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WEED SCIENCE

Distribution of Glyphosate-Resistant Palmer Amaranth (*Amaranthus palmeri*) in Georgia and North Carolina during 2005 and 2006

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ABSTRACT

Glyphosate-resistant Palmer amaranth biotypes have been confirmed in Georgia and North Carolina. A survey was conducted in both states to determine distribution of the resistant biotype(s). Knowledge of the distribution of glyphosate resistance will alert producers to the severity of the problem and hopefully encourage them to adopt resistance management programs. Palmer amaranth seed were collected from 136 fields in 10 Georgia counties and from 290 fields in 29 North Carolina counties. Glyphosate-resistant Palmer amaranth was detected in 10 Georgia counties and in 71 of 136 surveyed fields. In North Carolina, glyphosate-resistant Palmer amaranth was detected in 11 counties and in 49 of the 290 fields sampled. Hectares infested with the resistant biotype more than doubled between 2005 and 2008.

The world's first confirmed case of glyphosate resistance in an *Amaranthus* species occurred with Palmer amaranth in Georgia during 2005 (Culpepper et al., 2006; Heap, 2008). In the following year, scientists from North Carolina, South Carolina, Tennessee, and Arkansas were all studying suspected populations of glyphosate-resistant Palmer amaranth in their states as well. By the end of the 2006 production season, glyphosate-resistant Palmer amaranth was confirmed or being confirmed in North Carolina, South Carolina, Tennessee, and Arkansas (Heap, 2008; Scott et al., 2007; York et al., 2007).

Glyphosate resistance in Palmer amaranth poses serious ramifications for future weed management (Culpepper et al. 2007). Palmer amaranth was already one of the most troublesome weeds of agronomic crops across the southern United States (Webster 2005); resistance to glyphosate will only exacerbate the problem, especially in light of the widespread planting of glyphosate-resistant crops. Additionally, spread of resistance through pollen in this dioecious species (forced outcrossing) likely will be rapid (Sosnoskie et al., 2007).

A rapid growth rate and tall stature (Horak and Loughin 2000) make Palmer amaranth extremely competitive with all crops, especially cotton (*Gossypium hirsutum* L.). Research in Georgia during 2006 indicated that a single glyphosate-resistant Palmer amaranth spaced every 7 m of row and emerging with the crop reduced cotton yield 7% (MacRae et al., 2007). Palmer amaranth will also impact harvesting, as noted by Smith et al. (2000), where one Palmer amaranth every 3 m of row reduced mechanical harvesting efficiency by 2.4%.

Research indicates that economical management of glyphosate-resistant Palmer amaranth is very difficult with currently available herbicide technology in cotton (Culpepper et al. 2008a, 2008c; Whitaker et al. 2008a, 2008b). In 2006, numerous Georgia producers were forced to abandon their cotton fields due to their inability to control glyphosate-resistant Palmer amaranth with weed management programs that had previously provided excellent control. Surveys were conducted in Georgia and North Carolina to determine the distribution of the resistant biotype(s). Knowledge of the distribution is important in providing producers the best recommendations to manage this resistant biotype and potentially reduce its spread to non-infested areas.

MATERIALS AND METHODS

Field Sampling Techniques: Glyphosate resistance was suspected on one farm in Macon County, Georgia in 2004. Palmer amaranth seedheads were collected from 99 cotton fields in Macon County and two surrounding counties (Taylor and Dooly) during 2005 and from an additional 37 fields

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in seven counties in 2006 (Figure 1). Fields for sampling were concentrated in counties where resistance was suspected.

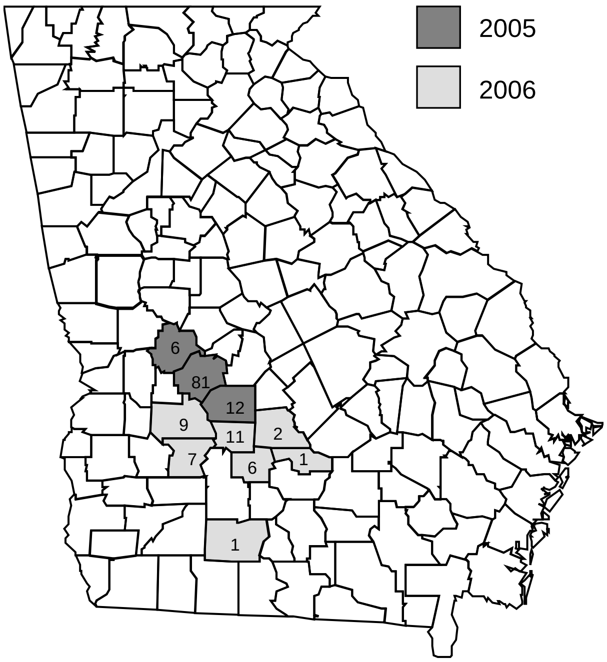

Figure 1. Georgia counties sampled for glyphosate-resistant Palmer amaranth in 2005 and 2006. Number within a county is the number of fields sampled.

Glyphosate resistance was initially suspected in three counties in North Carolina (Hoke, Robeson, and Wayne counties) in 2005 (Figure 2). In seven fields with suspected resistance, Palmer amaranth was found to survive glyphosate applied at two to four times normal application rates. Seed collection in the fall of 2005 was concentrated in the two general areas with suspected resistance, but an effort was made to sample all counties in the eastern portion of North Carolina plus four cotton production counties in the southwestern portion of the state (Figure 3). Seed were collected from a total of 290 cotton fields in 29 counties. Palmer amaranth was not found in three additional counties surveyed in northeastern North Carolina.

Sampling technique in both states included randomly harvesting a minimum of 30 seedheads from female plants spaced at least 10 m apart in infested fields while walking in a zig-zag pattern over the field. Cropping history and herbicide use for each field were unknown at the time of the survey. Glyphosate-resistant cultivars comprised 99% of the cotton planted in each state (USDA-AMS2007), hence there is a high probability that each field had been treated at least once with glyphosate. Seedheads were placed in paper bags and the GPS (global positioning system) coordinates of the field recorded. Bags containing the seedheads were placed in a greenhouse for drying. Seed were then threshed by hand and stored at 1 C until use. Seed germination exceeded fifty percent.

Greenhouse Screening: The screening was conducted during the fall and winter of 2005, 2006, and 2007. Samples from Georgia were screened in a greenhouse in Tifton, GA while those from North Carolina were screened in Raleigh, NC. Greenhouses were maintained at 32$\pm$5 C, and natural light was supplemented for 12 to 14 h each day by metal halide lamps (400 μE m^{-2} s^{-1}). Due to the large number of samples, all locations within a state could not be screened simultaneously. During each screening, previously confirmed glyphosate-resistant and -sensitive biotypes were included for comparison. Seed from each location and the control populations were planted separately into flats (10 cm by 15 cm, 7 cm deep) containing commercial potting media (Metro Mix 200 growing medium, Scotts-Sierra Horticultural Products Co., 14111 Scottslawn Road, Marysville, OH). Seedlings were thinned to 8 to 12 plants per flat within 2 d after emergence. Plants were watered by drip (Georgia) or overhead irrigation (North Carolina) and were fertilized (Peters Professional All Purpose 20-20-20 fertilizer, Scottslawn Road, Marysville, OH) as needed to maintain good growth.

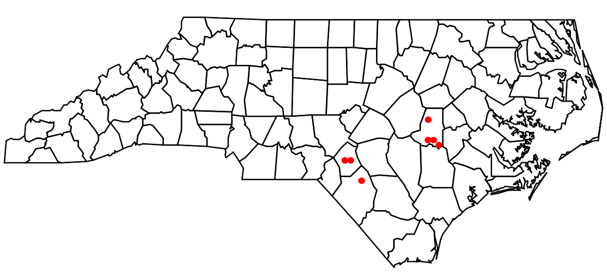

Figure 2. Glyphosate resistance initially suspected in seven fields in Hoke, Robeson, and Wayne counties during 2005 in North Carolina.

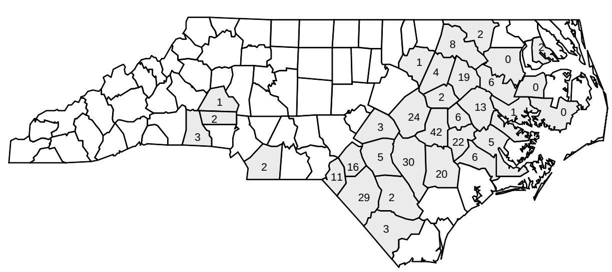

Figure 3. North Carolina counties sampled for glyphosate-resistant Palmer amaranth in 2005. Number within a county is the number of fields sampled.

Seedlings 7 to 10 cm tall were treated with the potassium salt of glyphosate (Roundup WEATHERMAX, Monsanto Company, St. Louis, MO) at 280 and 840 g a.e. ha^{-1}. In a preliminary study, glyphosate at 280 g ha^{-1} controlled sensitive biotypes at least 95% under the aforementioned greenhouse conditions. The higher rate, 840 g ha^{-1}, is the rate normally recommended for postemergence application to cotton under field conditions to control this pest (Anonymous, 2008). Glyphosate was applied with a CO_2-pressurized backpack sprayer (Georgia) or a spray chamber (North Carolina) calibrated to deliver 140 L ha^{-1} at 165 kPa. The experimental design was a randomized complete block (blocked by plant size) with treatments replicated three times, and the experiment was conducted twice. Visible Palmer amaranth control was estimated 21 d after glyphosate application using a scale of 0 to 100, where 0 = no control and 100 = death of all plants (Frans et al., 1986). Shoot fresh weight was recorded in North Carolina. Results were pooled across runs within location because of a lack of interaction. The following criteria were used in both states to determine resistance: plants controlled less than 50% by glyphosate at 840 g ha^{-1} were considered to be highly resistant; plants controlled less than 50% by glyphosate at 280 g ha^{-1} were considered to have a low level of resistance. Several samples had one or two plants poorly controlled while the remainder died; such samples were considered to be a mixed population, perhaps representing developing populations of glyphosate resistance in that field.

RESULTS AND DISCUSSION

The 10 counties surveyed in Georgia represent an intensive cotton production area containing over 125,000 ha (Boatright and McKissick, 2004). Palmer amaranth resistant to glyphosate was found in 71 of the 136 Georgia fields sampled, with resistance noted in all counties surveyed (Figure 4). Forty-nine of the 99 fields sampled in 2005 in Macon, Taylor, and Dooly counties contained glyphosate-resistant Palmer amaranth. Palmer amaranth from 23 of these fields was considered highly resistant to glyphosate. Twenty fields had Palmer amaranth with a low level of resistance, and six fields had mixed populations. Sixty-two percent of the 37 fields sampled in seven additional counties in 2006 contained glyphosate-resistant Palmer amaranth. Ten of those fields contained highly resistant Palmer amaranth, three contained Palmer amaranth with a low level of resistance, and nine had mixed populations.

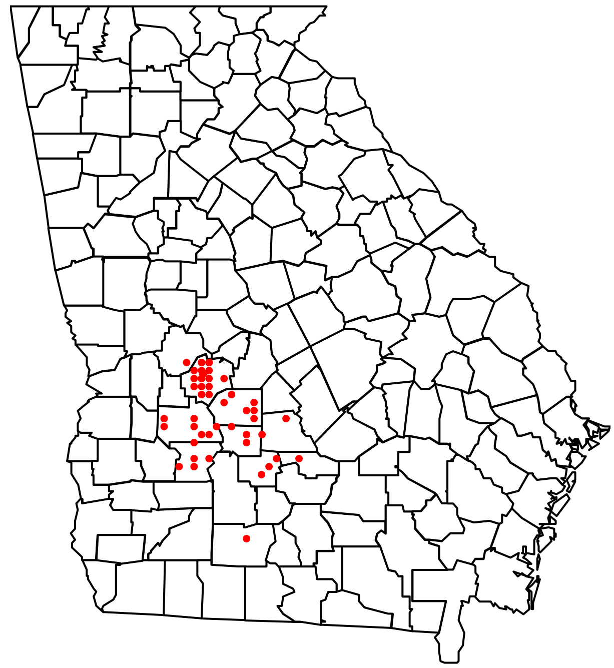

Figure 4. Location of 71 fields in Georgia with glyphoste-resistant Palmer amaranth during 2006.

Cotton production in North Carolina is located predominately in the eastern portion of the state. The 28 counties sampled in eastern North Carolina (Figure 3) produced 286,000 ha of cotton in 2005 while the four counties in the western portion of the state produced 3,000 ha (NCDACS, 2008).

Populations of Palmer amaranth resistant to glyphosate were found in 49 fields, or 17% of the fields sampled, scattered over 11 counties in North Carolina (Figure 5). Most of the resistant fields were located in or near the areas where resistance was initially suspected (Figure 2). Of the 49 fields with glyphosate resistance, 10 had a high level of resistance, 30 had a low level, and 9 had mixed populations.

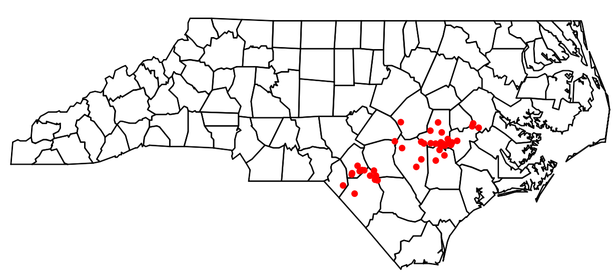

Figure 5. Location of 49 fields in North Carolina with glyphosate-resistant Palmer amaranth during 2005.

The level of resistance within these fields has not been quantified for all locations. However, in research conducted on the initial glyphosate-resistant population in Georgia, I_{50} values (glyphosate rate necessary for 50% inhibition) for visible control and shoot fresh weight were 8- and 6.2-times greater, respectively, relative to a known glyphosate-susceptible population (Culpepper et al. 2006). In one of the most resistant North Carolina populations, the I_{50} for shoot fresh weight reduction was 22-times greater than for a known susceptible population (York et al. 2007).

Glyphosate-resistant Palmer amaranth was found to be more widespread than initially suspected in 2005. Since conclusion of this survey, Extension personnel have observed glyphosate-resistant Palmer amaranth in additional counties and in many more fields in the counties originally found to be infested. It is conservatively estimated that glyphosate-resistant Palmer amaranth occurred on at least 120,000 hectares in 40 counties in Georgia and 75,000 hectares in 22 counties in North Carolina in 2008.

Results of this survey have been incorporated into recommendations and educational programs to increase producers' awareness of the problem and to encourage proactive management programs to reduce selection pressure in fields where the problem currently does not exist (Culpepper et al. 2008b; York and Culpepper 2008). Programs to prevent or delay resistance are strongly encouraged. Cotton production in fields infested with glyphosate-resistant Palmer amaranth will be feasible only with very aggressive management programs (Culpepper et al. 2008a, 2008c; Whitaker et al. 2008a, 2008b)

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