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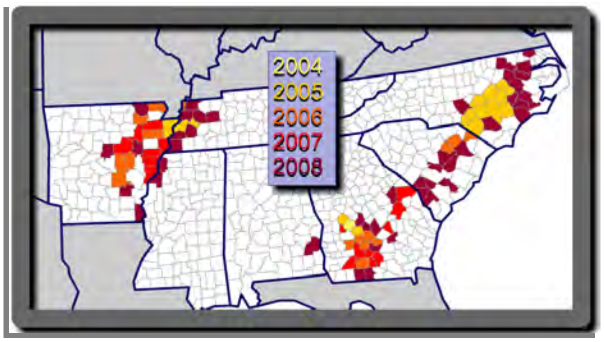
Glyphosate-Resistant Palmer Amaranth (*Amaranthus palmeri*) Spreads in the Southern United States (U.S.)

Glyphosate (*N*-phosphonomethyl glycine) is an exceptionally broad-spectrum herbicide that was first registered for use in 1974. Because of its lack of selectivity, glyphosate was originally used to control annual and perennial weeds in non-crop areas, in perennial crops such as vines, orchards, and plantations, for renovation of turf and timber, and as a pre-plant treatment in no-tillage systems. Applied only for such uses, no weeds were reported to have developed resistance to glyphosate for over twenty years. In 1996, soybean (*Glycine max*) cultivars transgenically modified for resistance to over-the-top treatment with glyphosate were commercialized. Subsequently, glyphosate was used in conjunction with transgenic, glyphosate-resistant soybean, canola (*Brassica napus*), cotton (*Gossypium hirsutum*), and corn (*Zea mays*) cultivars, and became the most widely-used herbicide in the world (Duke and Powles, 2008). In addition to its former uses, glyphosate has now been applied extensively and repeatedly in row-crops for control of annual weeds that have high rates of reproduction - thus greatly increasing the selection of weed populations for potential resistance. In the U.S., glyphosate is often used year after year on the same ground, even when crops are rotated, since the principal row-crop cultivars are all resistant to glyphosate. Since the introduction of transgenic glyphosate-resistant crops, fifteen weed species throughout the world have developed resistance to glyphosate

One of the most serious of the glyphosate-resistant weeds is Palmer amaranth because of its wide distribution through the southern and southwestern U.S., its rapid growth, its ability to compete with crops, and its very high reproductive potential (Klingaman and Oliver 1994; Rowland et al. 1999; Smith et al. 2000; Webster 2005; York et al. 2007). Glyphosate-resistant Palmer amaranth has emerged as a threat to economic weed control in cotton and soybean in the major row-crop growing areas of the southern U.S., particularly in the southeastern Coastal Plain and the north Delta region (Nichols et al. 2008). In this article, we update the distribution (Figure 1.) and the estimation of the area infested (Table 1.) with glyphosate-resistant Palmer amaranth populations, and we seek to alert the pest management community to the apparent rapid spread of this resistant weed.

For each county reported as having a glyphosate-resistant population, a field failure occurred, seed from the field were collected by state extension personnel, and F1 progeny were confirmed resistant in a greenhouse assay using multiple rates of glyphosate and compared to a susceptible local population as a reference (Figure 1.). In many cases, F2 progeny were tested as well. Last spring, we reported that 49 counties had at least one glyphosate resistant population (Nichols et al. 2008). At this time, using the same criteria, 93 counties have confirmed populations. Moreover, numerous other populations are pending confirmation, including populations in Florida and Louisiana that are in counties that are not contiguous with currently confirmed counties.

Figure 1: Counties with confirmed populations of glyphosate-resistant Palmer amaranth



Whereas the county data are documented, the area estimates are approximations (Table 1.). However, they are approximations made by experts who are directly dealing with the problem and supported in some states by surveys done by county extension agents. We do not purport that our estimates are precise, but they have been conscientiously made based on field observations in the affected areas. Moreover, since they have been made consistently by the same individuals using the same criterion, they are indicative of a trend. The categories „present', „moderate', and „severe' (Table 1.) indicate that: 1) resistant populations have been observed; 2) weed management practices had to be changed and escapes were present; and 3) weed management was extremely difficult, many escapes occurred, and in some cases fields were abandoned, respectively.

Table 1: Estimated Hectares Infested with Glyphosate-Resistant Palmer Amaranth*

State	---------- in Soybeans ----------			---------- in Cotton ----------			Total**
	Present	Moderate	Severe	Present	Moderate	Severe	
Alabama		104			104		415
Arkansas	87,996	107,153	27,967	28,963	45,182	13,053	310,315
Georgia	23,155	3,473	5,789	42,048	5,557	9,262	129,668
Mississippi	11,121	14,609	7,305	5,484	7,082	3,541	49,142
North Carolina	8,472	8,472	8,472	15,733	15,733	15,733	72,614
South Carolina	35,000	4,500	6,000	15,000	8,000	3,700	72,200
Tennessee	13,693	6,225	830	10,374	8,298	2,074	41,494
Total							675,848

*Estimated by State Cooperative Extension Cotton, Soybean, and/or Weed Specialists (See Authors) with assistance from County Cooperative Extension Agents.
**Total Infested Hectares is Greater than the Total for Soybean and Cotton alone, because Infestations in Corn and Peanuts were also provided by Alabama and Georgia.

Expansion of area covered by the resistant populations may be occurring in several ways, by seed, pollen, spreading of crop residues, such as cotton gin trash, and the occurrence of new resistance events. Movement of seed may occur over short distances when plants shed their seed, within and between fields by transport of seed on equipment, or by long range transport on equipment going to remote locations, by field spreading of cotton gin trash, or by birds. Since Palmer amaranth is dioecious and wind-pollinated, movement of pollen has been the subject of on-going investigation and is considered a significant means of spread (Sosnoskie et al. 2007). Inheritance of resistance in the first identified population was described as dominant and conferred by a single-gene (Culpepper et al., 2006). The pattern of expansion to adjacent counties is consistent with aerial movement of the resistance gene by pollen; it is likely abetted by movement of seed. After the initial resistant population was found in Georgia, additional resistant populations shortly were described in Arkansas, North Carolina, and Tennessee in counties that were more than 500 kilometers distant from the Georgia field where the resistance was first reported (Norsworthy et al. 2008; Culpepper et al. 2008, Steckel et al. 2009). Although the evidence is indirect, such a pattern of incidence suggests that more than one resistance event may have occurred.

Anticipated Impacts

Palmer amaranth is a very robust annual that frequently grows to 2 or more meters in height. It is a C4 plant that grows very rapidly and is drought tolerant. Seed production is prolific. Palmer amaranth is highly competitive with cotton, soybean, and corn; significant yield losses are likely to occur if Palmer amaranth populations survive in the crop. Even before being resistant to glyphosate, it was already considered one of the most difficult to control weeds in agronomic crops in the southern region (Webster, 2005).

Glyphosate, used with transgenic, glyphosate-resistant cultivars, is still the primary herbicide used for soybean and cotton weed control (http://usda.mannlib.cornell.edu/). In the affected areas, growers have been forced to use herbicides in addition to glyphosate in their weed management programs, thereby incurring input additional costs. Weed control in soybean still can be accomplished with use of protoporphyrinogen oxidase inhibiting herbicides, although excessive reliance solely on this mode of action will have an unfortunate but predictable result. In cotton, the seedling grows slower than do those of soybean and fewer modes of herbicide action are selective for the crop; thus weed control is more problematic in cotton in the affected areas. Overall weed management costs have increased for growers, and in certain of the most heavily infested counties in Georgia the use of primary tillage has increased, displacing conservation tillage hectarage which had expanded when glyphosate was highly effective. Given the rate of spread observed since the initial confirmation of resistance, it is probable that Palmer amaranth will be resistant to glyphosate throughout its range in the not too distant future. Such occurrences will likely result in crop yield and quality losses, increased herbicide costs, and the possibility of changing tillage and cropping systems.

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MONITORING THE RESISTANCE OF RED SPIDER MITE (*Oligonychus coffeae* Nietner) OF TEA TO COMMONLY USED ACARICIDES FROM THE DARJEELING FOOTHILLS AND PLAINS OF NORTH BENGAL, INDIA

ABSTRACT

Toxicity levels of five acaricides viz. ethion, dicofol, propargite, fenazaquin and fenpropathrin were determined in populations of the red spider mite (RSM), *Oligonychus coffeae.* Mite populations were obtained from tea plantations of Darjeeling foothills and their plains spreading over the Dooars (located between 26^0.16" to 27^0.0" N latitude and 88^0.4" to 89^0.53" E longitude) and Terai (25º 57" to 26^0 36" N, Latitude and 89^0 54" to 88^0 47" longitude) regions of North Bengal, India. LC_{50} values were found to be high for ethion and dicofol (261.585, 625.689 and 309.437, 403.349 ppm); intermediate for propargite (46.246 and 97.100 ppm); and low for fenpropathrin and fenazaquin (2.785, 9.383 and 4.523, 6.765 ppm, respectively). It was further observed that red spider mite populations in the tea planting zone of Terai showed significantly less susceptibility to all five acaricides used, than the populations of the Dooars. Levels of susceptibility corresponded to the amounts of