Lessons Learned From Glyphosate-Resistant Palmer Amaranth

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The production and profitability of cotton has been greatly improved by the development and release of genetically-modified, herbicide-tolerant cultivars, particularly those resistant to glyphosate. The proposed benefits of glyphosate-resistant (GR) crop technology include: improved weed control (including difficult-to-control flora such as perennials and volunteer crop plants) and reduced crop injury. Improved crop safety and weed control efficacy can, in turn, result in higher crop productivity, a reduction in total herbicide input, and decreased weed management costs. The adoption of GR cultivars has also allowed US cotton growers to engage, more readily, in conservation tillage. This transition has been especially beneficial for farmers in the SE Coastal Plain, where the soils are sandy, compacted, nutrient-poor and have low moisture-holding capacities.

Unfortunately, the widespread use of glyphosate across space and time has resulted in the development of GR weeds. In 2004, the existence of GR Palmer amaranth was confirmed at a 250 ha field site in Macon County, Georgia; production at this site had been a monoculture of GR cotton where glyphosate, often applied at reduced rates, was used, singly, for at least seven years. Within three years of its discovery, GR Palmer amaranth became the single greatest threat to the economic sustainability of cotton production. As of 2012, GR Palmer amaranth populations have been confirmed in at least 16 US states (http://www.weedscience.org/In.asp). Biotypes that are resistant to other herbicide classes (ALS-inhibitors, DNAs, 4-HPPD-Inhibitors and PSII-inhibitors have been documented throughout the US; Palmer amaranth biotypes with multiple-resistances have been identified in GA (glyphosate and ALS-inhibitors), MS (glyphosate and ALS-inhibitors) and KS (ALS-inhibitors, PSII-inhibitors and 4-HPPD-inhibitors) (http://www.weedscience.org/In.asp).

When acceptable weed control is not realized and Palmer amaranth is allowed to set seed, population densities can become quite high in infested fields. Research conducted at the University of Georgia indicated that Palmer amaranth seed densities exceeded 35,000 seeds per m^2 in a field where the GR biotype was ineffectively managed. Palmer amaranth seed are very small (approximately 1 mm in size) and possess limited nutrient reserves. Therefore, Palmer amaranth plants that become established in the field are likely germinating and emerging from relatively shallow depths within the soil profile. Results from a recent study in GA showed that the majority of Palmer amaranth seedlings emerged from depths up to 2.5 cm; less than 2% emergence was observed for Palmer amaranth seeds buried at depths greater than 10 cm.

Weed management has historically focused on the prevention of seedling establishment and growth (e.g. PRE and POST herbicides, cultivation, etc.); little attention has been provided to strategies that maximize seed depletion from the soil seedbank. A reduction in the number of seed reduces the number of individuals that will be subjected to chemical weed management, as well as the potential number of weed management survivors that can then replenish the seed bank. Recent research initiatives at the University of Georgia have evaluated the efficacy of a single deep tillage event to bury surface/near surface Palmer amaranth seeds to depths below their optimal emergence zone, thereby removing these individuals from the germinable seedbank. Results suggest that GR Palmer amaranth seed bank densities and emerged seedling densities can be reduced by 40 to 60%, as compared to undisturbed soil. However, the ultimate success of this proposed strategy for reducing weed populations is dependent, in part, by the dormancy and longevity of seeds in the soil.

In 2007 and 2008, a study was initiated to evaluate Palmer amaranth seed longevity in the soil seedbank. Glyphosate-resistant and -susceptible seed were hand-harvested and -cleaned and divided into replicate seed-lots of 100 seed each. Each seed-lot was mixed with sand, placed in nylon bags, and buried in a Tifton sandy loam at depths of 1 cm to 40 cm for up to three years. By 36 months, seed viability ranged from 9% (1 cm depth) to 22% (40 cm depth). Results suggest that seeds near the soil surface will not be as persistent as those that are more deeply buried. Results also suggest that deep burial of Palmer amaranth seeds may reduce in-field population densities, but only if the seeds that are present at the lowest depths have been buried for a sufficient period of time before the next soil inversion event.

In addition to seedbank depletion, research efforts in GA have also focused on reducing seed inputs within farming systems. Growers are advised to remove Palmer amaranth plants that have escaped weed control measures (but prior to them achieving reproductive maturity) in order to prevent seed set and return. Subsequently, GA cotton growers have engaged in significant hand-weeding efforts (92% of growers hand-weeded, on average, 52% of their cotton acreage) in order to maintain their fields as weed-free as possible. Unfortunately, growers, extension agents, and university research personnel have observed instances where: 1) previously pulled Palmer amaranth plants have re-rooted and become reestablished in a field and 2) plants that have been cut back (using hoes or machetes) have re-sprouted from dormant buds and resumed normal growth. Therefore, studies were developed to evaluate the potential of Palmer amaranth to grow and develop following defoliation occurring during a simulated hand-weeding failure.

Experimental plots were established in fields planted to glufosinate-tolerant cotton in 2010 and 2011. At flowering (June to August), Palmer amaranth plants were assigned to one of four defoliation treatments: no defoliation, removal of all stem and leaf tissue to the soil line (2011 only), removal of all stem and leaf tissue to a height of 2.5 cm above the soil line and removal of all stem and leaf tissue to a height of 15 cm above the soil line. Floral tissues from all plants in the trials were harvested when seeds were 50 to 75% mature and total seed mass and number were determined. Results from these experiments showed that Palmer amaranth plants cut back (all stem and leaf tissue removed) between 2.5 and 15 cm above the soil line were able to successfully regrow and achieve reproductive maturity. Although none of the defoliated plants achieved the same size as their intact counterparts, they were still able to produce significant amounts seed. Palmer amaranths that were allowed to grow and develop normally produced an average of 435,000 seeds per plant (in 2011); plants cut back to 2.5 and 15 cm above the soil line produced an average of 28,000 and 116,000 seeds per plant, respectively (in 2011). As a consequence, growers need to be aware that ineffectual salvage attempts could negate efforts designed to manage the size of Palmer amaranth populations in the field.

Results from studies conducted in Georgia suggest that practices aimed at altering the weed seedbank (either by enhancing removal or reducing inflow) may be useful for reducing in-field population densities. An analogous strategy is currently being evaluated in CA to determine if seed production by GR weeds can be similarly altered. Each year, orchard growers in California devote a considerable amount of their physical and financial resources towards herbicide applications. Unfortunately, complete (100%) weed control is not assured, even when the most effective chemical programs are employed. Weed escapes can occur for numerous reasons including: improper herbicide selection or inappropriate timing of chemical applications, unfavorable weather conditions, and the development of herbicide resistance in the target weed population, among others. As was stated previously, weeds that survive control operations are a significant concern for growers; seed produced by rogue plants can be returned to the soil may become management problems in subsequent seasons.

Herbicide efficacy is often diminished when products are applied to mature plants; however, there is evidence to suggest that weed seed production can be significantly reduced by late-season, pre-harvest chemical applications. A project was initiated in 2012 to evaluate the effects of POST (glyphosate, glufosinate, paraquat and saflufenacil) herbicides on the growth and seed production of GR weeds common in California orchards. Specifically, we evaluated the effects of sub-lethal and labeled application rates on the seed production and regrowth potential of hairy fleabane in a series of greenhouse and shade-house experiments. As anticipated, small plants (pre-bolting) were injured more than larger plants, regardless of herbicide used. Even when substantial regrowth occurred, weed seed production was reduced by the late season treatments. Interestingly, even glyphosate reduced seed head production in GR hairy fleabane by nearly two-thirds and caused malformations of the flowers and heads that were produced. In the coming year, the fleabane work will be validated in orchard studies, the effects of herbicides on fleabane seed viability will be evaluated, and the effects of late-season herbicides on junglerice seed production will be determined.