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Winter cover crops influence *Amaranthus palmeri* establishment

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ABSTRACT

Winter cover crops were evaluated for their effect on *Amaranthus palmeri* establishment and growth in cotton production. Cover crops examined included rye and four winter legumes: narrow-leaf lupine, crimson clover, Austrian winter pea, and cahaba vetch. Each legume was evaluated alone and in a mixture with rye. Cover crop biomass in monoculture was greatest for rye and lupine (>6750 kg ha^{-1}), while clover, pea, and vetch were less and ranged from 2810 to 4610 kg ha^{-1}. Cover crop biomass was more than doubled when rye was mixed with clover or vetch relative to the legume monoculture. In early-June, *A. palmeri* densities were 46 seedlings m^{-2} in the non-disturbed areas between cotton rows in the fallow, while populations were <4 seedlings m^{-2} with rolled vetch or pea and 18 and 29 seedlings m^{-2} in rolled clover and lupine. Rye and legume mixtures reduced *A. palmeri* densities to <3 seedlings m^{-2}, while rye monocultures had 8 seedlings m^{-2}. There were no differences in *A. palmeri* densities (≥144 plants m^{-2}) in the cotton row among cover crop treatments. By late-June, rye and winter pea controlled *A. palmeri* in the row middle >80% relative to the non-cover crop fallow treatment, while control from clover, vetch and lupine ranged from 64 to 70%. The relationship between *A. palmeri* control in between cotton rows and cover crop biomass was described by a log-logistic regression model with 4530 kg ha^{-1} providing median weed control (Bio_{50}); predicted *A. palmeri* control was 25, 50, and 75% from 2950, 4900, and 8600 kg ha^{-1} cover crop biomass, respectively. However, *A. palmeri* plants in the cotton rows prevented yield production in the absence of herbicides. Where *A. palmeri* was controlled with herbicides, the highest yields occurred following rye, with lower yields following lupin/rye mixture and treatments including pea. Management of herbicide resistant weed species requires diverse management tactics; this may include high-biomass cover crops to reduce weed establishment between crop rows. However, greater research effort is needed to devise weed management options for the crop row that do not rely exclusively on the diminishing array of herbicide tools.

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1. Introduction

Shifts to herbicide-tolerant weeds were predicted to occur within 8 years after the adoption of glyphosate-resistant crops (Shaner, 2000). Glyphosate-resistant *Amaranthus palmeri* was first observed in a continuous glyphosate-resistant cotton (*Gossypium hirsutum* L.) system in 2004 (Culpepper et al., 2006). *A. palmeri* has rapidly become the most troublesome weed species in the southern US (Webster and Nichols, 2012) due to its very high rates of C_4 photosynthesis, aggressive growth habit, ability to tolerate dry soil conditions, and high fecundity (Culpepper et al., 2010). Resistance to glyphosate in Georgia in this dioecious species is the over-expression of the site of action, resulting in glyphosate tolerance at levels 10-times beyond the recommended use rate (Gaines et al., 2010); this trait is spread maternally and through pollen (Sosnoskie et al., 2012).

Prior to the occurrence of glyphosate-resistant *A. palmeri*, growers in Georgia applied glyphosate two to three times a season. In response to glyphosate-resistant *A. palmeri*, growers have reverted to using preemergence herbicides and herbicide mixtures consisting of multiple mechanisms of action, increasing costs of weed control (Culpepper et al., 2010). Also, effectiveness of these additional herbicides is predicated on rainfall or irrigation to move them into the active zone of *A. palmeri* germination.

A. palmeri has developed resistance to multiple commonly used herbicides (Gossett et al., 1992; Heap, 2011; Wise et al., 2009). Successful management of herbicide resistant *A. palmeri* will require an integrated solution that is not based solely on herbicides. Cover crops may work in concert with herbicides in weed management systems. Previous studies have documented that cover crops improve soil structure and water infiltration rates (Touchton et al., 1984; Triplett and Dick, 2008), increase diversity of beneficial

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insects (Tillman et al., 2004), and competitively stress weeds throughout their lifecycle (Cardina et al., 1999; Sarrantonio and Gallandt, 2003). Emergence of small-seeded broadleaf plants of similar size to *A. palmeri* was reduced with increasing rates of mulch residue (Mohler and Teasdale, 1993; Teasdale and Mohler, 2000). The physical impediment and reduced light availability imposed by cover crops are important factors influencing establishment of *Amaranthus* species (Gallagher and Cardina, 1998; Hoffman and Regnier, 2006). High-biomass rye, legumes, and rye–legume mixtures will suppress weeds (Akemo et al., 2000; Norsworthy et al., 2010; Price et al., 2007; Reberg-Horton et al., 2012; Reeves et al., 2005; Timper et al., 2011), but the interactive effect of high-biomass rye and legumes has not been evaluated for *A. palmeri* suppression. Studies were conducted to evaluate, relative to rye monoculture, if rye–legume mixtures: 1) increase winter cover crop biomass, 2) reduce *A. palmeri* establishment and growth, and 3) improve cotton yield.

2. Materials and methods

Field experiments were established in the autumn of 2008 in both a grower's field near Ideal, GA and at the USDA-ARS Jones Research Farm in Chula, GA. The study was repeated at the Jones Research Farm with establishment in autumn of 2009. Both locations had naturalized populations of *A. palmeri*. Soil type at the Ideal farm was Dothan loamy sand, while soil at the Jones Research Farm was Tifton loamy sand. The experiment was designed as a split plot, with main plots as cover crop species and subplots as treated and nontreated with herbicides. For the main plots, cover crops were drilled in 18 cm rows in plots that were 7.6 m long and 3.6 m wide with four replications of each treatment arranged in a randomized complete block design. Preliminary studies on growth and biomass potential of winter cover crop species guided the selection of each species used in this experiment. Rye (*Secale cereale* L., 'Wrens Abruzzi', 100-seed weight of 1.8 g) was planted at 100 kg ha^{-1}, narrow-leaf lupine (*Lupinus angustifolius* L., 'TifBlue 78', 100-seed weight of 9.5 g) was planted at 78 kg ha^{-1}, Austrian winter pea (*Pisum* sativum ssp. arvense (L.) Poir, 100-seed weight of 10.4 g) was planted at 78 kg ha^{-1}, cahaba vetch (*Vicia sativa* × *V. cordata*, 'Cahaba white', 100-seed weight of 7.39 g) was planted at 17 kg ha^{-1}, and crimson clover (*Trifolium incarnatum* L., 'Dixie', 100-seed weight of 0.49 g) was planted at 20 kg ha^{-1}. Main plot treatments included each of these species planted alone and in mixture with rye at the listed rates. For the mixtures, rye was planted first and then the legume. There were two subplots: the first was not treated in order to evaluate the effect of the rolled mulches in suppressing *A. palmeri*; the second subplot was treated with the recommended herbicide program for management of glyphosate-resistant *A. palmeri* (Culpepper et al., 2011) to evaluate the effect of the cover crops on cotton growth and yield. Herbicide treatments included pendimethalin at 1.6 kg ai ha^{-1} and fomesafen 0.28 kg ai ha^{-1} PRE followed by glyphosate 0.84 kg ae ha^{-1} and s-metolachlor 1.3 kg ai ha^{-1} POST followed by POST-directed application of MSMA at 2.2 kg ai ha^{-1} and diuron at 1.3 kg ai ha^{-1}. At the Ideal farm, glufosinate at 0.53 kg ai ha^{-1} was substituted for glyphosate, as glyphosate-resistant *A. palmeri* predominated at this site, while the population at the Jones Research Farm had lower levels of glyphosate resistance. Approximately two weeks prior to cotton planting, cover crops were terminated following rye anthesis by rolling flat with a cylindrical roller/crimper and then applying glyphosate (0.84 kg ai ha^{-1}). Just before cotton planting, the area was strip tilled; the strip tillage unit consisted of residue cutters in front of a subsoil shank that disturbed approximately 18 cm wide strip, into which cotton was planted. Cotton was planted at Chula ('DP 949 B2RF') and Ideal ('Phytogen 375 WRF') in rows spaced 91 cm apart in the first two weeks of May following recommended seeding rates and fertilization practices (Collins et al., 2010). Preemergence herbicides were applied following cotton planting on the same day.

Data were collected throughout the cover crop and cotton life cycle. The amount of photosynthetically active radiation at the ground level, relative to full sun readings, was measured with a quantum line sensor on cloudless days between 1300 and 1400 h in the standing cover crop at crop termination and expressed as a percent light reduction. Cover crop biomass was sampled (2 m section of the second crop row) prior to crop rolling and measured after drying at 70 C. In early-June and late-July, measures of *A. palmeri* population densities in the cotton row of the nontreated subplots were made using four 0.25 m^2 quadrats that were 0.18 m wide and 1.4 m long (configured for the width of the strip tillage disturbance). In the non-disturbed row middle of the nontreated subplots, *A. palmeri* populations were evaluated using eight samples of the previously described quadrats. The increased number of samples was to ensure that a similar proportion of each disturbed and non-disturbed areas (which excluded wheel tracks of the tractor) within the plot were sampled. In late-June, visual estimates of *A. palmeri* control were evaluated using a scale of 0 (no control) to 100% (total control) in the non-disturbed cotton row middles with the rolled winter cover crop. Cotton growth was evaluated throughout the growing season by measuring cotton canopy width and plant height. At the conclusion of the season, above-ground *A. palmeri* biomass was harvested in an area measuring 0.91 cm wide and 2 m long, between plot rows three and four, which included the tilled strips where cotton was planted. After *A. palmeri* harvest, cotton was harvested and yield measured. Data were subjected to a mixed model ANOVA, with years, locations, and their interactions as random factors, while cover crop mixtures were fixed factors. Treatment means were separated using Fisher's Protected $LSD_{0.05}$. The relationship between cover crop biomass and *A. palmeri* control was fit to a log-logistic regression model,

$$y = \frac{d}{1 + \exp[b\{\mathrm{Log}(x) - \log(\mathrm{Bio}_{50})\}]}$$

where y is *A. palmeri* control, d is the upper limit of the regression, x is the rolled cover crop biomass, Bio_{50} is the cover crop biomass that provides median weed control, and b is the slope of the regression at Bio_{50} (Ritz et al., 2013; Seefeldt et al., 1995). An approximate $R^2_{\mathrm{nonlinear}}$ value (Askew and Wilcut, 2001; Jasieniuk et al., 1999) was calculated as:

$$R^2_{\mathrm{nonlinear}} = 1 - \left(\frac{\text{Residual sum of squares}}{\text{Corrected total sum of squares}}\right)$$

3. Results and discussion

3.1. Cover crop growth

Winter cover crops emerged within two weeks after planting, with no differences in rye stand establishment due to the presence or absence of legumes (data not shown). There was a reduction in clover plant stand when mixed with rye (Table 1), possibly due to the high rye seeding rates and rapid emergence and potential allelopathic nature of rye (Yenish et al., 1995). All other winter legume cover crops had similar populations with and without rye.

The tall (up to 1.5 m) and narrow architecture of rye at anthesis reduced full sun light 19% in the crop canopy, similar to clover, but lower than all other cover crops (Table 1). The greatest amount of light reduction occurred with erect and leafy lupine (97%) and