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Do cover crops suppress weeds in the U.S. Southeast? A meta-analysis

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Research Article

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Abstract

Cover crops (CCs) have shown great potential for suppressing annual weeds within agronomic cropping systems across the United States. However, the weed suppressive potential of CCs may be moderated by environmental and management factors that are specific to certain geographic areas and their associated characteristics. This may be particularly true within the U.S. Southeast, where higher mean annual temperature and precipitation generate favorable conditions for both CC and weed growth. To understand the effects of this regional context on CCs and weeds, a meta-analysis examining paired comparisons of weed biomass and/or weed density under CC and bare ground conditions from studies conducted within the Southeast was conducted. Data were identified and extracted from 28 journal articles in which weed biomass and/or weed density were measured along with cash crop yield data, if they were provided. Fourteen studies provided 142 comparisons for weed biomass; 23 studies provided 139 comparisons for weed density; and 22 studies, pooled over both weed response variables, provided 144 comparisons for cash crop yield. CCs had a negative effect on weed density ($P = 0.0016$) but no effect on either weed biomass ($P = 0.16$) or cash crop yield ($P = 0.88$). The mean relative reduction in weed density under CCs was 44%. Subsequent analyses indicated that CC biomass was the key factor associated with this reduction. Weed density suppression was linearly related to CC biomass; a 50% decrease in weed density was associated with 6,600 kg ha^{-1} of CC biomass. Edaphic, geographic, and other management factors had no bearing on this suppressive effect. This highlights the importance of generating adequate CC biomass if weed suppression is the primary objective of CC use and the potential for CCs to reduce weed density over diverse soil, climate, and farm management conditions.

Introduction

The U.S. Southeast is a geographically and edaphically diverse region typified by high relative temperatures and humidity coupled with mild winter conditions that are favorable to plant growth (Konrad and Fuhrmann 2013). From an agronomic perspective, the Southeast region comprises widely grown field crops such as corn (*Zea mays* L.) and soybean [*Glycine max* [L.] Merr.], in addition to those that are predominantly grown in this region, such as cotton (*Gossypium hirsutum* L.) and peanut (*Arachis hypogaea* L.) (Asseng 2013; Knox et al. 2014). Given the biophysical context of the region, weeds are ubiquitous, and infestations can be severe. Weed management in agronomic crops in the Southeast is based almost exclusively on herbicide-centric approaches (Norsworthy et al. 2012; Price et al. 2016b). While herbicides are a highly effective management tool, their efficacy is continually threatened by the potential for selecting herbicide-resistant weed biotypes (Menalled et al. 2016; Neve et al. 2014). The likelihood of this phenomenon is proportional to weed population size and the selection pressure imposed by herbicide (Menalled et al. 2016; Neve et al. 2014). Using ancillary practices that both limit selection pressure and maintain small population size are essential to the ongoing challenge of weed management in the Southeast region (Hand et al. 2021; Norsworthy et al. 2012; Price et al. 2016a). The deliberate use of varied practices that differ in the selection pressure that they impose on weeds is a central tenet of integrated weed management (IWM) approaches (Harker 2013; Menalled et al. 2016; Neve et al. 2014).

One such practice, the use of cover crops (CCs), has been studied extensively as a cultural tactic to limit weed germination, emergence, and growth (Teasdale 2018). CCs have been shown to alter these processes by altering light quantity and quality, providing a physical barrier, and increasing seed predation, among others (Teasdale 2018). CC use has steadily increased in the Southeast region, particularly in the last 10 to 15 yr (Wallander et al. 2021). While much of this recent uptick in adoption may be related to potential CC-based improvements around soil erosion and moisture retention, research has shown that the weed suppression–related benefits of

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this practice are important features of sustained CC use by farmers (Hancock et al. 2020). This has become increasingly true in the Southeast region, given the ongoing difficulty in managing several highly problematic weed species that have developed resistance to many commonly used herbicide sites of action. However, understanding if CCs provide weed-suppression benefits and what key factors either attenuate or amplify their ability to do so is critical to their success and continued adoption as a weed management practice.

Both global and regional meta-analyses on the effect of CCs on weeds have supported their potential as a weed management practice, but results have differed based on management and study scope (Nichols et al. 2020; Osipitan 2018; Osipitan et al. 2019). For example, Osipitan et al. (2019) found little to no difference in the suppressive ability of different CC species when looking at studies on a global basis across both agronomic and horticultural production systems, while Nichols et al. (2020) found that only grass CC species had a significant effect on the reduction of weed biomass within agronomic cropping systems of the U.S. Midwest.

Given the potential for context dependencies, we were interested in understanding how well CCs suppress weeds within agronomic cropping systems of the Southeast, focusing on weed biomass and weed density as response variables. We conducted a meta-analysis to explore the effects of CCs on weeds in the Southeast region and the moderating effect of a variety of factors on potential CC-based weed suppression. Specifically, we sought to answer the following questions: (1) Do CCs suppress weed biomass and/or weed density? (2) What is the magnitude of this effect? (3) Under which contexts is this effect greatest? (4) To what extent do trade-offs exist between weed suppression and cash crop yield?

Materials and Methods

Literature Search and Data Extraction

A systematic search of the literature was conducted using the Web of Science Core Collection, CAB Abstracts, and BIOSIS databases. The search was conducted from June through August of 2020 using the following Boolean string: ("weed management" OR "weed control" OR "weed science" OR "weed suppression") AND "cover crop" OR "catch crop" OR "green manure". An initial selection criterion required that all literature be peer reviewed and that studies were conducted in one of the nine U.S. Department of Agriculture–Agriculture Research Service Southeast (USDA-ARS SE) states within the contiguous United States; this region includes Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee (https://www.ars.usda.gov/southeast-area). Further filtering was based on identifying journal articles that measured the response variable weed biomass (WBIO) or weed density (WDEN) and measured said response variables in the same crop, at the same time point, with all management activities being identical, save for the presence of a fall-planted CC. The specifics of the literature search are documented in a PRISMA flowchart (Figure 1).

Paired comparisons of WBIO or WDEN were extracted from tables and/or figures within our selected journal articles. When data were presented solely in figure format, the GetData graph digitizer (http://getdata-graph-digitizer.com) was used to extract relevant data. For WDEN, if measurements were taken at multiple time points in a season, we either extracted data from the final WDEN measurement, if that value represented a cumulative seasonal total, or summed all values to generate a value for the cumulative seasonal total. For each comparison, we also extracted data for cash crop yield (CY), if provided. Relevant study information was extracted and assessed as potential moderator variables. Examples of relevant information include study duration and experimental design, geographic and pedological specifics, CC management details (CC species, type, planting method, termination method, termination date, biomass at termination), and the type of weeds present in a study.

Data Analysis

The response variables WBIO, WDEN, and CY were transformed into the natural log of the ratio between response value with CCs (numerator) and response value without CCs (denominator); that is, the log response ratio (LRR). This is a common practice to address the high degree of variance from studies given the spatial and temporal differences across selected publications (Philibert et al. 2012). In 11 comparisons of 281 total comparisons, either the treatment or control variable value was zero, so those comparisons were removed before analysis. Previous work has shown that adding an arbitrary small value to both numerator and denominator in order to compute an LRR can lead to unrealistic values and can even change values from negative to positive (Verret et al. 2017; Weisberger et al. 2019). Also, fewer than 20% of all studies reported measures of intra-study variance (e.g., standard deviation or standard error).

To minimize potential for unrealistic values during transformation, each response variable in a given study was weighted using a nonparametric method following the formula $(n \times n)/(n + n)$, where n is sample size (Lajeunesse 2013). Studies reporting greater sample size for a given response variable receive a greater weight than studies with lower sample size. The overall effect of a CC relative to no CC on each of the three response variables (LRR_{WBIO}, LRR_{WDEN}, LRR_{CY}) was assessed using random-effect models, with publication as the random effect and the weights calculated on the previous step, testing whether the overall mean was different than zero. Sensitivity analyses and publication bias were both assessed following statistical procedures from Nichols et al. (2020). Respectively, these analyses did not indicate the presence of studies that had a disproportionate effect on response variables of interest, nor did they indicate the presence of publication-level bias.

Conditional inference trees (CIT) were used as an analytical approach to explore potential interactions among our dependent variables. CIT have been increasingly used in agronomic studies to explore complex interactions among multiple independent variables and identify management effects on productivity and environmental quality (Bastos et al. 2021; Jaenisch et al. 2021; Lollato et al. 2019; Vann et al. 2021). CIT have also been used in the context of meta-analyses, where they are a particularly good fit when dealing with unbalanced data sets, missing data, and both categorical and continuous variables (Philibert et al. 2012; Pittelkow et al. 2015). CIT do not rely on parametric statistical assumptions, limiting bias and overfitting issues that are common in other regression tree approaches, and were specifically developed to identify interactions within complex data sets to facilitate interpretation (Hothorn et al. 2006; Nembrini 2019). Operationally, CIT use an algorithm that implements multiple null hypothesis tests between a chosen response variable (e.g., LRR_{WBIO}, LRR_{WDEN}, LRR_{CY}) and each independent variable (e.g., soil type or CC species). It then selects the independent variable with the strongest association to the response variable, determined by the lowest P-value, and performs a binary split in the data set at this juncture.

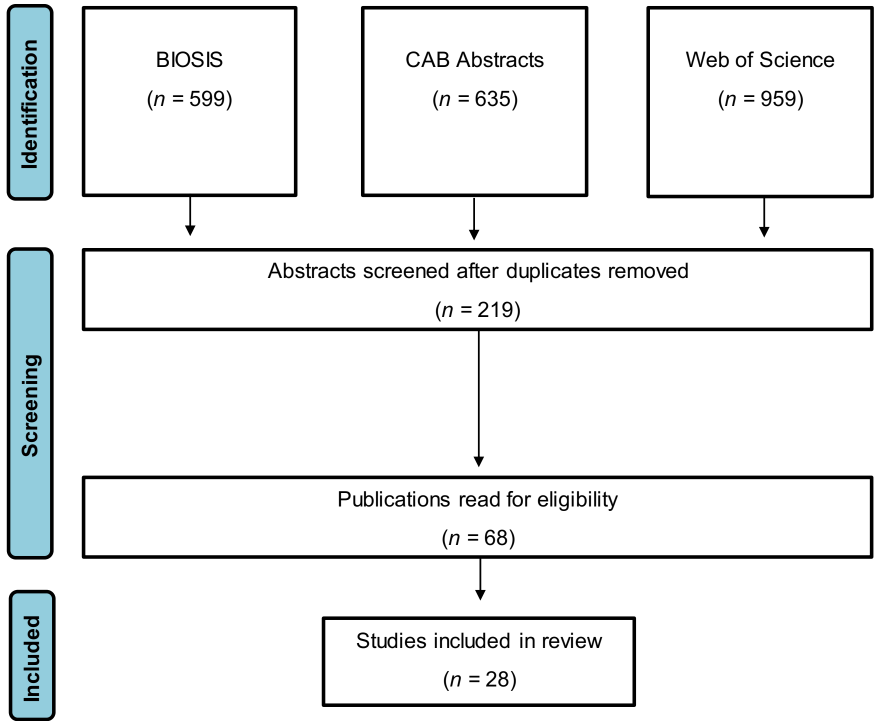

Figure 1. PRISMA diagram detailing the literature search.

This process is repeated recursively, resulting in a "tree" with multiple intermediate and terminal nodes (Mourtzinis et al. 2018).

The significance of our overall model of the CC effect on our three response variables guided the implementation of CIT. Consequently, a significant effect of CC occurred solely with respect to weed density (LRR_{WDEN}), and CIT analysis was performed only on this specific response variable. Tree terminal node means were further compared using a mixed-effect model, with LRR_{WDEN} as the response variable and terminal node membership (fixed effect) and publication (random effect) as the explanatory variables. Based on insights from Vann et al. (2021), and P-values, 20≤% of total observations were present at intermediate nodes, and ≥5% of total observations were present at terminal nodes to ensure adequate power ($n = 139$).

CIT identified CC biomass as an important moderator of LRR_{WDEN}; thus we further explored this relationship by regressing LRR_{WDEN} against CC biomass. A variety of linear and nonlinear relationships were fit to this relationship, and Akaike and Bayesian information criteria values were used to determine the best fit for the selection of a specific model (Müller et al. 2013). Finally, all paired values of LRR_{WBIO} or LRR_{WDEN} and LRR_{CY} were categorized as win (CC either decreased weed density/biomass or increased grain yield) or lose (CC either increased weed density/biomass or decreased grain yield), creating four quadrants. The number of observations in each win–lose quadrant was counted to assess the frequency of the concurrent effects of a CC on weed suppression and crop yield.

Data wrangling, statistical analysis, and visualization were performed in R software v. 3.6.2 (R Core Team 2021). Random- and mixed-effect models were run using the *lmer* function from the LME4 package (Bates et al. 2015). Fixed-effect models were run using the *lm* function from the STATS package. CIT were run using the *ctree* function from the PARTYKIT package (Hothorn and Zeileis 2015; Hothorn et al. 2006). Statistical significance of all model results was evaluated using alpha = 0.10.

Results and Discussion

Literature Search

After removal of duplicates and application of the filtering criteria described earlier, 219 abstracts were screened, leading to the selection of 68 peer-reviewed publications that met our initial selection criteria. These were read, and 28 papers were identified based on meeting all criteria, including proper comparisons of treatment (CC) and control (bare ground) groups, and were used for data extraction and analysis (Tables 1 and 2). The final studies meeting all criteria were published between 1985 and 2018. This generated a total of 281 paired comparisons; 142 comparisons were extracted from 14 papers for WBIO, and 139 comparisons from 23 papers for WDEN. While recent studies have looked at CC effects on weeds at a global scale (Osipitan 2018; Osipitan et al. 2019) and in cotton production systems specifically (Toler et al. 2019), the results of our literature search indicated the presence of only four and five shared publications, respectively. This limited amount of overlap highlights the novelty of our data set and analyses. All 15 categorical and continuous moderator variables, with associated sample size, moderator levels, and summary statistics, are presented in Table 1. All 28 studies and the associated LRRs are presented in Table 2. Studies represented all states from the USDA-ARS SE region, except for Louisiana. Given that this meta-analysis is specific to both region and production practices incorporating CCs, the number of papers is limited compared with meta-analyses addressing broader research questions. However, the papers included in the analysis are representative of the CCs and weeds prevalent in the region. Studies varied in the number of

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Table 1. List of moderators, levels, associated sample sizes, and summary statistics for categorical and continuous independent variables across all 28 studies.[a]

Categorical moderator variable (sample size, N)	Level (sample size, n)
CC species ($N = 241$)	Austrian winter pea[b] (n =2)
	Cahaba vetch[b] ($n = 1$)
	Cereal rye ($n = 112$)
	Cereal rye + Austrian winter pea ($n = 5$)
	Cereal rye + cahaba vetch ($n = 1$)
	Cereal rye + crimson clover ($n = 19$)
	Cereal rye + hairy vetch[b] ($n = 5$)
	Cereal rye + narrow-leaf lupine[b] ($n = 1$)
	Crimson clover ($n = 35$)
	Hairy vetch ($n = 28$)
	Italian ryegrass[b] ($n = 3$)
	Narrow-leaf lupin ($n = 1$)
	Oat[b] ($n = 3$)
	Rapeseed[b] ($n = 1$)
	Subterranean clover[b] ($n = 14$)
	Triticale[b] ($n = 1$)
	Wild radish[b] ($n = 1$)
	Winter wheat[b] ($n = 5$)
CC termination method ($N = 238$)	Herbicide ($n = 146$)
	Herbicide + mowing ($n = 12$)
	Herbicide + roller-crimping ($n = 52$)
	Mowing ($n = 6$)
	Roller-crimping ($n = 17$)
CC type ($N = 241$)	Brassica ($n = 2$)
	Grass ($n = 127$)
	Legume ($n = 81$)
	Mix ($n = 31$)
Crop species ($N = 241$)	Corn ($n = 78$)
	Cotton ($n = 109$)
	Peanut ($n = 5$)
	Soybean ($n = 49$)
Herbicide use ($N = 238$)	Herbicide not used ($n = 68$)
	Herbicide used ($n = 170$)
Location (state) ($N = 281$)	Alabama ($n = 62$)
	Arkansas ($n = 27$)
	Florida ($n = 4$)
	Georgia ($n = 35$)
	Mississippi ($n = 43$)
	North Carolina ($n = 92$)
	South Carolina ($n = 12$)
	Tennessee ($n = 6$)
Soil type ($N = 217$)	Clay ($n = 12$)
	Fine sand ($n = 4$)
	Loamy sand ($n = 51$)
	Sandy loam ($n = 79$)
	Silt loam ($n = 58$)
	Silty clay loam ($n = 4$)
	Silty loam ($n = 9$)
Tillage system ($N = 220$)	No-till ($n = 146$)
	Strip-till ($n = 24$)
	Tillage before CC establishment ($n = 50$)
Weed community composition ($N = 241$)	Community (> 1 species) ($n = 149$)
	Single species ($n = 92$)
Weed type (241)	Summer annual ($n = 224$)
	Summer annual + perennial ($n = 17$)
Continuous moderator variable (sample size, N)	Range (median)
CC biomass ($N = 186$)	0–12.9 (3.7)
CC seeding rate (kg ha^{-1}) ($N = 265$)	6–178 (80)
Soil OM% ($N = 105$)	0.4–2.0 (0.6)
Soil pH ($N = 90$)	5.5–6.9 (6.2)
Year of publication ($N = 241$)	1985–2019 (2011)

[a]Abbreviations: CC, cover crop; OM, organic matter.
[b]Austrian winter pean (*Pisum sativum* L.), Cahaba vetch (*Vicia sativa* L.), hairy vetch (*Vicia villosa* Roth), narrow leaf lupin (*Lupinus angustifolius* L.), Italian ryegrass (*Lolium multiflorum* Lam.), oat (*Avena sativa* L.), rapeseed (*Brassica napus* L.), subterranean clover (*Trifolium subterraneum* L.), triticale [×Triticosecale Wittm. ex A. Camus (Secale × Triticum)], wild radish (*Raphanus raphanistrum* L.), winter wheat (*Triticum aestivum* L.)

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Table 2. List of publications and associated natural log response ratios (LRR) for weed biomass (WBIO), weed density (WDEN), and crop yield (CY).

Publication	LRR_{WBIO}	LRR_{WDEN}	LRR_{CY}
Aulakh et al. 2012		✓	✓
Aulakh et al. 2013		✓	✓
Brown and Whitwell 1985		✓	✓
DeVore et al. 2012		✓	✓
DeVore et al. 2013		✓	✓
Hand et al. 2019		✓	✓
Koger et al. 2002	✓	✓	✓
Koger et al. 2005	✓	✓	✓
Lassiter et al. 2011		✓	
Malik et al. 2008		✓	✓
Norsworthy and Frederick 2005	✓		✓
Norsworthy et al. 2016		✓	✓
Palhano et al. 2018a		✓	✓
Price et al. 2012	✓	✓	✓
Price et al. 2016b		✓	✓
Reddy 2001	✓	✓	✓
Reddy 2003	✓	✓	✓
Reddy and Koger 2004	✓	✓	✓
Reddy et al. 2003	✓	✓	✓
Smith et al. 2011		✓	
Timper et al. 2011		✓	
Vann et al. 2018	✓		✓
Webster et al. 2013	✓	✓	✓
Wells et al. 2013		✓	
Wells et al. 2016	✓		
Wiggins et al. 2017		✓	
Yenish et al. 1996	✓		✓
Zotarelli et al. 2009	✓		✓

comparisons conducted at each site, with most sites associated with between one and five comparisons used in our analysis (Figure 2).

Overall Effects and the Role of CC Biomass

CCs reduced WDEN ($P < 0.0001$), but had no significant effect on WBIO (21% reduction, $P = 0.16$) (Figure 3). Over all studies, CCs reduced WDEN by an average of 44% (Figure 3). The results of CIT for LRR_{WDEN} returned five nodes, including three terminal nodes and two explanatory variables selected (Figure 4). An initial split in the data set occurred as a function of publication date, where data were aggregated into comparisons that occurred before and after 2002 (Figure 4). A second split resulted in an intermediate node that split all comparisons after 2002 based on a CC biomass threshold of 3,300 kg ha^{-1} (Figure 4). LRR_{WDEN} was greatest under study conditions published before 2002 (0.36, representing a 34% increase in LRR_{WDEN}, node 2); intermediate under study conditions published after 2002 and having less than 3,300 kg ha^{-1} CC biomass (−0.53, representing a 42% decrease in LRR_{WDEN}, node 4); and lowest under study conditions published after 2002 and having more than 3,300 kg ha^{-1} CC biomass (−0.87, representing a 58% decrease in LRR_{WDEN}, node 5). These results indicate that for studies conducted after 2002, CC biomass was the fundamental moderator associated with decreased WDEN; increased biomass above a 3,300 kg ha^{-1} threshold was associated with the greatest suppression on this response variable. The authors believe that changes could in LRR_{WDEN} could be due to a changing weed spectrum in the region during this time. Larger-seeded weed species became less troublesome during this period, while other smaller-seeded weed species became more prevalent (Webster and Nichols 2012). This divergence was around the time of the development and expansion of glyphosate-resistant weeds throughout the region (Reddy and Norsworthy 2010). Given that smaller-seeded weed species are more responsive to CC biomass, LRR_{WDEN} may have been reduced as a result.

Our results indicate that CC biomass was the key driver in reducing WDEN. CC biomass was linearly correlated with increased suppression of WDEN (decreased LRR_{WDEN}). Results of regression analysis found that a 50% relative reduction in WDEN was associated with 6,600 kg ha^{-1} of CC biomass (Figure 5). Analyses did not indicate the importance of any additional moderators, suggesting that the relative suppressive effect of CCs on WDEN is present across a wide range of edaphic conditions (e.g., soil texture and pH) and management choices (e.g., CCs and cash crop species selection, tillage system, and herbicide use). Both recent meta-analyses and experimental work have come to similar conclusions, particularly with respect to the effect of CC biomass (Baraibar et al. 2018; MacLaren et al. 2019; Nichols et al. 2020; Osipitan 2018; Osipitan et al. 2019). Nichols et al. (2020), who conducted an analogous meta-analysis of CC effects on weeds in the U.S. Midwest, also found that the relative effect of CC biomass was an important moderator of weed suppression, and this suppressive effect was unaffected by varied geographic environments, tillage and crop planting decisions, and herbicide use.

However, the results of Nichols et al. (2020) differed from ours in two important ways. First, within the Midwest context, CCs exhibited a suppressive effect on WBIO and not WDEN. Furthermore, CC type (grass, legume, forb) was an important moderator of this effect. That work found that grass CC (predominantly cereal rye [*Secale cereale* L.]) was associated with a significant mean WBIO reduction of 68%, while the 33% reduction associated with other CC types was not significant. In that study, the quantity of CC biomass associated with a 75% reduction of WBIO was 5,000 kg ha^{-1}. Conversely, our results only demonstrate a suppressive effect of CC biomass on WDEN; and neither CC species nor type were significant moderators. While the response variables were different across meta-analyses, these contrasting findings point to the importance of factors, such as heat-unit accumulation, that regulate CC biomass accumulation and CC persistence. Both field studies and modeling work have substantiated the effect of heat-unit accumulation on CC biomass and its potential impact on weeds (Baraibar et al. 2018; Nichols et al. 2020). To further quantify these regional differences, the maximum values for CC biomass in our study exceeded those recorded in Nichols et al. (2020) by approximately 3,500 kg ha^{-1}, highlighting the favorable climatic conditions of the Southeast to generate substantial biomass irrespective of CC type or species. However, not all biomass is created equal when it comes to weed suppression. Environmental factors not only affect CC biomass accumulation but also affect CC decomposition rates, which affects season-long weed suppression by the CC during the cropping season (Thapa et al. 2022). This could explain the ability of the CC to suppress weed density but allow for increased weed biomass due to greater heat units and rainfall in the cropping season.

The key determinants in generating sufficient CC biomass to suppress weeds are planting and termination dates; these two "windows" determine the cumulative amount of heat units to which a CC is exposed (Nichols et al. 2020; Price et al. 2016b). A study conducted across sites in Alabama and Florida examining the effects of four planting and four termination dates found that CC biomass values for cereal rye and crimson clover (*Trifolium incarnatum* L.), unsurprisingly, were greatest at the earliest planting date and latest termination date (i.e., the largest possible growth window). Conversely, CC biomass values for cereal rye and crimson clover were reduced by factors of eight and ten, respectively, when planting was latest and

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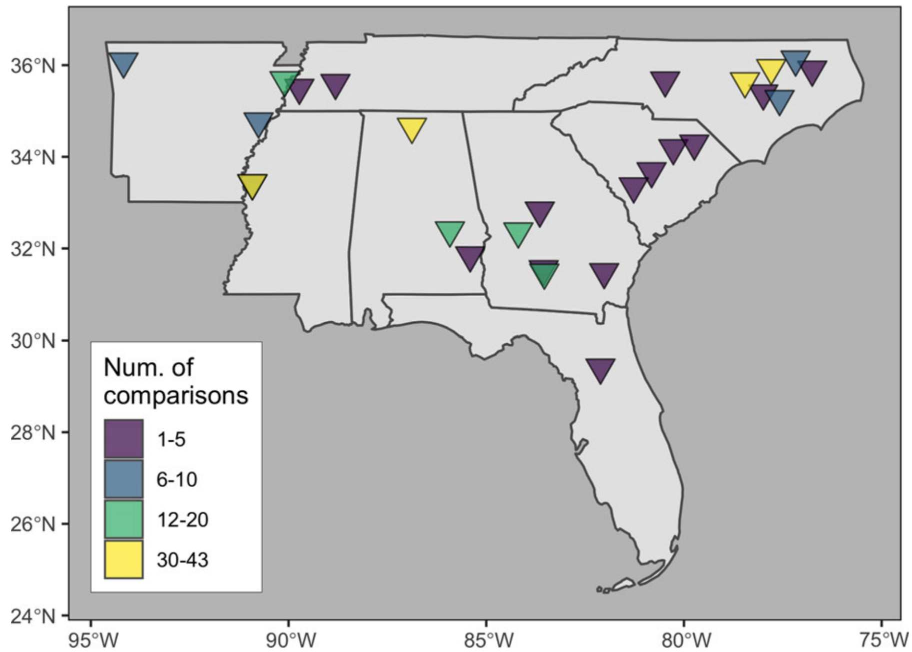

Figure 2. Map of study locations used in the meta-analysis. Triangles are colored according to the number of paired comparisons from each location.

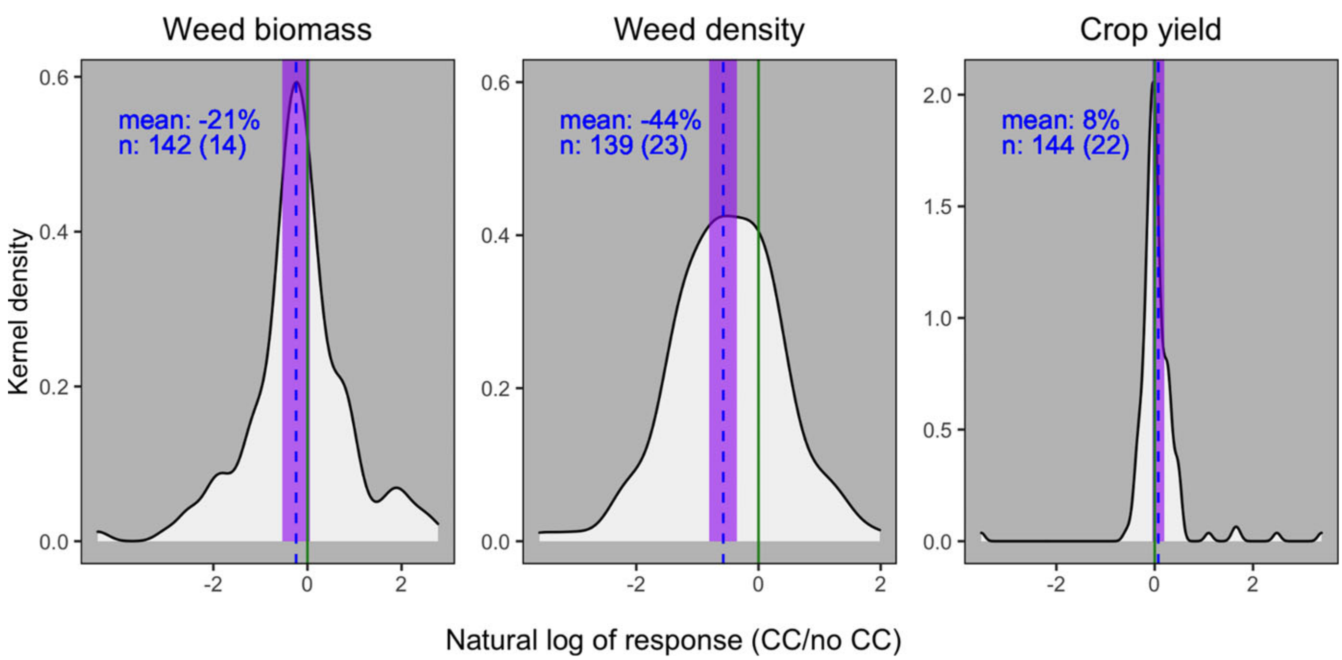

Figure 3. Overall mean effect of cover crop (CC) on weed biomass, weed density, and crop yield. The blue dotted line, purple bar, and green solid line represent the mean response, 95% confidence interval, and no response, respectively. Statistical difference (mean response is significantly different than zero) was assessed with $\alpha = 0.10$.

termination earliest (i.e., the smallest possible growth window) (Price et al. 2016b). While heat-unit accumulation is clearly the determinant in generating adequate CC biomass, this can be highly constrained by cash crop production practices requiring termination based on timing of cash crop planting, which may restrict CC biomass accumulation. This often entails the use of crop varieties that optimize the use of heat units and solar radiation. Practically speaking, this means that planting dates have become earlier and harvest dates later over time, which has become increasingly possible because of climate change (Cammarano and Tian 2018; Knox et al. 2014).

Due to these agronomic and economic realities, research has increasingly explored ways to establish CCs earlier and terminate them later without requiring wholesale changes in the adoption of shorter-season cash crop varieties. Establishment methods have made use of aerial CC seeding via planes and helicopters, as well as ground-driven equipment such as “highboy” applicators that do not damage the growing crop (Bergtold et al. 2019). However, these methods require higher CC seeding rates, due to greater seed and seedling losses (Bergtold et al. 2019). Additionally, the use of drill interseeding has been explored to combine earlier seeding (during

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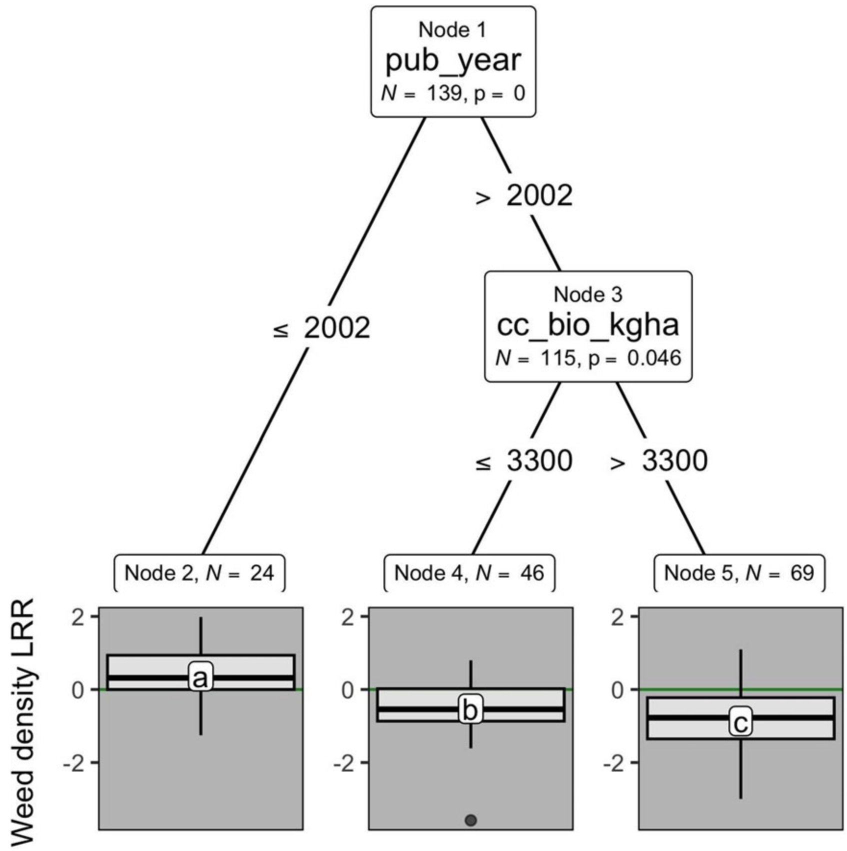

Figure 4. Conditional inference tree for weed density log response ratio (LRR_{WDEN}). Mean response for box and whisker plot followed by the same letter are not significantly different ($\alpha = 0.10$). pub_year is the publication year; cc_bio_kgha is the cover crop biomass in kg ha^{-1}.

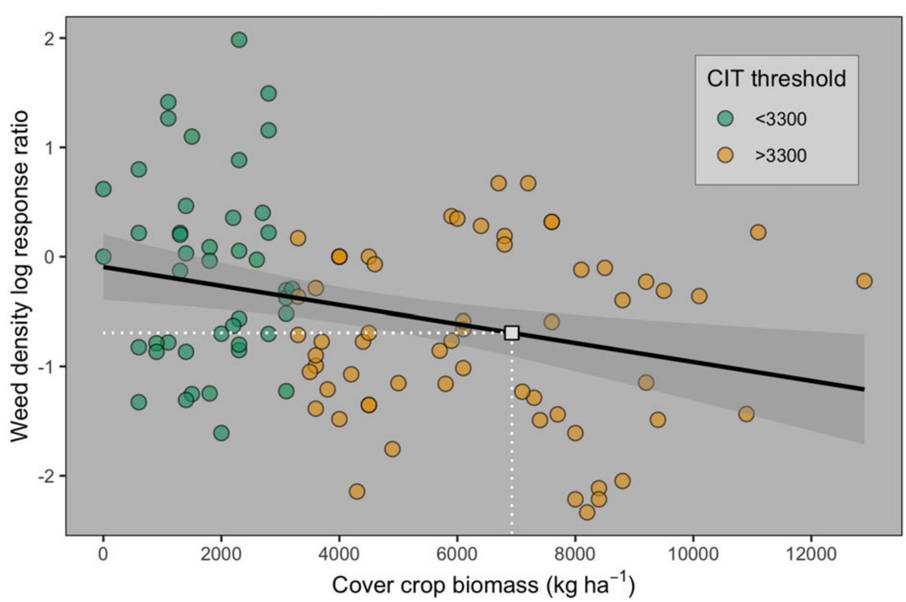

Figure 5. Weed density log response ratio (LRR_{WDEN}) as a function of cover crop (CC) biomass (kg ha^{-1}). Points are colored based on conditional inference tree (CIT) threshold: green values are those represented in the <3,300 kg ha^{-1} terminal node; yellow values are those represented in the >3,300 kg ha^{-1} terminal node. The white dotted line represents a 50% reduction in LRR_{WDEN} at an associated CC biomass value of 6,600 kg ha^{-1}.

cash crop vegetative development) and the benefits of a drill, namely good seed–soil contact (Curran et al. 2018). Findings on CC biomass via drill interseeding have been mixed and appear to be highly contingent on in-season weather patterns (Moore and Mirsky 2020; Stanton and Haramoto 2021). Drill interseeding also requires specialized equipment and may impact in-season

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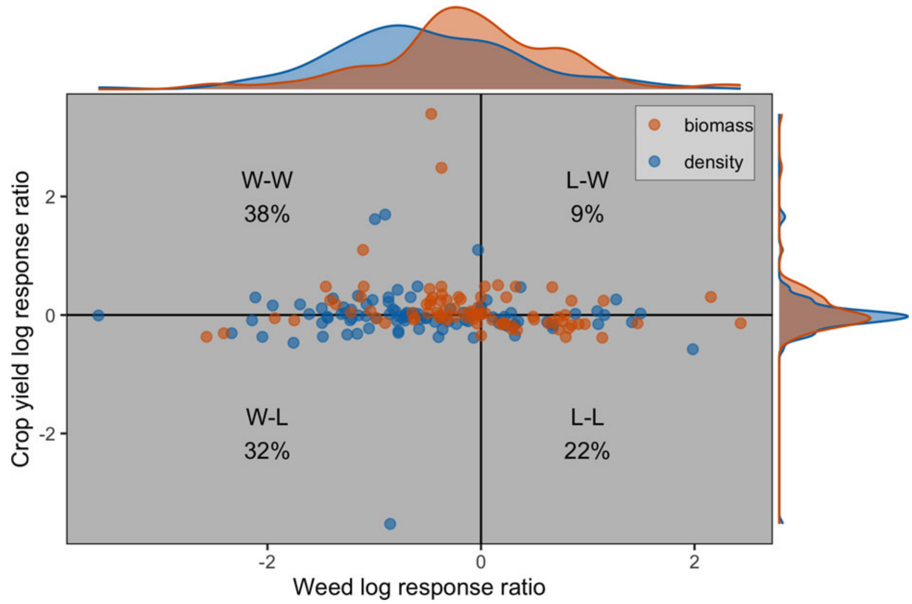

Figure 6. Crop yield and weed response log response ratio (LRR) plotted against each other. The distribution of LRR for crop yield and weeds is presented to the right of and above the graph. Circles and distribution curves correspond to weed biomass (orange) and weed density (blue) values, respectively. W-W, L-W, W-L, and L-L are win/lose quadrants where the first letter represents weed biomass/density (win if negative LRR, lose if positive LRR) and the second letter represents yield (win if positive LRR, lose if negative LRR). Comparisons where cover crop suppressed weed and improved yield (W-W) comprised 38% of all points.

herbicide management (Curran et al. 2018; Stanton and Haramoto 2021). Later termination of CCs has also been researched, and one method in particular, "planting green," has been receiving increasing research attention following from farmer experimentation (Grint et al. 2022; Quinn et al. 2021; Reed et al. 2019). Planting green entails planting a cash crop into a living CC and terminating the CC at the time of planting or shortly after to optimize the benefits of the CC (Reed and Karsten 2022). Research in Kentucky demonstrated that postplant CC termination of cereal rye, associated with a 21-d difference from standard CC termination practices, resulted in approximately twice as much CC biomass (Quinn et al. 2021). The relative merits and trade-offs of these warrant further investigation, particularly within the Southeast states upon which our analyses are based.

While greater CC biomass at planting is more effective at suppressing the germination and emergence of weed seedlings, particularly during the earlier part of the growing season, the ability of CC biomass to suppress the growth and development of WBIO in the Southeast may be constrained by the very same factors that make it successful in reducing WDEN. For example, faster accumulation of heat units and high relative humidity levels like those of the Southeast are equated with expedited rates of CC biomass decomposition, as well as weed growth and development (Reinhardt Piskackova et al. 2021; Thapa et al. 2022). Simply put, decreased CC biomass covering the soil over the course of the season coupled with a favorable environment for WBIO accumulation suggests a successful trajectory for any weeds that evade chemical or physical control. This is compounded by the fact that many of the most prevalent weed species in agronomic cropping systems of the Southeast are those that possess a C_4 photosynthetic pathway, which provides them a relative advantage over most crops in the region. Salient examples include annual and perennial grasses such as broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster] and johnsongrass [*Sorghum halepense* (L.) Pers.], in addition to the broadleaf Palmer amaranth (*Amaranthus palmeri* S. Watson), as well as nutsedge species (*Cyperus* spp.) (Rojas-Sandoval 2015; Sage 2017; Travlos et al. 2019; Wallace et al. 2013; Ward et al. 2013).

Given this fact, finding ways of reducing WDEN levels even further and dealing with escapes is paramount. Coupling CC use with herbicide best management practices is an essential part of this equation; particularly the use of overlapping residual chemistries, rotation of diverse herbicide sites of action, and the use of postemergence direct application (Norsworthy et al. 2012). However, despite a reduction in WDEN by approximately 50% relative to bare ground, we did not find evidence of a strong moderating effect of herbicide. Specifically, herbicide use did not surface as a node in our CIT analysis, suggesting that the suppressive effect of CCs on WDEN was the same across both herbicide-treated and untreated comparisons. Consequently, additional work will be necessary to optimize CC–herbicide interactions. While the study of CC–herbicide interactions is not new (Teasdale 1996), more recent work has elucidated the mechanisms behind how CCs and herbicides may synergistically limit weed seed germination and seedling survival (Bunchek et al. 2020; Wallace et al. 2019).

Additionally, studies within the Southeast have shown that few residual herbicides negatively impact the postharvest growth and establishment of CCs in the fall, suggesting that CC integration as an IWM tactic is not impeded by the current spectrum of active ingredients (Palhano et al. 2018b; Rector et al. 2020). Further integration of novel management practices may augment CC–herbicide synergies. One recent example involves the idea of "weed priming" (Oliveira et al. 2020). Authors from that study hypothesized that the use of plant hormones could either synchronize weed seed germination patterns or induce higher levels of dormancy. In either case, coupled with preemergence herbicide and CC use, this could be a highly effective practice to both increase the efficacy of preemergence herbicides and potentially limit selection pressure by minimizing the heavy reliance on postemergence herbicides. Empirical work is needed to substantiate these hypotheses, but this presents a creative approach to CC-based IWM.

Crop Yield and Weed Management Trade-Offs

Crop yield comparisons were pooled over our WBIO and WDEN comparisons, resulting in 144 comparisons across 22 publications. Our results indicated that LRR_{CY} was not significantly different from zero (8% increase, $P = 0.88$) (Figure 3). While CC-driven gains in soil conservation and moisture retention have been seen across varied sites within the Southeast, improvements to these properties may only improve crop yields in growing seasons when precipitation amounts may be limited or with the inclusion of a legume CC (Farmaha et al. 2022). LRR values for crop yield and both weed responses were graphed together to quantify the number of comparisons where both crop yield responses were above zero and weed responses were below zero, leading to the characterization of "win" and "lose" scenarios (Figure 6). The best possible outcome for increased yield and reduced weeds (win–win, or W-W) occurred across 38% of comparisons. These data also indicate that while 70% of all weed response comparisons were less than zero, only 47% of yield comparisons were above zero (Figure 5). This may be an artifact of the studies included in our analyses, as most were designed to evaluate the suppressive effect of CCs on weeds, but it may also suggest trade-offs around optimizing crop yield under CCs. Additionally, because crop yield response from comparisons was taken from broad temporal, geographic and management gradients, this may mask benefits accrued during years of precipitation deficit or nitrogen limitation.

Given the challenges of weed management in the Southeast region, CCs have an important role to play in IWM systems. While our results strongly highlight the role of CC biomass in reducing WDEN, we recognize the challenge of achieving certain thresholds given current agronomic and economic objectives and concerns stemming from farmers themselves. Increased interest and study around CC establishment and termination options show promise for balancing crop production and weed-suppression goals. This interest and excitement appear consistent across industry, farmer, and university stakeholders, suggesting that balancing multiple objectives in CC-based systems is a high priority that is drawing on a diversity of experience and knowledge. However, we end by cautioning that without proper support in the form of education and policy to both increase adoption and ensure best management practices, these collaborations and shared efforts will be impeded.

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References

Asseng S (2013) Agriculture and climate change in the Southeast USA. Pages 128–164 in Ingram KT, Dow K, Carter L, Anderson J, eds. Climate of the Southeast United States. NCA Regional Input Reports. Washington, DC: Island Press. https://doi.org/10.5822/978-1-61091-509-0_7

Aulakh J, Price AJ, Enloe S, Wehtje G, Patterson M (2013) Integrated Palmer amaranth management in glufosinate-resistant cotton: II. Primary, secondary and conservation tillage. Agronomy 3:28–42

Aulakh JS, Price AJ, Enloe SF, Van Santen E, Wehtje G, Patterson MG (2012) Integrated Palmer amaranth management in glufosinate-resistant cotton: I. Soil-inversion, high-residue cover crops and herbicide regimes. Agronomy 2:295–311

Baraibar B, Mortensen DA, Hunter MC, Barbercheck ME, Kaye JP, Finney DM, Curran WS, Bunchek J, White CM (2018) Growing degree days and cover crop type explain weed biomass in winter cover crops. Agron Sustain Dev 38:65

Bastos, LM, Rice, CW, Tomlinson, PJ, Mengel, D (2021) Untangling soil-weather drivers of daily N_2O emissions and fertilizer management mitigation strategies in no-till corn. Soil Sci Soc Am J 85:1437–1447

Bates, D, Mächler, M, Bolker, B, Walker, S (2015) Fitting linear mixed-effects models using lme4. J Stat Softw 67:1–48

Bergtold JS, Ramsey S, Maddy L, Williams JR (2019) A review of economic considerations for cover crops as a conservation practice. Renew Agric Food Syst 34:62–76

Brown SM, Whitwell T (1985) Weed control programs for minimum-tillage cotton (*Gossypium hirsutum*). Weed Sci 33:843–847

Bunchek JM, Wallace JM, Curran WS, Mortensen DA, VanGessel MJ, Scott BA (2020) Alternative performance targets for integrating cover crops as a proactive herbicide-resistance management tool. Weed Sci 68:534–544

Cammarano D, Tian D (2018) The effects of projected climate and climate extremes on a winter and summer crop in the southeast USA. Agric For Meteorol 248:109–118.

Curran WS, Hoover RJ, Mirsky SB, Roth GW, Ryan MR, Ackroyd VJ, Pelzer CJ (2018) Evaluation of cover crops drill interseeded into corn across the Mid-Atlantic region. Agron J 110:435–443

DeVore JD, Norsworthy JK, Brye KR (2012) Influence of deep tillage and a rye cover crop on glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) emergence in cotton. Weed Technol 26:832–838

DeVore JD, Norsworthy JK, Brye KR (2013) Influence of deep tillage, a rye cover crop, and various soybean production systems on Palmer amaranth emergence in soybean. Weed Technol 27:263–270

Farmaha BS, Sekaran U, Franzluebbers AJ (2022) Cover cropping and conservation tillage improve soil health in the southeastern United States. Agron J 114:296–316

Grint KR, Arneson NJ, Oliveira MC, Smith DH, Werle R (2022) Cereal rye cover crop terminated at crop planting reduces early-season weed density and biomass in Wisconsin corn–soybean production. Agrosyst Geosci Environ 5: e20245

Hancock G, Liu Y, Smith AR, Plastina A (2020) Motivations and challenges of cover crop utilization for Georgia crop production. J Am Soc Farm Manag Rural Appraisers 2020:122–128

Hand LC, Nichols RL, Webster TM, Stanley Culpepper A (2019) Cereal rye cover crop and herbicide application method affect cotton stand, Palmer amaranth (*Amaranthus palmeri*) control, and cotton yield. Weed Technol 33:794–799

Hand LC, Randell TM, Nichols RL, Steckel LE, Basinger NT, Culpepper AS (2021) Cover crops and residual herbicides reduce selection pressure for Palmer amaranth resistance to dicamba-applied postemergence in cotton. Agron J 113:5373–5382

Harker KN (2013) Slowing weed evolution with integrated weed management. Can J Plant Sci 93:759–764

Hothorn T, Hornik K, Zeileis A (2006) Unbiased recursive partitioning: a conditional inference framework. J Comp Graph Stat 15:651–674

Hothorn T, Zeileis A (2015) partykit: a modular toolkit for recursive partytioning in R. J Mach Learn Res 16:3905–3909

Jaenisch BR, Munaro LB, Bastos LM, Moraes M, Lin X, Lollato RP (2021) On-farm data-rich analysis explains yield and quantifies yield gaps of winter wheat in the US central Great Plains. Field Crops Res 272:108287

Knox P, Fuhrmann C, Konrad C (2014) Challenges and opportunities for southeast agriculture in a changing climate: perspectives from state climatologists. Southeastern Geo 54:118–136.

Koger CH, Reddy KN (2005) Effects of hairy vetch (*Vicia villosa*) cover crop and banded herbicides on weeds, grain yield, and economic returns in corn (*Zea mays*). J Sustain Agric 26:107–124

Koger CH, Reddy KN, Shaw DR (2002) Effects of rye cover crop residue and herbicides on weed control in narrow and wide row soybean planting systems. Weed Biol Manag 2:216–224

Konrad CE, Fuhrmann CM (2013) Climate of the Southeast USA: past, present, and future. Pages 8–42 *in* Ingram KT, Dow K, Carter L, Anderson J, eds. Climate of the Southeast United States. NCA Regional Input Reports. Washington, DC: Island Press. https://doi.org/10.5822/978-1-61091-509-0_2

Lajeunesse MJ (2013) Recovering missing or partial data from studies: a survey of conversions and imputations for meta-analysis. Pages 195–206 *in* Koricheva J, Gurevitch J, Mengersen K, eds. Handbook of Meta-analysis in Ecology and Evolution. Princeton, NJ: Princeton University Press

Lassiter BR, Jordan DL, Wilkerson GG, Shew BB, Brandenburg RL (2011) Influence of cover crops on weed management in strip tillage peanut. Weed Technol 25:568–573

Lollato RP, Ruiz Diaz DA, DeWolf E, Knapp M, Peterson DE, Fritz AK (2019) Agronomic practices for reducing wheat yield gaps: a quantitative appraisal of progressive producers. Crop Sci 59:333–350

MacLaren C, Swanepoel P, Bennett J, Wright J, Dehnen-Schmutz K (2019) Cover crop biomass production is more important than diversity for weed suppression. Crop Sci 59:733–748

Malik MS, Norsworthy JK, Culpepper AS, Riley MB, Bridges W (2008) Use of wild radish (*Raphanus raphanistrum*) and rye cover crops for weed suppression in sweet corn. Weed Sci 56:588–595

Menalled FD, Peterson RKD, Smith RG, Curran WS, Páez DJ, Maxwell BD (2016) The eco-evolutionary imperative: revisiting weed management in the midst of an herbicide resistance crisis. Sustainability 8:1297

Moore VM, Mirsky SB (2020) Cover crop biomass production across establishment methods in mid-Atlantic corn. Agron J 112:4765–4774

Mourtzinis S, Edreira JIR., Grassini P, Roth AC, Casteel SN, Ciampitti IA, Conley SP (2018) Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region. Field Crops Res 221:130–141

Müller S, Scealy JL, Welsh AH (2013) Model selection in linear mixed models. Stat Sci 28:135–167

Nembrini S (2019) Prediction or interpretability? Emerg Themes Epidemiol 16:1–3

Neve P, Busi R, Renton M, Vila-Aiub MM (2014) Expanding the eco-evolutionary context of herbicide resistance research. Pest Manag Sci 70:1385–1393

Nichols V, Martinez-Feria R, Weisberger D, Carlson S, Basso B, Basche A (2020) Cover crops and weed suppression in the U.S. Midwest: a meta-analysis and modeling study. Agric Environ Lett 5:e20022

Norsworthy JK, Frederick JR (2005) Integrated weed management strategies for maize (*Zea mays*) production on the southeastern coastal plains of North America. Crop Prot 24:119–126

Norsworthy JK, Korres NE, Walsh MJ, Powles SB (2016) Integrating herbicide programs with harvest weed seed control and other fall management practices for the control of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*). Weed Sci 64:540–550

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW, Barrett M (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci 60:31–62

Oliveira MC, Osipitan OA, Begcy K, Werle R (2020) Cover crops, hormones and herbicides: priming an integrated weed management strategy. Plant Sci 301:110550

Osipitan (2018) Cover crop for early-season weed suppression in crops: systematic review and meta-analysis. Agron J 110:2211–2221

Osipitan OA, Dille JA, Assefa Y, Radicetti E, Ayeni A, Knezevic SZ (2019) Impact of cover crop management on level of weed suppression: a meta-analysis. Crop Sci 59:833–842

Palhano MG, Norsworthy JK, Barber T (2018a) Cover crops suppression of Palmer amaranth (*Amaranthus palmeri*) in cotton. Weed Technol 32:60–65

Palhano MG, Norsworthy JK, Barber T (2018b) Sensitivity and likelihood of residual herbicide carryover to cover crops. Weed Technol 32:236–243

Philibert A, Loyce C, Makowski D (2012) Assessment of the quality of meta-analysis in agronomy. Agric Ecosyst Environ 148:72–82

Pittelkow CM, Linquist BA, Lundy ME, Liang X, van Groenigen KJ, Lee J, van Gestel N, Six J, Venterea RT, van Kessel C (2015) When does no-till yield more? A global meta-analysis. Field Crops Res 183:156–168

Price AJ, Balkcom KS, Duzy LM, Kelton JA (2012) Herbicide and cover crop residue integration for *Amaranthus* control in conservation agriculture cotton and implications for resistance management. Weed Technol 26:490–498

Price AJ, Monks CD, Culpepper AS, Duzy LM, Kelton JA, Marshall MW, Steckel LE, Sosnoskie LM, Nichols RL (2016a) High-residue cover crops alone or with strategic tillage to manage glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in southeastern cotton (*Gossypium hirsutum*). J Soil Water Conserv 71:1–11

Price AJ, van Santen E, Sarunaite L (2016b) Cover-crop management influences residue biomass and subsequent weed suppression in a conservation agriculture corn and cotton rotation. Pages 99–120 *in* Abdurakhmonov IY, ed. Cotton Research. InTechOpen.10.5772/61914

Quinn DJ, Poffenbarger HJ, Leuthold SJ, Lee CD (2021) Corn response to in-furrow fertilizer and fungicide across rye cover crop termination timings. Agron J 113:3384–3398

R Core Team (2021). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/

Rector LS, Pittman KB, Beam SC, Bamber KW, Cahoon CW, Frame WH, Flessner ML (2020) Herbicide carryover to various fall-planted cover crop species. Weed Technol 34:25–34

Reddy KN (2001) Effects of cereal and legume cover crop residues on weeds, yield, and net return in soybean (*Glycine max*) Weed Technol 15:660–668

Reddy KN (2003) Impact of rye cover crop and herbicides on weeds, yield, and net return in narrow-row transgenic and conventional soybean (*Glycine max*). Weed Technol 17:28–35

Reddy KN, Koger CH (2004) Live and killed hairy vetch cover crop effects on weeds and yield in glyphosate-resistant corn. Weed Technol 18:835–840

Reddy KN, Norsworthy JK (2010) Glyphosate-resistant crop production systems: impact on weed species shifts. Pages 165–184 *in* Nandula VK, ed. Glyphosate Resistance in Crops and Weeds: History, Development, and Management. Hoboken, NJ: Wiley

Reddy KN, Zablotowicz RM, Locke MA, Koger CH (2003) Cover crop, tillage, and herbicide effects on weeds, soil properties, microbial populations, and soybean yield. Weed Sci 51:987–994

Reed HK, Karsten HD, Curran WS, Tooker JF, Duiker SW (2019) Planting green effects on corn and soybean production. Agron J 111:2314–2325

Reed HK, Karsten HD (2022) Does winter cereal rye seeding rate, termination time, and N rate impact no-till soybean? Agron J 114:1311–1323

Reinhardt Piskackova TA, Reberg-Horton SC, Richardson RJ, Jennings KM, Franca L, Young BG, Leon RG (2021) Windows of action for controlling palmer amaranth (*Amaranthus palmeri*) using emergence and phenology models. Weed Res 61:188–198

Rojas-Sandoval J (2015) *Urochloa platyphylla* (broadleaf signalgrass). *In* CABI Compendium. Wallingford, UK: CAB International. doi: 10.1079/cabicompendium.9669

Sage RF (2017) A portrait of the C4 photosynthetic family on the 50th anniversary of its discovery: species number, evolutionary lineages, and Hall of Fame. J Exp Bot 68:e11–e28

Smith AN, Reberg-Horton SC, Place GT, Meijer AD, Arellano C, Mueller JP (2011) Rolled rye mulch for weed suppression in organic no-tillage soybeans. Weed Sci 59:224–231

Stanton VL, Haramoto ER (2021) Biomass potential of drill interseeded cover crops in corn in Kentucky. Agron J 113:1238–1247

Teasdale JR (2018) The use of rotations and cover crops to manage weeds. Pages 227–260 *in* Zimdahl R, ed. Integrated Weed Management for Sustainable Agriculture. Cambridge, UK: Burleigh Dodds Science

Teasdale JR (1996) Contribution of cover crops to weed management in sustainable agriculture systems. J Prod Agric 9:475–479

Thapa R, Tully KL, Reberg-Horton C, Cabrera M, Davis BW, Fleisher D, Gaskin J, Hitchcock R, Poncet A, Schomberg HH, Seehaver SA, Timlin D, Mirsky SB (2022) Cover crop residue decomposition in no-till cropping systems: insights from multi-state on-farm litter bag studies. Agric Ecosyst Environ 326:107823

Timper P, Davis RF, Webster TM, Brenneman TB, Meyer SLF, Zasada IA, Cai G, Rice CP (2011) Response of root-knot nematodes and Palmer amaranth to tillage and rye green manure. Agron J 103:813–821

Toler HD, Augé RM, Benelli V, Allen FL, Ashworth AJ (2019) Global meta-analysis of cotton yield and weed suppression from cover crops. Crop Sci 59:1248–1261

Travlos IS, Montull JM, Kukorelli G, Malidza G, Dogan FMN, Cheimona N, Peteinatos G (2019) Key aspects on the biology, ecology and impacts of Johnsongrass [*Sorghum halepense* (L.) Pers] and the role of glyphosate and non-chemical alternative practices for the management of this weed in Europe. Agronomy 9:717

Vann RA, Drake-Stowe K, Buol GS, Dunphy EJ (2021) Production practices that maximize soybean yield: What we have learned from the North Carolina soybean yield contest. Agron J 113:3399–3417

Vann RA, Reberg-Horton SC, Edmisten KL, York AC (2018) Implications of cereal rye/crimson clover management for conventional and organic cotton producers. Agron J 110:621–631

Verret V, Gardarin A, Pelzer E, Médiène S, Makowski D, Valantin-Morison M (2017) Can legume companion plants control weeds without decreasing crop yield? A meta-analysis. Field Crops Res 204:158–168

Wallace JM, Curran WS, Mortensen DA (2019) Cover crop effects on horseweed (*Erigeron canadensis*) density and size inequality at the time of herbicide exposure. Weed Sci 67:327–338

Wallace RD, Grey TL, Webster TM, Vencill WK (2013) Increased purple nutsedge (*Cyperus rotundus)* tuber sprouting with diurnally fluctuating temperatures. Weed Sci 61:126–130

Wallander S, Smith D, Bowman M, Claassen R (2021) Cover Crop Trends, Programs, and Practices in the United States. Washington, DC: U.S. Department of Agriculture, Economic Research Service, EIB-222. 31 p

Ward SM, Webster TM, Steckel LE (2013) Palmer amaranth (*Amaranthus palmeri*): a review. Weed Technol 27:12–27

Webster TM, Nichols RL (2012) Changes in the prevalence of weed species in the major agronomic crops of the Southern United States: 1994/1995 to 2008/2009. Weed Sci 60:145–157

Webster TM, Scully BT, Grey TL, Culpepper AS (2013) Winter cover crops influence *Amaranthus palmeri* establishment. Crop Prot 52:130–135

Weisberger D, Nichols V, Liebman M (2019) Does diversifying crop rotations suppress weeds? a meta-analysis. PLoS ONE 14:e0219847

Wells MS, Reberg-Horton SC, Mirsky SB (2016) Planting date impacts on soil water management, plant growth, and weeds in cover-crop-based no-till corn production. Agron J 108:162–170

Wells MS, Reberg-Horton SC, Smith AN, Grossman JM (2013) The reduction of plant-available nitrogen by cover crop mulches and subsequent effects on soybean performance and weed interference. Agron J 105:539–545

Wiggins MS, Hayes RM, Nichols RL, Steckel LE (2017) Cover crop and postemergence herbicide integration for Palmer amaranth control in cotton. Weed Technol 31:348–355

Yenish JP, Worsham AD, York AC (1996) Cover crops for herbicide replacement in no-tillage corn (*Zea mays*). Weed Technol 10:815–821

Zotarelli L, Avila L, Scholberg JMS, Alves BJR (2009) Benefits of vetch and rye cover crops to sweet corn under no-tillage. Agron J 101:252–260

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