-cropped wheat and soybean in three of the five years. Corn planted mid-April and mid-May produced greater estimated economic returns than double-cropped wheat and soybean in 2013 and 2016. Double-cropped wheat and corn generated greater estimated economic return than double-cropped wheat and soybean in 2016. Double-cropped wheat and corn and double-cropped wheat and soybean generated similar estimated economic returns in four of the five years. When averaged over the five years, peanut and cotton planted early May, late May, and double-cropped with wheat generated greater estimated economic returns than double-cropped wheat and soybean. Corn planted mid-April, mid-May, and Mid-June double-cropped with wheat generated similar estimated economic returns as grain sorghum and soybean double-cropped with wheat.

Analyzing the estimated economic returns generated from the double cropping systems using the ten-year high summer crop and wheat prices compared to the ten-year average soybean and ten-year high wheat prices using Dunnett's test is another tool in determining the feasibility of these non-traditional double cropping systems Table 1.10). In this pricing structure, there were ten non-traditional double cropping scenarios that generated greater estimated economic returns than double-cropped soybean and wheat. In 2013, estimated economic returns were greater for double-cropped corn, cotton, grain sorghum, and peanut with wheat than that of double-cropped soybean and wheat. In 2014, only estimated economic return of double-cropped peanut with wheat generated greater than that of double-cropped soybean and wheat while in 2015 only double-cropped grain sorghum with wheat generated greater estimated economic return than that of double-cropped soybean with wheat. In 2016, double cropping wheat with corn or peanut generated greater estimated economic returns than double-cropped soybean and wheat. The double cropping of wheat with cotton or peanut generated greater estimated economic return than double cropping wheat with soybean in 2017 as well as when averaged over years.

CONCLUSIONS

Double cropping corn, cotton, grain sorghum, peanut, and soybean with wheat has been considered by growers when determining feasibility of financially-sustainable economic returns based on crop price. In some years, grain sorghum and peanut yields were consistent across planting dates but summer crops tended to vary across years and planting dates. Summer crop yields tended to be greater when planted during the typical window prior to mid-June. Although, this was not the case for grain sorghum when averaged over planting dates, likely due to extreme year to year variability. Yield of mid-April and Mid-May planted corn exceeded yield of mid-June planted corn in all years. Corn, cotton, peanut, and soybean planted in early May or late May exceeded yield of mid-June plantings of these crops in most years of the study. Grain sorghum consistently produced the lowest estimated economic returns when not influenced by a high wheat price. Similarly, Thomason et al. (2017) found that double-cropped grain sorghum with wheat generated less net returns than double-cropped soybean with wheat. Averaged estimated economic returns of double-cropped wheat and soybean were greater than most other double-cropped summer crops with wheat when summer crop and wheat were set at the ten-year average price. Commodity price plays a major role in the determination of whether it is economically viable to produce certain crops in North Carolina. Estimated economic returns of double cropped wheat and peanut was greater or similar to estimated economic returns of double cropped wheat and soybean in some of the pricing structures. In most cases, double-cropping wheat with corn, cotton, or peanut when prices were set at \$0.32 kg^{-1}, \$2.33 kg^{-1}, and \$1.02 kg^{-1}, respectively, produced similar or greater estimated economic returns as double-cropped soybean with wheat. Estimated economic returns were greater or similar for all summer crops when summer crop and wheat prices were set at the ten-year high and soybean price was set at the ten-year average. This experiment documents the outcomes of double-cropping wheat with corn, cotton, grain sorghum, peanut or soybean and determines the feasibility during favorable circumstances. Exceptional consideration to all factors going into production would need to be evaluated before recommending a grower to pursue one of these non-traditional double-cropping systems, but after evaluation there is potential for these systems in North Carolina if prices used in this study are obtainable. An irrigation source is suggested for rapid germination whenever double-cropping especially when double-cropping with one of these non-traditional systems. Environmental impacts play a role differently from year to year in determining and measuring these impacts as shown in the varying yield in this study. An early frost occurrence or temperatures that would cease the growth of a crop before optimum maturity was not observed in the five years of the study. With the continuing onset of the first frost, the feasibility of these systems may be even more practicable in the near future.

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Table 1.1. Ten-year average and ten-year high prices for corn, cotton lint, cottonseed, grain sorghum, peanut, soybean, and wheat[a].

Crop	Average	High
	$ kg^{-1}	
Corn	0.21	0.32
Cotton lint	1.60	2.33
Cottonseed	0.20	0.28
Grain sorghum	0.17	0.27
Peanut	0.58	1.02
Soybean	0.42	0.62
Wheat	0.21	0.33

[a]Crop prices are from USDA-NASS and can be accessed at https://quickstats.nass.usda.gov.

Table 1.2. Cultivars and hybrids used for corn, cotton, grain sorghum, peanut, and soybean 2013-2017 at Lewiston-Woodville, NC.

	Cultivar or hybrid[a]				
Crop	2013	2014	2015	2016	2017
Corn	DK68-03 (L)	P1615 (L)	P1637 (L)	P1637 (L)	DK68-05 (L)
Cotton	DP0912 (E)	DP0912 (E)	DP1321 (EM)	DP1321 (EM)	PHY333 (EM)
Grain sorghum	83P17 (L)	83P17 (L)	83P17 (L)	83P17 (L)	83P17 (L)
Peanut	Bailey (EM)	Bailey (EM)	Bailey (EM)	Bailey (EM)	Bailey (EM)
Soybean	P95M82 (M)	AG5632 (M)	AG6536 (M)	AG6536 (M)	S56-G6 (M)
Wheat	Pioneer 26R20 (L)	Pioneer 26R20 (L)	Pioneer 26R20 (L)	Pioneer 26R20 (L)	Pioneer 26R20 (L)

[a]Abbreviation: E, early maturing cultivar or hybrid; M, mid-maturity cultivar or hybrid; EM, early to mid-maturity cultivar or hybrid; L, late maturing cultivar or hybrid

Table 1.3. Planting dates for corn, cotton, grain sorghum, peanut, and soybean 2013-2017 at Lewiston-Woodville, NC.

		Planting dates				
Crop	Planting date designation	2013	2014	2015	2016	2017
Corn	Mid-April	18 April	17 April	17 April	15 April	17 April
Corn	Mid-May	15 May	19 May	21 May	16 May	15 May
Corn	Mid-June	17 June	20 June	15 June	20 June	13 June
Cotton	Early May	2 May	6 May	12 May	5 May	3 May
Cotton	Late May	22 May	23 May	20 May	25 May	25 May
Cotton	Mid-June	17 June	20 June	15 June	20 June	13 June
Grain sorghum	Early May	14 May	5 May	12 May	5 May	3 May
Grain sorghum	Late May	6 June	23 May	21 May	25 May	25 May
Grain sorghum	Mid-June	17 June	20 June	15 June	20 June	13 June
Peanut	Early May	6 May	6 May	12 May	5 May	3 May
Peanut	Late May	22 May	23 May	21 May	25 May	25 May
Peanut	Mid-June	17 June	20 June	15 June	20 June	13 June
Soybean	Early May	8 May	5 May	12 May	5 May	3 May
Soybean	Late May	22 May	23 May	21 May	25 May	25 May
Soybean	Mid-June	17 June	20 June	15 June	20 June	13 June

Table 1.4. Summary of growing-season precipitation as recorded by the State Climate Office of North Carolina weather station at the Peanut Belt Research Station near Lewiston-Woodville, NC, 2013-2017.

	Precipitation				
Month	2013	2014	2015	2016	2017
	cm				
April	8.08	15.80	10.59	21.95	14.40
May	4.50	9.25	2.26	9.32	14.55
June	18.95	11.15	7.39	10.54	14.25
July	16.33	26.01	11.15	20.45	18.85
August	8.79	20.90	11.43	5.72	12.80
September	6.27	18.80	18.82	43.43	8.20
October	6.20	3.84	11.86	27.46	6.93
November	7.04	8.46	13.26	3.68	4.01
Total	76.16	114.21	86.76	142.55	93.99

Table 1.5. Yield of corn, cotton, grain sorghum, peanut, and soybean at Lewiston-Woodville, NC 2013-2017[a].

		Yield					
Crop	Planting date	2013	2014	2015	2016	2017	Pooled
		Kg ha^{-1}					
Corn	Mid-April	10,050 a	7,120 b	4,940 b	8,540 a	6,690 b	7,470 a
Corn	Mid-May	8,410 b	8,260 a	6,980 a	7,890 b	7,880 a	7,880 a
Corn	Mid-June	5,870 c	4,180 c	4,100 c	5,980 c	5,980 c	5,220 b
Cotton	Early May	1,500 b	1,340 a	620 c	1,030 a	1,670 a	1,230 a
Cotton	Late May	1,770 a	1,290 a	970 a	1,100 a	1,610 a	1,350 a
Cotton	Mid-June	1,310 b	580 b	740 b	760 b	1,220 b	920 b
Grain sorghum	Early May	6,410 a	5,230 a	4,990 a	4,000 a	3,220 b	4,770 a
Grain sorghum	Late May	5,120 b	5,230 a	5,550 a	4,720 a	5,830 a	5,290 a
Grain sorghum	Mid-June	6,670 a	1,850 b	5,510 a	3,650 a	3,570 b	4,250 a
Peanut	Early May	3,740 a	4,100 a	6,260 a	4,080 b	4,670 b	4,570 a
Peanut	Late May	3,810 a	4,140 a	4,300 b	5,620 a	7,070 a	4,990 a
Peanut	Mid-June	3,440 a	3,280 b	2,300 c	3,410 c	3,670 b	3,220 b
Soybean	Early May	3,320 b	2,950 ab	2,850 a	2,900 a	3,080 b	3,020 b
Soybean	Late May	4,190 a	3,030 a	2,930 a	2,870 a	3,580 a	3,320 a
Soybean	Mid-June	2,700 c	2,450 b	2,120 b	2,500 b	2,920 b	2,540 c
Wheat	Nov-Dec	3,650	4,630	4,270	1,970	6,270	4,150

[a]Means within a year and crop or within a crop when pooled over years followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$.

Table 1.6. Estimated economic returns for the ten-year average summer crop price and the ten-year average wheat price for corn, cotton, grain sorghum, peanut, and soybean 2013-2017[ab].

Crop			Estimated economic returns[c]					
Winter	Summer	Planting date	2013	2014	2015	2016	2017	Pooled
			$ ha^{-1}					
None	Corn	Mid-April	855 bc	309 bcd	-97 de	574 b	230 ef	374 c-f
None	Corn	Mid-May	553 d	522 ab	284 bc	455 bc	453 de	453 cde
Wheat	Corn	Mid-June	270 ef*	196 cde*	-2 d*	-15 efg	786 c*	247 efg
None	Cotton	Early May	946 b	684 a	-496 f	169 de	1214 b	503 bcd
None	Cotton	Late May	1375 a	600 ab	78 cd	289 cd	1120 b	692 ab
Wheat	Cotton	Mid-June	828 bc*	-154 f*	108 cd*	-420 i*	1125 b	297 def
None	Grain Sorghum	Early May	202 fg	34 def	-1 d	-142 gh	-253 g	-32 h
None	Grain Sorghum	Late May	18 g	34 def	79 cd	-38 efg	120 f	43 gh
Wheat	Grain Sorghum	Mid-June	443 de	-67 ef*	429 b	-305 hi*	605 cd*	221 fg*
None	Peanut	Early May	144 fg	321 bcd	1395 a	310 cd	606 cd	555 bc
None	Peanut	Late May	211 efg	340 bcd	419 b	1076 a	1798 a	769 a
Wheat	Peanut	Mid-June	292 def	351 bc	-250 e*	-115 fgh*	837 c*	223 fg*
None	Soybean	Early May	576 cd	427 abc	388 b	407 bc	481 de	459 cde
None	Soybean	Late May	925 b	458 abc	419 b	396 bc	691 cd	578 bc
Wheat	Soybean	Mid-June	527 d	608 ab	415 b	101 def	1141 b	559 bc

[a]Means within a year or for data pooled over years followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.
[b] * indicates significance at $p \leq 0.05$ when compared with estimated economic return of double cropped wheat and soybean using Dunnett's Procedure.
[c]Estimated economic returns associated with mid-June planted summer crops included revenue generated by summer crop plus wheat.

Table 1.7. Estimated economic returns for the ten-year average summer crop price and the ten-year high wheat price for corn, cotton, grain sorghum, peanut, and soybean 2013-2017[ab].

Crop			Estimated economic returns[c]					
Winter	Summer	Planting date	2013	2014	2015	2016	2017	Pooled
			$ ha^{-1}					
None	Corn	Mid-April	855 bcd	309 ef	-97 f	574 b	230 hi	374 e
None	Corn	Mid-May	553 e	522 cde	284 de	455 bc	453 gh	453 e
Wheat	Corn	Mid-June	704 cde*	776 bc*	468 cd*	232 de	1522 cd*	740 bcd
None	Cotton	Early May	946 bc	684 bcd	-496 g	169 def	1214 ef	503 de
None	Cotton	Late May	1375 a	600 cde	78 ef	289 cde	1120 f	692 bcd
Wheat	Cotton	Mid-June	1261 a*	404 e*	671 c*	-202 g*	1836 ab	794 ab
None	Grain Sorghum	Early May	202 f	34 f	-1 f	-142 g	-253 j	-32 f
None	Grain Sorghum	Late May	18 f	34 f	79 ef	-38 fg	120 i	43 f
Wheat	Grain Sorghum	Mid-June	884 bc	483 cde*	963 b	-58 fg*	1415 de*	737 bcd
None	Peanut	Early May	144 f	321 ef	1395 a	310 cde	606 g	555 cde
None	Peanut	Late May	211 f	340 ef	419 d	1076 a	1798 abc	769 abc
Wheat	Peanut	Mid-June	790 b-e	933 ab	263 de*	145 ef	1599 bcd*	746 bcd
None	Soybean	Early May	576 de	427 de	388 d	407 bcd	481 gh	456 e
None	Soybean	Late May	925 bc	458 cde	419 d	396 bcd	691 g	578 b-e
Wheat	Soybean	Mid-June	966 b	1157 a	930 b	330 bcde	1900 a	1057 a

[a]Means within a year or for data pooled over years followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

[b] * indicates significance at $p \leq 0.05$ when compared with estimated economic return of double cropped wheat and soybean using Dunnett's Procedure.

[c]Estimated economic returns associated with mid-June planted summer crops included revenue generated by summer crop plus wheat.

Table 1.8. Estimated economic returns for the ten-year high summer crop price and the ten-year average wheat price for corn, cotton, grain sorghum, peanut, and soybean 2013-2017[ab].

Crop			Estimated economic returns[c]					
Winter	Summer	Planting date	2013	2014	2015	2016	2017	Pooled
			$ $ ha^{-1}$					
None	Corn	Mid-April	1966 b	1097 de	450 f	1519 c	970 gh	1200 efg
None	Corn	Mid-May	1487 cd	1436 bcd	1056 c	1328 cd	1325 efg	1326 def
Wheat	Corn	Mid-June	920 ef	659 ef	451 f*	646 ef	1449 ef	825 gh
None	Cotton	Early May	2188 b	1793 ab	13 g	1015 d	2593 b	1520 cde
None	Cotton	Late May	2837 a	1666 abc	879 cde	1197 cd	2452 bc	1806 c
Wheat	Cotton	Mid-June	1912 bc*	327 f*	719 c-f	208 gh*	2129 cd	1059 fg
None	Grain Sorghum	Early May	881 ef	588 ef	528 ef	282 fgh	88 i	473 h
None	Grain Sorghum	Late May	560 f	588 ef	667 def	462 fg	738 h	603 h
Wheat	Grain Sorghum	Mid-June	1150 de	129 f*	1012 cd	81 h*	983 gh*	671 h
None	Peanut	Early May	1827 bc	2167 a	4212 a	2144 b	2710 b	2612 b
None	Peanut	Late May	1944 bc	2202 a	2353 b	3604 a	4980 a	3017 a
Wheat	Peanut	Mid-June	1842 bc*	1828 ab*	786 c-f	1420 c*	2487 bc*	1673 cd*
None	Soybean	Early May	1268 de	1044 de	985 cd	1014 d	1126 fgh	1087 fg
None	Soybean	Late May	1799 bc	1091 de	1032 cd	996 de	1444 ef	1272 ef
Wheat	Soybean	Mid-June	1092 de	1120 cde	857 cde	623 f	1753 de	1089 fg

[a]Means within a year or for data pooled over years followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

[b] * indicates significance at $p \leq 0.05$ when compared with estimated economic return of double cropped wheat and soybean using Dunnett's Procedure.

[c]Estimated economic returns associated with mid-June planted summer crops included revenue generated by summer crop plus wheat.

Table 1.9. Estimated economic returns for the ten-year high summer crop price and the ten-year high wheat price for corn, cotton, grain sorghum, peanut, and soybean 2013-2017[ab].

Crop			Estimated economic returns[c]					
Winter	Summer	Planting date	2013	2014	2015	2016	2017	Pooled
			$ ha^{-1}					
None	Corn	Mid-April	1966 bcd	1097 def	450 i	1519 cd	970 hi	1200 fg
None	Corn	Mid-May	1487 efg	1436 cd	1056 def	1328 cde	1325 fgh	1326 efg
Wheat	Corn	Mid-June	1353 fg	1239 cde	921 efg*	894 f	2184 de	1318 efg
None	Cotton	Early May	2188 bc	1793 bc	13 j	1015 ef	2593 cd	1520 def
None	Cotton	Late May	2837 a	1666 bc	879 fgh	1197 def	2452 cd	1806 cd
Wheat	Cotton	Mid-June	2346 b*	885 def*	1281 cde	427 g*	2840 bc	1556 de
None	Grain Sorghum	Early May	881 hi	588 f	528 hi	282 g	88 j	473 h
None	Grain Sorghum	Late May	560 i	588 f	667 ghi	462 g	738 i	603 h
Wheat	Grain Sorghum	Mid-June	1590 d-g	679 ef*	1546 c	328 g*	1792 ef*	1187 fg
None	Peanut	Early May	1827 cde	2167 ab	4212 a	2144 b	2710 c	2612 b
None	Peanut	Late May	1944 b-e	2202 ab	2353 b	3604 a	4980 a	3017 a
Wheat	Peanut	Mid-June	2340 b*	2410 a*	1299 cde	1680 c*	3249 b*	2196 c*
None	Soybean	Early May	1268 gh	1044 def	985 efg	1014 ef	1126 ghi	1087 g
None	Soybean	Late May	1799 c-f	1091 def	1032 d-g	996 ef	1444 fg	1272 efg
Wheat	Soybean	Mid-June	1531 d-g	1670 bc	1372 cd	852 f	2511 cd	1587 de

[a]Means within a year or for data pooled over years followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.

[b] * indicates significance at $p \leq 0.05$ when compared with estimated economic return of double cropped wheat and soybean using Dunnett's Procedure.

[c]Estimated economic returns associated with mid-June planted summer crops included revenue generated by summer crop plus wheat.

Table 1.10. Estimated economic returns for the ten-year high summer crop price and the ten-year high wheat price for corn, cotton, grain sorghum, and peanut, compared to the ten-year high wheat price and the ten-year average soybean price 2013-2017[ab].

Crop			Estimated economic returns[c]					
Winter	Summer	Planting date	2013	2014	2015	2016	2017	Pooled
			$ ha^{-1}					
None	Corn	Mid-April	1966 bcd	1097 efg	450 h	1519 cd	970 fg	1200 ef
None	Corn	Mid-May	1487 ef	1436 cde	1056 de	1328 cde	1325 g	1326 ef
Wheat	Corn	Mid-June	1353 fg*	1239 de	921 def	894 f*	2184 de	1318 ef
None	Cotton	Early May	2188 bc	1793 bc	13 i	1015 ef	2593 cd	1520 de
None	Cotton	Late May	2837 a	1666 bcd	879 efg	1197 def	2452 cd	1806 cd
Wheat	Cotton	Mid-June	2346 b*	885 e-h	1281 cd	427 g	2840 bc*	1556 de*
None	Grain Sorghum	Early May	881 hi	588 gh	528 gh	282 g	88 i	473 g
None	Grain Sorghum	Late May	560 i	588 gh	667 fgh	462 g	738 gh	603 g
Wheat	Grain Sorghum	Mid-June	1590 def *	679 fgh	1546 c*	328 g	1792 e	1187 ef
None	Peanut	Early May	1827 cde	2167 ab	4212 a	2144 b	2710 c	2612 b
None	Peanut	Late May	1944 b-e	2202 ab	2353 b	3604 a	4980 a	3017 a
Wheat	Peanut	Mid-June	2340 b*	2410 a*	1299 cd	1680 c*	3249 b*	2196 bc*
None	Soybean	Early May	576 hi	427 h	388 hi	407 g	481 hi	456 g
None	Soybean	Late May	925 ghi	458 h	419 h	396 g	691 gh	578 g
Wheat	Soybean	Mid-June	966 gh	1157 def	930 def	330 g	1900 e	1057 f

[a]Means within a year or for data pooled over years followed by the same letter are not significantly different according to Fisher's Protected LSD at $p \leq 0.05$.
[b] * indicates significance at $p \leq 0.05$ when compared with estimated economic return of double cropped wheat and soybean using Dunnett's Procedure.
[c]Estimated economic returns associated with mid-June planted summer crops included revenue generated by summer crop plus wheat.

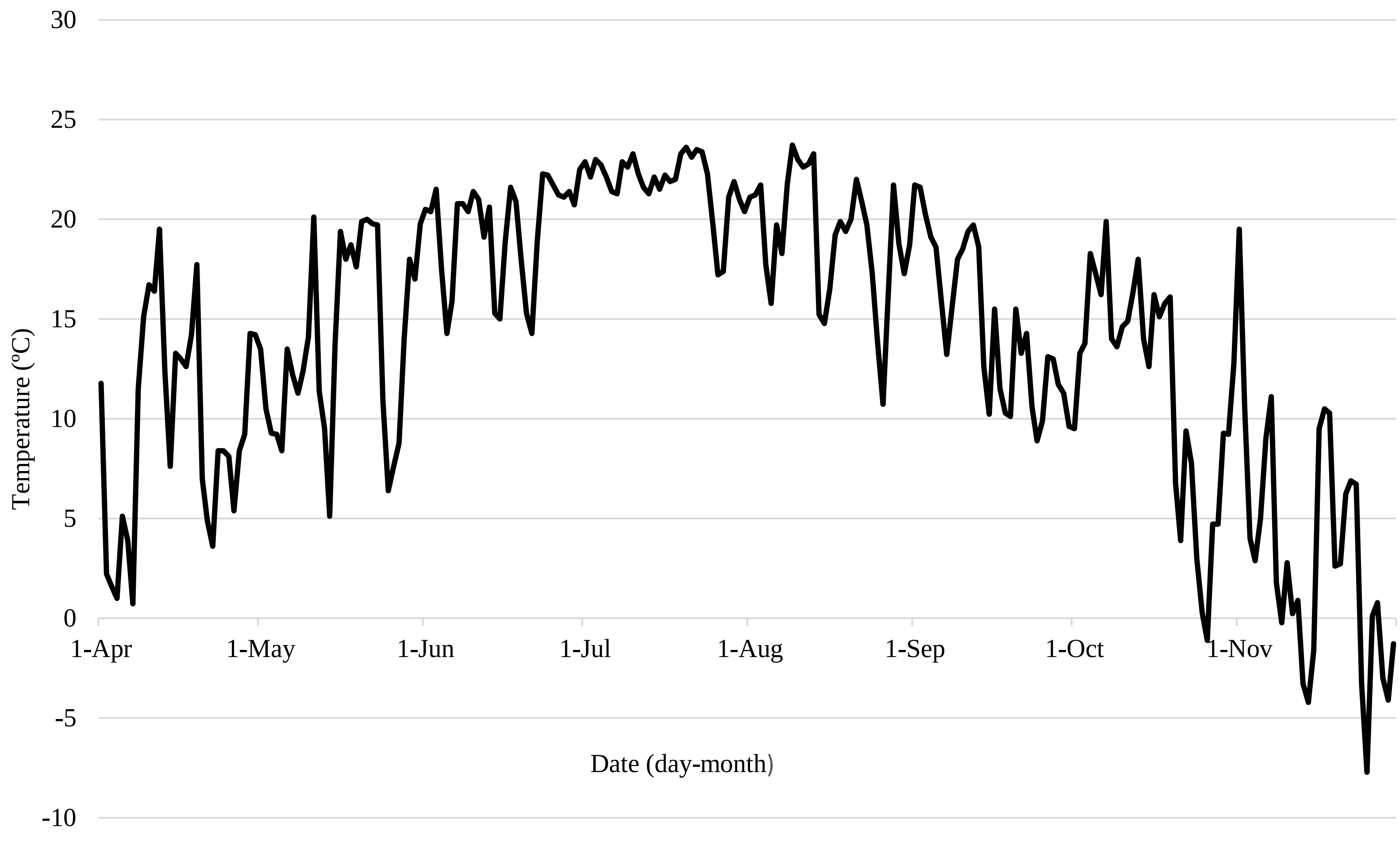

Figure 1.1. Minimum temperatures during the growing season in 2013.

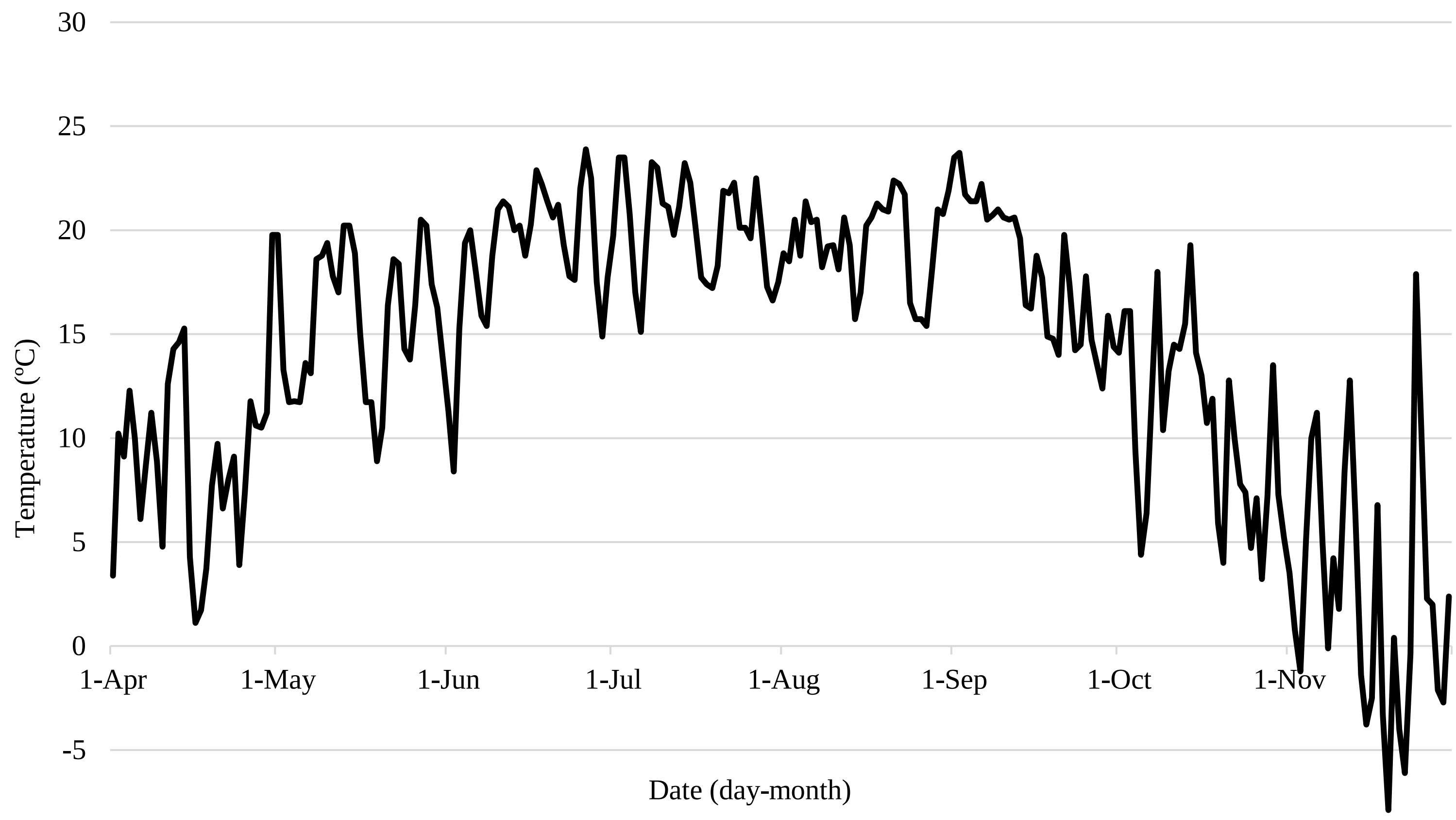

Figure 1.2. Minimum temperatures during the growing season in 2014.

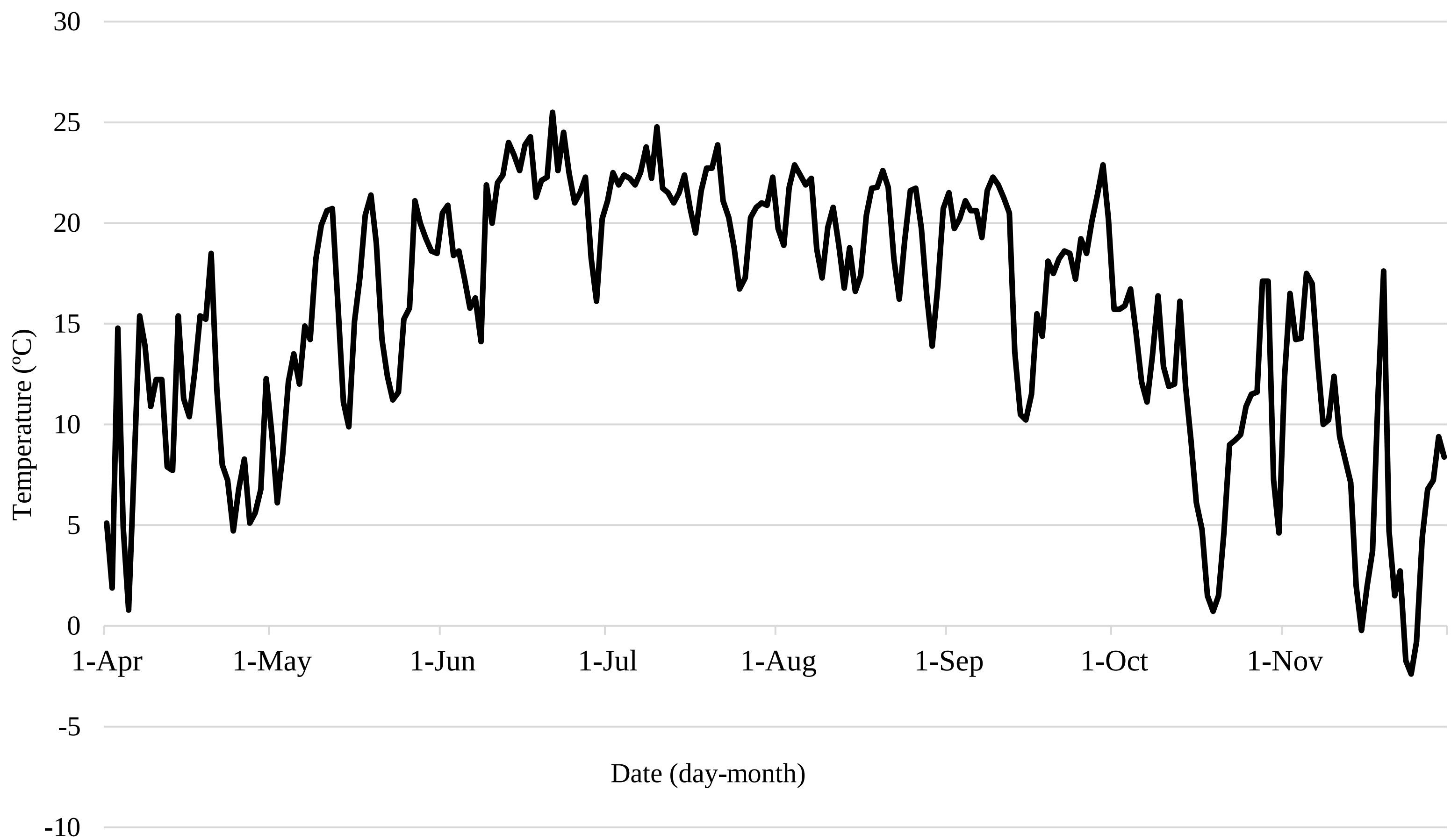

Figure 1.3. Minimum temperatures during the growing season in 2015.

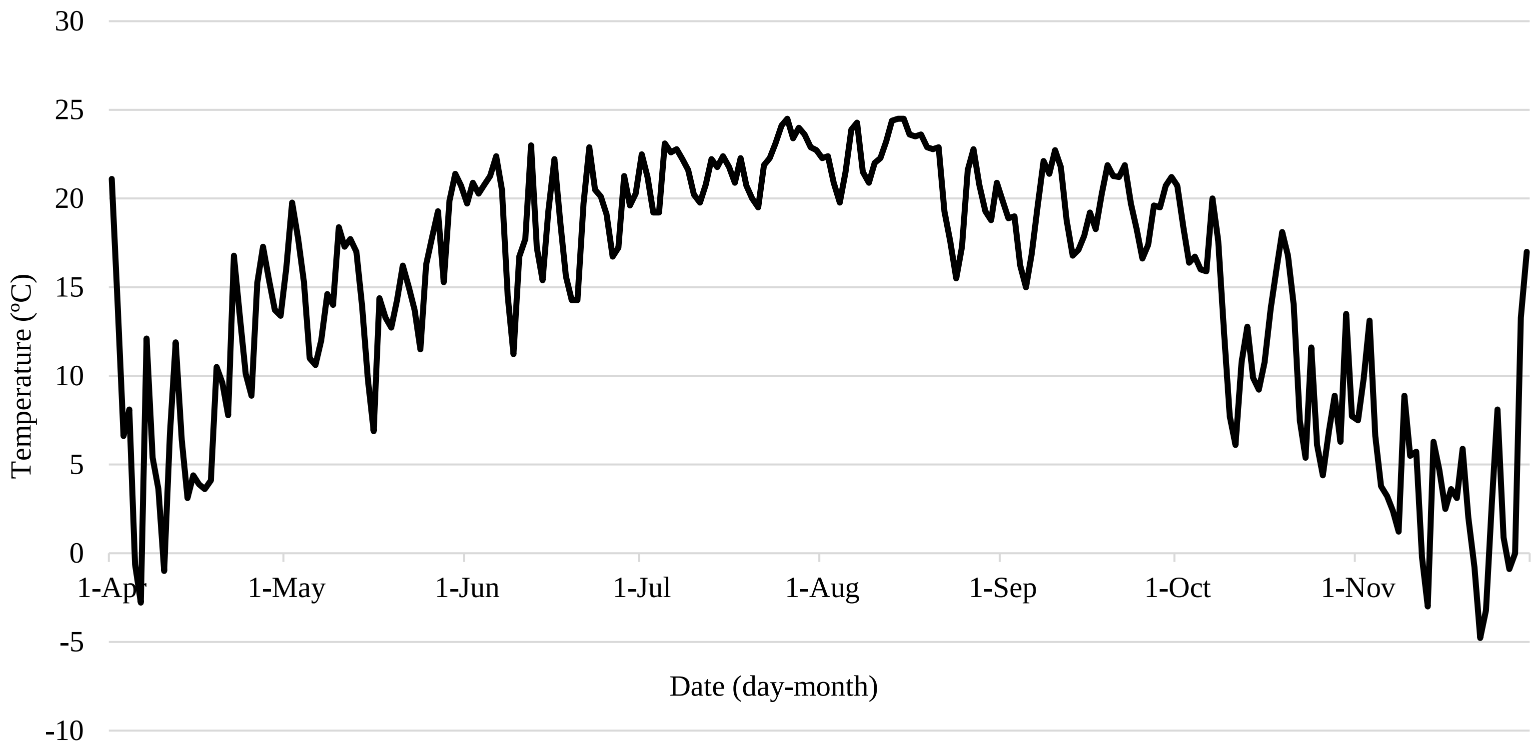

Figure 1.4 Minimum temperatures during the growing season in 2016.

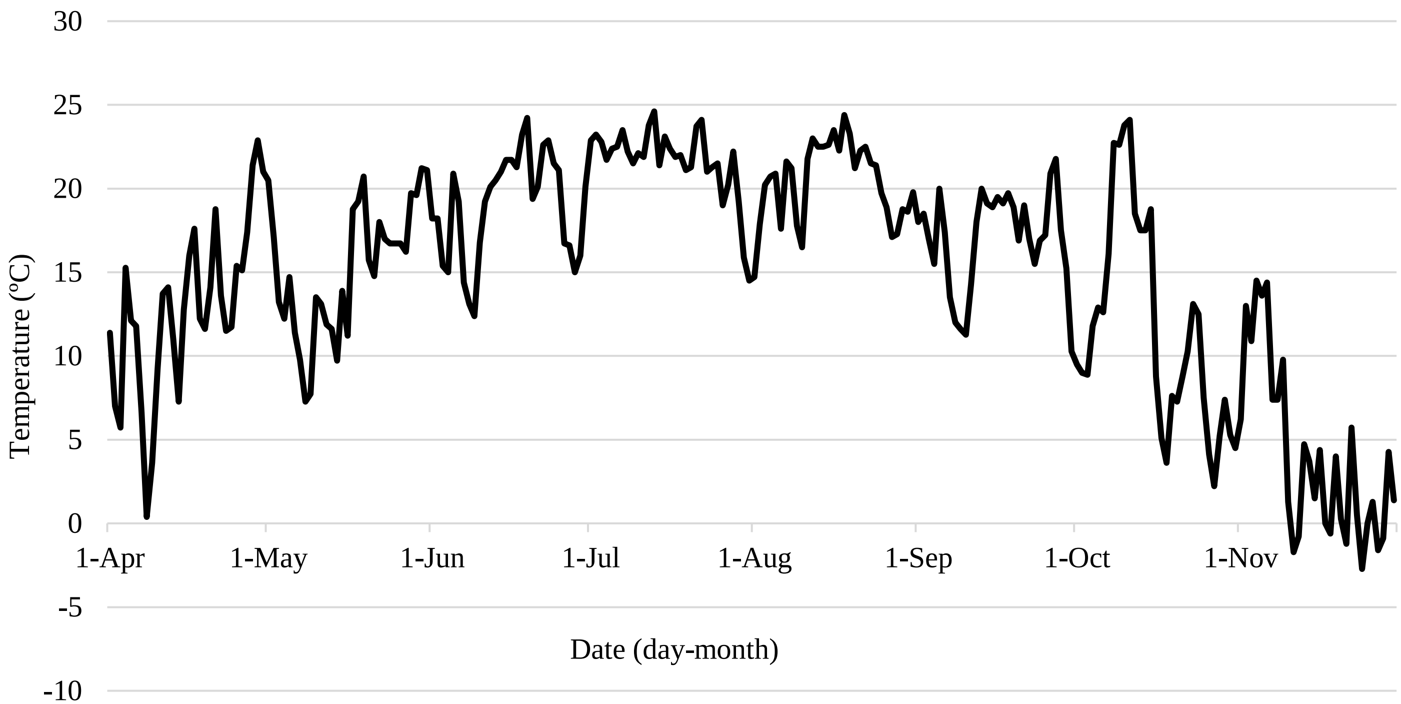

Figure 1.5. Minimum temperatures during the growing season in 2017.

CHAPTER 2

Influence of Timing and Intensity of Weed Management on Crop Yield and Contribution to Weed Emergence the Following Year

This chapter is written in the style and format for the Weed Science Society of America journal *Weed Technology*

ABSTRACT

Timing of weed control is important in determining crop yield. Research was conducted during 2016 and 2017 at two locations in North Carolina to determine weed control and yield of corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], and soybean [*Glycine max* (L.) Merr.] in the same experiment when various herbicides were applied postemergence (POST) to each crop at 2 or 6 weeks after planting (WAP) only; 2 and 4 WAP; 4 and 6 WAP; 2, 4, and 6 WAP along with a non-treated check (NTC). In absence of herbicides, yield loss was lower for corn than all other crops regardless of the weed complex. When common ragweed (*Ambrosia artemiisifolia* L.) and Texas millet (*Urochloa texana* L.) were present, grain sorghum relative yield was greater than yield of cotton and soybean. When Palmer amaranth (*Amanthus palmeri* S. Wats) and large crabgrass (*Digitaria sanguinalis* L.) were present, grain sorghum and soybean yield was similar and exceeded yield of cotton. Applying herbicides 2 WAP only or at least twice maximized yield of corn regardless of weed complex. Maximum cotton and soybean yield was obtained when at least two herbicide applications were made. Grain sorghum yield was optimized when herbicides were applied at least once beginning 2 WAP in presence of common ragweed and Texas millet or at least twice when initiated 2 WAP in presence of Palmer amaranth and large crabgrass. Corn generated the greatest economic return of all crops when no herbicide was applied or one application was made 2 WAP regardless of weed complex. When common ragweed and Texas millet were present, estimated economic return was greater in corn than other crops even when multiple herbicide applications were made. When Palmer amaranth and large crabgrass were present, estimated economic returns for corn and soybean were often similar and exceeded estimated economic returns of grain sorghum and cotton. In the year following weed management in these four crops,

common ragweed and Palmer amaranth densities were lower when herbicides were applied the previous season compared with the NTC regardless of previous crop. Applying herbicide 2 and 4, 4 and 6, and 2, 4, and 6 WAP reduced populations similarly. Variation in the effect of crop on weed density the following year was observed.

KEYWORDS: Timing of herbicide application, percent maximum yield, estimated economic return.

INTRODUCTION

Proper herbicide selection and timely application are fundamental for successful weed management in all crop production systems (Wilcut and Askew 1999). The critical weed-free period is important in understanding how weed interference can adversely affect crop growth and development (Gower et al. 2002). This is the time in which a weed species may coexist with a crop causing a yield reduction from weed interference but is often difficult to define because it is dependent on environment, weed species, and weed density (Hall et al. 1992). Application timing is crucial for an effective weed management program (Crow et al. 2016). Delayed herbicide application could result in crop yield reduction caused by weed interference while a POST application when weeds are too small may result in poor control of later-emerging weeds (Gower et al. 2002). Reducing weed population densities is a means for improving the efficiency of weed management tactics (Buhler 1996; Gallandt 2006; Mortensen et al. 2000). Weedy and invasive plants cost an estimated $30-40 billion annually through lost crop production, implementation of control measures, and by threatening biodiversity and functioning ecosystems (Colautti et al., 2006; McNeely, 2001; Myers and Bazely, 2003; Pimentel et al., 2000).

Palmer amaranth (*Amanthus palmeri* S. Wats) is among the most troublesome and economically damaging weeds in agronomic crops (Beckie 2006; Webster and Nichols 2012). Palmer amaranth is a summer annual, dioicous weed, that has been noted to grow 3 to 4 m tall (Horak and Peterson 1995). Palmer amaranth uses the C_4 photosynthetic pathway resulting in greater growth rates than C_3 plants, and the potential to grow up to 3.5 cm d^{-1} (Horak and Loughin 2000; Norsworthy et al. 2008). Rapid root expansion enables Palmer amaranth to compete successfully for water (Davis et al. 1967; Wiese 1968). High water use efficiency, rapid growth rate, abundant seed production, and herbicide resistance are factors that have enabled Palmer amaranth to become a competitive weed species (Bensch et al. 2003; Black et al. 1969; Burke et al. 2007; Chandi et al. 2013; Ehleringer 1983; Horak and Loughin 2000; Place et al. 2008; Sellers et al. 2003; Wright et al. 1999). When at least 8 Palmer amaranth plants in 10 m of row were present, intraspecific competition was detected (Morgan et al. 1997; Rowland et al. 1999). Seeds may germinate as early as 1 March and as late as 1 October in Texas and Tennessee (Crow et al. 2016; Keeley et al. 1987). Female plants have been reported to produce 200,000 to 600,000 seeds (Keely et al. 1987; Webster and Grey 2015). Massinga et al. (2001) found that increased densities and later emergence dates of Palmer amaranth resulted in decreased seed production per plant but an increase in the number of seeds per unit area. At low densities, plants tend to branch out while at higher densities they tend to grow taller with less lateral growth, altering leaf area distribution patterns among the plants (Massinga et al. 2003). Seedbank contributions from Palmer amaranth depend on many factors including the relative competiveness of the crop, interspecific and intraspecific interference, growing season length, time of emergence relative to its competitors, and edaphic and environmental factors (Webster and Grey 2015).

Palmer amaranth interference has been documented extensively in multiple agronomic crops. When Palmer amaranth emerges with corn (*Zea mays* L.), yield losses ranged from 11 to 91% at densities of 0.5 to 8 plants m^{-1} of row, respectively (Massinga et al. 2001). Yield losses were reduced when Palmer amaranth emerged later than corn with losses ranging from 7 to 35% at densities of 0.5 to 8 plants m^{-1} of row, respectively (Massinga et al. 2001). When photosynthetic photon flux interception was measured between the layers of the corn canopy, Massinga et al. (2003) found that Palmer amaranth had increased interception of radiation near the top of the canopy giving it a competitive advantage over corn. In cotton (*Gossypium hirsutum* L.), as few as 1 or 2 Palmer amaranth plants 10 m^{-1} of row causes ample yield losses to justify herbicide treatment (Rowland et al. 1999). Compared to the weed-free check, cotton lint yield was reduced by 11.5 to 92% when 1 to 8 palmer plants are present 10 m^{-1} of row, respectively, in 1996 (Rowland et al. 1999). Morgan et al. (2001) found that cotton lint yield was reduced 13.4 to 56.9% when 1 to 10 Palmer amaranth plants per 9.1 m or row were present. Cotton lint yield is more sensitive to Palmer amaranth and competition from other weeds than canopy volume and biomass (Buchanan and Burns 1970, 1971a, 1971b; Morgan et al. 2001; Street et al. 1985). Mechanical picker-harvest of cotton lint is considered impractical when Palmer amaranth densities exceed 6 plants per 9.1 m of row because of the potential damage to the harvester (Morgan et al. 2001). In grain sorghum [*Sorghum bicolor* (L.) Moench], Burnside and Wicks (1967) recommend that cultivation or POST herbicides be applied within 3 weeks after planting to avoid yield loss due to weed competition during early season growth. Yield-limiting weed competition occurs early in the growing season for grain sorghum, but weeds emerging later than 30 days after planting have little effect on yield (Burnside and Wicks 1967; Wiese et al.1964). Narrow row widths can reduce biomass of Palmer amaranth in absence of herbicides (Besancon et al. 2017). Chandi et al. (2012) reported a soybean yield reduction of 22% when 0.33 Palmer amaranth plants were present per m of row, while Klingaman and Oliver (1994) found a soybean yield loss of 17% at a Palmer amaranth density of 0.33plants per m of row.

Common ragweed (*Ambrosia artemiisifolia* L.) is a summer annual, herbaceous broadleaf weed affecting several row crops in the southeastern United States (Bassett and Crompton 1975; Deen et al. 1998; Nandula et al. 2017). Evolution of resistance in weeds to commonly used herbicides in controlling common ragweed has made management of this weed complicated in recent years (Ganie and Jhala 2017). Glyphosate-resistant (GR) common ragweed has been identified in 16 states in the United States (Heap 2018). Common ragweed plants can grow more than 2 m tall rapidly (Clewis et al. 2001), produce up to 62,000 seeds (Dickerson and Sweet 1971), and can produce on average 1.2 billion pollen grains (Fumanal et al. 2007). Common ragweed grows at rates of 0.1 cm d^{-1} during the juvenile phase and up to 2 cm d^{-1} during the terminal budding through flowering stage (Deen et al. 2001). Late fall and early spring soil tillage have been positively correlated to germination and population establishment of common ragweed (Bazzaz 1968; Keever 1950). Due to the longevity of seed viability, it is difficult to eliminate common ragweed from a site once established (Baskin and Baskin 1980). Common ragweed is generally controlled with herbicides in agronomic crops but often times plants are missed or emerge after POST applications (Radosevich et al. 1997; Simard and Benoit 2012). Increased common ragweed densities decrease pollen and seed production per plant but increase total pollen and seed production per area (Simard and Benoit 2012). Common ragweed plants growing without crop competition are capable of producing almost twice as much seed per unit biomass than plants competing with crops (Simard and Benoit 2012).

Common ragweed has been reported to be more competitive with soybean than with corn (Weaver 2001). In corn, a common ragweed density of greater than 32 plants m^{-2} reduced yield by 38% (Weaver 2001). Common ragweed competing with corn produced 51 seeds g^{-1} when measuring seed per unit biomass (Simard and Benoit, 2010). In soybean, with 2 to 4 common ragweed plants present 10 m^{-1} of row, yield was reduced 10 to 12% (Coble et al. 1981; Shurtleff and Coble 1985). When greater than 30 plants m^{-2} were present, Weaver (2001) reported yield loss of soybean between 65 and 70%. In North Carolina, common ragweed canopy intercepted 24, 38, and 45% of the photosynthetically active radiation 8, 10, and 12 weeks after soybean emergence, respectively (Coble et al. 1981). Common ragweed competing with soybean produced 46 seeds g^{-1} when measuring seed per unit biomass compared to 82 seeds g^{-1} when ragweed was grown alone (Simard and Benoit 2012).

The 2- to 3-week period after flowering is the critical time for weed management for most weed species to prevent weeds from producing viable seeds (Hill et al. 2016). Most weed management studies are only evaluated in a single growing season failing to quantify the impact these weed management strategies may have on contributing to the soil seedbank (Inman et al. 2016). Additionally, data comparing interference of weeds to multiple crops in the same experiment are limited in the peer-reviewed literature. This study was designed to evaluate the effects that timing of herbicide application have on weed control, yield, and estimated economic returns of corn, cotton grain sorghum and soybean in the same experiment as well as quantifying weed populations and cotton lint yield in the following growing season.

MATERIALS AND METHODS

Study Information. The experiment was conducted in North Carolina near Lewiston-Woodville (36.135 N, -77.177 W) and Rocky Mount (35.897 N, -77.675 W) during 2016 and 2017. Adjacent areas of the same field were used for different years at both locations. Soils included a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudult) at Lewiston-Woodville and an Aycock very fine sandy loam (fine-silty, siliceous, subactive, thermic Typic Paleudult) at Rocky Mount. The Lewiston-Woodville site was naturally infested with common ragweed and Texas millet (*Urochloa texana* L.), while the Rocky Mount site was naturally infested by Palmer amaranth and large crabgrass (*Digitaria sanguinalis* L.). Corn, cotton, grain sorghum, and soybean were planted in early May into conventionally-tilled, raised seedbeds. Plot size was 4 rows (91-cm spacing) by 9 m at both locations. With the exception of weed management, all other production and pest management practices were held constant and were designed to maximize yield (Edmisten et al. 2018; Heiniger et al. 2003; Stowe et al. 2017).

In 2016, corn hybrid P1637(Pioneer Hi-Bred International, Johnston, IA), cotton cultivar DP 1522 (Monsanto Co., St. Louis, MO), grain sorghum hybrid 83P17-N271 (Pioneer Hi-Bred International, Johnston, IA), and soybean cultivar AG 69X6 (Monsanto Co., St. Louis, MO) were planted at Lewiston-Woodville on 16 May, and corn hybrid Dyna-grow D55QC73 (Crop Production Services, Loveland, CO), cotton cultivar DP 1522 (Monsanto Co., St. Louis, MO), grain sorghum hybrid 83P17-N271 (Pioneer Hi-Bred International, Johnston, IA), and soybean cultivar AG 69X6 (Monsanto Co., St. Louis, MO) were planted at Rocky Mount on 9 May. In 2017 corn hybrid DKC 67-70(RR2) (Monsanto Co., St. Louis, MO), cotton cultivar DP 1522 (Monsanto Co., St. Louis, MO), grain sorghum cultivar 83P17-N271 (Pioneer Hi-Bred International, Johnston, IA), and soybean cultivar AG 69X6 (Monsanto Co., St. Louis, MO) were planted at Lewiston-Woodville on 4 May, and corn hybrid DKC 67-70(RR2) (Monsanto Co., St. Louis, MO), cotton cultivar DP 1522 (Monsanto Co., St. Louis, MO), grain sorghum cultivar 83P17-N271 (Pioneer Hi-Bred International, Johnston, IA), and soybean cultivar AG 69X6 (Monsanto Co., St. Louis, MO) were planted at Rocky Mount on 11 May.

Herbicide Treatments. Herbicide treatments consisted of a single application 2 weeks after planting (WAP), a single application 6 WAP, an application 2 WAP followed by an application 4 WAP, an application 4 WAP followed by an application 6 WAP, and an application 2 WAP followed by an application 4 WAP followed by an application 6 WAP. A no-herbicide control was included. Post applications 2, 4, and 6 WAP were applied to cotton in the vegetative cotyledon (VC), V1 to V2, and V4 to V6 growth stages, respectively (Elsner et al. 1979). Post applications 2, 4, and 6 WAP were applied when corn was in V2 to V3, V4 to V6, and V10 to V12 growth stages, respectively. POST applications 2, 4, and 6 WAP were applied when grain sorghum was in the 1, 2 to 3, and 4 to 5 growth stages, respectively (Vanderlip and Reeves 1972). POST applications 2, 4, and 6 WAP were applied when soybean was in the V2 to V3, V4 to V6, and V7 to V9 stages of growth, respectively (Fehr and Caviness 1971). Crop specific herbicide products, rates, and manufacturer details are listed in Tables 2.1 and 2.2. Crop oil concentrate (Agri-Dex®, Helena Chemical Co., Collierville, TN) at 1.0% (v/v) was applied with bentazon and quinclorac. Herbicides were applied using a CO_2 -pressurized backpack sprayer equipped with flat-fan nozzles (AIXR 11002 TeeJet® Air Induction XR flat-spray nozzles, TeeJet Technologies, Wheaton, IL) calibrated to deliver 140 L ha^{-1} at 152 kPa.

Treatments were arranged in a split plot design and were replicated 4 times at both locations. Prior to the first herbicide application, initial weed densities were recorded from 15 randomly determined sections across the entire test area using a 0.3 by 0.3 m square. Weed control was visually estimated 7, 10, and 20 WAP using a 0 to 100% scale where 0 was equal to no control and 100 was equal to complete control. Foliar chlorosis, necrosis, biomass, and population were considered when making the visual estimates.

Crop yield was determined in each year at optimum maturity and was adjusted to 15.5%, 13%, and 13% moisture for corn, grain sorghum, and soybean respectively. In order to compare across crops, crops were converted to percent of maximum yield. In each replication and crop, the plot with the greatest yield was considered 100% of maximum yield. Percent of maximum yield was calculated for all other treatments based on the plot in each replication with the greatest yield. Yield potential of each crop at each location is listed in Table 2.9 and signifies 100% of the maximum yield. Economic returns were estimated using modified North Carolina State University enterprise budgets for conventional tillage corn, cotton, grain sorghum, and soybean to accommodate a 400-ha operation in North Carolina (Washburn 2019). Costs were calculated for the different herbicide programs with herbicides/adjuvants, application cost, hauling, and drying and cleaning costs based on yield. Base costs excluding these variable costs were \$805 ha^{-1}, \$1,224 ha^{-1}, \$613 ha^{-1}, and \$589 ha^{-1} for corn, cotton, grain sorghum, and soybean, respectively. A ten-year average price of \$0.21 kg^{-1}, \$1.60 kg^{-1}, \$0.21 kg^{-1}, \$0.15 kg^{-1} and \$0.42 kg^{-1} received for corn, cotton lint, cotton seed, grains sorghum, and soybean, respectively, in the United States was used for estimated economic return analysis (USDA-NASS 2018).

Following planting of corn, cotton, grain sorghum, and soybean in 2016, the cotton cultivar DP 1522 (Monsanto Co., St. Louis, MO) was planted into the previous year’s plots in conventionally-tilled, raised seedbeds on 4 May and 11 May during 2017 at Lewiston-Woodville and Rocky Mount, respectively. In 2018 the cotton cultivar DP 1646 (Monsanto Co., St. Louis, MO) was planted 10 May and 15 May at Lewiston-Woodville and Rocky Mount, respectively, the year following corn, cotton, grain sorghum, and soybean in 2017. Within each plot, densities of common ragweed and Texas millet at Lewiston-Woodville and densities of Palmer amaranth and large crabgrass at Rocky Mount were determined 3, 7, and 20 WAP. Densities at 3 and 7 WAP were measured using a 0.3 by 0.3 m square in three randomly determined sections of each plot and then the average of each plot was converted to a m^{-2} basis. Due to reduced weed densities at 20 WAP, populations were determined by counting broadleaf and grasses present in the center two rows of the entire plot area and then converted to a m^{-2} basis. After initial weed densities were recorded 3 and 7 WAP in cotton, glyphosate was applied at Lewiston-Woodville. Glyphosate plus dicamba was applied 3 WAP followed by glyphosate only 7 WAP at Rocky Mount. These herbicides were applied over the entire test area.

Statistical Analyses. Data for control of common ragweed, Texas millet, Palmer amaranth, and large crabgrass; percent maximum yield; and broadleaf weed densities and cotton yield the second year of an experiment were subjected to analysis of variance using the GLIMMIX procedure in SAS (version 9.4; SAS Institute INC., Cary, NC). In one combined analysis, common ragweed and Palmer amaranth were defined as broadleaf weeds and subjected to ANOVA for a 4 (year and experiment combination) by 6 (timing of herbicide application) factorial arrangement (Table 2.3). When necessary, data for each location were subjected to ANOVA for a 2 (year) by 6 (timing of herbicide application) factorial arrangement (Tables 2.4 and 2.5). Timing of weed management treatments and experiments or locations were fixed factors, whereas replication was considered a random effect. Means for significant main effects and interactions were separated using Fishers Protected LSD at $p \leq 0.05$.

RESULTS AND DISCUSSION

When common ragweed and Palmer amaranth were defined as broadleaf weeds, the interaction of experiment by crop by timing of herbicide application was significant for broadleaf weed control 10 WAP, grass control 10 WAP, percent maximum yield, and estimated economic return (Table 2.3). Therefore, data were analyzed by location, which included the weed complex of common ragweed and Texas millet (Lewiston-Woodville) or Palmer amaranth and large crabgrass (Rocky Mount) (Tables 2.4 and 2.5). A 10-fold greater F-statistic for crop by timing of herbicide application was observed compared with the interaction of year by crop by timing of herbicide application at both locations for percent maximum yield. Because yield is the most important variable in this research, data for the interactions of crop by timing of herbicide application relative to weed control and estimated economic returns were also pooled over years. Pearson's correlation coefficients were constructed based on results of ANOVA (Table 2.6). Broadleaf weed and grass control 10 WAP and percent maximum yield as well as broadleaf and grass control 10 WAP and estimated economic returns were positively correlated ($p \leq 0.0001$, $R = 0.39$ to 0.75).

Common ragweed control. At 10 WAP, at least 93% common ragweed control was observed in both corn and soybean when at least one herbicide application was made regardless the timing of application (Table 2.7). In cotton, at least 97% control of common ragweed was noted when a single application was made 6 WAP or when at least two herbicide applications were made regardless the timing of application. In grain sorghum, common ragweed was controlled completely when a single application was made 2 WAP, when two applications were made 2 and 4 WAP, and when applications were made 2, 4, and 6 weeks after planting.

When herbicides were not applied, common ragweed control in corn and grain sorghum was at least 35% greater than control in cotton and at least 30% greater than control in soybean (Table 2.7). When a herbicide application was made 2 WAP only, at least 93% control of this weed was noted for corn, grain sorghum, and soybean. Common ragweed control in cotton was similar to control in soybean but less than control in corn and grain sorghum. At least 97% control of common ragweed was observed in corn, cotton and soybean when a single herbicide application was made 6 WAP and when two herbicide applications were made 4 and 6 WAP. Common ragweed was controlled effectively in corn, cotton, grain sorghum, and soybean when herbicides were applied twice at 2 and 4 WAP or when three applications of herbicide were made 2, 4, and 6 WAP.

In corn, Lindsey et al. (2012) documented 81, 87, and 96% control of common lambsquarters when glyphosate was applied Early POST, Mid POST, and Late POST.

Texas millet control. Texas millet was controlled at least 89% in corn when at least one herbicide application was made (Table 2.7). Control of Texas millet was similar without herbicides compared with a single herbicide application 2 WAP. At least 97% Texas millet control in cotton was observed when two herbicide applications were made at 4 and 6 WAP or when three applications were made 2, 4, and 6 WAP. In grain sorghum, Texas millet control ranged from 80 to 87%. In soybean, at least 92% control was noted when a single herbicide application was made 6 WAP or when at least two applications were made irrespective of the timing.

Palmer amaranth control. Palmer amaranth control was at least 90% 10 WAP in corn when herbicides were applied at least twice or when a single application was made 2 WAP

(Table 2.8). In cotton and soybean, at least 89% Palmer amaranth control was noted when herbicide applications were made at least twice irrespective of the timing.

When herbicides were not applied, Palmer amaranth control was greater in corn and soybean compared with control in cotton and grain sorghum (Table 2.8). When a single herbicide application was made 2 WAP, control of Palmer amaranth was greater in corn compared to control in cotton and grain sorghum. Control of Palmer amaranth in soybean was similar to control in corn and in grain sorghum when a single herbicide application was made 2 WAP. When a single herbicide application was made 6 WAP, control was greatest in corn and soybean compared with cotton and grain sorghum. Control of Palmer amaranth was greater in cotton compared to grain sorghum when a single herbicide application was made 6 WAP. When herbicides were applied twice, irrespective of the timing, control of Palmer amaranth was greater in corn, cotton, and soybean compared with grain sorghum. When three herbicide applications were made, control of Palmer amaranth in cotton and soybean was more effective than control of grain sorghum. Control of Palmer amaranth in corn was similar to control of Palmer amaranth in cotton, grain sorghum, and soybean when herbicides were applied 2, 4, and 6 WAP.

In cotton, Inman et al. (2017) documented 96% or greater Palmer amaranth control 8 WAP when three or more POST herbicide applications were made regardless of the timing sequence when applied within 5 WAP.

Large crabgrass control. At least 80% control of large crabgrass was obtained in corn when herbicide applications were made at least twice regardless the timing or when a single herbicide application was made 2 WAP (Table 2.8). In cotton, 78% or more control of large crabgrass was noted when herbicides were applied 4 and 6 WAP or when herbicides were applied 2, 4, and 6 WAP. In soybean, at least 84% control of large crabgrass was obtained when herbicide applications were made at least twice, regardless the timing. Poor large crabgrass control (<65%) was noted in grain sorghum with any herbicide application treatment.

Percent maximum yield. In order to compare across crops, yields were converted to percent of the maximum yield potential. At Lewiston-Woodville, corn yielded at least 89 percent of the maximum when a single herbicide application was made 2 WAP or when herbicides were applied at least twice regardless the timing (Table 2.10). Although common ragweed control for a single herbicide application 6 WAP resulted in 98% control, effects of early season weed interference were observed with the yield reduction noted. In cotton, yields of at least 93% of the maximum were obtained when applications were made 4 and 6 WAP or when herbicides were applied 2, 4, and 6 WAP. Yield of grain sorghum was at least 88% of the maximum when a herbicide was applied 2 WAP. In soybean, at least 88% of the maximum yield was noted when herbicide applications were made at least twice, regardless the timing.

When herbicides were not applied at Lewiston-Woodville, corn yielded more than grain sorghum, while grain sorghum yielded more than soybean or cotton (Table 2.10). When a single herbicide application was made 2 WAP, percent maximum yield of corn and grain sorghum was greater than that of cotton and soybean. Soybean yield relative to the maximum was higher than that of cotton. Corn yield was greater than yield of cotton and grain sorghum but similar to yield of soybean following a single herbicide application 6 WAP. Soybean yield was similar to cotton yield while both were greater than grain sorghum yield. When herbicides applications were made twice at 2 and 4 WAP, corn, grain sorghum, and soybean yields were greater than cotton yields. When herbicides were applied 4 and 6 WAP, yields were greater for corn, cotton, and soybean compared to grain sorghum. Maximum yields were noted across all crops following three herbicide applications 2, 4, and 6 WAP.

At Rocky Mount, at least 73% of the maximum yield was noted in corn when herbicide applications were made at least twice, regardless the timing, and when a single herbicide application was made 2 WAP (Table 2.11). Gower et al. (2003) found that corn grain yield was not affected by weeds if they were controlled prior to reaching 10-cm. Lindsey et al. (2012) noted no differences in corn grain yield as long as a single post herbicide application of glyphosate or glufosinate was applied prior to the V7 growth stage in herbicide resistant corn. In cotton and soybean, at least 83% of the maximum yield was noted when herbicide applications were made at least twice regardless the timing. Grain sorghum achieved 91% of the maximum yield when herbicides were applied twice at 2 and 4 WAP.

Following a single herbicide application 2 WAP or when no herbicides were applied, corn produced greater yields than grain sorghum, soybean, and cotton (Table 2.11). Grain sorghum and soybean also yielded greater than cotton. When a single herbicide application was made 6 WAP, corn and soybean produced greater yields than grain sorghum and cotton. 90% of the maximum yield was noted in all crops when herbicide applications were made 2 and 4 WAP. When herbicides were applied 4 and 6 WAP, corn, cotton, and soybean produced greater yields than grain sorghum.

In cotton, Inman et al. (2017) found cotton lint yield to decrease as number of POST herbicide applications decreased ranging from zero to five applications.

Estimated economic returns. At Lewiston-Woodville, estimated economic returns of at least \$1,149 ha^{-1} were obtained only in corn when herbicides were applied 2 WAP only; 2 and 4 WAP; and 2, 4, and 6 WAP (Table 2.10). Estimated economic returns were greater in corn than cotton, grain sorghum, and soybean when herbicides were not applied. Estimated economic returns were greater for grain sorghum and soybean than for cotton. When herbicides were applied twice 2 and 4 WAP, when herbicides were applied once 6 WAP, and when herbicide were applied 3 times 2, 4, and 6 WAP, estimated economic returns were greater for corn, followed by soybean, followed by cotton, followed by grain sorghum. Estimated economic returns were greatest for corn followed by soybean; soybean was greater than cotton; cotton was greater than grain sorghum following two herbicide applications at 4 and 6 WAP.

At Rocky Mount, estimated economic returns of at least \$1,263 ha^{-1} were noted in corn when herbicide applications were made once at 2 WAP and when herbicide applications were made twice at 2 and 4 WAP (Table 2.11). Estimated economic returns of at least \$1,276 ha^{-1} were also noted in soybean when herbicide applications were made at least twice, regardless the timing.

Regardless of the timing of herbicide applications, estimated economic returns for corn and soybean were always greater than returns of cotton and grain sorghum (Table 2.11). Following a single herbicide application 2 WAP or when herbicides were not applied, estimated economic returns were greater for corn than for soybean. When herbicides were applied 2, 4, and 6 WAP, estimated economic returns were greater for soybean than corn. Inman et al. (2017) found there to be little or no differences in estimated economic returns when three or more POST applications of herbicides were made to cotton.

Weed density the following season. When common ragweed and Palmer amaranth were defined as broadleaf weeds, the interaction of experiment by crop was significant for broadleaf and grass densities 3 WAP in cotton and for cotton lint yield (Table 2.12). Therefore, in one analysis broadleaf and grass densities 3 WAP in cotton as well as cotton lint yield were analyzed by crop and experiment. The main effect of timing of herbicide application was significant for broadleaf counts 3 WAP in cotton but not cotton lint yield. Therefore, the main effect of timing of herbicide application was analyzed pooled over experiments for broadleaf counts 3 WAP in cotton. The interaction of crop by timing of herbicide application was significant for grass counts 3 WAP. Broadleaf and grass control 10 WAP was negatively correlated with broadleaf and grass densities 3 WAP in cotton the following season (Table 2.6).

Broadleaf densities. Regardless of timing of application, when herbicides were applied the previous year, a reduction in the populations of broadleaf weeds in cotton was noted (Table 2.13). When herbicides were applied 2 and 4 WAP or three times (2, 4, and 6 WAP), densities of broadleaf weeds were reduced compared to when a single herbicide application was made 2 WAP or when herbicides were applied 4 and 6 WAP.

Common ragweed densities. At Lewiston-Woodville, when analyzed by experiment, common ragweed densities ranged from 112 to 162 and 21 to 58 plants m^{-2} in 2017 and 2018, respectively (Table 2.14). Common ragweed densities were lower following corn than following grain sorghum in 2017 and 2018. Common ragweed densities following cotton and soybean were similar to densities following corn and grain sorghum. Hill *et al*. (2016) found that common ragweed are able to produce viable seeds even when terminated at flowering or when immature seeds were present at termination. They also reported that impacts to the seedbank were lessened when common ragweed was terminated prior to flowering. In some cases, secondary dormancy of seeds can occur when the non-dormant seeds are exposed to favorable temperature and moisture, but an overriding factor inhibits the seed from germinating (Willemsen, 1975). Baskin and Baskin (1980) reported common ragweed seed viability of 39 years once in the seedbank. Weed emergence measured in the study may have included contributions from previous seasons common ragweed populations that were present before the study was initiated.

Palmer amaranth densities. At Rocky Mount, Palmer amaranth densities 3 WAP in cotton ranged from 56 to 75 and 60 to 183 plants m^{-2} in 2017 and 2018, respectively (Table 2.15). In 2017, previous crop had no effect on Palmer amaranth densities. However, during 2018, Palmer amaranth densities were greater following grain sorghum compared to following corn, cotton, and soybean. Menges (1987) reported that 6 years of weed-free Palmer amaranth management may be required to reduce the seedbank by 98%. Sosnoskie et al. (2013) reported that 36 months were required for Palmer amaranth seed burial to deplete the seedbank. Therefore, a longer study may be needed in order to observe the complete effect of weed management due to the abundance of seeds present in the seedbank.

Grass densities. When Texas millet and large crabgrass were analyzed as grass, densities were lowest following corn and grain sorghum for all herbicide treatments the previous year including the NTC (Table 2.13). In cotton following cotton, grass densities were the lowest when herbicide applications were made twice at 4 and 6 WAP and three times at 2, 4, and 6 WAP. In soybean, grass densities were lower when no herbicide applications were made or when at least two applications were made, regardless the timing.

Texas Millet densities. In 2017, previous crop had an effect on density of Texas millet in cotton the following season (Table 2.14). Density of Texas millet was lower following corn and grain sorghum compared to soybean. Densities following cotton were greater than densities following corn but similar to densities following grain sorghum. In 2018, previous crop had no effect on Texas millet densities in cotton.

Large crabgrass densities. In 2017, large crabgrass densities 3 WAP ranged from 63 to 95 plants m^{-2} (Table 2.15). Previous crop had no effect on large crabgrass densities in cotton. In

2018, large crabgrass densities ranged from 92 to 217 plants m^{-2}. Densities were reduced following corn, grain sorghum, and soybean compared to densities following cotton.

Cotton Lint Yield the year following. When experiments were pooled, herbicide applications in the previous year did not have an effect on cotton lint yield (Table 2.13). At Lewiston-Woodville, cotton lint yield ranged from 1830 to 1940 kg ha^{-1} in 2017 with previous crop having no effect on yield (Table 2.14). In contrast, in 2018, cotton lint yield ranged from 1160 to 1420 kg ha^{-1} with previous crop having an effect on yield. Lint yield following corn, cotton, and soybean was greater than lint yield following grain sorghum.

At Rocky Mount, previous crop had an effect on cotton lint yield in 2017 and 2018 (Table 2.15). In 2017, cotton lint yield ranged from 740 to 960 kg ha^{-1} and was greater following corn than following cotton, grain sorghum, and soybean. In 2018, cotton lint yield ranged from 880 to 1100 kg ha^{-1} with yield following corn and cotton being greater than yield following grain sorghum. When pooled aver experiments, timing of herbicide applications had no effect on cotton lint yield.

The value of these data relies on having four major agronomic crops all in one test allowing comparison across crops relative to weed control and yield. Also, this experiment allows one to analyze the effects that a single-season weed management decisions have on weed populations the following season. Results from these experiments indicate that fewer herbicide applications are needed in corn to optimize economic return compared with cotton or soybean. Relative yield of grain sorghum compared well with corn when a single herbicide was applied 2 WAP or when multiple applications were made so long as the first application occurred 2 WAP. Although these experiments do not constitute a true time of weed removal or duration of weed interference study, results do inform practitioners of the relative importance of timing and duration of weed management for major agronomic crops in North Carolina. The duration of these experiments was not long enough to truly know the ramifications of poor weed control in contributions to the seedbank. Differential efficacy of herbicides used in these crops also confounded results. The exception is comparisons of corn, cotton, and soybean where efficacy of herbicides was similar.

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Table 2.1. Herbicides used within each cropping system at 2, 4, and 6 WAP applications.

	Lewiston-Woodville		
Crop	**2 WAP**	**4 WAP**	**6 WAP**
Corn	glyphosate	glyphosate	glyphosate
Cotton	glyphosate	glyphosate	glyphosate
Grain sorghum	quinclorac	bentazon	bentazon
Soybean	glyphosate	glyphosate	glyphosate
	Rocky Mount		
Crop	**2 WAP**	**4 WAP**	**6 WAP**
Corn	glyphosate plus dicamba	glyphosate	glyphosate
Cotton	glyphosate plus dicamba	glyphosate plus dicamba	glyphosate
Grain sorghum	quinclorac	bentazon	bentazon
Soybean	glyphosate plus dicamba	glyphosate plus dicamba	glyphosate

Table 2.2. Herbicide active ingredient, trade name, formulation, application rate, and manufacturer.[a]

Herbicides	Trade name	Formulation concentration	Application Rate ha^{-1}	Manufacturer
bentazon sodium salt	Basagran®	479 g ai L^{-1}	556 or 1,112 g ai[a]	Arysta LifeScience
dicamba diglycolamine salt	Xtendimax™	350 g ae L^{-1}	563 g ae	Monsanto Co.
glufosinate-ammonium	Liberty® 280 SL	280 g ai L^{-1}	594 g ai	Bayer CropScience
glyphosate potassium salt	Roundup PowerMax®	540 g ae L^{-1}	947 g ae	Monsanto Co.
quinclorac dimethylamine salt	Facet®	180 g ae L^{-1}	316 g ae	BASF Chemical Co.

[a] Bentazon at 556 g ha^{-1} when applied 6 WAP following 4 WAP.

Table 2.3. Analysis of variance (P > F) for broadleaf and grass control 10 WAP, percent maximum yield, and estimated economic returns pooled across experiments.

Source of variation	Broadleaf control (10 WAP)	Grass control (10 WAP)	Percent maximum yield (%)	Estimated economic returns ($ ha^{-1})
Experiment (Exp)	19.7*	50.8*	5.5*	20.1*
Crop	20.7*	24.7*	43.2*	277.6*
Timing of herbicide application (HERB)	294.2*	19.9*	177.8*	110.3*
Exp × Crop	14.3*	5.0*	2.1*	30.9*
Exp × HERB	11.7*	2.4*	5.0*	4.8*
Crop × HERB	13.6*	4.87*	25.4*	26.9*
Exp × Crop × HERB	3.0*	1.56*	3.2*	3.2*

[a]A * indicates significance at $p \leq 0.05$.

Table 2.4. Analysis of variance (P > F) for common ragweed and Texas millet control 10 WAP, percent maximum yield, and estimated economic returns at Lewiston-Woodville.

Source of variation	Broadleaf control (10 WAP)	Grass control (10 WAP)	Percent maximum yield (%)	Estimated economic returns ($ ha^{-1})
Year	13.3*	4.0*	0.4	39.3*
Crop	9.5*	16.0*	36.2*	347.8*
Timing of herbicide application (HERB)	328.0*	25.4*	169.2*	135.5*
Year × Crop	4.6*	9.5*	3.1*	37.0*
Year × HERB	13.7*	1.5	6.9*	11.38*
Crop × HERB	22.3*	8.9*	28.4*	30.49*
Year × Crop × HERB	3.1*	1.2	2.1*	2.27*

[a]A * indicates significance at $p \leq 0.05$.

Table 2.5. Analysis of variance (P > F) for Palmer amaranth and large crabgrass control 10 WAP, percent maximum yield, and estimated economic returns at Rocky Mount.

Source of variation	Palmer amaranth control (10 WAP)	Large crabgrass control (10 WAP)	Percent maximum yield (%)	Estimated economic returns ($ ha^{-1})
Year	3.1	72.0*	3.5	24.3*
Crop	11.1*	9.3*	19.6*	102.9*
Timing of herbicide application (HERB)	96.9*	10.9*	59.1*	35.2*
Year × Crop	20.0*	3.2*	1.16	8.3*
Year × HERB	9.1*	2.4*	2.44*	1.0
Crop × HERB	3.9*	2.3*	9.41*	12.5*
Year × Crop × HERB	3.7*	2.0*	1.2	2.5*

[a]A * indicates significance at $p \leq 0.05$.

Table 2.6. Pearson correlation coefficients for broadleaf weed control 10 WAP, grass control 10 WAP, percent maximum yield, estimated economic returns, broadleaf weed densities 3 WAP in cotton, grass densities 3 WAP, and cotton lint yield[a].

Parameters	P > F	R
Broadleaf weed control 10 WAP versus percent maximum yield	< 0.0001	0.75
Grass control 10 WAP versus percent maximum yield	< 0.0001	0.39
Broadleaf weed control 10 WAP versus estimated economic returns	< 0.0001	0.57
Grass control 10 WAP versus estimated economic returns	< 0.0001	0.47
Broadleaf weed control 10 WAP versus grass control 10 WAP	< 0.0001	0.25
Broadleaf weed control 10 WAP versus broadleaf weed densities 3 WAP in subsequent cotton	< 0.0001	-0.44
Grass control 10 WAP versus grass densities 3 WAP in subsequent cotton	< 0.0001	-0.40
Percent maximum yield versus broadleaf weed densities 3 WAP in subsequent cotton	< 0.0001	-0.29
Percent maximum yield versus grass densities 3 WAP in subsequent cotton	0.0002	-0.20
Percent maximum yield versus subsequent cotton lint yield	0.0488	0.11

[a]Data are pooled over experiments.

Table 2.7. Common ragweed and Texas millet control 10 WAP, percent maximum yield, and estimated economic returns at Lewiston-Woodville[a].

	Weed control 10 WAP							
	Common ragweed				Texas millet			
Timing of Weed Management	Corn	Cotton	Grain sorghum	Soybean	Corn	Cotton	Grain sorghum	Soybean
WAP	%							
None	43 d	8 e	44 d	13 e	77 ghi	78 ghi	87 b-h	74 hi
2	99 a	85 b	100 a	93 ab	89 a-g	23 k	86 d-h	61 j
6	98 a	97 a	56 c	100 a	98 a-d	86 c-h	83 e-i	93 a-e
2 and 4	100 a	99 a	100 a	99 a	99 ab	72 ij	83 e-i	92 a-f
4 and 6	100 a	100 a	61 c	100 a	99 abc	97 a-d	87 b-h	98 a-d
2, 4, and 6	100 a	100 a	100 a	100 a	100 a	97 a-d	80 f-i	99 abc

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

Table 2.8. Palmer amaranth and large crabgrass control 10 WAP at Rocky Mount[a].

	Weed control 10 WAP							
	Palmer amaranth				Large crabgrass			
Timing of Weed Management	Corn	Cotton	Grain sorghum	Soybean	Corn	Cotton	Grain sorghum	Soybean
WAP	%							
None	49 i	14 k	22 k	42 ij	62 bcd	34 e	49 cde	48 cde
2	96 a-d	67 gh	78 efg	85 b-e	80 ab	40 de	43 cde	61 bcd
6	81 d-g	53 i	28 jk	69 fgh	69 bc	43 de	65 bcd	64 bcd
2 and 4	100 ab	98 abc	81 d-g	100 a	99 a	65 bc	43 cde	84 ab
4 and 6	90 a-e	96 a-d	58 hi	89 a-e	99 a	78 ab	44 cde	98 a
2, 4, and 6	100 abc	100 ab	84 c-f	100 ab	99 a	86 ab	46 cde	99 a

[a] Means within a weed species followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data are pooled over years.

Table 2.9. Yield potential for corn, cotton, grain sorghum, and soybean at Lewiston-Woodville and Rocky Mount.

	Lewiston-Woodville	Rocky Mount
Crop	kg ha^{-1}	
Corn	1,200	12,450
Cotton	1,160	643
Grain sorghum	5,970	2,690
Soybean	4,050	5,580

Table 2.10. Percent maximum yield and estimated economic returns at Lewiston-Woodville where common ragweed and Texas millet were present[a].

	Percent maximum yield				Estimated economic returns			
Timing of Weed Management	Corn	Cotton	Grain sorghum	Soybean	Corn	Cotton	Grain sorghum	Soybean
WAP	%				$ ha^{-1}			
None	66 f	1 j	33 hi	11 j	620 gh	-1203 o	-353 m	-403 m
2	97 a	28 i	91 ab	66 f	1317 a	-629 n	18 kl	473 hi
6	83 bcd	73 ef	43 h	74 def	1003 cd	203 jk	-346 m	608 gh
2 & 4	93 ab	78 cde	92 ab	94 ab	1204 ab	327 ij	-35 l	898 de
4 & 6	89 ab	96 a	54 g	88 abc	1113 bc	670 fg	-314 m	817 ef
2, 4, 6	91 ab	93 ab	88 abc	97 a	1149 abc	562 gh	-118 l	931 de

[a]Means within percent maximum yield and estimated economic returns followed by the same letter not significantly different according to Fisher's Protected LSD test at P $\leq$ 0.05. Data are pooled over years.

Table 2.11. Percent maximum yield and estimated economic returns at Rocky Mount where Palmer amaranth and large crabgrass were present[a].

Timing of Weed Management	Percent maximum yield				Estimated economic returns			
	Corn	Cotton	Grain sorghum	Soybean	Corn	Cotton	Grain sorghum	Soybean
WAP	%				$ ha^{-1}			
None	67 cd	2 g	35 ef	31 f	726 e	-1190 h	-484 g	135 f
2	93 a	37 ef	72 bcd	68 cd	1292 ab	-622 g	-445 g	915 cde
6	72 bcd	7 g	49 e	75 abc	816 de	-1099 h	-489 g	1072 bcd
2 & 4	93 a	93 a	91 a	90 a	1263 ab	206 f	-455 g	1396 a
4 & 6	87 ab	83 abc	51 de	88 ab	1134 abc	76 f	-552 g	1322 ab
2, 4, & 6	73 a-d	88 ab	75 abc	88 ab	737 de	117 f	-541 g	1276 ab

[a]Means within percent maximum yield and estimated economic returns followed by the same letter not significantly different according to Fisher's Protected LSD test at P $\leq$ 0.05. Data are pooled over years.

Table 2.12. Analysis of variance (P > F) for broadleaf and grass densities 3 WAP and cotton lint yield.

Source of variation	Broadleaf densities (3 WAP)	Grass densities (3 WAP)	Cotton lint yield
Experiment (Exp)	86.6*	24.6*	798*
Crop	22.7*	9.8*	4.7*
Timing of herbicide application (HERB)	9.1*	4.2*	0.4
Exp × Crop	9.27*	2.8*	6.0*
Exp × HERB	0.9*	0.8	1.5
Crop × HERB	1.0	2.1*	1.0
Exp × Crop × HERB	1.1	0.7	1.1

[a]A * indicates significance at $p \leq 0.05$.

Table 2.13. Broadleaf and grass densities 3 WAP in cotton and cotton lint yield. Data are pooled over experiments[a].

Timing of herbicide application	Densities in cotton 3 WAP					Yield
	Broadleaf	Grass				Cotton lint
	Pooled across crops	Corn	Cotton	Grain sorghum	Soybean	Pooled across crops
WAP	——— No. m^{-2} ———					——— Kg ha^{-1} ———
None	114 a	71 f	125 bcd	68 f	101 c-f	1260 a
2	85 b	85 c-f	157 ab	85 c-f	119 b-e	1270 a
6	79 bc	71 f	178 a	59 f	124 bcd	1260 a
2 & 4	67 c	88 c-f	130 bc	103 c-f	72 ef	1290 a
4 & 6	86 b	55 f	80 def	81 def	70 f	1270 a
2, 4, & 6	69 c	59 f	65 f	100 c-f	61 f	1280 a

[a]Means within broadleaf densities, grass densities, or cotton lint yield followed by the same letter not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.

Table 2.14. Common ragweed and Texas millet densities 3 WAP in cotton and cotton lint yield at Lewiston-Woodville.

Previous Crop	Densities in cotton 3 WAP				Yield	
	Common ragweed		Texas Millet		Cotton lint	
	No. m^{-2}				Kg ha^{-1}	
	2017	2018	2017	2018	2017	2018
Corn	112 b	21 b	69 c	61 a	1940 a	1410 a
Cotton	136 ab	37 ab	103 ab	74 a	1870 a	1360 a
Grain sorghum	162 a	58 a	82 bc	54 a	1840 a	1160 b
Soybean	140 ab	36 ab	112 a	58 a	1830 a	1420 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 2.15. Palmer amaranth and large crabgrass densities 3 WAP in cotton and cotton lint yield at Rocky Mount.

	Densities in cotton 3 WAP				Yield	
	Palmer amaranth		Large crabgrass		Cotton lint	
	No. m^{-2}				Kg ha^{-1}	
Previous Crop	2017	2018	2017	2018	2017	2018
Corn	64 a	60 b	64 a	92 b	960 a	1100 a
Cotton	75 a	72 b	95 a	217 a	740 b	1100 a
Grain sorghum	56 a	183 a	72 a	123 b	830 b	880 b
Soybean	63 a	62 b	63 a	131 b	830 b	1060 ab

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

CHAPTER 3

Impact of Weed Management on Peanut Yield and Weed Populations the Following Year

This chapter is written in the style and format for the American Peanut Research and Education Society publication *Peanut Science*

ABSTRACT

Field studies were conducted in 2016 and 2017 at two locations in North Carolina to evaluate control of common ragweed (*Ambrosia artemiisifolia* L.) (Lewiston-Woodville) and Palmer amaranth (*Amanthus palmeri* S. Wats) (Rocky Mount), peanut (*Arachis hypogaea* L.) yield, and estimated economic return when herbicides were applied postemergence (POST) at 2 or 6 weeks after planting (WAP) only, 2 and 4 WAP, 4 and 6 WAP, and 2, 4, and 6 WAP. A non-treated control (NTC) was also included, and clethodim was applied POST 6 WAP over the entire test area to remove interference from annual grasses. During the following growing season, cotton (*Gossypium hirsutum* L.) was planted directly back into the same plots to determine the impact of previous weed management on weed populations. In absence of herbicides, peanut yield was 880 and 1110 kg/ha at Lewiston-Woodville and Rocky Mount, respectively. At Lewiston-Woodville, yield ranged from 1760 to 2660 kg/ha with only one herbicide application, while at Rocky Mount peanut yield ranged from 2080 to 2480 kg/ha with this level of weed management. When herbicides were applied twice, peanut yield ranged from 2690 to 3280 kg/ha at Lewiston-Woodville and 3420 to 3840 kg/ha at Rocky Mount. The greatest yields were recorded when herbicides were applied three times (3680 kg/ha at Lewiston-Woodville and 5030 kg/ha at Rocky Mount). Applying herbicides increased the estimated economic return of peanut compared to the NTC. In cotton the following year, common ragweed populations at Lewiston-Woodville were greater following the NTC or a single herbicide application 2 WAP compared to the more intensive programs. Palmer amaranth populations at Rocky Mount the following year in cotton were not affected by weed management the previous year in peanut. These results inform practitioners of the relative importance of timing and

duration of weed management for peanut in North Carolina and how they influence weed emergence in the following rotational crop.

KEYWORDS: Timing of herbicide application, estimated economic return.

INTRODUCTION

Timely and effective herbicide spray programs are essential for adequate weed control in all agronomic crops (Wilcut and Askew, 1999). However, the rapid growth of many problematic broadleaf weeds ultimately creates a very small application window for effective control (Horak and Loughin, 2000). A major concern in the southeastern United States is crop interference from Palmer amaranth (*Amaranthus palmeri* S. Wats) and common ragweed (*Ambrosia artemisiifolia* L.). Not only do these broadleaf weeds intercept and limit light to the crop, they compete for other resources and may complicate mechanical harvest (Horak *et al*., 1994; Morgan *et al*., 2001; Young *et al*., 1982). Weeds must be controlled throughout the growing season to avoid yield losses in peanut (Jordan, 2018; Wilcut *et al*., 1995). As the duration of interference from weeds increases, yield of peanut and other crops often decreases (Zimdahl, 2004). When yield potential is greater, weeds have a greater effect on crop yield (Clewis *et al*., 2001). With increased importance of herbicide resistance, one management strategy is to minimize contributions of weed seed to the soil seedbank. A main concern in peanut (*Arachis hypogaea* L.) growing regions of the southeastern United States is the yield impacts associated with the presence of common ragweed or Palmer amaranth as well as how in-season control may affect weed presence in the following rotational crop.

Palmer amaranth, which originated in southern California and Mexico, has spread across the midsouth and southeastern United States, becoming an expensive problem for farmers to manage (Steckel, 2007). Morphological features and exceptional capability to produce flowers under proper photoperiods at almost any growth stage makes Palmer amaranth successful at exploiting unstable environments (Sauer, 1957). In California, Keeley *et al*. (1987) found that Palmer amaranth will begin to emerge in early March when soils have reached a temperature of 18 C and continue to emerge into October. In Georgia, Webster and Grey (2015) found that glyphosate-resistant Palmer amaranth planted in early May produced 446,000 seed per plant, while Palmer amaranth planted six weeks later produced 50 percent fewer seed. Palmer amaranth planted 9 and 12 weeks later had 89 and 99 percent fewer seeds, respectively (Webster and Grey, 2015). Horak and Loughin (2000) found that under natural growing conditions and in the absence of other weed or crop species, Palmer amaranth grew 0.18 to 0.21 cm/growing degree day (GDD). Because of its rapid growth rates, the application window for optimum control of Palmer amaranth may be relatively short (Horak and Loughin, 2000). The effective application interval for control of Palmer amaranth could be as soon as one week after weed emergence based on maximum height recommendations of commonly used herbicides (Jordan, 2018). Therefore, Palmer amaranth would be a good indicator species for timing of weed management when there are mixed populations involved (Burke *et al*., 2007).

Morgan *et al*. (2001) reported that when 1.1 Palmer amaranth plants/m of row were present, cotton (*Gossypium hirsutum L*.) yield was reduced by 54%. Yield loss of field corn (*Zea mays* L.) ranged from 11 to 91% at 0.5 to 8 plants/m of row when Palmer amaranth emerged with the corn (Massinga *et al*., 2001). At a density of one plant/m of row, yield loss in peanut was predicted to be 28% (Burke *et al*., 2007). Yield of soybean [*Glycine max* (L.) Merr.] was reduced 79% when 8 plants/m of row were present in a field study conducted in Kansas (Bensch *et al*., 2003). Not only can competing Palmer amaranth affect yields directly, it may also reduce harvesting efficiency, which is problematic for agronomic crops that are mechanically harvested (Young *et al.*, 1982). Smith *et al*. (2000) reported that when 1 Palmer amaranth is present/3 m of row in cotton, harvest time increased by 3.5 times that of weed-free cotton. The increased harvest time was a result of the operator having to stop the machine to dislodge stalks from moving parts (Smith *et al*., 2000). When Palmer amaranth densities exceed 1 plant/1.5 m of row, it is unfeasible to use a mechanical harvester due to potential damage to the machine (Morgan *et al*., 2001).

Common ragweed is a monoecious annual plant native to North America and is common to the temperate United States (Oosting, 1942). Germination and population establishment have been positively correlated with late fall and early spring soil tillage, which exposes seed to light and lower CO_2 levels (Bazzaz, 1968). The plant is monoecious meaning it has both male and female structures (Dickerson and Sweet, 1971). Common ragweed will generally dominate in the second year if soil disturbance is halted, shading out some of the species that dominated in the first year, such as crabgrass (*Digitaria* spp.) (Oosting, 1942), which relates to the increase of common ragweed problems in no-till or reduced tillage systems in soybean and corn (Jordan *et al*., 2014). Ragweed tends to emerge in late April as soil warms and will continue to emerge until temperatures become unfavorable sending the seeds back into dormancy (Jordan *et al*., 2014). Chemical or mechanical control of early emerging weed species could be utilized by implementing delayed planting of summer annual crops, but regular delayed plantings could cause a population shift and could potentially have negative impacts on yield (Werle *et al*., 2014). Leiblein‐Wild *et al*. (2014) found that optimum germination of common ragweed occurred at temperatures of 16-17 C but that germination was possible at 5 C. Maximum rate of height increase varied from 0.1 to 2 cm/day depending on competition, temperature, and water stress (Deen *et al*., 2001). Common ragweed costs North Carolina and Virginia peanut producers an estimated $66,485,000 in yield loss due to weed interference and decreased harvest efficiency (Bridges *et al*., 1994; Wilcut *et al*., 1995).

Coble et al. (1981) reported that 1 common ragweed/10 m of row would reduce soybean yield by 32.5 kg/ha on average. When grown in 30 percent shade, common ragweed has been noted to grow just as well as sweet corn (Zea mays L. var. rugosa) and dry bean (Phaseolus vulgaris Herrm) but much poorer than these crops in 73 percent shade (Dickerson, 1968). Predicted yield loss in peanut is 40 percent when 1 ragweed is present/m of crop row for the entire season (Clewis et al., 2001). Everman et al. (2008) observed the critical period of weed control in peanut for mixed broadleaf populations to be from 2.6 to 8 WAP. When grown with peanut, common ragweed aboveground biomass/plant decreased as common ragweed density increased, indicating intraspecific competition (Clewis et al., 2001). Greater incidences of late leaf spot disease in peanut, caused by Cercosporidium personatum syn. Passalora personata, have been noted with increased common ragweed aboveground biomass due to interception of foliar applied fungicides (Clewis et al., 2001; Royal et al., 1997).

The 2- to 3-week period after flowering is the critical time for weed management in most weed species to prevent weeds from producing viable seeds (Hill *et al*., 2016). Most weed management studies are only evaluated in a single growing season failing to quantify the impact these weed management strategies may have on contributions to the soil seedbank (Inman *et al*., 2016). This study was designed to evaluate the effects that timing of weed management have on weed control, peanut yield, estimated economic returns, and weed populations and cotton lint yield in the following growing season.

MATERIALS AND METHODS

The experiments were conducted in North Carolina near Lewiston-Woodville (36.135 N, -77.177 W) and Rocky Mount (35.897 N, -77.675 W) during 2016 and 2017. Adjacent areas of the same fields were used for different years at both locations. Soils included a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudult) at Lewiston-Woodville and an Aycock very fine sandy loam (fine-silty, siliceous, subactive, thermic Typic Paleudults) at Rocky Mount. The Lewiston-Woodville and Rocky Mount sites were naturally infested by common ragweed (129 plants/m^2 in 2016 and 61 plants/m^2 in 2017) and Palmer amaranth (54 plants/m^2 in 2016 and 65 plants/m^2 in 2017), respectively. Peanut cultivar ‘Bailey’ (Isleib *et al*., 2011) was planted into conventionally-tilled, raised seedbeds at a seeding rate designed to provide a final in-row population of 15 plants/m of row. Plot size was 4 rows (spaced 91 cm apart) by 9 m at both locations. Other than herbicide treatments imposed for the experiment, peanut was managed according to North Carolina Cooperative Extension Service recommendations (Jordan *et al*., 2018).

Treatments were arranged in a randomized complete block design and were replicated 4 times at Lewiston-Woodville and 3 times at Rocky Mount. Herbicide treatments consisted of a single application of paraquat plus bentazon 2 weeks after planting (WAP); a single application of imazapic plus lactofen 6 WAP; applications of paraquat plus bentazon 2 WAP followed by bentazon plus lactofen 4 WAP; bentazon plus lactofen 4 WAP followed by imazapic plus lactofen 6 WAP; and paraquat plus bentazon 2 WAP followed by bentazon plus lactofen 4 WAP followed by imazapic plus lactofen 6 WAP. A no-herbicide control was included. Clethodim was applied over the entire test area 6 WAP. At 2 and 4 WAP, peanut was in the vegetative growth stage while at 6 WAP peanut was in the flower (R1) growth stage (Boote, 1982; Balota, 2019). Herbicide rates and manufacturer details are listed in Table 3.1. Nonionic surfactant (Induce®, Helena Chemical Co., Collierville, TN) at 0.125% (v/v) was applied with paraquat plus bentazon. Crop oil concentrate (Agri-Dex®, Helena Chemical Co., Collierville, TN) at 1.0% (v/v) was applied with bentazon plus lactofen, imazapic plus lactofen, and clethodim. Herbicides were applied using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (AIXR 11002 TeeJet® Air Induction XR flat-spray nozzles, TeeJet Technologies, Wheaton, IL) calibrated to deliver 140 L/ha at 152 kPa.

Prior to the first herbicide application, initial weed densities were recorded from 15 randomly determined sections across the entire test area using a 0.3 by 0.3 m square. Weed control was visually estimated 7, 10, and 20 WAP using a 0 to 100% scale where 0 was equal to no control and 100 was equal to complete control. Foliar chlorosis, necrosis, biomass, and population were considered when making the visual estimates. Peanut pods were dug and vines inverted at optimum maturity based on pod and mesocarp color (Williams and Drexler, 1981). Within two weeks prior to digging and vine inversion, weeds were mowed above the canopy to improve efficiency of digging and vine inversion.

Following planting of peanut in 2016, the cotton cultivar DP 1522 (Monsanto Co., St. Louis, MO) was planted into the previous year’s plots in conventionally-tilled, raised seedbeds on 4 May and 11 May during 2017 at Lewiston-Woodville and Rocky Mount, respectively. In 2018 the cotton cultivar DP 1646 (Monsanto Co., St. Louis, MO) was planted 10 May and 15 May at Lewiston-Woodville and Rocky Mount, respectively, the year following peanut in 2017.

Within each plot, densities of common ragweed at Lewiston-Woodville and densities of Palmer amaranth at Rocky Mount were determined 3, 7, and 20 WAP. Densities at 3 and 7 WAP were measured using a 0.3 by 0.3 m square in three randomly determined sections of each plot and then the average of each plot was converted to a m^2 basis. Due to reduced weed densities at 20 WAP, populations were determined by counting common ragweed or Palmer amaranth present in the center two rows of the entire plot area and then converted to a m^2 basis. After initial weed densities were recorded 3 and 7 WAP in cotton, glyphosate was applied at Lewiston-Woodville. Glyphosate plus dicamba was applied 3 WAP followed by glyphosate only 7 WAP at Rocky Mount. These herbicides were applied over the entire test area.

Economic returns were estimated using a modified North Carolina State University enterprise budget for conventional Virginia market type peanut to accommodate a 400-ha operation in North Carolina (Washburn, 2019). Costs were calculated for the different treatments with respect to varying costs of herbicides and adjuvants, application cost, hauling, drying and cleaning, state check-off fee, and national assessment costs based on yield. A base cost of $1502/ha for peanut production before these respective inputs was used. A ten-year average price of $0.57/kg received for Virginia type peanuts in the United States was used for estimated economic return analysis (USDA-NASS, 2018).

Data for control of common ragweed and Palmer amaranth, peanut yield, estimated economic returns, broadleaf densities in cotton the following year, and cotton lint yield were subjected to analysis of variance using PROC GLIMMIX and PROC CORR procedures of SAS (version 9.4; SAS Institute INC., Cary, NC). In one combined analysis, common ragweed and Palmer amaranth were defined as broadleaf weeds and subjected to ANOVA for a 4 (year and experiment combination) × 6 (timing of herbicide application) factorial arrangement. Data for each location were also subjected to ANOVA for a 2 (year) × 6 (timing of herbicide application) factorial arrangement in separate analyses because of different broadleaf weeds at each location. Timing of herbicide application treatments and locations were fixed factors whereas replications were treated as random. Means for significant main effects and interactions were separated using Fisher's Protected LSD at $p \leq 0.05$.

RESULTS AND DISCUSSION

When common ragweed and Palmer amaranth were defined as broadleaf weeds for the statistical analyses with all four site-years, the interaction of experiment × timing of herbicide application was significant for broadleaf weed control 7, 10, and 20 WAP ($P \leq 0.0001$ to 0.0013); p-values for pod yield and estimated economic return were $P \leq 0.0663$. When comparing experiments with control of either common ragweed or Palmer amaranth, the interaction of year × timing of herbicide application was not significant for common ragweed control 7, 10, and 20 WAP; pod yield; and estimated economic return at Lewiston-Woodville or for Palmer amaranth control 10 and 20 WAP; pod yield; and estimated economic return at Rocky Mount (Tables 3.2 and 3.3). The interaction of year × timing of herbicide application was significant for Palmer amaranth control 7 WAP, however, this interaction was not significant for common ragweed control 7 WAP. Therefore, data for common ragweed control 7, 10, and 20 WAP, pod yield, and estimated economic return at Lewiston-Woodville (Table 3.4) and Palmer amaranth control 10 and 20 WAP, pod yield, and estimated economic return at Rocky Mount (Table 3.5) are presented pooled over years. Palmer amaranth control 7 WAP is analyzed by year at Rocky Mount because of a significant year × timing of herbicide application interaction.

Common ragweed control and peanut pod yield as well as common ragweed control and estimated economic returns were positively correlated ($p \leq 0.0001$; $R = 0.60$ to 0.68) regardless of when the visual estimates of weed control were recorded (Table 3.6). As was noted for the experiments at Lewiston-Woodville for common ragweed, peanut yield and estimated economic returns were positively correlated with Palmer amaranth control 7, 10, and 20 WAP ($p \leq 0.0001$, $R = 0.60$ to 0.68) (Table 3.7).

Weed Control. At Lewiston-Woodville, common ragweed control 7 WAP was at least 97% when 2 or more herbicide applications were administered or at least one application was made at 6 WAP (Table 3.4). Common ragweed control 10 WAP was 98% or greater when 2 or more herbicide applications were made. A single herbicide application 2 WAP was approximately 50% less effective as a single application 6 WAP. Control of common ragweed was optimum at 20 WAP when at least 2 herbicide applications were made. Common ragweed 20 WAP was controlled less effectively when a single herbicide application was made 2 WAP compared to a single application made 6 WAP. Jordan et al. (2009) noted increased control of common ragweed when imazapic was included in the herbicide program.

At Rocky Mount, Palmer amaranth control 7 WAP was at least 82% when herbicides were applied at least twice, regardless the timing in 2016 and 2017. In 2016, Palmer amaranth control form a single herbicide application 6 WAP was greater than control from a single application 2 WAP while in 2017 the opposite was true. In 2016, Palmer amaranth control was greater when any herbicide application was administered compared to the NTC. In 2017, Palmer amaranth control was similar following a single herbicide application 6 WAP or when no herbicides were applied. At 10 WAP, Palmer amaranth control was at least 89% when herbicide applications were administered at least twice regardless of timing. Palmer amaranth control at 10

WAP was at least 40% greater when a single application was administered compared to the untreated control. Palmer amaranth control at 20 WAP was greatest when herbicide applications were administered 2, 4, and 6 WAP.

Peanut Yield. At Lewiston-Woodville, peanut yield was 3,280 kg/ha when herbicide applications were made three times at 2, 4, and 6 WAP or when applications were made twice at 4 and 6 WAP only (Table 3.4). Peanut yield following two applications at 2 and 4 WAP, a single application at 6 WAP, or two applications at 4 and 6 WAP were similar. Yields were greater any time herbicides were applied compared to the NTC.

At Rocky Mount, a yield of 5,030 kg/ha was achieved when herbicides were applied three times at 2, 4, and 6 WAP (Table 3.5). Yield was greater when at least two applications were administered compared to when a single application was made 2 WAP only. Yields were similar when a single herbicide application was made regardless of the timing. Yields were also similar when two herbicide applications were made irrespective of the timing.

In these experiments the NTC reflected interference from broadleaf weeds only because clethodim was applied across the entire experiment, but there was 6 weeks of interference in some plots. For mixed weed populations in peanut, Everman *et al*. (2008) found that the critical timing of weed removal was 3.1 WAP in order to produce at least 95% of the maximum yield. Everman *et al*. (2008) also reported the critical-weed free period in peanut under interference with combined grass and broadleaf weeds, mixed grass species, and mixed broadleaf species to be 3.1 to 7.5 WAP, 4.3 to 9 WAP, and 2.6 to 8 WAP, respectively. Hill and Santleman (1969) found that when large crabgrass [*Digitaria sanguinalis* (L.) Scop.] was removed 3 WAP and control persisted for at least 6 WAP, peanut yield was not reduced compared to weed-free peanut. Based on percent of maximum yield noted for the herbicide programs in these experiments, the percent yield loss from season-long interference by common ragweed and Palmer amaranth was 77% and 78%, respectively. These yield loss assessments compare relatively well with yield loss predictions associated with the decision tool WebHADSS (WebHADSS, 2019). At similar average densities for each site year, theoretical yield loss was 80% and 79% for common ragweed at Lewiston-Woodville in 2016 and 2017, respectively. Theoretical yield loss was 79% in both 2016 and 2017 from Palmer amaranth interference at Rocky Mount.

Estimated Economic Returns. At Lewiston-Woodville, estimated economic returns were similar when a single herbicide application was made irrespective of the timing or when two applications were made at 2 and 4 WAP (Table 3.4). A single herbicide application 6 WAP produced similar estimated economic returns as when herbicide applications were made at least twice, either at 2 and 4 WAP or 4 and 6 WAP. Estimated economic returns were greater when two applications were made at 4 and 6 WAP or when three applications were made at 2, 4, and 6 WAP compared to a single application 2 WAP. Greater estimated economic returns were observed when any herbicide application sequence was made compared to non-treated peanut.

At Rocky Mount, estimated economic return was $349/ha when herbicides were applied 2, 4, and 6 WAP (Table 3.5). Estimated economic returns were similar when two herbicide applications were made irrespective of the timing. Two herbicide applications made at 4 and 6 WAP produced similar estimated economic returns as a single herbicide application made 2 WAP. Estimated economic returns were greater when at least two herbicide applications were made irrespective of the timing compared to when a single herbicide application was made 6 WAP.

Weed Densities the Year Following Peanut. When common ragweed and Palmer amaranth were defined as broadleaf weeds for the statistical analyses with all four site-years, the interaction of experiment × timing of herbicide application was not significant for broadleaf densities at 3, 7, and 20 WAP ($p \leq 0.3717$ to 0.8668). In the same analyses, the main effect timing of herbicide application was not significant for broadleaf densities at 3, 7, and 20 WAP ($p < 0.1021$ to 0.4039). In order to stay consistent with previous analyses considering broadleaf weed control, peanut pod yield, and estimated economic returns, broadleaf densities in cotton the year following peanut were analyzed by weed species. The interaction of year × timing of herbicide application was not significant for common ragweed densities at 3 and 20 WAP at Lewiston-Woodville (Table 3.8) or for Palmer amaranth densities at 3, 7, and 20 WAP at Rocky Mount (Table 3.9). The main effect of herbicide application timing was not significant for common ragweed densities at 20 WAP at Lewiston-Woodville or for Palmer amaranth densities at 3, 7, and 20 WAP at Rocky Mount. Therefore, common ragweed densities at 3 and 20 WAP are presented pooled over years while common ragweed densities at 7 WAP are presented by year (Table 3.10). Palmer amaranth densities at 3, 7, and 20 WAP are presented pooled over years (Table 3.11).

Common ragweed control in peanut and subsequent weed densities in cotton the following year were negatively correlated ($p \leq 0.05$, $R = -0.40$ to -0.47) regardless of when the visual estimates of percent control were recorded in peanut (Table 3.6). Peanut yield was a predictor of common ragweed density 3 WAP in cotton the following year ($p \leq 0.0001$, $R = -0.73$). This is not surprising because weed control is a relatively good predictor of peanut yield, hence lowering the contributions of seed to the soil seedbank. Palmer amaranth control, regardless of timing, was not a good predictor of Palmer amaranth densities in cotton the following year (Table 3.7). However, peanut yield was a marginal predictor of Palmer amaranth density 3 WAP in cotton the following year. This is not surprising because, although weed control is a relatively good predictor of peanut yield, it is not the only factor influencing yield.

At Lewiston-Woodville in cotton 3 WAP, common ragweed densities ranged from 95 to 189 plants/m^2 (Table 3.10). Common ragweed densities were at least 47% lower when herbicides were applied 2, 4, and 6 WAP compared to when herbicides were not applied or when a single herbicide application was made 2 WAP only. Common ragweed densities were lower when herbicides were applied at least twice the previous year or when a single application was made 6 WAP compared to when no herbicides were applied or when a single application was made 2 WAP. Densities recorded 3 WAP most likely are the best indicator of how weed management in peanut the previous season affected weed populations the following season in cotton. However, comparing weed emergence during the following year may not reflect fully the impact of weed management on the soil seedbank. In addition to seed fecundity, dormancy could impact the amount of weed escapes over a longer period of time than a single season. However, this measurement was recorded prior to any weed management strategies were administered in cotton during the subsequent season.

At 7 WAP, common ragweed densities ranged from 1 to 18 plants/m^2 in 2017 and 0 to 5 plants/m^2 in 2018 (Table 3.10). In 2017, Common ragweed densities following a single herbicide application 6 WAP, 2 applications 4 and 6 WAP, or 3 herbicide applications the previous year were lower than densities following no herbicides or a single application 2 WAP. In 2018, common ragweed densities were similar following no herbicide applications, a single herbicide application 2 or 6 WAP, applications 2 and 4 WAP, or applications 2, 4, and 6 WAP.

By 20 WAP, common ragweed populations were less than 1 plant/m^2 and timing of weed management in peanut the previous season had no effect on densities (Table 3.10). Hill *et al*. (2016) found that common ragweed can produce viable seeds when terminated at flowering and when immature seeds were present at termination. They also reported that terminating common ragweed prior to flowering reduced impact on the soil seedbank. In some cases, secondary dormancy of seeds can occur when the non-dormant seeds are exposed to favorable temperature and moisture, but an over riding factor inhibits the seed from germinating (Willemsen, 1975). Baskin and Baskin (1980) reported common ragweed seed viability of 39 years once in the seedbank. Weed emergence measured in the study may have included contributions from previous seasons common ragweed populations that were present before the study was initiated.

At Rocky Mount the year after peanut, Palmer amaranth densities ranged from 66 to 107 plants/m^2, 6 to 13 plants/m^2, and less than 1 plant/m^2 3, 7, and 20 WAP, respectively (Table 3.11). Weed management in peanut the previous season did not have an effect on Palmer amaranth densities in cotton 3, 7, or 20 WAP.

Menges (1987) reported that it may take up to 6 years of weed-free Palmer amaranth management to reduce the seedbank by 98%. Sosnoskie et al. (2013) reported that 36 months were required for Palmer amaranth seed burial to deplete the seedbank. Therefore, a two-year study may not have been long enough to observe the complete effect of weed management due to the abundance of seeds present in the seedbank.

Cotton Lint Yield the Year Following Peanut. When common ragweed and Palmer amaranth were defined as broadleaf weeds for the statistical analyses with all four site-years, the interaction of experiment × timing of herbicide application was not significant for cotton lint yield the year following herbicide applications in peanut ($p \leq 0.7206$). Yield of peanut negatively affected cotton yield the following year at Lewiston-Woodville ($p = 0.0005$, $R = -0.49$) (Table 3.6). Yield of peanut at Rocky Mount the previous year was not a good predictor of cotton yield the following year (Table 3.7).

At Lewiston-Woodville, cotton lint yield ranged from 1540 to 1690 kg/ha (Table 3.10) while at Rocky Mount cotton lint yield ranged from 920 to 1090 kg/ha (Table 3.11). Timing of weed management in peanut the previous year did not influence cotton lint yield at either location. Applying effective herbicides to cotton 3 WAP may have masked the potential impact of weed management the previous year on cotton yield. Weeds in cotton were controlled within the critical weed-free period for cotton in presence of Palmer amaranth and common ragweed, the predominate broadleaf weeds in this experiment. Glyphosate was applied at Lewiston-Woodville for each timing of application in cotton. Glyphosate-resistant biotypes of common ragweed was not present at Lewiston-Woodville. The combination of glyphosate plus dicamba was used at Rocky Mount because these populations of Palmer amaranth expressed resistance to glyphosate (Inman *et al*., 2016). Dicamba and glyphosate combined can be an effective management tool in fields with glyphosate-susceptible and glyphosate-resistant Palmer amaranth as well as prolonging resistance of other modes of action (Cahoon *et al*., 2014; Inman *et al*., 2016; Jalaludin *et al*., 2014; Norsworthy *et al*., 2012).

CONCLUSIONS

The presented research suggests the importance of timely and effective weed management in peanut. Effective control of common ragweed and Palmer amaranth can be achieved with proper timing of herbicide applications. Usually, the more intensive herbicide programs generated the greatest weed control, yield, and estimated economic returns. In the case of common ragweed, an intensive weed management approach in peanut the previous season showed a reduction in weed emergence the following year in cotton. Due to the abundance of Palmer amaranth seed in the seedbank, multiple years of implementation were likely needed to observe the benefits of an intensive weed management program.

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Table 3.1. Herbicide active ingredient, trade name, formulation, application rate, and manufacturer.

Herbicides	Trade name	Formulation concentration	Application rate/ha	Manufacturer
bentazon sodium salt	Basagran®	479 g ai/L	115 or 225 g ai[a]	Arysta LifeScience
clethodim	Select 2EC	240 g ai/L	210 g ai	Valent U.S.A Corp.
imazapic salt of ammonia	Cadre®	240 g ai/L	70 g ai	BASF Chemical Co.
lactofen	Cobra®	240 g ai/L	210 g ai	Valent U.S.A Corp.
paraquat dichloride	Gramoxone® SL 2.0	240 g ae/L	140 g ae	Syngenta Crop Protection

[a] Bentazon at 115 g/ha applied 2 WAP or 225 g/ha applied 4 WAP.

Table 3.2. Analysis of variance (P > F) for Common ragweed control 7, 10, and 20 WAP; pod yield; and estimated economic return as influenced by timing of herbicide applications in peanut at Lewiston-Woodville.

	Probability of a greater F-statistic[a]				
	Common ragweed control				
Source of variation	7 WAP	10 WAP	20 WAP	Yield Kg/ha	Estimated economic return $/ha
Year	0.1	0.1	1.9*	31.4*	31.4*
Timing of herbicide applications	67.9*	62.9*	47.7*	12.3*	9.3*
Year*Timing of herbicide applications	0.8	0.3	1.1	0.9	0.9

[a] * indicates significance at $p \leq 0.05$.

Table 3.3. Analysis of variance (P > F) for Palmer amaranth control 7, 10, and 20 WAP; pod yield; and estimated economic return as influenced by timing of herbicide applications in peanut at Rocky Mount.

	Probability of a greater F-statistic[a]				
	Palmer amaranth control				
Source of variation	7 WAP	10 WAP	20 WAP	Yield kg/ha	Estimated economic return $/ha
Year	0.3	3.6	10.8*	93.8*	93.8*
Timing of herbicide applications	36.8*	21.5*	6.1*	24.0*	19.8*
Year*Timing of herbicide applications	5.9*	1.0	0.7	1.7	1.7

[a] * indicates significance at $p \leq 0.05$.

Table 3.4. Common ragweed control 7, 10, and 20 WAP; pod yield; and estimated economic return as influenced by timing of herbicide applications in peanut at Lewiston-Woodville.[a]

	Common ragweed control				
Timing of herbicide applications	7 WAP	10 WAP	20 WAP	Peanut yield	Estimated economic return
WAP	%			Kg/ha	$/ha
None	8 c	5 c	2 d	880 d	-433 c
2	58 b	46 b	33 c	1760 c	-262 b
6	97 a	92 a	67 b	2660 b	-96 ab
2 and 4	99 a	98 a	95 a	2690 b	-103 ab
4 and 6	100 a	100 a	98 a	3280 ab	0 a
2, 4, and 6	100 a	100 a	98 a	3680 a	70 a

[a]Means within a column for common ragweed control 7, 10, and 20 WAP, peanut yield, and estimated economic return followed by the same letter are not significantly different according to Fisher's Protected LSD test at P $\leq$ 0.05. Data are pooled over years.

Table 3.5. Palmer amaranth control 7, 10, and 20 WAP; pod yield; and estimated economic return as influenced by timing of herbicide applications in peanut at Rocky Mount[a].

Timing of herbicide applications	Palmer amaranth control 7 WAP 2016	Palmer amaranth control 7 WAP 2017	Palmer amaranth control 10 WAP	Palmer amaranth control 20 WAP	Yield	Estimated economic return
WAP	%				Kg/ha	$/ha
None	10 d	15 b	27 c	45 d	1110 d	-385 e
2	50 c	81 a	70 b	69 bc	2480 c	-114 cd
6	77 b	30 b	67 b	55 cd	2080 c	-218 d
2 and 4	88 ab	99 a	90 a	83 ab	3840 b	134 b
4 and 6	96 a	82 a	89 a	65 bcd	3420 b	28 bc
2, 4, and 6	100 a	100 a	99 a	97 a	5030 a	349 a

[a]Means within a year for Palmer amaranth control 7 WAP or within a column for Palmer amaranth control 10 and 20 WAP, Yield, and Estimated economic return followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data for Palmer amaranth control 10 and 20 WAP, Yield, and Estimated economic return are pooled over years.

Table 3.6. Pearson correlation coefficients for common ragweed control, peanut pod yield, estimated economic returns, common ragweed densities 3 WAP in cotton, and cotton lint yield at Lewiston-Woodville.

Parameters	P > F	R
Common ragweed control 3 WAP in peanut versus peanut yield	< 0.0001	0.66
Common ragweed control 10 WAP in peanut versus peanut yield	< 0.0001	0.68
Common ragweed control 20 WAP in peanut versus peanut yield	< 0.0001	0.64
Common ragweed control 3 WAP in peanut versus estimated economic returns	< 0.0001	0.63
Common ragweed control 10 WAP in peanut versus estimated economic returns	< 0.0001	0.64
Common ragweed control 20 WAP in peanut versus estimated economic returns	< 0.0001	0.60
Common ragweed control 3 WAP in peanut versus common ragweed densities 3 WAP in cotton	0.0013	-0.46
Common ragweed control 10 WAP in peanut versus common ragweed densities 3 WAP in cotton	0.0010	-0.47
Common ragweed control 20 WAP in peanut versus common ragweed densities 3 WAP in cotton	0.0058	-0.40
Peanut yield versus cotton lint yield	0.0005	-0.49
Peanut yield versus common ragweed densities 3 WAP in cotton	<0.0001	-0.73

Table 3.7. Pearson correlation coefficients for Palmer amaranth control, peanut pod yield, estimated economic returns, Palmer amaranth densities 3 WAP in cotton, and cotton lint yield at Rocky Mount.

Parameters	P > F	R
Palmer amaranth control 3 WAP in peanut versus peanut yield	< 0.0001	0.63
Palmer amaranth control 10 WAP in peanut versus peanut yield	0.004	0.47
Palmer amaranth control 20 WAP in peanut versus peanut yield	< 0.3563	0.16
Palmer amaranth control 3 WAP in peanut versus estimated economic returns	0.0001	0.60
Palmer amaranth control 10 WAP in peanut versus estimated economic returns	0.0081	0.44
Palmer amaranth control 20 WAP in peanut versus estimated economic returns	0.4276	0.14
Palmer amaranth control 3 WAP in peanut versus Palmer amaranth densities 3 WAP in cotton	0.2149	-0.22
Palmer amaranth control 10 WAP in peanut versus Palmer amaranth densities 3 WAP in cotton	0.1915	-0.23
Palmer amaranth control 20 WAP in peanut versus Palmer amaranth densities 3 WAP in cotton	0.1047	-0.28
Peanut yield versus cotton lint yield	0.6361	-0.08
Peanut yield versus Palmer amaranth densities 3 WAP in cotton	0.0792	-0.31

Table 3.8. Analysis of variance (P > F) for Common ragweed densities 3, 7, and 20 WAP; and cotton lint yield as influenced by timing of herbicide applications in peanut at Lewiston-Woodville.

	Probability of a greater F-statistic[a]			
	Common ragweed densities			Cotton lint yield
Source of variation	3 WAP	7 WAP	20 WAP	kg/ha
Year	43.9*	28.0*	7.8*	167.2*
Timing of herbicide applications	4.2*	3.1*	0.2	0.9
Year*Timing of herbicide applications	1.1	4.7*	0.2	0.9

[a] * indicates significance at p $\leq$ 0.05.

Table 3.9. Analysis of variance (P > F) for Palmer amaranth densities 3, 7, and 20 WAP; and cotton lint yield as influenced by timing of herbicide applications in peanut at Rocky Mount.

	Probability of a greater F-statistic[a]			
	Palmer amaranth densities			Cotton lint yield
Source of variation	3 WAP	7 WAP	20 WAP	Kg/ha
Year	5.1*	18.8*	10.9*	0.8
Timing of herbicide applications	0.3	0.1	0.7	0.4
Year*Timing of herbicide applications	0.1	0.1	0.5	0.8

[a] * indicates significance at $p \leq 0.05$.

Table 3.10. Common ragweed densities 3, 7, and 20 WAP as influenced by timing of herbicide applications in peanut at Lewiston-Woodville[a].

Timing of herbicide applications	Common ragweed density 3 WAP	Common ragweed density 7 WAP 2017	Common ragweed density 7 WAP 2018	Common ragweed density 20 WAP	Cotton lint yield
WAP	plants/m²				kg/ha
None	189 a	18 a	1 b	0.07 a	1640 a
2	179 ab	17 a	1 b	0.01 a	1590 a
6	98 c	1 c	2 ab	0.07 a	1690 a
2 and 4	126 bc	11 ab	3 ab	0.04 a	1600 a
4 and 6	118 c	5 bc	5 a	0.06 a	1590 a
2, 4, and 6	95 c	7 bc	0 b	0.06 a	1540 a

[a]Means within a column for common ragweed density 3 and 20 WAP and cotton lint yield or within a year for common ragweed density 7 WAP followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Data for common ragweed density 3 and 20 WAP and cotton lint yield are pooled over years.

Table 3.11. Palmer amaranth densities 3, 7, and 20 WAP as influenced by timing of herbicide applications in peanut at Rocky Mount[a].

Timing of herbicide applications	Palmer amaranth densities 3 WAP	7 WAP	20 WAP	Cotton lint yield
WAP	plants/m			kg/ha
None	94 a	13 a	0.65 a	920 a
2	107 a	10 a	0.40 a	970 a
6	88 a	8 a	0.58 a	1020 a
2 and 4	101 a	10 a	0.22 a	1090 a
4 and 6	96 a	8 a	0.58 a	1020 a
2, 4, and 6	66 a	6 a	0.28 a	970 a

[a]Means within a column for Palmer amaranth density 3, 7, and 20 WAP and for cotton lint yield followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$. Palmer amaranth density 3,7, and 20 WAP and cotton lint yield data are pooled over years.