ABSTRACT

ROBINSON, BRIDGET LYNN. Evaluation of Weed Scouting Methods and the Effects of Glyphosate Drift in North Carolina Peanut (\textit{Arachis hypogaea}) Production. (Under the direction of Dr. John W. Wilcut.)

Research was conducted to evaluate weed scouting methods in peanut, and the effects of glyphosate drift in peanut. Weeds were scouted on-farm in eight North Carolina counties during 2003 and 2004. A total of 16 unique fields were scouted, and weed species and density data were collected using four different scouting methods. HADSS (Herbicide Application Decision Support Software) was used to determine expected net return, yield loss ($ and %), and total treatment costs for each field. Net returns were averaged for optimal treatments in each field to determine the whole-field expected net return. Values of theoretical net return for the optimal treatment in each field ranged from $244 to $1,444 per ha, and averaged $867 per ha for all sixteen fields. The windshield method, while quickest, was also the least accurate at making herbicide recommendations. The range method was more accurate at estimating broadleaf weed densities than grass or sedge weed densities. The count method required the most time for completion (30 min). The maximum theoretical loss for fields scouted with the windshield method was as high as $528/ha. The windshield method resulted in accurate (top 10%) herbicide recommendations at least 82 and 77% of the time in 2003 and 2004, respectively. To evaluate peanut injury and pod yield when exposed to glyphosate, five experiments were conducted during 2001 and 2002 in North Carolina. Glyphosate was applied to 10 to 15 cm diameter peanut plants at rates ranging from 9 to 1,120 g ai/ha. Visual injury was noted 7 DAT when glyphosate was applied at 70 g/ha and higher. Glyphosate at 280 g/ha or higher injured the peanut plant and reduced pod yield compared with non-treated peanut. Shikimic acid accumulation was negatively correlated
with visual injury and pod yield. Shikimic acid presence can be detected using plant samples, and accumulation can be an effective diagnostic tool for determining exposure to glyphosate in peanut 7 DAT, but not at 14, 21 and 31 DAT.
EVALUATION OF WEED SCOUTING METHODS AND THE EFFECTS OF GLYPHOSATE DRIFT IN NORTH CAROLINA PEANUT (ARACHIS HYPOGAEA) PRODUCTION

by

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A thesis submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Master of Science

CROP SCIENCE & AGRICULTURE EDUCATION

Raleigh

2005

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"Cultivators of the earth are the most valuable citizens. They are the most vigorous, the most independent, the most virtuous, and they are tied to their country and wedded to its liberty and interests by the most lasting bands."

23 August 1785

Thomas Jefferson to John Jay
BIOGRAPHY

Bridget Lynn Robinson was born on 14 January 1977 to Don and Sue Robinson of Jefferson, Oregon. She and her younger brother, Nolan, were raised with an appreciation for farming from an early age; spending many happy days working, playing outside, and traveling around Oregon.

Bridget graduated from Jefferson High School in 1995, and was involved with numerous activities including FFA, 4-H, Choir, Spanish, and School Government. During her trip to the National FFA Convention she decided that her future career would be focused on agriculture education and awareness. She attended Oregon State University where she was involved in the Crop Science Club, the Crops Judging Team, and a course that took her on a two-week tour of European agriculture. The highlight of her undergraduate career was a nine-month study abroad at Lincoln University in Canterbury, New Zealand. She graduated with her degree in Crop Science in May of 1999.

Summers spent working in two research labs; Agri-Seed Testing and the USDA-ARS (National Forage Seed Production Research) were educational and enjoyable. At the USDA, she was introduced to agricultural research as part of a long-term cropping system research project focusing on forage crops. Friendships with Kristine Reid Neese, Bill Gavin, and Dr. Jeffery Steiner were very influential in her decision to pursue graduate education.

In 2000, Bridget began graduate studies at North Carolina State University in the department of Agricultural and Extension Education. She assisted Dr. George Bostick and Dr. Beth Wilson in teaching computing and biotechnology classes, and decided to pursue a degree in Crop Science while concurrently completing her degree in Agricultural Education. She increased her knowledge of research with Dr. John Wilcut’s program as she was
immersed in field research, teaching and presenting at professional meetings. During her third year of graduate work, the opportunity arose to work for Dr. Gail Wilkerson. During her tenure there she continued researching weed science while finishing the requirements for her M.S. Degree.

Bridget is a member of Gamma Sigma Delta and Omicron Tau Theta, as well as numerous professional agronomy societies. She served as secretary of the crop science graduate student association in 2002 & 2003, and competed in the Graduate Weed Contest. In 2002, she received the George Washington Carver award from the National Peanut Board, first place in the graduate student poster competition at the Southern Weed Science Society, third place in the graduate student speaking contest at the American Peanut Research and Education Society, and third place in the graduate student speaking contest at the Crop Protection School.
ACKNOWLEDGEMENTS

I would like to sincerely thank Dr. John Wilcut for serving as my major advisor in Crop Science and Dr. Jim Flowers for serving as my major advisor in Agricultural Education. I would also like to thank Drs. David Jordan, Gail Wilkerson, and Gary Moore for serving on my graduate committee. In addition, I would also like to thank the whole Wilkerson lab for their friendship, guidance and laughs. I am appreciative of the help of Dr. Ian Burke, Scott Clewis, Sarah Hans Lancaster, Dr. Wendy Pline-Srnić, Dr. Andrew Price, Walter Thomas, and Shawn Troxler and would also like to thank my fellow graduate students for their friendships and assistance.

I am grateful to my parents and the rest of my family for encouraging me to set goals, travel, and attain all that I set my mind to do. They have provided the lessons that have taught me the importance of pulling together and working toward goals. I would also like to thank Shep and his family for their love. Shep has always encouraged me to take advantage of my opportunities in school, supported my decisions and laughed with me at my over-commitment tendencies. I also want to thank Phil and Linda for providing me a home-away-from home during my studies in North Carolina. It is not without the support of Shep, Mom & Dad, Nolan, or Phil & Linda that I would be submitting this thesis

Lastly, I express my thankfulness to God for his blessings, never-ending love, and foresight to create situations that better us.
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North Carolina peanut production. Peanut (*Arachis hypogaea* L.) is an important food crop worldwide and is valued for its oil, for eating out of the shell, as well as for many processed products including peanut butter. It is believed that the center of origin for peanut was the Mato Grosso region of Brazil in South America. The crop was taken to Africa as barter in the slave trade, and eventually brought to be cultivated in the United States. Extensive efforts have been made to catalogue the germplasm, and to breed new cultivars that are better yielding and have disease resistance (Stalker and Simpson 1995). North Carolina is an important area of production for peanut, based upon the climate and soil conditions found in the northeastern part of the state (Sholar et al. 1995). More that 500,000 hectares of peanuts are grown annually in the United States, and approximately 40,000 hectares are in the Virginia-Carolina region (Brown 2005). Most peanut grown in North Carolina are Virginia market-types, and their larger pods are preferred over runner peanuts for eating out of the shell (Sholar et al. 1995; Brown 2005). The smallest Virginia pods may be substituted for runner peanuts and used for making peanut butter (Brown 2005). There is some interest in growing runner and Spanish-type peanuts in North Carolina (Jordan 2005a), but the main production areas for these two peanut types are in Georgia and Texas.

In North Carolina, peanut is usually planted in early May (Jordan 2005a) on raised beds (Henning et al. 1982) in single rows spaced 91 to 102 cm apart (Sholar 1995). Before planting, most fields are mechanically hilled into raised beds, and treated with metam sodium to help guard against the development of cylindrocladium black rot (CBR), *Cylindrocladium*
parasiticum, a soil-borne disease for which there are few treatments except planting resistant varieties and rotating crops every three years (Shew 2005). Typical at-planting treatments include rhizobium inoculant to encourage root nodulation for nitrogen fixation, and aldicarb applied in-furrow to guard against thrips and leafhoppers (Brandenburg 2005). Seasonal applications of lime, nitrogen, phosphorus, and potassium fertilizers ensure that proper soil nutrition is present for peanut growth (Jordan 2005a), and seasonal applications of various herbicides, fungicides and insecticides are used to control common pests (Sherwood et al. 1995; Wilcut et al. 1995). Early season weed control is important for reducing weed competition, and many growers choose to treat with preemergence (PRE) and preplant incorporated (PPI) herbicides at the time of land preparation. Typical weather conditions in North Carolina encourage disease formation, and foliar and soil borne leaf diseases are especially detrimental to yield in late season (Shew 2005). Biweekly fungicide regimes are used to reduce disease populations. Other common treatments include applications of landplaster (gypsum) to encourage pegging and pod formation, and plant growth regulators to create row definition at harvest. Most peanut varieties grown in North Carolina require 142 to 160 days (2,520 to 2,770 growing degree days) to mature (Jordan 2005a). After determining optimal pod maturity (using the hull-scrape method to determine mesocarp color) (Williams and Drexler 1981) peanuts are inverted and picked in September and October.

**Weed management in peanut.** It is important to provide season-long control of weeds due to the fact that peanut is slow to canopy, has low tolerance to weed pressure (Jordan 2005b; Wilcut et al. 1995), and is difficult to harvest if excessively weedy. Weeds in peanut are detrimental due to interference, which is a term that describes the competition for resources
such as sunlight, water and nutrients (Barbour et al. 1994). Additionally, weeds serve as hosts for pests, interfere with insecticide and fungicide deposition, and impede harvest when they become entangled in harvest equipment (Wilcut et al. 1995). Some of the most common weeds in the southeastern U.S. VC region include common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemesiifolia* L.), common cocklebur (*Xanthium strumarium* L.), various *Ipomoea* species, various *Amaranthus* species, yellow nutsedge (*Cyperus esculentus* L.) and various annual grasses (Bridges et al. 1994).

Crop rotation and cultivation are two cultural practices that can help manage weeds, insects, and soil-born diseases from year to year in peanut. Drawbacks to cultivation include damage to peanut pegs which increases the incidence of stem and pod diseases, and turning over of new weed seeds in the soil profile (Jordan 2005b). Chemical weed control can be achieved using PRE or PPI herbicides early in the season based upon weed species present in past years, or postemergent (POST) herbicides based upon weed species that have emerged in the current year. PRE and PPI herbicides rarely provide season-long control of the whole spectrum of weeds (Wilcut et al. 1995), and are often amended with POST herbicides in peanut (Jordan 2005b). Weed control is important for reducing yield losses as well as reducing the number of weeds deposited in the soil seed bank, which potentially reduces the number of seeds that will germinate in subsequent growing seasons.

**Decision Support Software.** Computerized models based upon economic thresholds, often referred to as decision support systems (DSS), have been developed for many crops and assist users in predicting crop/weed interactions and the resulting yield loss. Constantly evolving, DSSs are now defined as interactive computerized tools that can be used to help answer questions, solve problems, and make recommendations (Shaw 2005).
General threshold models have been developed and validated for many pests (including weeds and insects) and a wide variety of crops in recent years (Black et al. 1993; Jensen et al. 2000; Holsapple and Whinston 1996; Renner et al. 1999). Decision models have been developed for specific crops including corn (*Zea mays* L.) (Buhler et al. 1996a), cotton (*Gossypium hirsutum* L.) (Hearne and Bange 2002; Bange et al. 2003; Scott et al. 2001), soybean (*Glycine max* (L.) Merr.), (Berti and Zanin 1997; Buhler et al. 1996b; Monks et al. 1995), sugarbeet (*Beta vulgaris*) (Schribbs et al. 1990), sunflower (*Helianthus annus*) (Castro-Tendero and Garcia-Torres 1996), and wheat (*Triticum aestivum*) (Kwon et al. 1995; Pasqual 1994).

Other threshold models are focused upon the specific relationships between herbicides and crops (Forcella et al. 1996; Jensen et al. 2000; Stigliani and Resina 1993; Swinton and King 1994). HADSS, (Herbicide Application Decision Support Software) is a computer program developed at North Carolina State University that is currently in use for corn, cotton, soybean, and peanut (Bennett et al. 2003; Sturgill et al. 2003) in North Carolina.

HADSS has been adapted for use in several other Southeastern states of the US, and it successfully assists growers (and those advising them) in the selection process for PRE, PPI, and POST herbicides based on efficacy and cost (Wilkerson et al. 2002). Validation studies thus far include: cotton and soybean in Mississippi (Rankins et al. 1998), cotton, corn, soybean, and peanut in North Carolina (Bennett et al. 2003; Scott et al. 2002 and 2001; White and Coble 1997; Wilkerson et al. 1991), cotton in Oklahoma (Murdock and Murray 2002), peanut and soybean in Georgia (MacDonald et al. 1998; Monks et al. 1995), soybean in Louisiana (Pankey et al. 2000), and cotton in Texas (Lyon et al. 2000).
The use of DSS programs helps users to consider all aspects of the economic decision making process that surrounds the management of the crop including: the value of the crop, herbicide and application costs, herbicide efficacy, estimated yield loss if weeds are not controlled, and crop/weed competition relationships (Wilkerson et al. 1991).

Basing herbicide applications on HADSS (Jordan et al. 1999; MacDonald et al. 1998; Scott et al. 2002; White and Coble 1997) and similar decision aids (Rankins et al. 1998) has been just as (and sometimes more) effective as prophylactic applications. The extensive validation projects have increased awareness of these tools, and shown that their use can increase profitability at the farm level if scouting costs can be kept within reason.

**Weed scouting in peanut.** Development of decision models has driven research of sampling methods in crops, and decision models provide a basis for evaluation of the scouting techniques. Most weed scouting procedures are based upon guidelines developed for insects and diseases because many of the same biological premises hold true for all three types of pests (Berti et al. 1992; Gold et al. 1996; Johnson et al. 1996; Krueger et al. 2000). For optimal sampling, fields should be scouted not only for weed presence, but also for size, number and species diversity.

Weed scouting research is confounded by several factors, one of which is the fact that weeds are known to be non-uniformly distributed (growing in unevenly distributed patches) (Lindquist et al. 1998; Thornton et al. 1990). In general, the spatial distribution of weeds in agronomic fields is represented by the negative binomial (Wiles et al. 1992c), where the parameter k is a factor that is inversely related to the degree of patchiness. This phenomenon may be attributed to seed deposition in the soil from previous years (the weed seed bank), soil type, mechanized patterns in the field such as harvest etc, and other topographical
features of the field. Wiles and Brodahl (2004) found that there were several factors that influence weed growth patterns in a field, including past management of the field, seed bank density, seed size, method of dispersal, and density, and especially type of irrigation in the field. Tillage was also found to be a factor in their study, showing that there were differences between furrow-irrigated fields and fields with center pivot irrigation. Another confounding aspect of weed scouting is the human error element (Wiles et al. 1993). Scouts may miscount, over or underestimate weed densities, tend toward larger or smaller populations of weeds in the field, or follow a pattern when moving through the field.

Scouting methods have been explored and debated in the literature, resulting in many different conclusions. Methods can be evaluated by the cost of the sampling method as compared to the value of the information collected and recommendations generated (Nyrop et al. 1986). The bottom line of weed sampling is to obtain an accurate enough estimate of weed species and populations to prescribe an effective uniform treatment for the field (Wiles 2005). It is not enough to simply know that weeds are non-uniformly distributed in agronomic fields. If the patterns of weed distribution can be predicted, sampling methods may become more efficient and generate better herbicide recommendations (Weisz et al. 1995). The traditional method of weed sampling, described as discreet or full-count, is done by selecting random quadrats of a certain size in a field and counting all weeds within the quadrat (Gold et al. 1996; Krueger et al. 2000, Rew and Cousens 2000). Weed density estimates for the whole field are then interpolated from these values. This approach is more appropriate if weeds are truly random within a field, and tends to sample a very small percentage of the entire field. Two other approaches suggested for weed scouting are binomial and censored sampling. In binomial sampling, mean densities are estimated from
sample quadrats. The quadrat is either counted or not counted when it contains a certain number of weeds and utilizes a pre-set cut-off point. In censored sampling (also called presence/absence sampling), weeds in each quadrat are counted and the cut-off point is zero (Gold et al. 1996). Both of the latter methods are used in entomology, and lend themselves to site specific applications (Krueger et al. 2000). Various automated scouting methods have also been explored, with images being captured via GPS (Gerhards and Christensen 2003; Rew et al. 1996). At this time, computer generated weed maps are still in the developmental phases and tend to be cost prohibitive to the average farmer.

Site-specific weed control is based upon the premise that a grower does not need to spray an entire field to kill weeds that may only occur in small portions of the field, (Johnson et al. 1996). One method that has been investigated is variable-rate herbicide application utilizing grid sampling (a field is divided into a systematic grid and weeds are counted or estimated within each grid) (Wilkerson et al. 2004). Research has shown that in some cases these methods could greatly reduce herbicide applications by as much as 70% (Wilkerson et al. 2004), however this approach may not be practical in production fields due to the time and cost associated with this level of scouting (Clay et al. 1999). Cost evaluations have also shown that these methods also may not be attractive to growers due to the specialized equipment that is needed for variable-rate herbicide applications.

Due to the time and cost of in-depth scouting, growers often make herbicide recommendations using limited knowledge about the overall spatial composition of weed species present (Clay and Johnson 2002). Herbicide recommendations are more apt to be effective if based upon true representations of weed densities in a field (Jordan et al. 2003; Krueger et al. 2000; Wiles et al. 1992a). If the herbicide used is not effective at controlling
the weeds, or if the rate of herbicide exceeds that which is really needed for adequate control, the grower may accumulate unnecessary expenses. While the optimal herbicide treatments are more likely to be chosen with more in depth scouting procedures, less intensive scouting procedures can also result in choosing the correct herbicide recommendation – however the margin for error is much greater with less intensive scouting (Wiles et al. 1992b).

**Economic Thresholds.** When weed densities reach levels that could cause economic losses due to reduced crop yield and quality, and the benefit of treatment outweighs the cost of treatment, an economic threshold is set (Coble and Mortensen 1991; Zimdahl 1988). In pest control, economic thresholds have been explored for weeds, insects, and plant pathogens. Economic thresholds, first proposed by entomologists, have slowly been adopted by weed scientists. Economic thresholds are set for individual species, and can become complicated when multi-species weed complexes exist in a field (Wilkerson et al. 2002).

A model that estimates yield loss as a function of weed density (Cousens 1985) has been utilized in HADSS and other pesticide DSSs. Additionally, weed species are assigned a relative competitive index (CI) on a scale from 0 to 10 (Coble and Mortensen 1991; Wilkerson et al. 1991). A weed with a CI of 1 is relatively less competitive than a weed with a CI of 10, which is much more competitive and has the potential to create more yield loss for a given level of infestation. It has been shown that only 0.2 fall panicum (*Panicum dichotomiflorum* Mich) plants/m and 3.2 goosegrass (*Eleusine indica* (L.) Gaertn) plants/m could result in as much as 25% yield loss (York and Coble 1977; McCarty and Coble 1983). One Florida beggarweed (*Desmodium tortuosum* (S.W.) D.C.) plant/m could result in season-long yield losses ranging from 20 to 40% (Buchanan et al. 1982). Common cocklebur, a weed with a CI of 10 in peanut, was shown to reduce yields by 15, 30 and 50% at densities of
2, 4, and 8 plants/7.6m of row, respectively (Brecke and Royal 1990). Various research has shown that a weed-free period of 4 to 6 weeks in peanut will significantly reduce yield losses in peanut (Buchanan et al. 1982).

An action threshold is defined as the time when you decide to take action, and do something to control the pest (Radosevich et al. 1997). Threshold values for some weed species may be adjusted to take into consideration the impacts of that weed on subsequent crops grown in that field, the weed’s impact upon crop value and ease of harvest, or the role of that weed as a host to other pests (Radosevich et al. 1997). Additionally, if a crop is stressed by drought, or being attacked by several other pests, you may choose to lower the action threshold in order to take action sooner.

**Glyphosate Use.** Glyphosate is a non-selective broad spectrum herbicide that effectively controls over 300 grass, sedge, and broadleaf weeds (Franz et al. 1997). It is the active ingredient in Roundup®, and many other glyphosate formulations. Absorbed on-contact through the leaves of a plant, glyphosate is highly mobile within the phloem of plants, making it an effective herbicide for perennial plants. Environmentally, the mammalian toxicity of glyphosate is low. Glyphosate is also relatively safe in the environment because it is adsorbed onto soil particles and is not easily leached into groundwater.

When conventional plants are treated with glyphosate they cannot produce the aromatic amino acids essential to their survival. Glyphosate inhibits the biosynthesis of tryptophan, tyrosine and phenylalanine by inhibiting the enzyme 5-enolpyruvylshikimate 3-phosphate (EPSP) synthase (Pline et al. 2002; Ray 1989; Schönbrunn et al. 1998; Steinrucken and Amrhein 1980; Thomas et al. 2005) (EC 2.5.1.19). Although ESPS is the only known
enzyme target of glyphosate, it affects many physiochemical and physiological processes that are essential to plant growth (Cole 1985).

First discovered in the early 1970s, glyphosate was registered by Monsanto (Baylis 2000). USDA statistics show that the use of glyphosate has increased: in 1996, 4, 13, and 25% of the land was treated with glyphosate in corn, cotton, and soybean, respectively. In 2003 19, 69, and 87% of the land was being treated for corn, cotton, and soybean (National Agriculture Statistics Service 1997, 2004).

**Herbicide Resistant Crops.** The introduction of the glyphosate resistance gene (Brashaw et al. 1997) into crops in 1996 has caused an enormous shift in weed control practices. Moving from the use of a wide range of PRE, PPI and POST herbicides to an all-inclusive application of glyphosate across a range of crops represents an opportunity for improved weed management (Wilcut et al. 1996). Glyphosate and other broad-spectrum herbicides, such as glufosinate, were historically applied in burndown and PRE situations, but now producers plant herbicide resistant crops and may repeatedly apply the herbicide throughout the growing season as needed (Mendelson 1998; Shaner 2000). This paradigm shift also raises concerns about the development and control of herbicide resistance in weedy relatives (Shaner 2000), as well as the control of volunteer herbicide resistant-weeds within herbicide resistant crops (York et al. 2005).

The increase of glyphosate use has been most evident in U.S. soybean, and cotton production (Owen 2000; Shaner 2000), and less evident in U.S. corn production. Glyphosate-resistant (GR) Roundup Ready® cotton was first commercially available to farmers in 1996, but many growers experienced abnormal boll development and yield losses (Pline et al. 2002) in the first several growing seasons. Monsanto has since altered their GR
cotton varieties, and growers have experienced far less problems. GR soybean was first available on a limited basis in 1997. GR corn was first available in 1998, but its acceptance in the U.S. has been less aggressive than that of both GR cotton and GR soybean.

In North Carolina, there were over 40,000 hectares of peanut grown in the 2002 growing season (Brown 2005). During the same year GR cotton cultivars were planted on more than 75% of the cotton hectarage in North Carolina (A. C. York, personal communication; National Agricultural Statistics Service 2002). Additionally, 80 to 90% of the soybean hectarage and 15% of the corn hectarage in North Carolina are planted to GR varieties (E. J. Dunphy; A. C. York, personal communication).

**Herbicide Drift.** The majority of the agricultural chemicals used to control pests are applied as liquid spray droplets. In environmental situations that favor volatilization and redeposition, these droplets can drift away from the intended target. Improper application techniques (Wauchope et al. 1982) and windy weather can influence the occurrence of drift. Applications of herbicides in temperature inversions can also encourage the occurrence of drift. Droplet size is the single most important factor in reducing drift, with highly driftable droplets measuring \(<105 \mu\text{m}\). Research has shown that a number of spray nozzles (Jones et al. 2003) - especially air induction nozzles (Hanks et al. 2002) and drift adjuvants reduce drift (Jones et al. 2002) and do not negatively affect levels of weed control.

Because glyphosate is one of the most commonly used herbicides in modern crop production (Askew and Wilcut 1999; Askew et al. 2002; Culpepper and York 1999; Culpepper et al. 2000; Scott et al. 2001; Thomas et al. 2005), and complete weed control often requires multiple POST herbicide applications, a greater risk exists for off-target movement of glyphosate (Owen 2000). Research has shown that herbicide drift is anywhere
between $1/10^{th}$ and $1/100^{th}$ of the applied rate (Al-Khatib and Peterson 1999), which is considered to be sub-lethal, but nonetheless damaging to susceptible crops. Drift has been shown to be more damaging when it occurs early in a plant’s growth cycle (Snipes et al. 1992), but is not always correlated to yield loss (Ellis and Griffin 2002) and may need to be recurring in order to cause yield losses (Gilreath et al. 2001).

Spray drift and herbicide uptake in a plant can be influenced by a number of factors including: herbicide composition, spray droplet size, plant size and age, plant stress and other environmental conditions (Ellis and Griffin 2002; Feng et al. 2003). In the southeastern U.S., most postemergence herbicide treatments in soybean are made in late June to mid-July. Growers generally make two or more postemergence applications of glyphosate during the year. Corn, a common rotation crop in peanut, is generally planted earlier in the season and postemergence herbicide drift is less likely to pose a threat to peanut during its reproductive growth phase. Off-target movement of herbicides such as glyphosate is a concern, especially when the drift is into a non-GR crop such as peanut, and damaging levels could be fatal to the crop.
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CHAPTER 2


**Abstract:** On-farm trials were conducted in eight different peanut-producing counties of North Carolina in 2003 and 2004. A total of 16 unique fields were scouted, and weed species and density data were collected using four different scouting methods. The herbicide decision support system HADSS was used to determine expected net return, yield loss ($ and %), and total treatment costs for each field. Net returns were averaged for optimal treatments in each field to determine the whole-field expected net return. Values of theoretical net return for the optimal treatment in each field ranged from $244 to $1,444 per ha, and averaged $867 per ha for all sixteen fields. Forty-four different weed species were found. The windshield method required the least amount of time to complete, but was also the least accurate when making herbicide recommendations. Using the whole-field estimate method, a wide range of weed species were observed that were not always documented when using the range or count method. The range method, while relatively accurate overall, was best when weeds numbered 35 or less. The range method was slightly more accurate at estimating broadleaf weed densities than grass or sedge weed densities. Herbicide recommendations using the count method were more accurate due to quality of data collected. The count method was also the most expensive method based upon the time required for completion (30 min). The theoretical maximum loss for fields scouted using the windshield method was as high as $528/ha. The windshield method resulted in accurate (top 10%) herbicide recommendations at least 82 and 77% of the time in 2003 and 2004, respectively.
**Nomenclature:** Peanut, *Arachis hypogaea* L.

**Additional index words:** decision support system, economic threshold, integrated pest management, weed management, weed interference, and weed scouting.

**Abbreviations:** DSS, decision support systems; HADSS, Herbicide Application Decision Support System; IPM, integrated pest management; POST, postemergence; PPI, preplant incorporated; PRE, preemergence; TNR, theoretical net return.

**INTRODUCTION**

Agronomic weeds tend to grow in patches (Cardina et al. 1997, Wiles et al. 1992c), and postemergence (POST) herbicide recommendations are often made using limited knowledge about the overall spatial composition of weed species present in a particular field (Clay and Johnson 2002). Mistakes in herbicide decision-making can be costly to growers if unnecessary herbicide expenses are incurred, or if a herbicide treatment is chosen that is not effective at controlling the weed spectrum in the field (Wiles et al. 1992b). Research has shown that accurate scouting procedures are important for choosing an economical and effective herbicide treatment plan (Gerhards and Christensen, 2003; Wiles et al. 1992b), and prove to be essential in profitable peanut (*Arachis hypogaea* L.) production (Jordan 2003). Additionally, the scouting procedures need to be specifically designed to account for the biology of weeds, and not simply adapted from other areas of research (Rew and Cousens 2000) such as entomology and plant pathology.

Computerized decision aids have been developed and validated for a variety of agronomic crop pests and locations (Bange et al. 2004; MacDonald et al. 1998; Neeser et al. 2004;
Pasqual 1994; Scott et al. 2002; White and Coble 1997; Wilkerson et al. 2002). HADSS,¹ (Herbicide Application Decision Support Software) is designed to assist growers (and those advising them) in the selection process for PRE (preemergence) and POST herbicides based on efficacy and cost (Bennett et al. 2003; Wilkerson et al. 2002). The North Carolina version of HADSS is currently in use for corn (Zea mays L.), cotton (Gossypium hirsutum L.), soybean [Glycine max (L.) Merr.], and peanut (Bennett et al. 2003; Sturgill et al. 2003).

Herbicide recommendations generated by HADSS utilize economic thresholds (Cousens 1985), which incorporate projected yield and value of the crop, herbicide application costs, predicted yield loss if weeds are not controlled, and herbicide efficacy (Bennett et al. 2003). Basing herbicide applications on HADSS or its precursor HERB (Wilkerson et al. 1991) has been as effective as, and sometimes better than, prophylactic applications (Jordan et al. 1999; MacDonald et al. 1998; Scott et al. 2002; White and Coble 1997).

Actual weed populations and distributions cannot be determined until emergence; a busy time for growers, crop consultants, extension agents, and herbicide dealers. In many cases, weed control decisions are based upon past weed populations and/or the effectiveness of herbicide applications made in previous years. Research shows that postemergence herbicide applications based upon scouting data are often more effective at controlling weeds than are general herbicide applications based upon past programs (Jordan et al. 2003; Munier-Jolain et al. 2002). When weed scouting does occur, it is usually done quickly and from a limited vantage point in the field (roadside or field entrance) that may not capture the true distribution and presence of weeds. Additionally, if weed spatial distributions are ignored,

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and users assume a regular distribution of weeds instead of an irregular population a DSS may over or underestimate yield loss or recommend an inappropriate herbicide treatment (Wiles et al. 1992a). Research has also shown that while the whole population tends to be clumped, populations of individual weeds are not evenly distributed over the whole field (Wiles et al. 1992c).

Proponents of integrated pest management (IPM) practices are focused on reducing inputs into a system in order to increase profitability and to decrease negative environmental impacts. IPM methods use multiple control tactics to target pest biology (Buhler et al. 2000). HADSS uses economic thresholds to (1) suggest herbicide options, (2) rank herbicides based on efficacy, (3) recommend herbicide rates (often reduced), and (4) present an overall estimated economic outlook for the system (inputs, losses, and income). In order for HADSS and similar programs to make accurate herbicide treatment recommendations, users must make a quick but accurate assessment of weeds present in the field. Early assessments of weed distribution and density are very important in row crops because of the potential yield loss from interference (Mutch and Michalak 1985).

Guidelines for specific weed scouting methods in peanut are limited in the literature. Attempts are being made to develop better scouting procedures in row crops that are less time intensive, but will still be cost effective (Gold et al. 1996; Jordan et al. 2003; Krueger et al. 2000; Wiles et al. 1992b). The more time spent scouting and gathering information in the field, the better the recommendation (Krueger et al. 2000; Wiles et al. 1992a); however grid sampling is not practical in production agriculture due to the cost associated with this level of scouting (Clay et al. 1999). Murdock and Murray (2002) found that estimating weed populations in cotton and peanut was just as effective as counting weeds when using the data.
to generate herbicide recommendations in combination with a DSS. Others have suggested that site specific and/or censored weed sampling techniques would reduce time, but still be accurate enough to generate herbicide recommendations (Johnson et al. 1996). The censored techniques include subjective weed sampling where species and densities are recorded (high, medium, or low) or quantitative sampling where there are arbitrary cutoff numbers set as the economic threshold value.

Due to the poor competitive ability of peanut and the need to efficiently dig and invert pods and vines prior to combining, weed management programs have relied heavily on prophylactic and corrective herbicide applications (Wilcut et al. 1995). Although herbicide programs can be expensive, this approach to weed management has historically been successful in part due to the relatively high value of peanut at the farm level compared with the majority of other row crops. In light of recent changes in federal farm legislation, closer scrutiny of economic decisions regarding pest management at the farm level is needed (Bullen et al. 2002; Chvosta et al. 2002; Jordan et al 1999).

The objectives of this study were: (1) to obtain estimates for scouting times and quality of herbicide recommendations using four different scouting procedures, (2) to compare herbicide recommendations made by the extension agent (and/or farmer) with those generated by HADSS, and (3) to acquaint extension agents with HADSS and obtain evaluations on performance.

**MATERIALS AND METHODS**

Sixteen on-farm trials were conducted in the peanut belt region of North Carolina, (one field per year in Bertie, Edgecombe, Gates, Hertfort, Nash, Perquimans, Pitt, and Washington counties) in 2003 and 2004. County extension agents were responsible for selecting fields
that ranged from 3-4 ha in size, obtaining permission from the grower to establish the scouting trials, and maintaining contact with the grower throughout the season. Fields were generally selected based upon the agents past experience working with the farmer, and the presence of weeds in the field at the time of scouting. Dell Axim² handheld computers were purchased for each of the county agents, and agents attended at least one training session during the spring to learn how to use the computer and associated scouting programs. The agent and two research assistants visited the field approx. 3-4 weeks post-plant, and scouted weeds using four different methods; recording information on weed species, size and density. Weed populations were counted/estimated in the field in an area measuring approx. 9.3m² (0.84m x 10m). The agent visited the field in two follow-up trips to record weed populations remaining after herbicides were applied by the grower. Fourteen of the sixteen (88%) fields were treated with PRE, preplant incorporated (PPI), and at-cracking herbicides prior to scouting (Table 1), while two of the sixteen fields received no herbicide treatment prior to scouting.

Based on input from local crop consultants and extension agents, four unique scouting methods were developed and used to obtain weed density estimates and counts from each field. The four methods were: **Method 1** - (windshield): scouts stood at the entrance to the field; estimating and recording weed species and densities visible from that point. **Method 2** - (whole-field estimate): Scouts walked through the field in a loop pattern and took note of weed species present as they walked. Weed densities were recorded after scouts completed the loop. **Method 3** - (range): Scouts walked through the field in the same general loop pattern, stopping in six randomly selected areas of the field (18 different unique areas total).

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² Dell AXIM X5. Dell Computer Corporation. 1 Dell Way Round Rock, Texas 78682-0001
At each stop, scouts independently estimated weed densities using a range of 1-5 (Table 2) for broadleaf, sedge, and grass weeds (where one is a very low population and five is a very high population). This method was intended to mimic the scouting methodology utilized by several commercial crop consultants in North Carolina (A. Averitt, personal communication, 2002). Method 4 - (count): Scouts walked through the field using the same technique from method 3, however scouts did not estimate weed populations, but rather counted individual weed species at each of the 6 stops. In 2004 the count method was performed twice in each field (method 4a and 4b) to provide an independent estimate of weed population densities (using counts from 18 locations within the field) against which data from all four scouting methods could be compared. For each method, all three scouts traveled together through the field, but scouted areas approximately 30 m apart (Figure 1). Times were recorded for each scouting method in each field.

The first step in data analysis was to determine the optimal treatment for each field and to estimate theoretical net return over herbicide investment (TNR) for all other possible treatments. HADSS Version 2005 was used to determine TNR for every potential postemergence treatment for all 16 fields. TNR was based upon expected weed-free yield, herbicide prices, peanut selling price ($500/ton), weed competitiveness, and herbicide efficacies. Soil moisture (adequate in all fields), and weed size used in HADSS were based on conditions in the field at the time of scouting. Projected weed-free pod yield was estimated by the extension agent in consultation with the grower. Count data from all three scouts (18 locations in each field) were entered into HADSS to obtain an estimate of the expected net return at each scouting stop for each potential herbicide treatment. These returns were then averaged across each field to determine the field average TNR for every
treatment. The treatment with the highest TNR averaged across all 18 scouting stops within a field was considered to be the optimal treatment. All treatments were ranked in terms of TNR calculated in this manner, and the loss for any treatment was calculated as the difference between its TNR and that for the optimal whole-field treatment. In 2004, the data from the two separate scouting loops using Method 4 performed by each scout were used to provide independent estimates of TNR for each potential treatment.

The next step in data analysis was to obtain a treatment recommendation from HADSS using estimated weed densities from each of the three scouts using each scouting method. These recommendations were compared in terms of TNR, percent of times the recommendation was in the top 10% of recommendations in TNR, and time required for completion. In 2003, only Methods 1, 2, and 3 were compared using TNR estimated using Method 4 data; in 2004, all four scouting methods were compared. Methods 1, 2, 3, and 4a were compared in terms of TNR estimated from data collected using Method 4b, then Methods 1, 2, 3, and 4b were compared using TNR estimated from data collected using Method 4a. A field average density was estimated for each weed species for Method 3 data by translating the index recorded for each scouting stop to the weed density shown in Table 2. The density estimates for all six stops were then averaged to provide a weed density estimate for each scout.

ANOVA using the general linear models procedure in SAS (SAS 2001) on scouting times was carried out on both years combined, fitting effects for year, county in year, method, and year by method. ANOVA’s were also conducted on the optimal net returns for each field, scout and scouting method to evaluate differences in scouting methodology with respect to loss ($/ha) for each method. Loss data were analyzed by year due to differences in scouting
methodology using the count method in 2004, and counties were treated as a blocking factor.
Log loss values were square root transformed to stabilize variances. Main effects and
interactions for the optimal net return were tested and reported for each scouting method.
Mean separations were performed on transformed and non-transformed data using Fisher’s
protected LSD test (p>0.05).

RESULTS AND DISCUSSION

Weed Populations. Forty-four different grass, sedge and broadleaf weed species in the
cotyledon to 4 leaf stage were found across the 18 fields at the time of scouting (Table 3),
and may represent weeds that are hard to control with soil-applied herbicides (Jordan 2005).
Weed populations varied considerably from field to field; in Washington county in 2003 19
different species were found, whereas in Pitt county in 2004, only four weed species were
found. Weed populations were considerably reduced with postemergence herbicide
treatments following the first scouting trip, and the agent rarely found weed densities which
required herbicide treatment in subsequent scouting trips.

Scouting Time. Scouting fields for weeds increases the overall cost of weed control (Berti et
al. 2003), so the time required to accomplish this task is important. Average scouting times
for each of the methods are as follows: windshield method = 6 minutes per scout, whole-field
estimate method = 15 minutes per scout, range method = 20 minutes per scout, count method
= 28 minutes per scout (Table 4). The count method (Method 4) was the most precise
approach used, but this method requires a considerable amount of time, and may not be cost
effective to the grower. The count method required significantly more time to complete than
all the other methods in both years.
Scouting Accuracy. When weed densities were estimated by averaging the estimates from all three scouts in each field, the windshield, whole-field, and range scouting methods all tended to overestimate density slightly at low densities and underestimate density substantially at high densities, compared to the count method (Figure 2). The windshield method gave less predictable density estimates than the other methods, as indicated by the very low $R^2$ value. Density estimates made using count data from the two separate loops in 2004 (Methods 4a and 4b) were found to be highly correlated (Figure 2d). Colbach et al. (1999) found that random sampling (ranges or counts in this study) resulted in the best representation of the weed species present in the scouting process by not over- or under-representing species. It is surmised that the success of a particular sampling method depends on the actual distribution of weeds in the field: even the windshield method was relatively accurate in fields where weed populations were fairly uniform across the field, e.g., Hertford County in 2004 (data not shown). Research in North Carolina soybean fields (Wiles et al. 1992b) found that those with aversions to making risky herbicide recommendations should take the extra care to scout fields thoroughly, and to not assume that weeds are regularly distributed across a field. The addition of multiple weed species into the yield loss calculations makes a decision much more complicated than in situations where only a single species is considered (Brain and Cousens 1990) because weeds compete with each other as well as with the crop (Cousens et al. 1984).

The range method (Method 3) more closely resembles current scouting techniques used by county agents and crop advisors than the other methods that were included. Since an index value of 5 at any scouting stop was converted to a density estimate of 20 weeds per $9.3\text{ m}^2$ for broadleaf and sedge species, and to an estimate of 125 for grasses, it is not surprising that...
very high weed densities were underestimated using this method. Field average densities using count data ranged from 0.1 to 132, and from 0.1 to 98 weeds per 9.3 m² for grass and broadleaf species, respectively. Although it might be possible to construct a rating system that gave a more accurate estimate of field average weed population densities, the ranges used in this study were designed to reflect those used by professional scouts in North Carolina which are based in part on a consideration of potential damage from a given weed population. Yield loss is not a linear function of density. For example, a broadleaf weed with a competitive index of 5 on a 0 to 10 scale is estimated by HADSS to cause a 64% yield loss with a density of 20 weeds per 9.3 m² and a 72% loss with a density of 40.

It is interesting to note that the number of weed species observed in a given field varied from method to method. A larger number of weed species were found using Method 2 when scouts looped through the field, noting all species as they walked, than using either Method 3 or 4 when scouts stopped at a limited (18) number of places in the field, recording only the weeds found in those locations. When summed over all three scouts, average number of weed species found per field using each method was as follows: windshield method – 5.6; whole-field estimate method – 10.2; range method – 6.9; count method – 6.7. This finding suggests that the weeds in these fields were not uniformly distributed across the field. Rew and Cousens (2001) remark that weeds are unique in that there are usually several weed species that are present in large numbers, and a large number of species that are only present in very low numbers scattered throughout the field. It should be noted that the purpose of scouting is primarily to assist in making sound weed management decisions rather than solely to estimate weed population densities. Previous studies have shown that the cost of additional
sampling rapidly exceeds the value, when the objective is solely to make a herbicide decision (Wiles et al. 1993; Krueger et al. 2000).

The spatial distribution of weeds is not the only possible source of sampling error that might occur when making postemergence herbicide decisions. Individual scouts also have a certain level of error depending on years of experience and tendency to over or underestimate actual weed populations (Wiles et al. 1993). Scouts may also unknowingly gravitate toward areas in the field with higher or lower weed densities.

**Herbicide Recommendations.** Research suggests that late season weed infestations may contribute to yield losses due to interference with harvest (Scott et al. 2002). In that research, net returns in 12 of 24 standard POST herbicide application systems were improved with the use of the HADSS system, and in all cases the net returns were at or above what would have been present for the traditional POST herbicide systems in North Carolina peanut. In the present study, intensive scouting efforts (range and count methods) significantly increased the accuracy of herbicide recommendations, and resulted in higher TNR than did scouting techniques that relied on field-wide estimates (windshield method).

Values of TNR for the optimal treatment in each field ranged from $244 to $1,444 per ha, and averaged $867 per ha for all sixteen fields (Table 5). As expected, counting weeds in a specific area (9.3 m²) resulted in slightly more accurate herbicide recommendations in most cases than did methods that involved estimates. Average dollars lost per ha in 2003 increased from $17 to $41 using the range and windshield methods respectively, and in 2004 from $15 to $56 using the range and windshield methods, respectively.

Several fields (Washington 2003, Hertford 2003, and Nash 2003 and 2004) contained distinctly different weed complexes based upon the topography of the field. Due to this
spatial variation in weed populations, scouting methods that involved walking through the field resulted in higher TNR and different herbicide recommendations than did the windshield method where estimates were taken from only one vantage point. The theoretical maximum loss for these fields was quite high when based upon data collected using the windshield method, up to $528/ha (Table 5). This theoretical yield loss is high because the optimal herbicide treatment would not have been chosen using that scouting data, and weed pressure would have decreased peanut yields. Obviously, these losses are artificial in that they assume no corrective action will be taken even in the event of catastrophic herbicide failure. Other long-term research has confirmed that threshold-based weed management strategies prove to be more cost effective than spraying the typical herbicide regime every year (Munier-Jolain et al. 2002).

The percentage of times that the TNR for the herbicide recommendation was within 10% of TNR for the optimal treatment was greater for the count and range methods than for the windshield or whole-field estimate methods (Table 6). However, even when using the windshield method, chances were high (82% in 2003, and 77% in 2004) that the herbicide treatment that was chosen was within 10% of the top treatment recommendation. HADSS users are told to consider recommendations within 10% of the top TNR recommendations in the list to be equal. Individual herbicide recommendations were also taken into account (Table 7) and compared to the agent’s/grower’s recommendations. In general, the agents and farmers recommended herbicides with which they were familiar, and which they knew would control the worst weed problems in the field. Of the agent/grower recommendations, only one matched the first HADSS recommendation, however there were four other
agent/grower recommendations that occurred in the top 10% of the HADSS recommendations.

**HADSS Evaluation.** One of the aims of this research was to increase awareness of HADSS in the local agricultural community. Extension personnel involved with this project were quite experienced with peanut production, and had been involved with the profession for an average of 18 years. Agents were encouraged to provide feedback on the utility of the program, grower perceptions of the program, as well as the user-friendliness of the handheld computers via survey questions (Appendix 1.)

Overall, agents regarded the HADSS program favorably, and following extensive training sessions and several seasons of practical use in the field, were quite competent with using the program to give recommendations. In general, agents thought that HADSS was useful, and was best used for early season decision-making in peanut. Additionally, agents remarked that the program was especially useful during the growing season because it was mobile, and they were better prepared to answer questions from growers in person or over the telephone because they always had access to the program. Both agents and growers expressed appreciation about seeing specific information listed in HADSS on potential yield loss and cost estimates, and were reassured when the HADSS recommendations were nearly or exactly the same as the treatment that they were intending to recommend. In several cases, HADSS has been useful to new agents who were unfamiliar with a crop or herbicides registered for use in that crop. When questioned about the scouting methods that seemed to be most useful, it was interesting to note that not one agent felt that the range method was most helpful or accurate in this study, even though the range method was developed in response to agent requests for a faster way to accurately scout weed populations. It is
possible that the scale used for the range method (Table 2) and the resulting calculations that were necessary for recording differences between the values for grasses and broadleaves might have been confusing to the scouts. Increased familiarity with this scouting method in Year 2 decreased time required to scout each field by half (Table 4).

Research has shown that adoption of information technology into farming systems is slow, but more successful when mediated by extension personnel (Kuhlman and Brodersen 2001). Research with Texas cotton growers showed that most growers were involved with some IPM practices, and average net return from the farm increased as the number of IPM practices increased (Thomas et al. 1990). Other research has shown that peanut farmers are more likely to accept new ideas in the area of IPM when they are given the chance to learn the concepts in person (Troost et al. 1992). There were positive correlations between acceptance of the IPM program and age, level of education, and familiarity with the new IPM concepts. Several agents confirmed this in the questionnaire; stating that in order to increase farmer use of HADSS, they would need to be able to use the program first-hand to see the results (Appendix 1). Feedback from this study showed that growers are less likely to use a DSS for herbicide decision making on the farm, but would rather rely on their own knowledge or consult respected professionals like extension agents or crop consultants. Agents also mentioned that although the growers were very interested in the methods and results of this study, they were unlikely to make significant changes from their current practices. Growers were also concerned over weed escapes in portions of the field if current populations did not warrant treatment, as well as the time required for scouting. Additionally, while many growers have an internet connection and can access HADSS at no
cost, the cost of handheld computers at this time might be prohibitive of widespread adoption of HADSS use in the field.

There was enough interest in this research that users asked for more programs to be developed that could be installed on the handheld computer and incorporated into their profession. Future proposed improvements include the capability for long-term storage of HADSS on an SD memory card that would preserve the program in the event of a low battery, and also facilitate easier software updates. At the conclusion of the study, users requested additional updates to the program and continued to request yearly updates (including herbicide price changes and weed additions) to the program. Agents also mentioned that a weed identification program rich in photographs would be helpful as they were scouting fields and entering information into HADSS.

In summary, scouting efforts, whether minimal or extensive, almost always improved herbicide decisions and resulted in greater TNR’s to the grower. More in-depth scouting efforts may be slightly more costly, but will most likely pay for themselves due to higher net returns, improved weed control, and reduction in risk. The effectiveness of utilizing different scouting procedures may vary between fields, and the value of more intensive scouting methods depends upon the weed spectrum present. In this study, it was shown that even when minimal scouting efforts were made using method 1, herbicide recommendations were almost always within 10% of the optimal recommendation. Theoretical losses as high as $528 per hectare were observed in situations where the optimal herbicide treatment was not selected.

Establishing and developing scouting techniques in the future, while continuing to verify DSS like HADSS, will increase the utility of threshold-based weed management strategies.
Applying herbicides only when economically justified, and selecting the most appropriate treatment based upon efficacy data may increase the profitability of peanut production systems and is certainly more responsible to the environment. Additionally, programs such as HADSS allow users to examine herbicides within another class or family of herbicides, which is important in light of recent concerns about resistance issues.

ACKNOWLEDGMENTS

The author wishes to thank the peanut growers of North Carolina and Cooperative Extension Service Field Faculty: Al Cochran, James Pearce, Richard Rhodes, Byron Simonds, Paul Smith, Lewis Smith, Charlie Tyson, Sam Uzzell, and Frank Winslow for their scouting assistance. Additionally, gratitude is expressed to Cavell Brownie, professor in the Department of Statistics, for her statistical support. Appreciation is expressed to the USDA-CSREES for financial funding of this project.
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Table 1. Preemergence (PRE), preplant incorporated (PPI) and at-cracking herbicide treatments applied to peanut fields prior to scouting.

<table>
<thead>
<tr>
<th>Year</th>
<th>County</th>
<th>PPI</th>
<th>PRE</th>
<th>At-cracking</th>
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<tr>
<td>2003</td>
<td>Bertie</td>
<td>Pendimethalin</td>
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<td>--</td>
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<tr>
<td></td>
<td>Edgecombe</td>
<td>Pendimethalin + imazethapyr</td>
<td>Dimethenamid</td>
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<td></td>
<td>Gates</td>
<td>--</td>
<td>Metolachlor + diclosulam</td>
<td>--</td>
</tr>
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<td></td>
<td>Hertford</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Nash</td>
<td>Pendimethalin + metolachlor</td>
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</tr>
<tr>
<td></td>
<td>Perquimans</td>
<td>Diclosulam + pendimethalin</td>
<td>Dimethenamid</td>
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<td>Pendimethalin</td>
<td>--</td>
<td>Paraquat + metolachlor</td>
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<td>Washington</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
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<td>--</td>
<td>Metolachlor</td>
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<td>Metolachlor + flumioxazin</td>
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<td>Gramoxone</td>
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Table 2. Index values, and the associated density ranges for broadleaf, sedge, and grass weeds, where 1 = low population, and 5 = high population. Each weed species contained within the sample area was assigned a rating from 1 to 5.

<table>
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<th>Value used in calculating average</th>
<th>Range</th>
<th>Grasses</th>
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<td>13.5</td>
<td>76-100</td>
<td>88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&gt;15</td>
<td>20.0</td>
<td>&gt;100</td>
<td>125</td>
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<td></td>
</tr>
</tbody>
</table>
Table 3. Broadleaf, sedge, and grassy weeds observed by one or more scouts using one or more scouting methods in 16 North Carolina peanut fields.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific name</th>
<th>Bayer Codea</th>
<th># of fields found in</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bermudagrass</td>
<td><em>Cynodon dactylon</em> (L.) Pers.</td>
<td>CYNDIA</td>
<td>5</td>
</tr>
<tr>
<td>Broadleaf signalgrass</td>
<td><em>Brachiaria platyphylla</em> (Munro ex Wright) Nash</td>
<td>BRAPP</td>
<td>5</td>
</tr>
<tr>
<td>Carpetweed</td>
<td><em>Mollugo verticillata</em> L.</td>
<td>MOLVE</td>
<td>10</td>
</tr>
<tr>
<td>Common chickweed</td>
<td><em>Stellaria media</em> (L.) Vill.</td>
<td>STEME</td>
<td>1</td>
</tr>
<tr>
<td>Cutleaf evening primrose</td>
<td><em>Oenothera laciniata</em> Hill.</td>
<td>OEOLA</td>
<td>1</td>
</tr>
<tr>
<td>Common cocklebur</td>
<td><em>Xanthium strumarium</em> L.</td>
<td>XANST</td>
<td>13</td>
</tr>
<tr>
<td>Common pokeweed</td>
<td><em>Phytolacca Americana</em> L.</td>
<td>PHYTAM</td>
<td>2</td>
</tr>
<tr>
<td>Common purslane</td>
<td><em>Portulacca oleracea</em> L.</td>
<td>POROL</td>
<td>3</td>
</tr>
<tr>
<td>Common ragweed</td>
<td><em>Ambrosia artemesitfolia</em> L.</td>
<td>AMBEL</td>
<td>9</td>
</tr>
<tr>
<td>Cowpea</td>
<td><em>Vigna Savi</em></td>
<td>VIGNA</td>
<td>1</td>
</tr>
<tr>
<td>Curly dock</td>
<td><em>Rumex crispus</em> L.</td>
<td>RUMCR</td>
<td>2</td>
</tr>
<tr>
<td>Dandelion</td>
<td><em>Taraxacum officinale</em> G.H. Weber ex Wiggers</td>
<td>TAOFO</td>
<td>2</td>
</tr>
<tr>
<td>Dogfennel</td>
<td><em>Eupatorium capillifolium</em> (Lam.) Small</td>
<td>EUPCP</td>
<td>1</td>
</tr>
<tr>
<td>Eastern black nightshade</td>
<td><em>Solanum ptychanthum</em> Dunal</td>
<td>SOLPT</td>
<td>3</td>
</tr>
<tr>
<td>Plant Name</td>
<td>Scientific Name</td>
<td>Code</td>
<td>Value</td>
</tr>
<tr>
<td>----------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>Eclipta</td>
<td><em>Eclipta prostrata</em> (L.) L.</td>
<td>ECLAL</td>
<td>5</td>
</tr>
<tr>
<td>Entireleaf morningglory</td>
<td><em>Ipomoea hederacea</em> Jacq. var. integriuscula Gray</td>
<td>IPOHG</td>
<td>6</td>
</tr>
<tr>
<td>Goosegrass</td>
<td><em>Eleusine indica</em> L.</td>
<td>ELEIN</td>
<td>2</td>
</tr>
<tr>
<td>Hemp sesbania</td>
<td><em>Sesbania exaltata</em> (Raf.) Rydb. ex A.W. Hill</td>
<td>SEBEX</td>
<td>1</td>
</tr>
<tr>
<td>Henbit</td>
<td><em>Lamium purpureum</em> L.</td>
<td>LAMAM</td>
<td>6</td>
</tr>
<tr>
<td>Horsenettle</td>
<td><em>Solanum carolinense</em> L.</td>
<td>SOLCA</td>
<td>12</td>
</tr>
<tr>
<td>Horseweed</td>
<td><em>Conyza canadensis</em> (L.) Cronq.</td>
<td>ERICA</td>
<td>3</td>
</tr>
<tr>
<td>Italian ryegrass</td>
<td><em>Lolium multiflorum</em> Lam.</td>
<td>LOLMU</td>
<td>1</td>
</tr>
<tr>
<td>Ivyleaf morningglory</td>
<td><em>Ipomoea hederacea</em> Jacq.</td>
<td>IPOHE</td>
<td>12</td>
</tr>
<tr>
<td>Jimsonweed</td>
<td><em>Datura stramonium</em> L.</td>
<td>DATST</td>
<td>2</td>
</tr>
<tr>
<td>Large crabgrass</td>
<td><em>Digitaria sanguinalis</em> (L.) Scop.</td>
<td>DIGSA</td>
<td>11</td>
</tr>
<tr>
<td>Mouseear chickweed</td>
<td><em>Cerastium vulgatum</em> L.</td>
<td>CERVU</td>
<td>1</td>
</tr>
<tr>
<td>Nodding spurge</td>
<td><em>Euphorbia maculata</em> auct. non L.</td>
<td>EPHNU</td>
<td>1</td>
</tr>
<tr>
<td>Pale smartweed</td>
<td><em>Polygonum lapathifolium</em> L.</td>
<td>POLLA</td>
<td>1</td>
</tr>
<tr>
<td>Pennsylvania smartweed</td>
<td><em>Polygonum pensylvanicum</em> L.</td>
<td>POLPY</td>
<td>1</td>
</tr>
<tr>
<td>Pitted morningglory</td>
<td><em>Ipomoea lacunosa</em> L.</td>
<td>IPOLA</td>
<td>16</td>
</tr>
<tr>
<td>Prickly sida</td>
<td><em>Sida spinosa</em> L.</td>
<td>SIDSP</td>
<td>7</td>
</tr>
<tr>
<td>Purple nutsedge</td>
<td><em>Cyperus rotundus</em> L.</td>
<td>CYPRO</td>
<td>5</td>
</tr>
<tr>
<td>Species</td>
<td>Scientific Name</td>
<td>Bayer Code</td>
<td>Code</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------------------------------------------------</td>
<td>------------</td>
<td>------</td>
</tr>
<tr>
<td>Redroot pigweed</td>
<td><em>Amaranthus retroflexus</em> L.</td>
<td>AMARE</td>
<td>7</td>
</tr>
<tr>
<td>Sicklepod</td>
<td><em>Cassia obtusifolia</em> L.</td>
<td>CASOB</td>
<td>9</td>
</tr>
<tr>
<td>Spotted spurge</td>
<td><em>Euphorbia maculata</em> L.</td>
<td>EPHMA</td>
<td>1</td>
</tr>
<tr>
<td>Spreading dayflower</td>
<td><em>Commelina diffusa</em> Burm.f.</td>
<td>COMDI</td>
<td>2</td>
</tr>
<tr>
<td>Swinecress</td>
<td><em>Coronopus didymus</em> (L.) Sm.</td>
<td>COPDI</td>
<td>1</td>
</tr>
<tr>
<td>Tall morningglory</td>
<td><em>Ipomoea purpurea</em> (L.) Roth</td>
<td>PHBPU</td>
<td>8</td>
</tr>
<tr>
<td>Texas panicum</td>
<td><em>Panicum texanum</em> Buckl.</td>
<td>PANTE</td>
<td>1</td>
</tr>
<tr>
<td>Tropic croton</td>
<td><em>Croton glandulosis</em> var. <em>septentrionalis</em> Muell.-Arg.</td>
<td>CVNGS</td>
<td>3</td>
</tr>
<tr>
<td>Trumpet creeper</td>
<td><em>Campsis radicans</em> (L.) Seem. ex Bureau</td>
<td>CMIRA</td>
<td>9</td>
</tr>
<tr>
<td>Volunteer corn</td>
<td><em>Zea mays</em> L.</td>
<td>ZEAMX</td>
<td>4</td>
</tr>
<tr>
<td>Wild radish</td>
<td><em>Raphanus raphanistrum</em> L.</td>
<td>RAPRA</td>
<td>3</td>
</tr>
<tr>
<td>Yellow nutsedge</td>
<td><em>Cyperus esculentus</em> L.</td>
<td>CYPES</td>
<td>10</td>
</tr>
</tbody>
</table>

* The Bayer Code is a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.
Table 4. Time (min) required to scout 18 peanut fields using four different scouting methods in North Carolina in 2003 and 2004, averaged over three scouts.

<table>
<thead>
<tr>
<th>Year</th>
<th>County</th>
<th>Windshield</th>
<th>Whole-field</th>
<th>Ranges</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>Bertie</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Edgecombe</td>
<td>5</td>
<td>20</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>5</td>
<td>30</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Hertford</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Nash</td>
<td>5</td>
<td>20</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Perquimans</td>
<td>5</td>
<td>15</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Pitt</td>
<td>15</td>
<td>15</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Washington</td>
<td>10</td>
<td>15</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>2003 AVE</td>
<td>8</td>
<td>19</td>
<td>26</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>2004 AVE</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Bertie</td>
<td>4</td>
<td>13</td>
<td>15</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Edgecombe</td>
<td>5</td>
<td>15</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>4</td>
<td>11</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Hertford</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Nash</td>
<td>5</td>
<td>8</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Perquimans</td>
<td>4</td>
<td>12</td>
<td>12</td>
<td>23</td>
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<td>8</td>
<td>14</td>
<td>37</td>
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<tr>
<td></td>
<td>Washington</td>
<td>5</td>
<td>17</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>2004 AVE</td>
<td>5</td>
<td>12</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>2 Yr. AVE</td>
<td>6c</td>
<td>15b</td>
<td>20b</td>
<td>30a</td>
</tr>
</tbody>
</table>

*a* Means within a column followed by the same letter are not significantly different according to Fisher’s LSD (p > 0.05).
Table 5. Theoretical net returns (TNR) and loss ($/ha) as estimated by HADSS for the sixteen fields when the windshield, whole-field estimate, range and count methods were used to obtain weed population information.

<table>
<thead>
<tr>
<th>Year</th>
<th>County</th>
<th>TNR, optimal treatment</th>
<th>Estimated loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windshield</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>Bertie</td>
<td>1,445</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Edgecombe</td>
<td>823</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>750</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Hertford</td>
<td>865</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Nash</td>
<td>890</td>
<td>157</td>
</tr>
<tr>
<td></td>
<td>Perquimans</td>
<td>1,182</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Pitt</td>
<td>323</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Washington</td>
<td>625</td>
<td>26</td>
</tr>
<tr>
<td>2004</td>
<td>2004 AVE</td>
<td>863</td>
<td>41a</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>--</td>
<td>228</td>
</tr>
<tr>
<td>2004</td>
<td>Bertie</td>
<td>286</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Edgecombe</td>
<td>990</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>810</td>
<td>33</td>
</tr>
<tr>
<td>Location</td>
<td>Mean</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>---------------</td>
<td>--------</td>
<td>-----</td>
<td>------</td>
</tr>
<tr>
<td>Hertford</td>
<td>244</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Nash</td>
<td>860</td>
<td>276</td>
<td>130</td>
</tr>
<tr>
<td>Perquimans</td>
<td>1,229</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Pitt</td>
<td>575</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>Washington</td>
<td>651</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>2004 Average</td>
<td>705</td>
<td>56a</td>
<td>32ab</td>
</tr>
<tr>
<td>Maximum</td>
<td>--</td>
<td>528</td>
<td>246</td>
</tr>
</tbody>
</table>

*Means within a column followed by the same letter are not significantly different according to Fisher’s LSD (p> 0.05).*
Table 6. Scouting methodology and HADSS recommended treatment with a TNR within 10% of the optimal treatment.

<table>
<thead>
<tr>
<th>Year</th>
<th>Scouting Method</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>Windshield</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>Whole-field estimate</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>Count</td>
<td>--</td>
</tr>
<tr>
<td>2004</td>
<td>Windshield</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>Whole-field estimate</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Range</td>
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</tr>
<tr>
<td></td>
<td>Count</td>
<td>98</td>
</tr>
</tbody>
</table>
Table 7. Herbicide recommendations generated in HADSS compared to extension agent and farmer recommendations.

<table>
<thead>
<tr>
<th>Year</th>
<th>County</th>
<th>HADSS recommendation</th>
<th>TNR</th>
<th>Agent/grower recommendation</th>
<th>TNR</th>
<th>Within 10% of top recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>Bertie</td>
<td>Lactofen + imazapic</td>
<td>585</td>
<td>Imazapic + 2,4-DB</td>
<td>544</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Edgecombe</td>
<td>Basagran + aciflourfen</td>
<td>333</td>
<td>Paraquat + basagran</td>
<td>69</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>Gates</td>
<td>Paraquat + basagran + aciflourfen</td>
<td>304</td>
<td>Clethodim fb basagran + aciflourfen</td>
<td>296</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Hertford</td>
<td>Clethodim fb basagran + aciflourfen</td>
<td>350</td>
<td>Paraquat + metolachlor</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>Nash</td>
<td>Lactofen + imazapic</td>
<td>361</td>
<td>Sethoxidim + 2,4-DB</td>
<td>244</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>Perquimans</td>
<td>Clethodim fb basagran + aciflourfen</td>
<td>479</td>
<td>Clethodim fb basagran + aciflourfen</td>
<td>479</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>Pitt</td>
<td>Paraquat + basagran + aciflourfen</td>
<td>131</td>
<td>Paraquat + basagran</td>
<td>60</td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>Washington</td>
<td>Paraquat + basagran + aciflourfen</td>
<td>253</td>
<td>Paraquat + basagran</td>
<td>233</td>
<td>yes</td>
</tr>
</tbody>
</table>
2004  Bertie  Paraquat + basagran + aciflourfen  98  Basagran + aciflourfen  77  yes

Edgecombe  Lactofen + imazapic  376  2,4-DB + basagran + aciflourfen + imazethapyr  **  **

Gates  Lactofen + clethodim  293  Imazapic + basagran + aciflourfen + 2,4-DB  **  **

Hertford  Paraquat  77  Clethodim fb basagran + aciflourfen + 2,4-DB  31  no

Nash  Paraquat + 2,4-DB  357  Imazapic  262  no

Perquimans  Clethodim fb basagran + aciflourfen  488  Clethodim fb aciflourfen + 2,4-DB  **  **

Pitt  Paraquat + basagran + aciflourfen  190  Basagran + aciflourfen  44  no

Washington  Paraquat + 2,4-DB  227  Basagran + imazapic  **  **

** Recommendations did not appear on the list generated by HADSS; therefore no TNR could be calculated

fb = followed by
Figure 1. Field diagram indicating each of the three scouts positions in the field when scouting.
\[ y = 0.50x + 2.07 \]
\[ R^2 = 0.21 \]

\[ y = 0.61x + 1.70 \]
\[ R^2 = 0.63 \]
Figure 2. Comparison of estimated weed densities using a) windshield (Method 1), b) whole-field (Method 2), c) range (Method 3), and d) count (Method 4a) scouting methods. Each data point on the graph represents the estimated average density of one species in one field using data from all three scouts.
CHAPTER 3

Yield and Physiological Response of Peanut (*Arachis hypogaea* L.)

to Glyphosate Drift

**Abstract:** Five experiments were conducted during 2001 and 2002 in North Carolina to evaluate peanut injury and pod yield when glyphosate was applied to 10 to 15 cm diameter peanut at rates ranging from 9 to 1,120 g ai/ha. Shikimic acid accumulation at 7 days after treatment was determined in three of the five experiments. Levels of visual injury (foliar chlorosis, necrosis, biomass reduction, and stand reduction) were made for all five experiments at 7 DAT. Visual injury was detected at rates of glyphosate 70 g/ha and higher. Glyphosate at 280 g/ha or higher injured the peanut plant and reduced pod yield. Glyphosate at rates of 1,120 g/ha resulted in complete death to peanut in all years and locations. Shikimic acid accumulation increased as the rate of glyphosate increased. Shikimic acid accumulation was negatively correlated with visual injury and pod yield. Glyphosate at rates above 140 g/ha resulted in decreased pod yield at all locations in both years. When glyphosate was applied at 280 g ai/ha, a yield loss of 20% was experienced. When shikimic acid levels at 7 DAT reached more than 200 to 250 µg/g tissue at all locations, there was consistent peanut crop injury. Shikimic acid presence can be detected in plant samples, and accumulation can be an effective diagnostic tool for determining exposure to glyphosate in peanut 7 DAT, but not at 14, 21, and 31 DAT.

**Nomenclature:** Glyphosate; peanut, *Arachis hypogaea* L., ‘NC-12C’.

**Additional Index Words:** Herbicide drift, shikimic acid.
Abbreviations:DAT, days after treatment; EPOST, early postemergence over the top; EPSPS, 5-enolpyruvylshikimate-3-phosphate synthase [EC 2.5.1.19]; GR, glyphosate-resistant; POST, postemergence; PRE, preemergence; WAP, weeks after planting.

INTRODUCTION

Glyphosate is a non-selective herbicide used to control annual, perennial and biennial grasses, sedges, and broadleaf weeds (Franz et al. 1997). Adoption of glyphosate-resistant (GR) crops has increased greatly since 1996 due to the simplicity of using a broad spectrum, non-residual herbicide with flexibility of application timing (Shaner 2000) and low mammalian toxicity. This increase has been most evident in soybean \(\textit{Glycine max} (L)\) Merr. and cotton \(\textit{Gossypium hirsutum} L.\) (Owen 2000; Shaner 2000). Yearly USDA statistics show that in 1996 glyphosate was applied to 4, 13, and 25% of the corn, cotton, and soybean hectarage planted in the U.S., respectively. In 2003, those numbers increased to 19, 69, and 87% for each of the three crops, respectively. Specific data for North Carolina suggests that 90% of the soybean hectarage and at least 80% of the cotton hectarage is treated with glyphosate (National Agriculture Statistics Service 1997, 2004).

In the Mid-Atlantic and Southeastern Coastal Plain of the United States, peanut are often grown in fields adjacent to corn, cotton, and soybean. Because glyphosate is not residual, multiple POST applications are often required to control weed infestations in these crops (Askew and Wilcut 1999; Askew et al. 2002; Culpepper and York 1999; Culpepper et al. 2000; Scott et al. 2001; Thomas et al. 2004a, 2004b). The potential exists for off-target movement of glyphosate into peanut, a non-GR crop. Due to the increase in GR crop hectarage, off-target glyphosate movement into non-GR crops due to drift has become an increasing concern. Spray drift and herbicide uptake in a plant can be influenced by a number of factors including:
herbicide composition, spray droplet size, plant size and age, plant stress and other environmental conditions (Ellis et al. 2002; Feng et al. 2003).

Many crops, depending on growth stage, are sensitive to glyphosate drift and can experience yield loss (Al-Khatib et al. 2003; Burke et al. 2005; Ellis and Griffin 2002; Thomas et al. 2005). Kurtz et al. (2003) reported yield loss in rice (*Oryza sativa* L.) when treated with approximately one-half of the registered rate of glyphosate. Extensive work in non-transgenic soybean demonstrated variable yield reductions depending on rate and timing of application (Al-Khatib and Peterson 1999). Non-transgenic cotton has also been shown to be sensitive to simulated rates of glyphosate ranging from 140 g/ha to 1,129 g/ha (Ellis and Griffin 2002; Lyon et al. 2003; Thomas et al. 2005). Other research has shown that GR cotton may exhibit yield losses due to boll abscission and pollen abnormalities from non-registered glyphosate treatments (Pline et al. 2002). In North Carolina, there were over 40,000 hectares of peanut grown in the 2002 growing season (Brown 2003). During the same year GR cotton cultivars were planted on more than 75% of the cotton hectarage in North Carolina (A. C. York, personal communication; National Agricultural Statistics Service 2002). Additionally, 80-90% of the soybean hectarage and 15% of the corn hectarage in North Carolina were planted to GR varieties (E. J. Dunphy; A. C. York, personal communication). Most postemergence herbicide treatments in soybean are made in late June to mid-July, and growers generally make two or more postemergence applications of glyphosate during the year. Corn, a common rotation crop in peanut, is generally planted earlier in the season and postemergence herbicide drift, although less likely, could still pose a threat to peanut during its reproductive growth phase.

Glyphosate treated plants accumulate shikimic acid (a precursor to shikimate-3-phosphate) as a result of the inhibition of 5-enolpyruvyl-shikimate-3-phosphate (EPSP) synthase (E.C. 2.5.1.19)
(Pline et al. 2002; Ray 1989; Steinrucken and Amrhein 1980; Thomas et al. 2005). EPSP synthase is the initial enzyme in the metabolic pathway that produces phenylalanine, tyrosine and tryptophan, which are essential aromatic amino acids required for protein synthesis and overall plant growth (Franz et al. 1997). Shikimate-3-phosphate is converted to shikimic acid; a physiological process unique only to the herbicide glyphosate (Cole 1997). Shikimic acid is easily measured in plant tissue using a spectrophotometer (Pline et al. 2002; Singh and Shaner 1998).

The objectives of this research were: (1) to determine the visual injury and yield response of peanut to eight incremental rates of glyphosate; (2) to evaluate if shikimic acid accumulates in peanut in response to glyphosate, and (3) to correlate shikimic acid accumulation to peanut injury and yield.

**MATERIALS AND METHODS**

Field experiments were conducted at the Peanut Belt Research Station located near Lewiston-Woodville, NC in 2001 and 2002, and at the Upper Coastal Plain Research Station located in Rocky Mount, NC in 2002. Soil was a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudults) with 1.0% organic matter and a pH of 5.9 at both locations. Additional experiments at Lewiston-Woodville in 2001 and 2002 were conducted on a Goldsboro loamy sand (fine-loamy, siliceous, Aquic Paleudults) with 2.1% organic matter and pH 6.0. Experiments were conducted in conventionally tilled seedbeds. The peanut variety ‘NC-12C’ was planted in all experiments in early May at a depth of 5 cm, and at a rate of 13 seeds/m-row. Plot size was 4 rows (91-cm row spacing) by 6-10 m long. Insect and disease management programs were based upon recommendations from the North Carolina Cooperative Extension Service (Brandenburg 2003; Shew 2003). Plots were maintained weed-free with PRE applications of metolachlor at 1.4
kg ai/ha plus diclosulam at 0.026 kg ai/ha and POST applications of bentazon plus aciflourfen at 0.84 kg ai/ha plus a nonionic surfactant (NIS)\(^3\) at 0.25% (v/v) when experiments were on the Norfolk sandy loam soil. The herbicide program on the Goldsboro loamy sand included pendimethalin PPI at 0.84 kg ai/ha followed by metolachlor PRE at 1.4 kg ai/ha followed by aciflourfen (0.28 kg/ha) plus bentazon (0.56 kg/ha) plus 2,4-DB (0.28 kg ai/ha) applied POST. All herbicides and rates of application were made according to North Carolina Cooperative Extension Service recommendations (Jordan 2003).

To simulate herbicide drift, glyphosate\(^4\) was applied POST approximately 4 weeks after planting (WAP) to the center two rows of each plot. Peanut was 10 to 15 cm in diameter when glyphosate was applied at rates of 0.0, 9, 18, 35, 70, 140, 280, 560, and 1,120 g ha, representing 0.0, 0.78, 1.55, 3.13, 6.25, 12.5, 25, 50 and 100% respectively of the registered use rate for corn, cotton, and soybean. Glyphosate was applied with a CO\(_2\)-pressurized backpack sprayer calibrated to deliver 140 L/ha at 206 kPa through 110002EVS spray nozzles\(^5\) or 80012 flat fan nozzles.

Visual estimates of percent peanut injury were recorded in all plots at 7, 14, 21, and 35 DAT using a scale of 0 (no injury symptoms) to 100 (complete death of all plants, or no plants present) (Frans et al. 1986). Cumulative values for foliar chlorosis, necrosis, biomass reduction, and stand reduction were used when making the visual estimates compared with the no-glyphosate

\(^3\) Induce (90% alkylarylpolyoxyalkaneether and free fatty acids), Helena Chemical Co., 5100 Poplar Ave., Memphis, TN 38137.

\(^4\) Roundup UltraMAX, isopropylamine salt of glyphosate with surfactant, Monsanto Agricultural Co., 800 N. Lindbergh Ave., St. Louis, MO 63167.

\(^5\) TeeJet Spray Nozzles, Spraying Systems Co., PO Box 7900, Wheaton, Il 60189.
control. Peanut were dug and vines inverted in early to mid October of both years. Peanut pods were combined 4 to 7 d after vine inversion. Final yield was adjusted to 8% moisture.

**Shikimic Acid Quantification.** A modified spectrophotometric method was used to quantify shikimic acid accumulation in the peanut plant tissue for three of the experiments (Lewiston A 2001, 2002, and Rocky Mount 2002.) (Pline et al. 2001; Singh and Shaner 1998). One leaf disk per plant was removed along the midrib of the third most expanded peanut leaf using a standard paper hole-punch\(^6\). A total of ten leaf disks were collected from the two middle rows of the plot at 7, 14, 21, and 28 d after glyphosate was applied. Leaf disks were systematically collected from the non-glyphosate control first, with subsequent collections made from plots treated at the next highest glyphosate rate. The metal paper hole punch was rinsed after sampling each plot using a 5:1 solution of water:ammonia to minimize sample contamination. The ten leaf disks were placed in microcentrifuge tubes containing 0.5 mL of 0.01 M H\(_2\)SO\(_4\) and stored on ice for transportation to the lab. Leaf tissue samples were ground in collection solution and 0.25 mL of 0.4 M NaH\(_2\)CO\(_3\) was added to each sample. The solution was placed in a freezer at -20\(^\circ\) C until assay. To assay, samples were thawed for one hour and centrifuged at 10,000 g for 5 minutes. A 20 μL aliquot of supernatant from each sample was added to a vial containing 0.5 ml of 1% (w/v) periodic acid. Both a blank vial and an experimental vial were prepared for each test sample. After oxidizing for 2 h, water (0.5 ml) was added to sample blank vials, and 0.5 ml 1N (NaOH) was added to sample experimental vials. Glycine (0.3 ml of 0.1M) was immediately added to all samples. Both sample sets were analyzed at 380 nm using a spectrometer\(^7\). A

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\(^6\) 7 mm, aluminum paper hole-punch

\(^7\) Perkin-Elmer UV/VIS 10 Spectrometer Lambda 10. Perkin-Elmer Inc., 45 William Street Wellesley, MA 02481-4078, USA.
standard curve was developed using pure shikimic acid standards\(^8\) with known concentrations (Pline et al. 2002). Accumulation values were determined from comparison with the standard curve, and were used for the statistical analysis.

**Experimental Design and Statistical Analysis.** Field plots were arranged in a randomized complete block design with 3 (Lewiston A 2001, 2002, and Rocky Mount 2002) or 4 (Lewiston B 2001 and 2002) replications per treatment. Data for visual injury, shikimic acid accumulation and pod yield were subjected to analysis of variance (ANOVA) using the general linear models procedure in SAS version 8.0 (SAS 2001). Means for appropriate main effects and interactions were separated using Fisher’s Protected LSD test at \( p \geq 0.05 \). Correlations (\( p \geq 0.05 \)) among peanut injury, shikimic acid accumulation, and pod yield were determined. In addition, a non linear least squares procedure was used to estimate coefficients for nonlinear models (NLIN). Peanut injury, shikimic acid accumulation, and yield reduction were modeled using a logistic dose curve (Equation 1) to show the relationships between variables (Seefeldt et al. 1995). This procedure aimed to fit the non-linear regression to a response curve, and to remove the location effect for yield.

\[
Y = A + B \left( 1 - \frac{1}{1 + \left( \frac{\text{Rate}}{I_{50}} \right)^d} \right)
\]  

[1]

In these functions, \( A + B \) represents the upper limit, \( A \) is the lower limit, and \( B \) is the difference between the upper and lower limit, while \( d \) is the slope and \( I_{50} \) is the dose giving 50% response.

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\(^8\) Shikimic acid S-5375, Sigma Chemical Co., PO Box 14508, St. Louis, MO 63178.
RESULTS AND DISCUSSION

**Crop Injury.** Peanut injury symptoms were characteristic for glyphosate and manifested by one or more of the following: distorted leaf shape, leaf cupping and necrosis, interveinal chlorosis, and stunting (Atkinson 1985). There was a significant test by treatment interaction at all locations. Herbicide injury symptoms developed slowly, and were marginally visible at 7 DAT, with symptoms being more marked at the 140 g/ha rate and above (Figure 1). Chlorotic injury at 7 DAT was present in plants treated with the highest rates of glyphosate (140 g/ha and above). This injury increased in severity over time, and resulted in eventual plant injury and death in peanuts treated with 560 and 1,120 g/ha rates of glyphosate. The early-evaluation ratings (7 DAT) showed that plots treated with glyphosate at the 1,120 g/ha rate resulted in at least 95% crop injury (Figure 1), which is consistent with data reported by Jain et al (1999). There was a significant (p < 0.05) test by treatment effect. In Lewiston A in 2001 the response curve of visual injury was consistent with the accumulation of shikimic acid. At 18 g/ha, injury was just visually detectable when rated at 7 DAT. In Lewiston B in 2001 and 2002, injury was 33% or greater at rates of 140 g/ha and above. Injury at rates of 70 g/ha and below ranged from 0 to 34% (Figure 1). Glyphosate at rates of 1,120 g/ha resulted in complete death to the peanut plant in all years and locations. Early injury was also correlated to peanut yield losses (Table 1), whereas others have found that injury symptoms are poorly related to yield reduction in corn (Al-Khatib et al. 2000), grain sorghum (Al-Khatib et al. 2003), rice (Kurtz and Street 2003), and wine grape (*Vitis vinifera* L.) (Bhatti et al. 1997).

Injury symptoms at 14 DAT (data not shown) were much more developed, and similar to those reported in soybean (Al-Khatib and Peterson 1999) and grain sorghum (*Sorghum bicolor* (L.) Moench) (Al-Khatib et al. 2003). Later injury ratings (35 and 84 DAT) were marked; the
greatest injury occurred at the 70 g/ha rate and higher at Lewiston A 2001, 560 g/ha in Lewiston A 2002, and 140 g/ha in Rocky Mount 2002. Many of the plants treated at the highest rates (560 and 1,120 g/ha) suffered complete death by harvest, and thus did not flower, peg, or produce peanut pods. Research has shown that herbicide injury is more severe when carrier volume is adjusted to reflect the reduced herbicide rates (Banks and Schroeder 2002; Ellis and Griffin 2002, Ellis et al. 2002). Although carrier volume was not adjusted to reflect the glyphosate rates in this research, it must be noted that the potential for peanut injury may actually be much higher when carrier volume is taken into consideration.

Glyphosate is an effective herbicide when used to control volunteer peanut in other crops, and is also registered for pre-season burndown treatments in peanut (York et al. 1994). However, care should be taken when glyphosate is being applied to crops growing in the vicinity of peanut that are in the vegetative or reproductive growth stages.

**Shikimic Acid Accumulation.** Shikimic acid accumulation increased as the rate of glyphosate increased (Figure 2). There was a significant test by treatment interaction, and in all years and locations, peanut yields decreased as shikimic acid accumulation increased. These responses show an inverse relationship between peanut yield and shikimic acid accumulation (Table 1). Shikimic acid was detected at the 140, 280, 560, and 1120 g/ha rates of glyphosate when samples were taken 7 DAT (Figure 2). Samples taken at 14, 21, and 31 DAT did not show measurable levels of shikimic acid. No accumulation was observed at rates at or below 70 g/ha at any location where shikimic acid levels were measured (Lewiston A 2001, 2002, and Rocky Mount 2002). Glyphosate movement may have been inhibited by the drought conditions during the 2002 growing season (Figure 4) because it is transported in the phloem of an actively growing plant (Bromilow and Chamberlain 2000; Duke 1988). Significant drought stress resulted in
slightly different shikimic acid levels, and varied depending on the irrigation system in place
(Lewiston-Woodville is irrigated using a lateral move irrigation system and the Rocky Mount
site is irrigated with a traveling gun). Shikimic acid levels were much higher in 2001 at the
highest rate of glyphosate (580 µg/g tissue) than in either 2002 site (207 and 165 µg/g tissue),
respectively. In 2001, injury was visually detectable 7 DAT at 35 g/ha before measurable
shikimic acid accumulation occurred. The initial response of peanut injury at low glyphosate
rates appeared to be minor, however as the shikimic acid accumulation levels increased, so did
injury (Figure 1 and Figure 2).

**Yield.** There are significant (p \( \leq \) 0.05) treatment by location interactions, therefore peanut yield
data are discussed separately by location. Yields for non-treated peanut were 3900, 2910 kg/ha
at Lewiston A 2001 and 2002 respectively, 4050 kg/ha in Rocky Mount 2002, and 2580 and
4190 kg/ha at Lewiston B in 2001 and 2002 respectively (Table 1.) Growing conditions were
favorable for high yield potential in Lewiston A in 2001 (Figure 4) and consequently, nontreated
peanut yielded well (Figure 3, Table 1). However, in 2002 yields in the Lewiston A nontreated
plots were much lower due to the significant drought mentioned before. Conversely, Lewiston B
2002 yields (4190 kg/ha) and Rocky Mount yields (4050 kg/ha) were higher than those recorded
in the previous year. In Rocky Mount, there was a similar response to that of Lewiston A of the
same year; once glyphosate rates increased to 140 and 280 g/ha there was a rapid increase in
shikimic acid accumulation and a decrease in peanut yield.

At three sites (Lewiston B 2001, 2002, and Rocky Mount 2002), yield of peanut treated with 9
g/ha was higher than the yield of the nontreated plot, and in three other plots (Lewiston B 2001,
2002, and Lewiston A 2001) the yield of peanut treated with 35 g/ha was higher than the yield of
the peanut treated with 18 g/ha. These data suggest that extremely low rates of herbicides may
actually stimulate plant growth. This phenomenon can also be seen in the Lewiston B 2001 plots where yields were actually slightly higher at the 18 g/ha of glyphosate than they were at the 9 g/ha rate. The glyphosate product “Quotamaker”, an extremely low concentration of glyphosate, was once registered for use as a yield enhancer and growth regulator in peanut but was discontinued after one year of use (Colvin et al. 1990).

Glyphosate rates above 140 g/ha resulted in decreased pod yield at all locations in both years (Figure 3). When shikimic acid levels at 7 DAT reached more than 200 to 250 µg/g tissue at all locations, there was consistent peanut crop injury. This loss in yield is consistent with other glyphosate research in legumes; Wallace et al. (1998) showed that the practice of spraytopping pastures with low rates of glyphosate reduced the seed yield, quality and size of subterranean clover (Trifolium subterraneum L.). Preliminary research to isolate glyphosate-tolerant lines of peanut has also shown that peanut seedling growth is severely restricted, and plants eventually become highly necrotic when seedling roots are exposed to sub-lethal rates of glyphosate in nutrient solution (Jain et al. 1999).

In addition to the ANOVA analysis, data have been transformed using the NLIN (non linear model) procedure in order to express yield information as a prediction of the percent yield reduction (Figure 3). There was a strong treatment by location interaction when all locations were analyzed. The relationship between % yield reduction, yield and rate of glyphosate at each location is described by the fitted curve in Figure 3.

The relationships between peanut injury and yield, peanut injury and shikimic acid accumulation, and shikimic acid accumulation and yield are shown in Table 2. The correlations are strong between injury and yield (-0.59 < r < -0.92) at all five locations, as well as between
injury and shikimic acid accumulation ($0.75 < r < 0.95$) and shikimic acid accumulation and yield ($-0.75 < r < -0.87$).

In summary, this study showed that peanut injury at all locations increased rapidly with glyphosate rates of 140 g/ha and higher. Glyphosate at rates of 280, 560, and 1,120 g/ha resulted in significant crop injury, reduced peanut yield, and caused economic loss. Additionally, corresponding increases in shikimic acid accumulation were directly related to peanut yield; with yields decreasing as shikimic acid accumulation increased.

Shikimic acid accumulation is directly related to crop injury and yield losses. Crop injury, which was a cumulative summation of crop discoloration, crop stunting, and stand reduction, increased with increasing rates of glyphosate treatment. Early (7 DAT) evaluations of injury were based upon crop discoloration. Ratings later in the season (14 and 21 DAT) were based upon injury symptoms that included crop stunting, stand reduction, and complete death of the peanut plant. The observations of peanut injury and measurements of shikimic acid accumulation are very highly correlated to the losses in yield in peanut and to economic losses (Table 2).

Shikimic acid accumulation can be an effective diagnostic tool for determining exposure to glyphosate in peanut 7 DAT, but not at 14, 21 and 31 DAT. In order to detect shikimic acid presence, peanut leaf tissue samples need to be taken 7 DAT if signs of chlorosis are noted or if a drift event is suspected. If samples are taken later than 7 DAT, shikimic acid will be non-detectable using our laboratory procedures. Additionally, this data can be used to estimate yield losses if glyphosate is accidentally added to a spray tank instead of crop oil concentrate or nonionic surfactant, all three of which are very similar in color.
ACKNOWLEDGEMENTS

Appreciation is expressed to the staff at the Peanut Belt Research Station and the Upper Coastal Plain Research Station for assistance with these experiments. A special thanks to Scott Clewis and Dewayne Johnson for their technical assistance, and Dr. Cavell Brownie, professor in the Department of Statistics, for statistical consultation.
LITERATURE CITED


Table 1. Mean pod yields for peanut treated with eight rates of glyphosate at five North Carolina locations, 2002-2004.

<table>
<thead>
<tr>
<th>Location</th>
<th>Rates of glyphosate (g ai/ha)</th>
<th>Peanut yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>8.7</td>
</tr>
<tr>
<td>Lewiston A 2001</td>
<td>3930</td>
<td>3700</td>
</tr>
<tr>
<td>Lewiston A 2002</td>
<td>2940</td>
<td>2610</td>
</tr>
<tr>
<td>Lewiston B 2001</td>
<td>2580</td>
<td>2790</td>
</tr>
<tr>
<td>Lewiston B 2002</td>
<td>4190</td>
<td>4610</td>
</tr>
<tr>
<td>Rocky Mount 2002</td>
<td>4080</td>
<td>4100</td>
</tr>
</tbody>
</table>
Table 2. Correlations of pod injury vs. yield, pod injury vs. shikimic acid, and shikimic acid vs. yield in five locations for peanut treated with eight rates of glyphosate in North Carolina.

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Location</th>
<th>P value</th>
<th>R value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peanut Injury vs. yield</td>
<td>Lewiston A 2001</td>
<td>&lt;0.0001</td>
<td>-0.90</td>
</tr>
<tr>
<td></td>
<td>Lewiston A 2002</td>
<td>&lt;0.0001</td>
<td>-0.83</td>
</tr>
<tr>
<td></td>
<td>Lewiston B 2001</td>
<td>&lt;0.0001</td>
<td>-0.59</td>
</tr>
<tr>
<td></td>
<td>Lewiston B 2002</td>
<td>&lt;0.0001</td>
<td>-0.83</td>
</tr>
<tr>
<td></td>
<td>Rocky Mount 2002</td>
<td>&lt;0.0001</td>
<td>-0.92</td>
</tr>
<tr>
<td>Peanut injury vs. shikimic</td>
<td>Lewiston A 2001</td>
<td>&lt;0.0001</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>Lewiston A 2002</td>
<td>&lt;0.0001</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Rocky Mount</td>
<td>&lt;0.0001</td>
<td>0.86</td>
</tr>
<tr>
<td>Shikimic acid accumulation vs. yield</td>
<td>Lewiston A 2001</td>
<td>&lt;0.0001</td>
<td>-0.86</td>
</tr>
<tr>
<td></td>
<td>Lewiston A 2002</td>
<td>&lt;0.0001</td>
<td>-0.75</td>
</tr>
<tr>
<td></td>
<td>Rocky Mount 2002</td>
<td>&lt;0.0001</td>
<td>-0.87</td>
</tr>
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</table>
Figure 1. Early peanut injury seven days after treatment at eight different glyphosate rates in five different locations in North Carolina.
Figure 2. Shikimic acid accumulation 7 DAT in peanut at eight different glyphosate rates in three different locations in North Carolina.

\[ Y = 2.5 + 493 \left( 1 - \frac{1}{1 + \left( \frac{\text{Rate}}{0.81} \right)^{1.58}} \right) \]

\[ R^2 = 0.70 \]
Figure 3. Peanut pod yield reduction (%) at eight different glyphosate rates in five different locations in North Carolina.
Figure 4. Total precipitation for each location and year: Lewiston-Woodville (http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?nc4962) and Rocky Mount (http://cirrus.dnr.state.sc.us/cgi-bin/sercc/cliMAIN.pl?nc7400) respectively, compared to the 47 and 48 year average for each location (http://www.sercc.com/climateinfo/historical/historical_nc.html).
Appendix 1.

Observations and Comments from Extension Agents.

*Agents were given the chance to answer questions about their observations and experiences with this study. The answers to the survey are presented here anonymously.

1. **What was the farmer/grower’s impression of this approach to weed management?**
   - This farmer does a lot of tank mix spraying. He will mix up a tank mix with "A" herbicide and spray 95% of fields with it. He will then mix up tank mix "B" to spray an additional 25% of fields that have additional weed populations. He scouts a couple of fields and then makes up his prescription tank mixes for all fields based on that data.
   - The farmer was concerned about weed escapes if the herbicide recommendation was one that didn’t kill all of the weeds in the field. He was also concerned with the time factor involved in scouting individual fields.
   - The farmer liked being able to view the assessment of weed populations and possibilities for control. However, he did not like not having applications in the mix to allow for residual materials to be applied at-cracking.
   - The grower felt good because the HADSS recommendations were exactly what he was planning on applying. The cost estimate was helpful for decision-making.
   - The farmer was interested in the methods and results, but not likely to change his current practice (which is very limited scouting before herbicide applications).
   - The farmer feels like the HADSS program can be of great help especially when used early in the season. Growers generally like the fact that cost comparisons can be made on the spot.

2. **What was your impression (as the agent) of this approach to weed management?**
   - The predicted yield losses that are generated by HADSS, at times, seem to be overestimates.
   - A farmer should do some representative scouting for his fields (each field individually) and then decide on the herbicide to be sprayed for the season.
   - The ability to see potential yield loss from various weed populations is an excellent part of the program. Pocket herb does not seem to encompass all treatment options.
   - I think that this program will work for our needs with a little more refining.
• We got good herbicide recommendations by knowing and entering weed populations. I like the ability to adjust the program to target predominant weed groups present in the field.

• This is a good technique. After scouting and spraying one of the recommended treatments, the field is reasonably clean now. Estimating weeds without actually counting them (range method) may be all that is necessary. Most farmers simply want clean (weed free) peanuts.

• I thought that this method worked well. From my standpoint and time constraints, I would most likely use the loop and estimate density method.

• I enjoyed using the program with several growers. This is good information and is helpful when making herbicide decisions.

3. How can HADSS be improved?

• The program would be easier to use if the screen was bigger, but I know that you don’t have any control over that!

• It would be helpful to have a quick and accurate way to assess weed populations.

• It doesn’t seem like all possible herbicide combinations are included in the list.

• It would be helpful if there was a weed identification tool on the handheld computer that could be used in conjunction with HADSS.

• Keep the chemical prices updated on a yearly basis.

4. Which scouting method gave the best picture of the field weed population? Why?

• Method 2: the whole field estimate. It was obviously a better sample of what is in the field.

• Method 3: the whole field estimate. Broadleaf and grassy weeds that need to be controlled are identified, and can be controlled. A farmer simply wants clean peanuts.

• Method 4: the count method. I thought that stopping and actually counting the weed population at random locations gave the best picture of the weed population. However, one may only need a relative estimate of the weeds present to formulate a herbicide plan.

• Method 4: the count method. This method gave the best information. However, it may not be necessary to know species amounts for control recommendations.

• Method 4: the count method. This method was more detailed and took out much of the human error possibility that occurs when estimating.

• Method 4: the count method. This method gave a more intense look at the field and was fairly time efficient.
5. How can the scouting procedure be improved?

- Create a standardized list of low, medium, high populations for the weeds and use this to enter info and create recommendations. Also, group together botanically similar weeds (for example: prickly sida, spurred anoda, and tropic croton) because control is similar.
- Use a range or index of weed populations that may only have three separations, high, medium and low.
- We need to consider that there are differences in the distribution of weeds; often dense weed populations occur in small areas only. The weed control recommendations should consider these isolated areas of dense weed growth.
- The count method was the best approach to obtaining accurate weed densities, but you have to market a scouting program that is practical. It is going to be a marriage of science and practicality, and the best scouting program is the one where you stop at 6 different random places in the field and estimate weed species and density.

6. What needs to be done next to increase the usefulness of this approach?

- The program would be easier to use if only the top 5 herbicide recommendations were listed. Scouting would also be simpler if there were fewer categories of weeds to choose from.
- In order to increase farmer and agents’ use of this program, there needs to be a better way of identifying weed species. If weed photos are incorporated into the decision aid it would bridge the problem of not being familiar with the weed species. Most people are hesitant to ask for help in the identification process - but if they had an easy guide the problem would be alleviated.
- Farmers are going to be hesitant to adopt this technology when the prices of handheld computer are still at least $500.
- It would be helpful to present this program at winter production meetings, and increase awareness with local farmers.
- Continue research in order to compile more data for support of HADSS.

Other comments:

- HADSS is a program with tremendous utility, especially when used to make decisions in early to mid-season peanuts.
- This program needs to be marked to professionals in the field (consultants, custom applicators). The program is more in depth than what most growers are willing to do to obtain a spray program; however the program does not need to be compromised in any way.