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Use of Wild Radish (*Raphanus raphanistrum*) and Rye Cover Crops for Weed Suppression in Sweet Corn

Mayank S. Malik, Jason K. Norsworthy, A. Stanley Culpepper, Melissa B. Riley, and William Bridges, Jr.*

Field experiments were conducted near Blackville, SC, and Tifton, GA, in 2004 and 2005, to evaluate the effect of wild radish and rye cover crops on weed control and sweet corn yield when used in conjunction with lower-than-recommended herbicide rates. Cover crop treatments included wild radish, rye, and no cover crop, alone and in conjunction with half and full rates of atrazine (0.84 and 1.68 kg ai ha^{-1}) plus *S*-metolachlor (0.44 and 0.87 kg ai ha^{-1}) applied before sweet corn emergence. Florida pusley, large crabgrass, spreading dayflower, ivyleaf morningglory, and wild radish infested the test sites. Wild radish and rye cover crops without herbicides reduced total weed density by 35 and 50%, respectively, at 4 wk after planting (WAP). Wild radish in conjunction with the full rate of atrazine plus *S*-metolachlor controlled Florida pusley, large crabgrass, and ivyleaf morningglory better than rye or no cover crop treated with a full herbicide rate in 2004 at Blackville. In 2005, at Blackville, weed control in sweet corn following wild radish cover crop plots alone was not different from that following rye. Wild radish or rye in conjunction with a half or full rate of atrazine and *S*-metolachlor controlled $>$ 95% Florida pusley, wild radish, and large crabgrass in sweet corn at Tifton during both years. Ten glucosinolates, potential allelopathic compounds, were identified in wild radish, including glucoiberin, progoitrin, glucoraphanin, glucoraphenin, glucosinalbin, gluconapin, glucotropaeolin, glucoerucin, glucobrassicin, and gluconasturtin. Sweet corn yields at Blackville and Tifton following wild radish or rye cover crops were similar between the half and full rates of atrazine plus *S*-metolachlor. Sweet corn in wild radish or rye cover crop plots without herbicides produced less-marketable ears than herbicide-treated plots, indicating that a combination of cover crops and herbicides are required to optimize yields and to obtain desirable weed control.

Nomenclature: Atrazine; *S*-metolachlor; Florida pusley, *Richardia scabra* L. RCHSC; ivyleaf morningglory, *Ipomoea hederacea* Jacq. IPOHE; large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; spreading dayflower, *Commelina diffusa* Burm. f. COMDI; wild radish *Raphanus raphanistrum* L. RAPRA; rye, *Secale cereale* L. 'Wrenz'; sweet corn, *Zea mays* L. 'Silver Queen', 'Summer Sweet', 'Prime Plus'.

Key words: Allelopathy, cover crops, glucosinolates, IWM, reduced herbicide rates.

Wild radish, a member of the Brassicaceae family, is a facultative winter annual that germinates throughout fall and winter and matures from March to June in the southeastern United States (Schroeder et al. 1989). It is distributed throughout the United States in all but eight states (USDA-NRCS 2007). Besides the United States, it is widespread in Australia, England, Kenya, and South Africa (Cheam 1986).

Allelopathy is defined as an interaction where one plant has a direct effect on another through the release of chemical compounds from roots, shoots, leaves, or flowers (Booth et al. 2003, Rice 1995). An aqueous extract from oven-dried biomass of wild radish produced an allelopathic response to prickly sida (*Sida spinosa* L.), pitted morningglory (*Ipomoea lacunosa* L.), and sicklepod (*Senna obtusifolia* L.) (Norsworthy 2003). The volatile compounds released from soil incorporated chopped tissues of Brassicaceae plants, such as white mustard (*Sinapis alba* L.), brown mustard [*Brassica juncea* (L.) Cross], black mustard [*Brassica nigra* (L.) Koch], leafy turnip (*Brassica campestris* L.), rapeseed (*Brassica napus* L.), and garden cress (*Lepidium sativum* L.), and inhibited seed germination of hemp sesbania [*Sesbania herbacea* (P. Mill.) McVaugh] up to 100% (Vaughn and Boydston 1997).

Wild radish, like other Brassicaceae plants, produces glucosinolates (GSLs) (Cole 1976), which can be converted to isothiocyanates (ITCs) by myrosinase activity (Peterson et al. 2001). ITCs and other products from GSLs have important pesticidal properties (Chew 1988). ITCs can play a significant role in weed suppression (Peterson et al. 2001; Norsworthy and Meehan 2005a,b), and have nematicidal, fungicidal (Smolinska et al. 1997), and insecticidal properties (Borek et al. 1998). The seedmeal of some Brassicaceae species, such as white mustard, produces glucosinalbin, which is hydrolyzed to the ionic form of 4-hydroxybenzyl ITC (SCN^{-}), which is released within 48-h after incorporation of white mustard seedmeal (Borek and Morra 2005). This ITC is well known for its herbicidal properties. Benzyl ITC, when applied to soil at concentrations ranging from 0 to 10,000 nmol g^{-1}, reduced Texas panicum [*Urochloa texana* (Buckl.) R. Webster], large crabgrass, and sicklepod densities by 68 to 93% (Norsworthy and Meehan 2005 a). A number of GSLs have been identified in wild radish, namely 4-methyl thio-3 butenyl GSL, 3-(methyl thio) propyl GSL, and the aliphatic 2-propenyl GSL, allyl GSL, and glucoiberin (Cole 1976). These GSLs are distributed in roots, shoots, and leaves of wild radish and are stored in vacuoles (Belles 2002). GSLs produced by Brassicaceae plants are rapidly hydrolyzed to ITCs when tissues are macerated. Suppression of soil-borne pests through production of allelochemicals produced from green manure is known as *biofumigation* (Brown and Morra 1997).

Wild radish may be used as a cover crop in summer vegetables because of its allelopathic and GSL production potential (Cole 1976; Norsworthy 2003). Field corn (*Zea mays* L.) has exhibited tolerance to wild radish in greenhouse experiments (Norsworthy 2003); therefore, wild radish may be used as a component of an integrated weed management system in field or sweet corn. Brassicaceae plants, such as rapeseed, have been successfully used as green manure before

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planting potato (*Solanum tuberosum* L.) in the Pacific Northwest, reducing weed density and weed biomass as much as 85 and 96%, respectively (Boydston and Hang 1995). The Brassicaceae cover crops, such as white mustard, cover the ground quicker and produce more biomass than cereal cover crops such as oats (*Avena sativa* L.) (Stivers-Young 1998). The fall–planted Brassicaceae cover crops limit the moisture for many winter weeds by drying the soil surface quickly (Rogasik et al. 1992; Singh et al. 2006). Hence, a natural infestation of wild radish, if properly managed, may be effectively used as a biofumigant in vegetable crops. Besides weed suppression, wild radish would offer benefits similar to other cover crops, such as reduced soil erosion, conservation of soil moisture, and increased soil organic matter (Sojka et al. 1991).

Rye is a commonly used cereal cover crop because of its allelopathic properties in addition to providing a physical, weed suppressive mulch, resulting in suppression of numerous weeds (Liebl et al. 1992). The use of a rye cover crop with half the recommended rate of atrazine plus metolachlor in sweet corn resulted in excellent control of redroot pigweed (*Amaranthus retroflexus* L.) and yellow nutsedge (*Cyperus esculentus* L.) in field experiments in Arkansas (Burgos and Talbert 1996). The allelochemicals BOA [(3H)-benzoxazolinone] and DIBOA [(2,4-dihydroxy-1,4-(2H) benzoxazine-3-one] released from rye resulted in inhibition of small- to medium-seeded weed species, such as Palmer amaranth (*Amaranthus palmeri* S. Wats.), large crabgrass, goosegrass [*Eleusine indicia* (L.) Gaertn.], and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], whereas large-seeded crops, such as cucurbits and sweet corn, were tolerant (Burgos and Talbert 2000).

Winter cover crops produce plant residues that can create an unfavorable environment for weed emergence in early spring (Teasdale 1996). These cover crops provide early season weed control and may reduce the quantity of herbicide needed for effective weed control. Wallace and Bellinder (1992) reported that a no-till rye cover crop in conjunction with reduced rates of linuron, metolachlor, and metribuzin provided > 90% redroot pigweed control and > 93% common lambsquarters (*Chenopodium album* L.) control in sweet corn, snap beans (*Phaseolus vulgaris* L.), potato, and tomato (*Lycopersicon esculentum* L.). Rye without additional herbicides provided > 70% weed control for 6 wk.

Wild radish is abundant in most production fields throughout the southeastern United States (Webster and MacDonald 2001) and, because of its allelopathic potential (Norsworthy 2003), may be used as an additional weed management tool in sweet corn with comparable or superior results to rye, allowing herbicide rates to be reduced while still maintaining effective weed control. Therefore, the objectives of this research were (1) to evaluate the effect of wild radish and rye cover crops alone and in conjunction with reduced and full recommended herbicide rates on weed control and sweet corn vigor and yield, and (2) to quantify GSL production by wild radish.

Materials and Methods

Field experiments were initiated at the Edisto Research and Education Center near Blackville, SC, and at the Coastal Plain Experiment Station near Tifton, GA, in fall 2003 and 2004. The test site near Blackville was in the same field both years and was a Dunbar sandy loam with a pH of 6.0 and 0.6% organic matter. The Tifton site was a Tifton sand with pH of 5.9 and 1% organic matter in 2004 and Tifton sandy loam with a pH of 5.9 and 1.3% organic matter in 2005. The experimental design was a split-plot arrangement of cover crops (main plot) and weed control (subplot) with four replications at both locations.

'Wrenz' rye and wild radish were seeded at 90 kg ha^{-1} and 34 kg ha^{-1} on March 1, 2004, and November 30, 2004, at Blackville. The test area contained a natural infestation of wild radish, but plots were overseeded to ensure a uniform stand. Wrenz rye and a natural population of wild radish were used as cover crops at Tifton. Rye was planted at 63 kg ha^{-1} on December 9, 2003, and November 5, 2004, at Tifton. The major weed species infesting the test site included Florida pusley, large crabgrass, ivyleaf morningglory, spreading dayflower, and wild radish. These weeds were spread all across the test sites both years. There were some other weeds also present at the test site, but they were very sparse, i.e., they were present in few plots and absent in others. These included Palmer amaranth, yellow nutsedge, broadleaf signalgrass [*Urochloa platyphylla* (Nash) R.D. Webster], Texas panicum, and horseweed [*Conyza canadensis* (L.) Cronq]. Plots were flail-mowed to a height of 1 cm 4 wk before planting sweet corn at Blackville. The cover crops were at flowering stage at the time of mowing. Glyphosate was applied to kill the cover crops before planting sweet corn at Tifton in both years. 'Silver Queen' sweet corn was strip-till seeded into mowed plots on May 7, 2004, and April 22, 2005, at Blackville. 'Summer Sweet' and 'Prime Plus' were planted on April 2, 2004, and April 4, 2005, respectively, at Tifton. The plot size was 1.8 by 7.6 m at both locations with 97-cm-wide rows. Cover crop treatments included wild radish, rye, and weedy cover crop plots, excluding wild radish. Weed control treatments consisted of a nontreated control, hand-weeded control, atrazine at 0.84 kg ai ha^{-1} plus *S*-metolachlor at 0.44 kg ai ha^{-1} (one-half rate) applied immediately after planting, and atrazine at 1.68 kg ha^{-1} plus *S*-metolachlor at 0.87 kg ha^{-1} (full rate) applied immediately after planting. Fertilizer was applied at 78 kg ha^{-1} N–P–K (19–19–19) 1 month before planting corn at Blackville. All plots were side-dressed with 80 kg ha^{-1} N approximately 5 wk after corn emergence. Overhead irrigation was applied at Blackville during extended periods of no rainfall. Fertilizer was applied at 92 kg ha^{-1} N–P–K (19–19–19) at planting, and plots were side-dressed with 31 kg ha^{-1} N at Tifton. Irrigation was applied once weekly at Tifton.

Cover crop and weed biomass were collected before terminating the cover crops at Blackville. Cover crop biomass was collected randomly from all the cover crop plots in 1-m^2 quadrats. Weed biomass was also randomly collected from the weedy cover plots in 1-m^2 quadrats. Cover crop and weed biomass were also later collected at 2, 4, 6, and 8 wk after sweet corn planting (WAP) at Blackville. Cover crop biomass from Blackville was oven-dried at 66 C for 2 wk, and dry weights were recorded. GSLs in root and shoot tissue from Blackville were extracted and analyzed (Anonymous 1992). Dried root and shoot tissues were ground to pass through a 1-mm screen, and 300 mg of tissue was placed in a 20-ml vial with 70% methanol (10 ml, high-performance liquid chromatography [HPLC] grade) heated to 70 C. Two surrogates (75 µl, 16 mM, 2-propenyl GSL and benzyl GSL) were added to each sample. Samples were vortexed and placed in a water bath at 70 C for 20 min. Samples were again vortexed, cooled on crushed ice for 10 min, and centrifuged at 3,000 $\times$ *g* for 5 min. The supernatant (3 ml) was added to an A-25 column (0.6 ml) and was allowed to drip through slowly. The column was then washed with 1 ml distilled water followed by 1 ml of 0.02 M sodium acetate buffer (pH 5). The sephadex column was then layered with 100 μl of sulphatase (81 units), which was capped after one drop of solution passed through the column. After 24 h, the desulphoglucosinolates were eluted from the column with 1 ml water and then brought up to a 2-ml final volume with water. Each sample was passed through a 0.2-μm filter into a 2-ml vial, and desulphoglucosinolates were quantified by injecting 30 μl of the elutant into an HPLC[1] system equipped with a diode array detector set at 229 nm. A reverse-phase column[2] was used for separation. The mobile phase was 100% water for 5 min, followed by a linear elution gradient over the next 25 min to 65% water and 35% acetonitrile, which was held for 3 min. The solvent flow rate was 0.5 ml min^{-1}. GSLs were compared with known standards and with a previously published report (Anonymous 1992) to ensure proper identification.

Weed densities by species in a 1-m^2 quadrat in nonweeded plots were recorded every two weeks. Weed control was estimated visually by species on a scale of 0 to 100, where 0 equals no control, and 100 equals complete control 2, 4, 6, and 8 WAP at Blackville. Visual ratings of weed control were conducted to estimate the weed control by herbicide treatments. Sweet corn vigor was assessed on a similar rating scale on the same day of weed control evaluation, where 0 equals healthy plants, and 100 equals plant death. Sweet corn vigor was estimated based on growth and coloration. Weeds were removed from hand-weeded plots at 2, 4, 6, and 8 WAP at Blackville, whereas at Tifton, weeds were removed whenever weed control within a plot dropped below 85%. Stand counts of sweet corn plants per 1-m row and per 3-m row were taken at Blackville and Tifton, respectively. Heights of sweet corn plants in a 1-m row were taken at Blackville 2, 4, 6, and 8 WAP , whereas heights of eight sweet corn plants were recorded at Tifton. The plants were harvested, along with their roots, after the measurements were taken. The plants were harvested along a 1-m row, and eight plants were harvested at Tifton. Root length of sweet corn plants was also recorded at Tifton every 2 wk. Weed biomass was collected from 1-m^2 quadrats in the nonweeded plots at 2, 4, 6, and 8 WAP at Blackville. The biomass was oven-dried at 66 C for 2 wk, and dry weights were recorded. Sweet corn ears were harvested once at both locations. Fresh corn ears per plot were counted, and yield was recorded as total ears ha^{-1} and as marketable ears ha^{-1} in Blackville, with marketable ears being full size ears without insect damage. Sweet corn yield was only recorded as marketable ears ha^{-1} at Tifton.

A statistical model for a split-plot design with repeated measures was created that included terms for the main plot factor, cover crop, and the subplot factor, herbicide; the repeated measure per year, and all appropriate interactions. The significance of these main effects and interactions was analyzed using ANOVA. If significant interactions were found, means for individual year, cover crop, and herbicide combinations were estimated separately. If no significant interactions were found, main effect means were estimated. Fisher's Protected LSD test was used to determine specific differences among means. All calculations were performed using SAS PROC MIXED, and all tests used $\alpha = 0.05$. Assumptions for ANOVA were assessed, and the data set appeared to satisfy those assumptions.

Results and Discussion

Biomass Production. *Cover Crop Biomass*. The major weeds in the cover crop and weedy cover plots included Florida pusley, large crabgrass, spreading dayflower, ivyleaf morningglory, and wild radish. The other weeds present included yellow nutsedge, Palmer amaranth, broadleaf signalgrass, and horseweed. However, they were not uniformly distributed across the test site. The quantity of cover crop biomass produced at Blackville did not differ between cover crops, with rye producing 226 g m^{-2}, and wild radish producing 255 g m^{-2} of biomass by sweet corn planting, averaged over years (data not shown). There was 183 g m^{-2} of weed biomass without a cover crop at sweet corn planting (data not shown). The weed biomass in rye plots averaged 151 g m^{-2} and in wild radish plots, only 77 g m^{-2}.

Weed Biomass. Weed biomass produced in sweet corn following the weedy cover, rye, and wild radish treatments averaged 338, 236, and 213 g m^{-2} at 4 WAP, respectively (data not shown). Weed biomass in weedy cover, rye, and wild radish cover crop plots declined to 308, 75, and 102 g m^{-2} by 8 WAP, likely because of the competitiveness of sweet corn (data not shown). Hence, rye and wild radish cover crops reduced weed biomass 68% and 52%, respectively relative to weedy cover. A rapeseed similarly reduced early season weed biomass in potato 50 to 96% (Boydston and Hang 1995).

Weed Densities. Nontreated sweet corn plots at Blackville were infested with Florida pusley, large crabgrass, spreading dayflower, and ivyleaf morningglory in both years and wild radish in 2005. The wild radish and rye cover crops reduced Florida pusley and total weed density in sweet corn through 4 WAP (Table 1). Florida pusley densities were reduced 63% by rye and 55% by wild radish at 4 WAP. Large crabgrass, spreading dayflower, and ivyleaf morningglory densities were similar among cover crops at 4 WAP, but density of these weeds was less than that of Florida pusley, which made it difficult to detect potential differences among cover crop treatments. Total weed density was reduced 50% by rye and 35% by wild radish 4 WAP. The effect of cover crops in reducing weed density was short lived as evidenced by weed densities being similar among cover crops for all weed species by 8 WAP (Table 1). Hence, wild radish and rye cover crops alone may provide initial weed suppression, but additional weed management will be needed. Other Brassicaceae cover crops, such as winter rapeseed (var. Jupiter), have been found to reduce weed densities as much as 85% in potato (Boydston and Hang 1995). Additionally, rye and rye plus hairy vetch (*Vicia villosa* Roth) cover crops reduced redroot pigweed density 50% in sweet corn (Burgos and Talbert 1996). Yellow mustard (*Sinapis alba* L. var. Idagold), canola (*Brassica napus* L. var. Hyola), and winter rapeseed (var. Dwarf essex) cover crops reduced common lambsquarters, redroot pigweed, and wild mustard (*Sinapis arvensis* L.) densities up to 34% (Haramoto and Gallandt 2005), a level of early season control similar to that observed in our trials. Similarly, Al-Khatib et al. (1997) reported that mustard (*S. alba*) biomass reduced weed density in green pea (*Pisum sativum* L.) by 17%.

Table 1. Effect of cover crop on Florida pusley (RCHSC), wild radish (RAPRA), large crabgrass (DIGSA), ivyleaf morningglory (IPOHE), and spreading dayflower (COMDI) density in nontreated plots at 4 and 8 wk after planting (WAP) sweet corn at Blackville, SC, averaged over 2004 and 2005.[a]

	4 WAP						8 WAP					
Cover crop[b]	RCHSC	DIGSA	COMDI	IPOHE	RAPRA[c]	Total	RCHSC	DIGSA	COMDI	IPOHE	RAPRA	Total
	No. m^{-2}											
Weedy cover	101 a	28 a	4 a	2 a	6 b	150 a	48 a	36 a	5 a	4 b	1 a	110 a
Rye	37 b	18 a	7 a	3 a	7 ab	75 b	32 a	46 a	10 a	11 a	1 a	116 a
RAPRA	46 b	24 a	7 a	2 a	11 a	98 b	34 a	47 a	7 a	3 b	1 a	107 a

[a] For each cover crop and weed, means within a column followed by same letter are not significantly different based on Fisher's Protected LSD at $\alpha = 0.05$.
[b] Cover crop treatments: Weedy cover, no cover crop; Rye, rye cover crop; RAPRA, wild radish cover crop.
[c] Means for RAPRA weed densities are only presented for 2005 because RAPRA densities were only recorded in 2005.

Weed Control. Although some initial reduction in weed density occurred through 4 WAP, remaining weeds flourished in the absence of a herbicide. There was a location by year interaction for all weed species; therefore, data were analyzed separately by years for both Blackville and Tifton. There was a cover crop by herbicide interaction for control of Florida pusley, large crabgrass, spreading dayflower, wild radish, and ivyleaf morningglory at Blackville. Similarly, there was a cover crop by herbicide interaction for control of Florida pusley, wild radish, and large crabgrass at Tifton.

Florida Pusley Control. Florida pusley was present at both Blackville and Tifton during 2004 and 2005 (Tables 2 and 3). The rye cover crop alone at both locations in either year provided less than 55% Florida pusley control at 4 or 8 WAP. Similar results occurred for wild radish alone, except in 2005 at Tifton, when Florida pusley control was 92% at 4 WAP and 90% at 8 WAP. Although not quantified, it is possible that glucosinolate production in wild radish was much higher at Tifton in 2005 than at the other sites and years, resulting in improved weed suppression by the wild radish cover crop. This could also be attributed to greater wild radish biomass produced that year. Glucosinolate production in Brassicaceae plants is strongly dependent upon environmental conditions during development (Charron et al. 2005) and may have caused the improved effectiveness of the wild radish cover crop at Tifton in 2005.

Wild radish or rye in conjunction with the half rate of atrazine plus *S*-metolachlor controlled 64 to 86% of Florida pusley 4 WAP at Blackville over both years. At Tifton, the reduced rate of atrazine plus *S*-metolachlor controlled Florida pusley extremely well ($\geq$ 93% at 4 WAP both years), regardless of cover crop. Increasing the atrazine plus *S*-metolachlor rate did not improve Florida pusley control at Tifton at 4 and 8 WAP, but the higher rate did sometimes improve control at Blackville, especially at 8 WAP. In other research, a rye cover crop in conjunction with reduced rates of linuron, metolachlor, and metribuzin controlled redroot pigweed and common lambsquarters well in sweet corn (Wallace and Bellinder 1992). In Arkansas, a rye cover crop in conjunction with atrazine plus metolachlor controlled redroot pigweed and Palmer amaranth season long in sweet corn (Burgos and Talbert 1996).

Large Crabgrass Control. Large crabgrass was present at Blackville in 2004 and 2005 and present at Tifton only in 2005 (Tables 2 and 3). At both sites, rye alone controlled large crabgrass less than 50%. At Blackville, wild radish alone controlled large crabgrass no more than 59%, but at Tifton in 2005, large crabgrass control was 76% at 4 WAP. The addition of the reduced rate of atrazine plus *S*-metolachlor to wild radish or rye cover crops controlled large crabgrass at least 77% through 4 WAP. Further increasing the rate of atrazine plus *S*-metolachlor did not improve large crabgrass control in wild radish or rye plots at 4 WAP, but the higher rate did improve control at Blackville at 8 WAP. Burgos and Talbert (1996) reported that rye and wheat (*Triticum aestivum* L.) cover crops in conjunction with half recommended rates of atrazine plus metolachlor (1.1 kg ha^{-1} and 1.1 kg ha^{-1}) controlled goosegrass season long.

Wild Radish Control. Although wild radish was used as a "natural" cover crop in this research, it also emerged in the sweet corn crop at Blackville in 2005 and at Tifton in 2004 and 2005 (Tables 2 and 3). Hence, wild radish was considered a weed that needed to be controlled, and thus, ratings were taken to determine the effectiveness of each cover crop and herbicide program for control of wild radish. Wild radish control did not differ between wild radish and rye plots without herbicides at Blackville, ranging from 70 to 75% control at 4 WAP. At Tifton in 2004, rye alone was more effective than the wild radish cover crop in controlling wild radish. Conversely, the wild radish cover crop was superior to rye in 2005 at Tifton for controlling wild radish. The addition of atrazine plus *S*-metolachlor to all cover crop treatments controlled at least 83% wild radish, with no differences in control between rates within each location and year at 4 and 8 WAP.

Spreading Dayflower Control. Spreading dayflower was present only at Blackville in 2004 and 2005 (Table 2). The wild radish or rye cover crop alone did not control spreading dayflower through 4 WAP. In both years, wild radish in conjunction with the half rate of atrazine plus *S*-metolachlor controlled at least 80% of spreading dayflower through 4 WAP. Increasing the atrazine plus *S*-metolachlor rate did not improve spreading dayflower control at 4 WAP, but it did improve control at 8 WAP.

Ivyleaf Morningglory Control. Ivyleaf morningglory was present at the test site at Blackville in both years (Table 2). Similar to other weeds studied, atrazine plus *S*-metolachlor was needed for acceptable ivyleaf morningglory control. The use of atrazine plus *S*-metolachlor in wild radish or rye plots controlled ivyleaf morningglory at least 80% at 4 WAP, with no difference in control between rates. The higher rate of atrazine plus *S*-metolachlor provided superior ivyleaf morningglory control at 8 WAP.

Glucosinolate Production. Ten GSLs were identified in wild radish from Blackville, namely glucoiberin [3-(methylsulfinyl)

Table 2. Effect of cover crop and herbicide treatment on Florida pusley (RCHSC), large crabgrass (DIGSA), spreading dayflower (COMDI), entireleaf morningglory (IPOHE), and wild radish (RCHSC) control at 4 and 8 wk after planting (WAP) sweet corn at Blackville, SC, in 2004 and 2005.[a]

Cover crop[b]	Herbicide treatment[c]	2004								2005									
		4 WAP				8 WAP				4 WAP					8 WAP				
		RCHSC	DIGSA	COMDI	IPOHE	RCHSC	DIGSA	COMDI	IPOHE	RCHSC	DIGSA	COMDI	IPOHE	RAPRA	RCHSC	DIGSA	COMDI	IPOHE	RAPRA
		% Control																	
Weedy cover	W	0 d	0 c	0 d	0 d	0 f	0 d	0 e	0 f	13 d	8 d	6 f	5 d	21 c	18 e	9 d	6 e	10 e	83 c
	LR	54 bc	58 ab	88 ab	79 ab	46 b	26 c	65 b	54 c	71 b	70 b	74 d	76 b	76 ab	46 d	63 b	80 b	65 c	88 bc
	FR	79 ab	73 ab	98 a	91 a	65 c	44 b	83 a	71 b	75 b	84 ab	89 bc	80 b	84 ab	89 ab	88 a	93 a	88 ab	93 ab
Rye	W	41 c	49 b	40 c	28 c	23 e	19 c	21 d	30 de	61 c	33 c	70 d	61 c	70 ab	21 e	6 d	14 e	13 e	83 c
	LR	64 bc	77 ab	71 abc	83 ab	44 de	39 b	24 cd	24 e	76 b	91 a	93 abc	80 b	87 ab	58 c	64 b	66 c	73 bc	90 ab
	FR	78 ab	83 a	95 a	88 ab	59 c	45 b	35 c	33 d	86 a	95 a	96 a	84 ab	90 a	93 a	92 a	92 a	94 a	96 a
RAPRA	W	61 bc	59 ab	51 bc	66 b	24 e	8 d	20 d	35 d	55 c	44 c	44 e	55 c	75 ab	23 e	20 c	39 d	33 d	94 ab
	LR	80 ab	79 ab	80 ab	90 ab	41 cd	26 c	59 b	84 a	86 a	86 ab	88 c	80 b	83 ab	63 c	64 b	61 c	66 bc	90 b
	FR	95 a	85 a	97 a	92 a	80 a	91 a	81 a	88 a	86 a	91 a	95 ab	90 a	90 a	84 b	93 a	93 a	81 ab	92 ab

[a] Cover crop and herbicide treatment means within a column followed by same letter are not significantly different based on Fisher's Protected LSD at $\alpha = 0.05$.
[b] Cover crop treatments: Weedy cover, no cover crop; Rye, rye cover crop; RAPRA, wild radish cover crop.
[c] Herbicide treatment: W, no herbicide treatment; LR, half rate of atrazine (0.84 kg ai ha^{-1}) plus *S*-metolachlor (0.44 kg ai ha^{-1}); FR, full rate of atrazine (1.68 kg ha^{-1}) plus *S*-metolachlor (0.87 kg ha^{-1}).

propyl], progoitrin [(2R)-2-hydroxybut-3-enyl], glucoraphanin [4-(methylsulfinyl) propyl], glucoraphenin [4-(methylsulfinyl) but-3-enyl], glucosinalbin (*p*-hydroxybenzyl), gluconapin [but-3-enyl], glucotropaeolin (benzyl), glucoerusin [4-(methylthio) butyl], glucobrassicin [3-indoylmethyl], and gluconasturtin (2-phenylethyl) (Table 4). In general, identified GSLs that were produced in 2004 were also produced in 2005, with exception of glucoraphanin, glucoraphenin, and glucoerusin, which were not produced in 2005. Differences in environmental conditions have previously been shown to affect GSL occurrence and production (Ju et al. 1980). In addition to environmental affects on GSLs, Norsworthy et al. (2007) also found GSLs to differ between roots and shoots of Brassicaceae cover crops. Furthermore, in the same research, not all GSLs were detected in both years of the study, again, evidence of environmental regulation of GSLs. Glucoraphenin was only produced in 2004, comprising 18% of the total GSLs. Glucotropaeolin was the prominent GSL produced in 2005, comprising 10.2% of the total GSLs. Wild radish produced 4.3 μmol g^{-1} (2,092 μmol m^{-2}) and 1.12 μmol g^{-1} (545.9 μmol m^{-2}) of glucoraphenin and glucotropaeolin, respectively, in 2004, and 2.09 μmol g^{-1} (649.2 μmol m^{-2}) of glucotropaeolin in 2005. Other GSLs ranged from 0.03 μmol g^{-1} to 0.4 μmol g^{-1} (14.5 to 196.5 μmol m^{-2}) in 2004 and 0.04 to 0.31 μmol g^{-1} (13.2 to 94.9 μmol m^{-2}) in 2005. Greater total GSL production incorporated in soil in 2004 (11,206.7 μmol m^{-2}) compared with 2005 (4,844.9 μmol m^{-2}) was partially due to more wild radish biomass in 2004 than 2005. However, total GSLs per gram of wild radish were 23.06 μmol g^{-1} in 2004 compared with 20.52 μmol g^{-1} in 2005, which are not different statistically. Kirkegaard and Sarwar (1998) previously reported 18 different GSLs were produced in roots and shoots of 13 Brassicaceae species. These included GSLs glucoiberin, glucoerucin, glucoraphanin, gluconapin, progoitrin, gluconasturtin, glucotropaeolin, and glucobrassicin identified in our study of wild radish. The aliphatic, aromatic, and indolyl GSLs produced ranged from 0.1 μmol g^{-1}(glucoraphanin) in winter rape (*Brassica napus* L. var. *annua*) to a high of 34.8 μmol g^{-1} (gluconapin) in wild turnip (*Brassica tournefortii* Gouan) (Kirkegaard and Sarwar 1998). GSLs undergo hydrolysis in the presence of enzyme myrosinase to release ITCs, which have herbicidal properties (Norsworthy and Meehan 2005a,b). The GSLs glucoiberin, glucoerucin, glucoraphanin, gluconapin, gluconasturtin, and glucotropaeolin have been shown to hydrolyze to form ITCs, which have potential herbicidal properties and can potentially be used as biofumigants (Kirkegaard and Sarwar 1998). The ITCs hydrolyzed from glucoerucin, glucotropaeolin, glucoiberin, gluconapin, and glucoraphenin include erucin, benzene acetonitrile, iberin, 4-butenyl ITC, and sulforaphene, respectively (Vaughn et al. 2006). These GSLs were identified in seed meals of 15 different plant species and the ITCs inhibited the germination of sicklepod (*Cassia obtusifolia* L.) (Vaughn et al. 2006). Similarly, benzyl, phenylethyl, 3-butenyl, and 4-pentenyl ITC produced by hydrolysis of glucotropaeolin, gluconasturtin, gluconapin, and glucobrassicanapin were shown to inhibit the mycelial growth of cereal root pathogens (Sarwar et al. 1998). Hence, the GSLs glucoerucin, glucotropaeolin, glucoiberin, gluconapin, and glucoraphenin identified in wild radish may have potential herbicidal activity for weeds in vegetables, which may provide some weed control without affecting yields.

Table 3. Effect of cover crop and herbicide treatment on Florida pusley (RCHSC), wild radish (RAPRA), and large crabgrass (DIGSA) control at 4 and 8 wk after planting (WAP) sweet corn at Tifton, GA.[a]

		2004				2005					
		4 WAP		8 WAP		4 WAP			8 WAP		
Cover crop[b]	Herbicide treatment[c]	RCHSC	RAPRA	RCHSC	RAPRA	RCHSC	RAPRA	DIGSA	RCHSC	RAPRA	DIGSA
		% Control									
Weedy cover	W	0 d	0 d	0 c	0 d	0 e	0 d	0 e	0 c	0 d	0 c
	LR	99 a	99 a	97 a	100 a	97 ab	99 a	83 ab	92 ab	95 a	56 b
	FR	99 a	99 a	100 a	100 a	98 a	99 a	90 bc	97 a	93 ab	75 a
Rye	W	54 b	64 b	30 b	67 b	15 d	30 c	19 d	0 c	0 d	13 c
	LR	99 a	99 a	100 a	100 a	94 abc	99 a	91 ab	88 b	88 ab	75 a
	FR	99 a	99 a	100 a	100 a	95 bc	99 a	93 a	94 ab	91 ab	81 a
RAPRA	W	38 c	31 c	23 b	23 c	92 c	86 b	76 c	90 ab	76 c	58 b
	LR	99 a	97 a	98 a	97 a	97 ab	98 a	95 a	92 ab	88 ab	78 a
	FR	99 a	99 a	100 a	100 a	97 ab	98 a	90 ab	88 b	86 b	71 ab

[a] Cover crop and herbicide treatment means within a column followed by same letter are not significantly different based on Fisher's Protected LSD at $\alpha = 0.05$.
[b] Cover crop treatments: Weedy cover, no cover crop; Rye, rye cover crop; RAPRA, wild radish cover crop.
[c] Herbicide treatment: W, no herbicide treatment; LR, half rate of atrazine (0.84 kg ai ha^{-1}) plus *S*-metolachlor (0.44 kg ai ha^{-1}); FR, full rate of atrazine (1.68 kg ha^{-1}) plus *S*-metolachlor (0.87 kg ha^{-1}).

Sweet Corn Injury, Height, and Root Length. Sweet corn emergence was not affected by cover crop and herbicide program. Furthermore, there was no cover crop by herbicide interaction for sweet corn height at either location. Sweet corn heights differed among cover crops at Blackville, but not at Tifton (Table 5). Sweet corn height at Blackville in rye plots was similar to that without a cover crop, but sweet corn at 4 WAP was 2 cm taller in wild radish plots than in rye and plots with no cover crops. The shorter sweet corn in rye compared with wild radish may be due to either an allelopathic effect from the rye cover crop (Barnes and Putnam 1986) or some beneficial effect of the wild radish. It was concluded that wild radish does not negatively affect sweet corn growth under field conditions.

Averaged over cover crops, herbicide programs had no effect on sweet corn height at Blackville and Tifton. No injury to sweet corn plants was observed from both half and full rates of atrazine plus *S*-metolachlor with any cover crop (data not shown), which was expected because both herbicides are labeled PRE in sweet corn.

There was no significant cover crop by herbicide program interaction for root lengths at Tifton, averaged over years, but the main effects of cover crop and herbicide program were significant at 4 and 8 WAP. Sweet corn root lengths were greater in wild radish plots compared with rye and with no cover-crop plots at 4 WAP (Table 6). By 8 WAP, sweet corn roots in both wild radish and rye plots were approximately 10% longer than those without a cover crop.

Averaged over cover crops, the low and high rates of atrazine plus *S*-metolachlor and hand-weeded plots had root lengths of 24 to 25 cm compared with 22-cm root lengths in nontreated plots 8 WAP (Table 2). The reduced root lengths in nontreated plots are attributed to weed competition.

Sweet Corn Yield. The cover crop by herbicide program by year by location interaction was significant for sweet corn yields; hence, sweet corn yields were analyzed separately for Blackville and Tifton locations. The cover crop by herbicide program by year interaction was nonsignificant at Blackville and Tifton; therefore, sweet corn yields were pooled across years.

At Blackville, sweet corn in wild radish and rye plots in conjunction with half and full rates of atrazine plus *S*-metolachlor produced 30,000 to 34,000 ears ha^{-1}, whereas weedy cover plots with half and full rates of herbicide produced 11,000 and 16,000 ears ha^{-1} (Table 7). Hand-weeded plots had comparable yields regardless of cover crop treatment. Sweet corn in wild radish plots with no herbicide

Table 4. Glucosinolates detected in tissues of wild radish harvested in summer 2004 and 2005 at Blackville, SC.

	Concentration[a]							
	2004				2005			
Glucosinolate	μmol g^{-1}	SE[b]	μmol m^{-2}	SE	μmol g^{-1}	SE	μmol m^{-2}	SE
Glucoiberin	0.03	0.01	14.5	5.1	0.31	0.14	94.9	45.2
Progoitrin	0.06	0.01	27.2	3.2	0.23	0.13	72.2	39.2
Glucoraphanin	0.27	0.02	130.2	11.9	ND		ND	
Glucoraphenin	4.3	0.54	2,091.7	261.4	ND		ND	
Glucosinalbin	0.14	0.01	70.4	2.3	0.07	0.04	23	13.7
Gluconapin	0.03	0.01	16.6	2.5	0.04	0.01	13.2	3.3
Glucotropaeolin	1.12	0.99	545.9	482.1	2.09	2.09	649.2	486.9
Glucoerusin	0.2	0.05	99.6	26.3	ND		ND	
Glucobrassicin	0.24	0.04	116.3	18	0.04	0.01	12.2	2.8
Gluconasturtin	0.4	0.04	196.5	17.8	ND		ND	
Other[c]	16.26	2.58	7,902.4	3	17.7	5.27	3979.6	717.0
Total	23.06	3.2	11,206.7	1,456.9	20.52	3.88	4844.9	901.9

[a] ND, none detected.
[b] Standard error of each mean is included for each glucosinolate where $n = 4$.
[c] Other glucosinolates include the glucosinolates that were not identified.

Table 5. Effect of cover crop and herbicide treatment on sweet corn height at 4 wk after planting at Blackville, SC and Tifton, GA, averaged 2004 and 2005.

Treatment	Plant height[a]	
	Blackville, SC	Tifton, GA
	cm	
Cover Crop[b]		
Weedy cover	27 b	25 a
Rye	27 b	25 a
RAPRA	29 a	25 a
Herbicides[c]		
W	27 a	26 a
HW	28 a	25 a
LR	28 a	25 a
FR	28 a	24 a

[a] For each cover crop and herbicide treatment, means within a column followed by same letter are not significantly different based on Fisher's Protected LSD at $\alpha = 0.05$.

[b] Cover crop treatments: Weedy cover, no cover crop; Rye, rye cover crop; RAPRA, wild radish cover crop.

[c] Herbicide treatment: W, no herbicide treatment; HW, hand-weeded; LR, half rate of atrazine (0.84 kg ai ha^{-1}) plus *S*-metolachlor (0.44 kg ai ha^{-1}); FR, full rate of atrazine (1.68 kg ha^{-1}) plus *S*-metolachlor (0.87 kg ha^{-1}).

Table 6. Effect of cover crop and herbicide treatment on sweet corn root length at 4 and 8 wk after planting (WAP) at Tifton, GA, averaged over 2004 and 2005.

	Root length[a]	
Treatment	4 WAP	8 WAP
	cm	
Cover crop[b]		
Weedy cover	13 b	22 b
Rye	14 b	24 a
RAPRA	15 a	24 a
Herbicide[c]		
W	14 ab	22 b
HW	15 b	25 a
LR	14 ab	24 a
FR	13 a	24 a

[a] For each cover crop and herbicide treatment, means within a column followed by same letter are not significantly different based on Fisher's Protected LSD at $\alpha = 0.05$.

[b] Cover crop treatments: Weedy cover, no cover crop; Rye, rye cover crop; RAPRA, wild radish cover crop.

[c] Herbicide treatment: W, no herbicide treatment; HW, hand-weeded; LR, half rate of atrazine (0.84 kg ai ha^{-1}) plus *S*-metolachlor (0.44 kg ai ha^{-1}); FR, full rate of atrazine (1.68 kg ha^{-1}) plus *S*-metolachlor (0.87 kg ha^{-1}).

produced a greater number of ears (21,000 ears ha^{-1}) compared with rye and weedy cover plots, which produced 9,000 and 7,000 ears ha^{-1}, respectively. The yields were lower in weedy cover plots compared with rye and wild radish cover crop plots. This may be due to the weed competition and early season weed control in wild radish and rye cover crop plots. In previously published research, sweet corn following rye cover crop in conjunction with half and full rates of atrazine plus metolachlor produced yields similar to sweet corn following a full herbicide rate without a cover crop (Burgos and Talbert 1996). Similarly, potato planted following a rapeseed green manure yielded 17% more tuber weight compared with no rapeseed (Boydston and Hang 1995).

At Tifton, all plots treated with half and full rates of atrazine plus *S*-metolachlor produced 56,000 to 65,000 ears ha^{-1}, regardless of cover crop treatment. Hand-weeded, wild radish plots produced 74,000 sweet corn ears ha^{-1}, which was greater than hand-weeded, rye plots (63,000 ears ha^{-1}) and hand-weeded, weedy cover plots (67,000 ears ha^{-1}). Sweet corn in rye and wild radish plots without herbicide produced 42,000 and 38,000 ears ha^{-1}, respectively, compared with 26,000 ears ha^{-1} produced in weedy cover plots without herbicide. Burgos and Talbert (1996) also reported that half rates of atrazine plus metolachlor were required to provide season-long weed control and optimize sweet corn yields. The yields were higher at Tifton than at Blackville because of greater corn earworm [*Heliothis zea* (Boddie)] damage at Blackville. The 'Prime Plus' corn planted at Tifton was resistant to the corn earworm, whereas the 'Silver Queen' sweet corn planted at Blackville was not resistant to corn earworm, resulting in a reduction in the number of marketable ears at Blackville. The corn earworms were not controlled at Blackville because measurements were taken on whether the cover crops had any influence on the population of corn earworm. The yield was less in weedy plots because of competition from the uncontrolled weeds compared with the hand-weeded plots and low rates and full rates of herbicides.

Overall, the results indicate that cover crops alone did not provide sufficient weed control to prevent sweet corn yield loss. Wild radish and rye without herbicides reduced the density of Florida pusley as much as 65%, whereas total weed density was reduced up to 50% at 4 WAP. Atrazine plus *S*-metolachlor at half the recommended rates controlled early season weeds, resulting in sweet corn yields comparable to the full rate treatments with the same herbicides. Sweet corn, following wild radish and rye, treated with half and full rates of atrazine plus *S*-metolachlor produced comparable yields. These results are similar to those reported by Burgos and Talbert (1996), where rye and rye plus hairy vetch reduced redroot pigweed density early in the season, and when used in conjunction with half rates of atrazine plus metolachlor provided season-long weed control and optimum sweet corn yields. With the presence of wild radish in many production fields throughout the southeastern United States, wild radish can serve as a natural cover crop providing weed suppression

Table 7. Number of sweet corn marketable ears (×1,000 ha^{-1}) from Blackville, SC, and Tifton, GA, averaged over the years 2004 and 2005.[a]

Cover crop[b]	Herbicide treatment[c]	Marketable ears	
		Blackville, SC	Tifton, GA
		No. × 1,000 ha^{-1}	
Weedy cover	W	7 f	26 e
	HW	29 ab	67 ab
	LR	11 ef	59 bc
	FR	16 de	63 bc
Rye	W	9 f	42 d
	HW	24 bc	63 bc
	LR	30 ab	57 bc
	FR	30 ab	59 bc
RAPRA	W	21 cd	38 d
	HW	30 ab	74 a
	LR	34 a	56 c
	FR	30 ab	65 abc

[a] For each cover crop and herbicide treatment, means within a column followed by same letter are not significantly different based on Fisher's Protected LSD at $\alpha = 0.05$.

[b] Cover crop treatments: Weedy cover, no cover crop; Rye, rye cover crop; RAPRA, wild radish cover crop.

[c] Herbicide treatment: W, no herbicide treatment; HW, hand-weeded; LR, half rate of atrazine (0.84 kg ai ha^{-1}) plus *S*-metolachlor (0.44 kg ai ha^{-1}); FR, full rate of atrazine (1.68 kg ha^{-1}) plus *S*-metolachlor (0.87 kg ha^{-1}).

in sweet corn equivalent to that of a rye cover crop early in the growing season. Furthermore, atrazine plus *S*-metolachlor rates can be reduced when using a wild radish or rye cover crop without sacrificing sweet corn yield, making these cover crops an important component of an integrated approach to weed management in sweet corn.

Sources of Materials

[1] 1090 Hewlett Packard HPLC, Agilent Technologies, Wilmington, DE 19808.

[2] LiChrosorb RP-18 column 150 × 3.2 mm 5 μm, Alltech Associates, Inc., 2051 Waukegan Road, Deerfield, IL 60025-1899.

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Literature Cited

Al-Khatib, K., C. Libbey, and R. Boydston. 1997. Weed suppression with *Brassica* green manure crops in green pea. Weed Sci. 45:439–445.

Anonymous. 1992. Rapeseed determination of glucosinolate content, Part I: method using high-performance liquid chromatography. Geneva: International Organization for Standardization (ISO) Reference 9167-1,1992(E).

Barnes, J. P. and A. R. Putnam. 1986. Evidence for allelopathy by residues and aqueous extracts of rye. Weed Sci. 34:384–390.

Belles, D. 2002. Glucosinolate Biosynthesis, Genetics, and Allelopathic Potential. http://www.colostate.edu/Depts/Entomology/courses/en570/papers_2002.htm. Accessed: September 13, 2004.

Booth, B. D., S. D. Murphy, and C. J. Swanton. 2003. Interactions between populations I: competition and allelopathy. Page 126 *in* Weed Ecology in Natural and Agricultural Systems. Cambridge, MA: CABI.

Borek, V., L. R. Elberson, J. P. McCaffrey, and M. J. Morra. 1998. Toxicity of isothiocyanates produced by glucosinolates in *Brassica* sp. to black vine weevil eggs. J. Agric. Food Chem. 46:5318–5323.

Borek, V. and M. J. Morra. 2005. Ionic thiocyanate (SCN^-) production from 4-hydroxybenzyl glucosinolate contained in *Sinapis alba* seed meal. J. Agric. Food Chem. 53:8650–8654.

Boydston, R. A. and A. Hang. 1995. Rapeseed (*Brassica napus*) green manure suppresses weeds in potato (*Solanum tuberosum*). Weed Technol. 9:669–675.

Brown, P. D. and M. J. Morra. 1997. Control of soil-borne plant pests using glucosinolate-containing plants. Adv. in Agron. 61:168–231.

Burgos, N. R. and R. E. Talbert. 1996. Weed control and sweet corn (*Zea mays* var. rugosa) response in no-till system with cover crops. Weed Sci. 44:355–361.

Burgos, N. R. and R. E. Talbert. 2000. Differential activity of allelochemicals from *Secale cereale* in seedling bioassays. Weed Sci. 48:302–310.

Charron, C. S., A. M. Saxton, and C. E. Sams. 2005. Relationship of climate and genotype to seasonal variation in the glucosinolate-myrosinase system, I: glucosinolate content in ten cultivars of *Brassica oleracea* grown in fall and spring seasons. J. Sci. Food Agric. 85:671–681.

Cheam, A. H. 1986. Seed production and seed dormancy in wild radish (*Raphanus raphanistrum*) and some possibilities for improving control. Weed Res. 26:405–413.

Chew, F. S. 1988. Biological effects of glucosinolates. Pages 155–181 *in* H. G. Cutler, ed. Biologically Active Natural Products: Potential Use in Agriculture. Washington, DC: American Chemical Society.

Cole, R. A. 1976. Isothiocyanates, nitriles, and thiocyanates as products of autolysis of glucosinolates in cruciferea. Phytochem. 15:759–762.

Haramoto, E. R. and E. R. Gallandt. 2005. Brassica cover cropping, I: effects on weed and crop establishment. Weed Sci. 53:695–701.

Ju, H. Y., C. Chong, B. B. Bible, and W. J. Mullin. 1980. Seasonal variation in glucosinolate composition of rutabaga and turnip. Can. J. Plant Sci. 60:1295–1302.

Kirkegaard, J. A. and M. Sarwar. 1998. Biofumigation potential of brassicas, I: variation in glucosinolate profiles of diverse field-grown brassicas. Plant Soil 201:71–89.

Sarwar, M., J. A. Kirkegaard, P.T.W. Wong, and J. M. Desmarchelier. 1998. Biofumigation potential of brassicas, III: in vitro toxicity of isothiocyanates to soil-borne fungal pathogens. Plant Soil 201:103–112.

Liebl, R. A., F. W. Simmons, L. M. Wax, and E. W. Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybeans (*Glycine max*). Weed Technol. 6:838–846.

Norsworthy, J. K. 2003. Allelopathic potential of wild radish (*Raphanus raphanistrum*). Weed Technol. 17:307–313.

Norsworthy, J. K., M. S. Malik, P. Jha, and M. B. Riley. 2007. Suppression of *Digitaria sanguinalis* and *Amaranthus palmeri* using autumn-sown glucosinolate-producing cover crops in organically grown bell pepper. Weed Res. 47:425–432.

Norsworthy, J. K., J. T. Meehan, IV. 2005a. Herbicidal activity of eight isothiocyanates on Texas Panicum (*Panicum texanum*), large crabgrass (*Digitaria sanguinalis*), and sicklepod (*Senna obtusifolia*). Weed Sci. 53:515–520.

Norsworthy, J. K. and J. T. Meehan, IV. 2005b. Use of isothiocyanates for suppression of Palmer amaranth (*Amaranthus palmeri*), pitted morningglory (*Ipomoea lacunosa*), and yellow nutsedge (*Cyperus esculentus*). Weed Sci. 53:884–890.

Peterson, J., R. Belz, F. Walker, and K. Hurle. 2001. Weed Suppression by release of isothiocyanates from turnip–rape mulch. Agron. J. 93:37–43.

Rice, E. L. 1995. Biological Control of Weeds and Plant Diseases: Advances in Applied Allelopathy. Norman, OK: University of Oklahoma Press. 439.

Rogasik, J., M. Smukalski, and S. Obenauf. 1992. Cover crops on sandland in Germany: husbandry and fate of nitrogen. Asp. Appl. Biol. 30:309–316.

Schroeder, J. 1989. Wild radish (*Raphanus raphanistrum*) control in soft red winter wheat (*Triticum aestivum*). Weed Sci. 37:112–116.

Singh, H. P., D. R. Batish, and R. K. Kohli. 2006. Handbook of Sustainable Weed Management. Binghamton, NY: Haworth. 79.

Smolinska, U., G. R. Knudsen, M. J. Morra, and V. Borek. 1997. Inhibition of *Aphanomyces euteiches* f. sp. pisi by volatiles produced by hydrolysis of *Brassica napus* seed meal. Pl. Dis. 81:288–292.

Sojka, R. E., D. E. Karlen, and W. J. Busscher. 1991. A conservation tillage update from the Coastal Plain Soil and Water Conservation Research Center of South Carolina: a review of previous research. Soil Tillage Res. 21:361–376.

Stivers-Young, L. 1998. Growth, nitrogen accumulation, and weed suppression by fall cover crops following early harvest of vegetables. Hortic. Sci. 33:60–63.

Teasdale, J. R. 1996. Contribution of cover crops to weed management in sustainable agricultural systems. J. Prod. Agric. 9:475–479.

[USDA-NRCS] US Department of Agriculture–National Resource Conservation Service. 2007. Plant Profile for Wild Radish (*Raphanus raphanistrum* L.). http://plants.usda.gov/java/nameSearch; Accessed: November 29, 2007.

Vaughn, S. F. and R. A. Boydston. 1997. Volatile allelochemicals released by crucifer green manures. J. Chem. Ecol. 23:2107–2115.

Vaughn, S. F., D. E. Palmquist, and S. M. Duval. 2006. Herbicidal activity of glucosinolate-containing seedmeals. Weed Sci. 54:743–748.

Wallace, R. W. and R. R. Bellinder. 1992. Alternative tillage and herbicide options for successful weed control in vegetables. Hortic. Sci. 27:745–749.

Webster, T. M. and G. E. MacDonald. 2001. A survey of weeds in various crops in Georgia. Weed Technol. 15:771–790.

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