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Herbicide and Cover Crop Residue Integration in Conservation Tillage Tomato

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<http://dx.doi.org/10.5772/62320>

Abstract

The increased adoption of conservation tillage in vegetable production requires more information on the role of various cover crops in weed control, tomato quality, and yield. Three conservation-tillage systems utilizing crimson clover, turnip, and cereal rye as winter cover crops were compared to a conventional black polythene mulch system, with or without herbicide, for weed control and tomato yield. All cover crops were flattened with a mechanical roller/crimper prior to chemical desiccation. Herbicide treatments included a PRE application of S-metolachlor ($1.87 \text{ kg a.i. ha}^{-1}$) either alone, or followed by an early POST metribuzin ($0.56 \text{ kg a.i. ha}^{-1}$) application followed by a late POST application of clethodim ($0.28 \text{ kg a.i. ha}^{-1}$). Except for spotted spurge and tall morningglory only the main effect of herbicide treatments and cover crops affected weed control. For the majority of the weeds, no significant differences in weed control were observed with rye residue and plastic mulch treatments; however, turnip and crimson clover residue failed to control most weeds. Rye residue provided 86% large crabgrass, 80% goosegrass and 84% Broadleaf signalgrass control. Yellow nutsedge was controlled 65% by plastic mulch and only 60% by Rye residue. Pokeweed was controlled 80% by plastic mulch treatment. S-metolachlor applied PRE was sufficient in controlling leafy spurge and tall morningglory in plastic mulch and rye residue plots. Yield was less following either crimson clover or turnip cover crops compared to rye or the polythene mulch system. Application of herbicides resulted in better yields compared to the no-herbicide treatments. Economic analysis indicated that there was no significant difference between using a rye cover crop or plastic under any of the alternative herbicide treatment regimes in 2005. This research demonstrates the possibility of growing tomato in conservation tillage systems using high residue cover crops and herbicides to maintain season long weed control.

Keywords: conservation agriculture, cover crop, fruit, conservation tillage, weed suppression, vegetable

Nomenclature

S-metolachlor; metribuzin; clethodim; broadleaf signalgrass, *Brachiaria platyphylla*, BRAPP; large crabgrass, *Digitaria sanguinalis* DIGSA; leafy spurge, *Euphorbia esula* L. EPHES; common pokeweed, *Phytolaca americana*, PHATAM; yellow nutsedge, *Cyperus esculentus* L. CYPES; tomato, *Lycopersicon esculentum* L.; crimson clover, *Trifolium incarnatum* L.; rye, *Secale cereale* L.; turnip, *Brassica rapa* L.

Abbreviations

PRE, preemergence;

POST, postemergence

Tomato (*Lycopersicon esculentum* L.) is the most popular fruit in the world. Nearly 1.7 million tons of fresh market field grown tomatoes were produced in the U.S. in 2005 [1]. The U.S. produces more than 11% of the world's tomato crop. Tomato production systems typically utilize conventional tillage, a bedded plastic mulch culture, and multiple herbicide applications to control weeds. These conventional tillage systems enhance soil erosion and nutrient loss by reducing rainfall infiltration [2]. Additionally, tillage increases aeration which increases the rate of organic matter mineralization in the surface soil, thus reducing soil organic matter content, soil cation exchange capacity, and potential productivity [3, 4].

Plastic mulch can increase soil temperature which can expedite tomato harvest earliness [5]. Tomato harvest was not early following a hairy vetch mulch system [6, 7]. The use of plastic mulches in sustainable or organic production systems is in question by some producers and consumers since the mulch itself is non-biodegradable and made of non-renewable resources. Another environmental disadvantage with using plastic mulch vs. organic mulches is increased chemical runoff from plastic mulch systems and subsequent offsite chemical loading [8]. Thus, the intensive use of pesticides in vegetable production has resulted in ecological concerns. Therefore, alternative production practices that reduce tomato production inputs while maintaining yield and quality are desired.

One alternative for alleviating the aforementioned concerns is the use of high residue cover crops combined with reduced tillage. Cover crops in conservation-tillage systems can be terminated during early reproductive growth by mechanically rolling and treating with burndown herbicides to leave a dense mat of residue ($>4,500 \text{ kg ha}^{-1}$) on the soil surface into which cash crops are planted [9, 10]. Adoption of high residue cover crops is increasing in southeastern US corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.) row crop systems [11–13]. Because the southeastern US typically receives adequate rainfall in the winter months, timely planted winter cover crops can attain relatively high maturity and biomass before termination. Cover crops can enhance the overall productivity and soil quality by increasing organic matter and nitrogen content [14], as well as aid in water conservation by increasing soil water infiltration rates [15]. Additionally, previous research has also focused on weed control provided by high residue cover crops in both field and vegetable crops [11, 16, 17].

Winter cover crop biomass can affect subsequent early season weed control [18–20]. Cover crop residue facilitates weed control by providing an unfavorable environment for weed germination and establishment under the residue, as well as allelopathy [21, 22]. Teasdale and Daughtry [23] reported 52–70% reduction in weed biomass with live hairy vetch cover crop compared to a fallow treatment owing to changes in light and soil temperature regimen under the vetch canopy. Teasdale and Mohler [21] reported that legume mulches such as crimson clover and hairy vetch (*Vicia villosa* Roth) suppressed redroot pigweed (*Amaranthus retroflexus* L.) at an exponential rate as a function of residue biomass.

However, adoption of cover crops in tomato production has been limited because (1) currently available transplanters have problems penetrating heavy residue and (2) heavy cover crop residue can intercept delivery of soil-active herbicides. Research in the last two decades has extensively debated the advantages and disadvantages of cover crops vs. conventional plastic mulch systems for tomato production. Better or comparable tomato yields with hairy vetch cover crop system have been reported compared to the conventional polyethylene mulch system [24, 25]. Akemo et al. [26] also reported higher tomato yield with spring sown cover crops than the conventionally cultivated check. Weed control with cover crops however varies with cover crop species, amount of residue produced, and environmental conditions. Teasdale [21] reported that biomass levels achieved by cover crops before termination was sufficient only for early season weed control. Supplemental weed control measures are usually required to achieve season long weed control and to avoid yield losses [16, 27].

Cereal rye and crimson clover are two common winter cover crops widely used in the southeastern U.S. Both cover crops contain allelopathic compounds and produce residues that inhibit weed growth [28, 29]. Brassica cover crops are relatively new in the southeastern US but, are becoming increasingly popular due to their potential allelopathic effects. Therefore, the objectives of this research were to evaluate: 1) weed control in three different high residue cover crop conservation tillage systems utilizing the Brazilian cover crop management system, and 2) tomato stand establishment, yield, and net returns of conservation-transplanted tomatoes compared to the polythene mulch system following three different herbicide management systems.

1. Materials and methods

1.1. Field experiment

The experiment was established in autumn 2004 and 2005 at the North Alabama Horticulture Experiment Station, Cullman, AL on a Hartsell fine sandy loam soil (Fine-loamy, siliceous, sub-active, thermic Typic Hapludults). The experimental design was a randomized complete block with four replicates. Plot size at both locations was 1.8 by 6 m containing a single row of tomatoes with a 0.5 m spacing between plants.

The three winter cover crops [cereal rye cv Elbon, crimson clover cv AU Robin and turnip (*Brassica rapa* L subsp. *rapa* cv Civastro)] were compared to black polythene mulch for their

weed suppressive potential and effect on yield and grade of fresh market tomatoes. Winter cover crops were planted with a no till drill each fall. Rye was seeded at a rate of 100 kg ha^{-1} , whereas clover and turnip were seeded at 28 kg ha^{-1} . Nitrogen was applied at a rate of 67 kg ha^{-1} on rye and turnip plots in early spring of each year. Cover crops were terminated at flowering stage in late spring. To determine winter cover crop biomass production, plants were clipped at ground level from one randomly selected 0.25 m^2 area per replicate immediately before termination. Plant samples were dried at 65°C for 72 hours and weighed. Cover crops were terminated with a mechanical roller crimper prior to an application of glyphosate at $1.12 \text{ kg a.e. ha}^{-1}$. The rolling process produced a uniform residue cover over the plots.

All four cover systems (three winter cover crops plus plastic mulch) were evaluated with and without herbicide for weed control. Herbicide treatments included a preemergence (PRE) application of *S*-metolachlor ($1.87 \text{ kg a.i. ha}^{-1}$) either alone or followed by an early postemergence (EPOST) metribuzin ($0.56 \text{ kg a.i. ha}^{-1}$) application, followed by a late POST (LPOST) application of clethodim ($0.28 \text{ kg a.i. ha}^{-1}$). These three herbicide treatments were applied in a factorial combination with the four mulch treatments. Additionally, a fallow no herbicide treatment plot was included in each replication. The PRE application occurred one day before transplanting, the EPOST application was applied two weeks after transplanting, and the LPOST application was delayed until tomatoes were near mid-bloom. The PRE herbicide treatment in plastic mulch plots were applied before laying the plastic on top of the beds and POST treatments were applied over the total surface of the beds including tomato plant openings. Tomato cv. 'Florida 47' seedlings were transplanted on 4th April 2005 and on April 9th in 2006.

Tomato seedlings were planted with a modified RJ No-till transplanter (RJ Equipment, Blenheim, Ontario, Canada), which included a subsoiler shank installed to penetrate the heavy residue and disrupt a naturally occurring compacted soil layer found at both experimental sites at a depth of 30–40 cm. Additionally, two driving wheels were utilized (one wheel on each side of the tomato row) instead of the original single wheel at the center of the row, to improve stability and eliminate drive wheel re-compaction of the soil opening created by the shank. The plastic-mulch plots were conventionally tilled utilizing a tractor mounted rototiller prior to bedding and plastic installation; tomatoes were hand transplanted in the plastic mulch each year. Water was applied to all the plots immediately after transplanting. Thereafter, plots were irrigated every other day using a surface drip tape. General production practices included staking and fertilization. Fertilizer 13-13-13 was applied prior to planting achieving $448 \text{ kg of N ha}^{-1}$ and then $7.8 \text{ kg of calcium nitrate ha}^{-1}$ was applied once every week with the irrigation system.

Weed control was evaluated by visual ratings (0% = no control, 100% = complete control) 28 days after treatment (DAT) of the EPOST herbicide application. All weed species present were evaluated for control (as a reduction in total above ground biomass resulting from both reduced emergence and growth). Stand establishment was determined by counting the number of living tomato plants in each plot two weeks after LPOST application. Ripe tomatoes were hand harvested from the entire plot area in weekly intervals and sorted according to size (small, medium, large, and extra large categories).

1.2. Statistical analysis

Non-normality and heterogeneous variances were encountered with percent control data. Various approaches were tried to alleviate these statistical problems and the arcsine transformation was deemed the best compromise between achieving normality of residuals and among treatment homogeneity of variances. The transformed data were subjected to mixed models analysis of variance as implemented in JMP statistical software. Years, herbicide treatments and ground cover treatments were considered fixed effects while their interaction with treatment replication was considered random effects. Differences between treatments means were determined by Fisher's protected LSD ($\alpha = 0.05$) where year by treatment interactions were not significant data pooled across years.

1.3. Economic analysis

Enterprise budgets were generated using Mississippi State (2005) vegetable planning budgets [30]. These budgets were based on a standard yield of 39,230 kg ha⁻¹ (35,000 lbs ac⁻¹). Seed and plant costs include the cost of cover crop seed (Turnip—\$146 ha⁻¹; Crimson Clover—\$58 ha⁻¹; Rye—\$49 ha⁻¹) and the cost of tomato transplants (\$838 ha⁻¹). Fertilizer costs included the cost of N application and calcium nitrate for the cash crop (\$228 ha⁻¹), as well as, the additional N applied for the rye and turnip cover crops (\$68 ha⁻¹). Herbicide costs were based on treatment applications as described above and varies with cover crop x herbicide treatment combinations. Insecticide and fungicide costs followed extension recommendations and varied by year due to different climatic conditions (i.e. insecticide and fungicide costs were \$122 ha⁻¹ and \$189 ha⁻¹ in 2006, respectively). Harvesting costs are based on custom rates for harvesting, packing, and grading of tomatoes based on hand harvesting. Supplies costs represent purchase of stakes, string, buckets, as well as other harvesting and planting supplies. Irrigation costs are broken into the variable cost of water application (\$26 ha⁻¹) and the fixed costs of the machinery (\$1890 ha⁻¹). Irrigation costs were calculated based on the cost of surface drip tape and pumping 152 mm of water every week from surface water reservoirs located on both experiment stations.

Machinery costs are broken into variable and fixed costs. Variable machinery costs represent the cost fuel, as well as repair and maintenance costs. Fixed machinery costs represent cost of machinery purchase based on an annual payment of loan, interest, taxes, and depreciation. Labor costs represent operator labor for machinery, as well as hand labor in the field. Equipment used during production included a no-till drill for sowing cover crops, a tractor mounted cover crop roller (Bingham Brothers Inc., Lubbock, TX, USA), a tractor mounted rototiller, and a modified RJ tomato transplanter. For all the fungicide and insecticide applications, a JACTO vegetable air blast sprayer (Jacto Inc., Tualatin, OR, USA) mounted on a John Deere 4030 tractor (Moline, IL, USA) was used.

The interest on operating capital represents the opportunity costs of investing monies spent on variable costs in its next best alternative. This is calculated based using an interest rate of 7% over an investment period of six months (length of the tomato growing season). Overhead and management costs represent those costs that pertain to the operation of the whole farm that are partially attributed to the vegetable production enterprise, such as the costs for

property taxes and insurance. Overall costs fluctuated between \$22,131 ha⁻¹ to \$22,822 ha⁻¹ due to changes in herbicide treatments and cover crop regimes.

Net revenue data, representing the return over total costs, was estimated by calculating total revenues for each plot on a per hectare basis and subtracting total costs. Only data from the Cullman, AL location was utilized for this analysis. Total crop revenue (\$ ha⁻¹) was calculated by multiplying the price of tomatoes (\$0.63 kg⁻¹) times the plot yield (kg ha⁻¹) [1]. Total costs were calculated using the cost budgets, adjusted for year (i.e. insecticide and fungicide costs). All estimates were calculated using 2005 dollars to minimize variability due to price fluctuations, allowing comparisons over time. Net revenue data was analyzed using analysis of variance as implemented in SAS® using PROC Mixed. Difference between treatments means were determined by single degree of freedom contrasts.

2. Results and discussion

2.1. Cover crop biomass

The quantity of cover crop biomass produced at both locations differed among cover crops, with rye producing 9363 kg ha⁻¹, and crimson clover producing 5481 kg ha⁻¹ of dry matter. Turnip produced least biomass at 3860 kg ha⁻¹.

2.2. Weed control

The major weeds in the cover crop and plastic mulch plots included yellow nutsedge (*Cyperus esculentus* L.), smooth pigweed (*Amaranthus hybridus* L.), pokeweed (*Phytolaca americana* L.), tall morningglory [*Ipomoea purpurea* (L.) Roth], goosegrass [*Eleusine indica* (L.) Gaertn.], leafy spurge (*Euphorbia esula* L.), and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster] and ivyleaf morningglory (*Ipomoea hederacea* Jacq.). Other weed species included wild radish (*Raphanus raphanistrum* L.), Virginia buttonweed (*Diodia virginiana* L.), smallflower morningglory (*Jacquemontia tamnifolia* (L.) Griseb.). Weed control data for only the major weed species is discussed in this manuscript.

2.2.1. Broadleaf signalgrass

Broadleaf signalgrass was present only at Cullman in 2005. Averaged over ground cover treatments (**Table 1**), broadleaf signalgrass was controlled 11% without herbicides. Control improved significantly with herbicide application. S-metolachlor applied PRE controlled broadleaf signalgrass 79%; control improved to 97% when S-metolachlor PRE was followed by EPOST application of metribuzin fb LPOST clethodim application. Averaged over herbicide treatments (**Table 1**), turnip and crimson clover residue controlled broadleaf signalgrass 57% and 55% respectively. Control was significantly higher in rye and plastic mulch plots at 81% and 84% respectively compared to turnip and crimson clover plots.

Effect/ source	CYPES	AMAPA	DIGSA	BRAPP	ELEIN	PHTAM	PHBPU	EPHES	IPOHE	DIQVI	IAQTA	RAPRA
Environment (E)	0.401	0.044	<0.001	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cover (C)	0.186	0.104	0.388	0.003	0.006	0.001	<0.001	<0.001	0.074	<0.001	<0.001	0.015
C × E	0.090	0.173	0.021	NA	NA	NA	NA	NA	NA	NA	NA	NA
Treatment (T)	0.021	0.006	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.496	0.157	0.058	<0.001
T × E	0.001	0.376	<0.001	NA	NA	NA	NA	NA	NA	NA	NA	NA
C × T	0.268	0.981	0.143	0.307	0.254	0.762	0.009	0.004	0.968	0.788	0.891	0.763
C × T × E	0.762	0.447	0.41	NA	NA	NA	NA	NA	NA	NA	NA	NA
Weeds were present in												
Year	Location											
2005	Cullman	Cullman		Cullman	Cullman	Cullman	Cullman	Cullman				
2006	Cullman	Cullman	Cullman						Cullman			
2006	Tuskegee	Tuskegee	Tuskegee							Tuskegee	Tuskegee	Tuskegee

CYPES, yellow nutsedge; AMAPA, palmer amaranth; DIGSA, large crabgrass; BRAPP, broadleaf signalgrass; ELEIN, goosegrass; PHTAM, pokeweed; PHBPU, tall morningglory; EPHES, leafy spurge; IPOHE, ivyleaf morningglory; DIQVI, virginia buttonweed; IAQTA, smallflower morningglory; RAPRA, wild radish.

Table 1. Analysis of variance for weed control^a.

2.2.2. Goosegrass

Goosegrass was present only at Cullman 2005. Averaged over all ground cover treatments (**Table 1**), goosegrass could not be controlled (6%) without herbicides. *S*-metolachlor PRE controlled goosegrass 76%. *S*-metolachlor PRE fb metribuzin EPOST fb clethodim LPOST controlled goosegrass 96%. Averaged over herbicide treatments (**Table 1**), turnip and crimson clover residue controlled goosegrass ≤ 60%. Rye residue and plastic mulch provided similar (80% and 79%) and higher control than turnip and crimson clover.

2.2.3. Pokeweed

Pokeweed was present at Cullman 2005. Averaged over ground cover treatments (**Table 1**) pokeweed was controlled 16% without herbicides. Control improved significantly with *S*-metolachlor PRE at 60% and *S*-metolachlor PRE fb metribuzin EPOST fb clethodim LPOST at 83%. Averaged over herbicide treatments (**Table 1**), turnip and crimson clover residue controlled pokeweed ≤ 40%. Rye residue controlled pokeweed 68% whereas pokeweed control was 86% in plastic mulch plots. However, the differences were not significant ($P = 0.324$) for rye and plastic mulch plots.

2.2.4. Smooth pigweed

Smooth pigweed was present at Cullman site during both the years. Averaged over ground cover treatments (**Table 2**), similar to other aforementioned weeds, smooth pigweed was controlled 9% in 2005 and 50% in 2006. None of the herbicide treatments provided acceptable control of smooth pigweed (≤70%). Averaged over herbicide treatments (**Table 1**) control was in general less in 2005 compared to 2006. Turnip residue suppressed smooth pigweed 30% in 2005 and 67% in 2006. Smooth pigweed was controlled 12% in 2005 and 52% in 2006 in

crimson clover plots. Control was better in plastic mulch plots in 2005 (73%) but trend reversed in 2006, where rye plots recorded 71% and plastic mulch plots provided 57% control of smooth pigweed. However, differences in smooth pigweed control in rye and plastic mulch plots were not significant in either year.

Herbicide treatments		Cullman 2005				Cullman 2006			Tuskegee 2006						
Preemergence	Postemergence	BRAPP	ELEIN	PHTAM	AMACH	CYPES	AMACH	CYPES	DIGSA	IPOHE	CYPES	DIGSA	DIQVI	JAQTA	RAPRA
		%													
None	None	11	6	16	9	30	50	80	73	76	84	6	64	82	13
S-metolachlor	None	79	76	60	43	84	65	89	90	88	68	28	48	51	9
S-metolachlor	metribuzin fb clethodim	97	96	83	69	95	70	83	81	81	77	90	36	56	59
P-values from contrasts:															
PRE + POST vs. PRE alone		0.002	0.002	0.110	0.141	0.183	0.958	0.800	0.624	0.781	0.837	<0.001	0.761	0.949	0.003
PRE + POST vs. non treated		<0.001	<0.001	<0.001	<0.001	<0.001	0.546	0.973	0.793	0.907	0.856	<0.001	0.214	0.184	0.006
PRE alone vs. non treated		<0.001	<0.001	0.013	0.098	<0.001	0.717	0.682	0.284	0.539	0.510	0.133	0.587	0.103	0.965

Information about herbicide rate and application timing can be found in **Table 5**.

Table 2. Effect of herbicide treatments on broadleaf signalgrass (BRAPP), goosegrass (ELEIN), pokeweed (PHTAM), smooth pigweed (AMACH), and yellow nutsedge (CYPES), large crabgrass (DIGSA), Virginia buttonweed (DIQVI), smallflower morningglory (JAQTA), and wild radish (RAPRA) control at Cullman and Tuskegee AL.

2.2.5. Yellow nutsedge

Yellow nutsedge was present at all the site years in this experiment. Averaged over ground cover treatments (**Table 1**), S-metolachlor applied PRE controlled yellow nutsedge only 55%. Bangarwa et al., have also reported less than 70% control of yellow nutsedge with S-metolachlor applied PRE in transplanted tomato in polyethylene mulch. Yellow nutsedge control increased to 70% when S-metolachlor was fb metribuzin EPOST fb clethodim LPOST. Averaged over herbicides rye residue provided 60% and Polyethylene mulch 65% control of yellow nutsedge.

2.2.6. Ivyleaf morningglory

Ivyleaf morningglory control did not differ among herbicide treatments. Averaged over herbicide treatments (**Table 1**), turnip and rye residue provided 94% and 90% control of ivyleaf morningglory. Control was 66% in crimson clover plots and 70% in plastic mulch plots.

2.2.7. Large crabgrass

No significant differences in large crabgrass control were observed among herbicide treatments. Averaged over herbicide treatments (**Table 1**) large crabgrass control was 88% in both turnip and rye plots. Control was 75% in crimson clover and plastic mulch plots.

2.2.8. Tall morningglory

Ground cover by herbicide treatment interaction was significant for tall morningglory control (**Table 3**). Ground cover treatments failed to control tall morningglory without

herbicides (0–23%). Application of *S*-metolachlor controlled tall morningglory 41% in turnip plots but no control was observed in crimson clover plots. However, the same treatment provided good control of tall morningglory in plastic mulch (94%) and rye residue (98%) plots. *S*-metolachlor PRE fb metribuzin EPOST fb clethodim LPOST controlled tall morningglory ≤ 50% in turnip and crimson clover plots but controlled tall morningglory 98% in plastic mulch plots. Tall morningglory control declined to 71% in rye residue plots when *S*-metolachlor PRE was fb metribuzin EPOST fb clethodim LPOST.

Ground cover	Turnip	Turnip	Turnip	Clover	Clover	Clover	Plastic	Plastic	Plastic	Rye	Rye	Rye
Herbicide treatment	None	Pre	Pre + Post	None	Pre	Pre + Post	None	Pre	Pre + Post	None	Pre	Pre + Post
Variable costs												
Seeds/plants	984	984	984	896	896	896	838	838	838	887	887	887
Fertilizer	295	295	295	228	228	228	228	228	228	295	295	295
Herbicides	16	68	109	16	68	109	0	68	109	16	68	109
Insecticides	182	182	182	182	182	182	182	182	182	182	182	182
Fungicides	232	232	232	232	232	232	232	232	232	232	232	232
Scouting/soil tests	19	19	19	19	19	19	19	19	19	19	19	19
Custom harvest/grade/pack	7888	7888	7888	7888	7888	7888	7888	7888	7888	7888	7888	7888
Supplies (stakes, buckets, etc.)	6719	6719	6719	6719	6719	6719	6719	6719	6719	6719	6719	6719
Irrigation ^b	26	26	26	26	26	26	26	26	26	26	26	26
Machinery ^c	658	660	665	637	640	644	608	610	615	658	661	665
Labor ^d	559	565	575	550	555	565	1159	1164	1174	559	565	575
Interest on operating capital ^e	571	573	575	565	567	569	582	584	586	568	570	572
Total variable costs	18,150	18,211	18,268	17,958	18,019	18,076	18,480	18,558	18,615	18,050	18,111	18,168
Fixed costs												
Machinery ^c	1085	1090	1101	1026	1032	1043	998	1003	1014	1084	1090	1101
Irrigation ^b	1890	1890	1890	1890	1890	1890	1890	1890	1890	1890	1890	1890
Overhead/management ^f	1271	1275	1279	1257	1261	1265	1294	1299	1303	1264	1268	1272
Total fixed costs	4245	4255	4270	4173	4183	4198	4181	4192	4207	4238	4248	4263
Total costs	22,395	22,466	22,538	22,131	22,202	22,274	22,661	22,750	22,822	22,288	22,359	22,431

Note: Information about herbicide rate and application timing can be found in **Table 5**.

Source: Costs were based on cost estimates from Mississippi State (2005).

^a The following assumptions were made in the estimation of the budgets: (i) plant 11960 plants ha⁻¹; (ii) fertigation was for 1 hr week⁻¹; (iii) 15.24 cm (6 in.) of water was applied during the growing season; and (iv) base yield was 39,230 kg ha⁻¹ (35,000 lbs ac⁻¹). The yield assumption was needed for calculating harvesting/grading/packing costs.

^b Variable irrigation costs represents expenditures for application of water during the growing season. Fixed irrigation costs represent the costs of the machinery for performing irrigation.

^c Variable machinery costs represent costs for fuel, maintenance and repair. Fixed machinery costs represent the costs of purchasing the machinery, interest and depreciation.

^d Labor costs represent the costs of operating machinery and hand labor during the growing season.

^e The interest on operating capital represents the opportunity cost of investing the monies spent on variable costs into vegetable production.

^f Overhead and management fixed costs represent overall farm management costs and general expenses for the whole farm that are partially applicable to the vegetable enterprises undertaken.

Table 3. Cost budgets (USD ha⁻¹) for tomato production by cover crop and herbicide treatment system at Cullman, AL, 2005^a.

2.2.9. Leafy spurge

Ground cover by herbicide treatment interaction was significant for leafy spurge also. Turnip and crimson clover residue failed to control leafy spurge with or without herbicides (**Table 3**).

Application of *S*-metolachlor alone controlled leafy spurge 86% in plastic mulch plots and 97% in rye residue plots. Control of leafy spurge increased in plastic mulch plots, when *S*-metolachlor PRE was fb metribuzin EPOST fb clethodim LPOST but decreased under rye residue.

This research demonstrates that high residue cover crops like rye can provide improved weed control compared to black polyethylene mulch. Crimson clover and turnip residue in general were less effective in controlling summer annual weeds. This could partially be due to less biomass production by these cover crops and also rapid decomposition of the legume residue due to lower C:N ratio. Decomposition rate of Brassicas is between grasses and legumes [31]. Another important factor which could have facilitated increased weed control by rye residue is rolling rye with mechanical roller crimper prior to its termination with glyphosate. The rolling process resulted in a uniform mat of residue on the soil surface that was a substantial physical barrier for weed seedlings to emerge through, compared to tomato plant openings in the plastic mulch system that provides no barrier. Despite improved weed control, herbicides were always required to provide acceptable weed control by ground cover treatments, which is in agreement with the previous research [16]. The PRE application alone was also not sufficient in controlling a majority of weeds. Yenish et al. [32] also reported inconsistent control with cover crop residue and concluded herbicides were always required to achieve optimum weed control in corn. However, Yenish et al. [32] cautioned weed control should not be the only criterion in selection of cover crops. Factors like cost and ease of establishment, impact on yield should be taken into consideration before selecting a cover crop.

2.3. Tomato stand establishment

No significant difference in stand establishment among the plastic mulch and rye residue plots. Crimson clover plots had fewer tomato plants compared to other treatments at Cullman 2005; however, the differences were not significant. Non-significant differences in tomato stand establishment were observed among ground cover treatments at Cullman 2006.

2.4. Tomato yield

Tomatoes were harvested only at the Cullman location in 2004 and 2005. There was no winter cover crop by herbicide interaction. Thus, the model reduces to a main effects model for winter cover crop and herbicide treatment effects. Tomato fruit yield was greater in 2005 compared to 2006. Pooled over herbicide treatments (**Table 4**), tomato yield was similar following rye cover and plastic mulch systems. Both these systems yielded 50 Mg ha⁻¹ and 51 Mg ha⁻¹ marketable tomato respectively in 2005, and 38 Mg ha⁻¹ in 2006. However, the number of rotten tomato was more in plastic mulch plots than in rye plots in 2005, whereas no differences in total and marketable tomato yield were observed in these systems in 2006. Crimson clover plots yielded least in 2005. The lower yields following clover were likely due to higher weed interference in these systems. Yield was similar in turnip and crimson clover plots in 2006. Non-significant differences in tomato yield among ground cover treatments were observed in 2006. Averaged across ground cover treatments (**Table 2**), both herbicide regimen resulted in better yields compared to the no herbicide plots during both the years. Higher yields

were obtained with the system containing both PRE and POST herbicide applications. Teasdale and Abdul-Baki [15] also concluded that marketable tomato yields were lower in cover crop treatments without herbicides than the corresponding treatments with herbicides in two of three years. No significant cover or herbicide treatment differences ($P > 0.50$) were observed for marketable classes of fruit, although there was a difference in frequency of market classes between the two years (data not shown). The number of small and medium-sized fruits was greater in 2005 than in 2006.

Cover	Cullman					Cullman					Tuskegee				
	2005					2006					2006				
	AMACH	BRAPP	CYPES	ELEIN	PHTAM	AMACH	CYPES	DIGSA	IPOHE		CYPES	DIGSA	DIQVI	JAQTA	RAPRA
	%														
Brassica	30	57	53	58	25	67	95	88	94	69	38	39	56	14	
Crimson clover	12	55	70	50	38	52	69	75	66	80	39	54	71	9	
Plastic	73	84	85	80	86	57	71	75	70	75	72	0	12	29	
Rye	46	81	87	79	65	71	94	88	90	80	33	90	96	56	
P-values from contrasts															
Brassica vs. Clover	0.770	0.998	0.591	0.886	0.904	0.916	0.219	0.726	0.139	0.992	1.000	0.864	0.860	0.992	
Brassica vs. Plastic	0.050	0.023	0.043	0.107	0.002	0.970	0.234	0.719	0.190	0.820	0.014	0.301	0.190	0.820	
Brassica vs. Rye	0.782	0.055	0.023	0.137	0.101	0.997	0.999	1.000	0.967	0.069	0.970	0.014	0.035	0.069	
Clover vs. Plastic	0.005	0.016	0.446	0.017	0.009	0.997	1.000	1.000	0.995	0.663	0.016	0.069	0.038	0.663	
Clover vs. Rye	0.243	0.036	0.302	0.023	0.348	0.817	0.263	0.735	0.277	0.038	0.957	0.084	0.180	0.038	
Plastic vs. Rye	0.324	0.981	0.993	0.999	0.337	0.907	0.278	0.727	0.378	0.366	0.005	<0.001	<0.001	0.366	

Information about herbicide rate and application timing can be found in **Table 5**.

Table 4. Effect of ground cover treatments on broadleaf signalgrass (BRAPP), goosegrass (EELEIN), pokeweed (PHTAM), smooth pigweed (AMACH) and yellow nutsedge (CYPES), ivyleaf morningglory (IPOHE), smallflower morningglory (JAQTA), and wild radish (RAPRA) control at Cullman and Tuskegee AL.

Preemergence ^a		Postemergence ^a	
Herbicides	Rate (kg ha ⁻¹)	Herbicides	Rate (kg ha ⁻¹)
None	–	None	–
S-metolachlor	1.87	None	–
S-metolachlor	1.87	Metribuzin fb Clethodim	0.56 + 0.28

All preemergence herbicides were applied on the day of tomato transplanting. Postemergence application of metribuzin was accomplished 4 weeks after transplanting tomato followed by clethodim application at bloom initiation.

Table 5. Details of herbicide treatment rates and application timings.

Herbicide treatments		PHBPU				EPHES			
		Ground treatment				Ground treatment			
Preemergence	Postemergence	Turnip	Crimson clover	Plastic	Rye	Turnip	Crimson clover	Plastic	Rye
		%							
None	None	0	0	23	21	0	0	35	21
S-metolachlor	None	41	0	94	99	4	0	86	97
S-metolachlor	metribuzin fb clethodim	47	21	98	71	0	43	98	71
P-values from contrasts									
PRE + POST vs. PRE alone		1.000	0.999	1.000	0.470	1.000	0.793	0.939	0.592

	PHBPU			EPHES				
PRE + POST vs. non treated	0.762	0.999	0.004	0.550	1.000	0.793	0.006	0.443
PRE alone vs. non treated	0.895	1.000	0.022	0.003	1.000	1.000	0.231	0.003

Information about herbicide rate and application timing can be found in **Table 5**.

Table 6. Effect of ground cover and herbicide treatments on tall morningglory (PHBPU) and leafy spurge (ESULA) control at Cullman, AL in 2005.

Cover	2005	2006	2006	2005		2006	
	Cullman		Tuskegee	Total	Marketable	Total	Marketable
	No. of Plants ha ⁻¹			Mg ha ⁻¹			
Brassica	10903	10671	8274	49	42	36	29
Crimson clover	9743	10980	6495	38	33	36	29
Plastic	12140	11135	6263	59	50	38	31
Rye	11522	11599	8351	58	51	38	31
P-values from contrasts							
Brassica vs. Clover	0.657	0.901	0.073	0.323	0.375	1.000	1.000
Brassica vs. Plastic	0.609	0.723	0.036	0.331	0.400	0.972	0.996
Brassica vs. Rye	0.926	0.180	1.000	0.462	0.348	0.970	0.998
Clover vs. Plastic	0.106	0.987	0.988	0.007	0.013	0.975	0.995
Clover vs. Rye	0.312	0.514	0.058	0.014	0.010	0.973	0.997
Plastic vs. Rye	0.926	0.723	0.027	0.996	1.000	1.000	1.000

Information about herbicide rate and application timing can be found in **Table 5**.

Table 7. Effect of ground cover treatments on tomato stand establishment at Cullman and Tuskegee AL and tomato yield at Cullman in 2005 and 2006.

		Cullman		Tuskegee	2005		2006	
Herbicide Treatments		2005	2006	2006	Total	Marketable	Total	Marketable
Preemergence	Postemergence	No of Plants ha ⁻¹			Mg ha ⁻¹			
None	None	11193	10381	6901	47	40	30	24
S-metolachlor	None	11019	11599	7365	50	42	40	33
S-metolachlor	metribuzin fb clethodim	11019	11309	7771	56	49	41	33
P-values from contrasts								
PRE + POST vs. PRE alone		1.000	0.730	0.789	0.452	0.366	0.991	0.997
PRE + POST vs. non treated		0.978	0.054	0.342	0.227	0.145	0.107	0.161
PRE alone vs. non treated		0.978	0.010	0.734	0.890	0.856	0.135	0.139

Information about herbicide rate and application timing can be found in **Table 5**.

Table 8. Effect of herbicide treatments on tomato stand establishment at Cullman and Tuskegee AL and yield at Cullman in 2005 and 2006.

Treatment		Net Returns		
Grond Cover	Herbicide	2005		2006
		USD ha ⁻¹		
Turnip	None	7838	abc	-4199
Turnip	Pre	3461	ab	4654
Turnip	Pre + Post	6176	abc [†]	390

Treatment		Net Returns		
Crimson clover	None	-765	ab	566
Crimson clover	Pre	-1067	ab	-1274
Crimson clover	Pre + Post	8288	abc	2101
Plastic	None	9487	bc	-4884
Plastic	Pre	8720	abc	4563
Plastic	Pre + Post	9918	bc	2280
Rye	None	4060	abc	-190
Rye	Pre	13,924	c	341
Rye	Pre + Post	12,311	bc	1295

Single degree of freedom contrasts were conducted with SAS® PROC MIXED to examine differences between least square means at $P < 0.05$. Least square means followed by the same letter are not significantly different.

Table 9. Least square means of net returns over total costs for all the cover crop by herbicide systems at Cullman, AL. Information about herbicide rate and application timing can be found in **Table 5**.

2.5. Economic analysis

Economic costs of tomato production varied by treatment combination, but differences in costs due to treatment differences were relatively small overall, never larger than 3 percent of total costs (**Table 5**). Yield differences between treatments resulted in significant changes in total costs. Given that tomatoes were hand harvested, the cost of custom harvesting was the most significant cost of production (roughly 35 percent of total costs). Harvesting costs are a function of tomato yield. As yield increases, harvesting costs increase as more tomatoes need to be harvested from the field. Given that tomato yield varied significantly, this affected the total costs across treatments when calculating net returns. Furthermore, yield is a significant factor in calculating total crop revenue, resulting in significant variations in total crop revenue across treatments. Thus, primary differences in net revenue were primarily due to differences in tomato yields across treatments. However, given yield impacts both costs and revenues, net returns may not move in the same direction as yield.

In 2005, for all cover crop by herbicide system interactions, rye receiving only a PRE application provided the highest returns (\$13,924 ha⁻¹) followed by rye receiving both herbicide applications (\$12,211 ha⁻¹) (**Table 5**). The lowest returns in 2005 were from clover with only a PRE application (-\$1067 ha⁻¹) followed by clover with no herbicide application (-\$765 ha⁻¹). Both treatments with the highest return were significantly different from the two treatments with the lowest returns in 2005. For all the treatment combinations in between, excluding turnips with a PRE application, treatment differences were insignificant. In addition, results in 2005 indicate that there is no significant difference between using a rye cover crop or plastic under any of the alternative herbicide treatment regimes.

In 2006, the returns in general were significantly lower compared to 2005. In addition, differences in net returns between treatment combinations were not statistically significant (**Table 5**). The highest net returns were from using turnips with only a PRE application (\$4654 ha⁻¹), followed by plastic with only a PRE application (\$4563 ha⁻¹). Clover and rye returns were maximized when both PRE and POST herbicide application were applied. For the herbicide

treatments, the highest returns were achieved with only the PRE emergence application and lowest when herbicides were excluded.

Our study indicates that winter cover crop residue can provide early season weed control with supplemental use of EPOST herbicides. However, total reliance on a winter cover crop for weed control was not sufficient, and in all cases herbicides were required to provide season-long weed control to maintain tomato yield. As hypothesized, it was evident that the use of winter cover crop for weed control cannot completely replace herbicides. However, by reducing the use of PRE herbicides, growers can decrease the amount of pesticide introduced into the environment. Our results further indicate that performance of a rye winter cover crop was either equal or comparable to plastic mulch in controlling weeds and maintaining tomato yields, thus reducing the need for tillage and other seedbed preparation operations. Tomato establishment was also not affected by presence of high residue at the time of transplanting, which is a valid concern in high residue conservation tillage systems. These findings can further the development of sustainable farming systems.

Results in this paper are short term effects of converting from a conventional plastic mulch system to three high-residue conservation tillage systems. These results indicate the economic possibility of growing fresh market tomatoes utilizing a conservation tillage system while maintaining yields and economic returns. However, the long term impact of these systems on yield and profitability require further investigation.

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