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Planting Date Impacts on Soil Water Management, Plant Growth, and Weeds in Cover-Crop-Based No-Till Corn Production

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ABSTRACT

Low input and organic farmers are utilizing cover crop mulches in corn (*Zea mays* L.) production. Corn planting is typically delayed to improve the efficacy of mechanical termination with roller-crimpers. During the late spring, as cover crops are allowed to grow to maximize biomass production, soil moisture reserves can become depleted, thereby directly impacting early season growth of the subsequent cash crop. A 4 site-year study was conducted in North Carolina (Goldsboro, Kinston, and Salisbury) to evaluate the effects of timing of corn planting after roller-crimping a cover crop mulch, on soil moisture, crop stand, weed pressure and corn yield. Two cover crop mixtures were compared: winter pea [P/R, *Pisum sativum* ssp. *arvense* (L.) Poir.], and hairy vetch (HV/R, *Vicia villosa* Roth) were both mixed with cereal rye (*Secale cereale* L.). Both cover crop treatments produced biomass greater than 7000 kg ha^{-1} dry matter at all sites. Delayed planting after the cover crops were rolled-crimped did not enhance the soil volumetric water content (VWC) within the upper 10 cm. However, at Kinston in 2012, the VWC was 23% greater in the HV/R when compared to P/R and no-mulch treatments. The corn planting date across all 4 site-years did not affect weed biomass. Corn (2011) in the cover crop treatments yielded equivalent to their weed-free no-till without cover crop mulch counterparts. These results support the viability of rolled-crimped cover crop mulches as a lower energy input alternative to existing organic corn systems that rely solely on intensive tillage for weed management.

Weed and fertilizer management are among the greatest challenges associated with organic corn production (Mirsky et al., 2013). Without the reliance on chemical fertilizer and chemical weed control methods, intensive primary and frequent secondary tillage, in combination with the use of organic N fertilizer, are essential to ensure maximum corn yield. The negative effects associated with annual inversion tillage, such as reduction in soil organic matter, reduced soil aggregate stability (Stenberg et al., 2000), increased erosion (Holland, 2004), as well as heightened fuel and labor costs (Bernstein et al., 2011; Ryan, 2010) are well understood, and are among some of the most critical problems associated with organic corn production (Peigné et al., 2007).

New mulch-based technologies are being developed and evaluated that have the potential to reduce tillage in organic systems (Delate et al., 2012; Mirsky et al., 2012; Reberg-Horton et al., 2012). A cover crop-based approach where roller crimpers lay cover crops down into a uniform surface mulch and corn is no-till planted into the residue is one such approach (Teasdale et al., 2012). This cover crop-based approach was originally developed in Brazil (Derpsch et al., 1991) and gained interest in the United States after the USDA-ARS National Soil Dynamics Laboratory improved on the roller-crimper design, and was promoted by the Rodale Institute (Kornecki et al., 2009; Rodale Institute, 2012). The roller-crimper is a ground-driven implement designed to terminate and manage cover crops before cash crop planting (Davis et al., 2010; Mirsky et al., 2013; Reberg-Horton et al., 2012; Teasdale et al., 2012; Wells et al., 2013).

Cover crop-based organic rotational no-till corn production has rarely achieved comparable yield to conventional no-till systems (Parr et al., 2011). This has largely been due to the constraints of the production system such as the need for high cover crop biomass levels to control weeds (Smith et al., 2011; Reberg-Horton et al., 2012). Corn yields in organic no-till systems are quite variable due to: challenges in cutting cover crop residue in the planting row and achieving adequate seed-to-soil contact; insect damage; delayed and staggered germination;

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Abbreviations: HV/R, hairy vetch and cereal rye; NT, no-till without cover crop mulch; P/R, winter pea and cereal rye; VWC, volumetric water content; WAP, weeks after planting; +H, herbicide weed control; -H, non-herbicide weed control.

and insufficient N contributions from the cover (Delate et al., 2012; Mirsky et al., 2012; Teasdale et al., 2012)."

Beyond crop population constraints, reduced corn yield in the cover crop-based system can also be attributed to inconsistent weed control and drought stress. Sufficient weed control with mulches requires higher biomass levels than hairy vetch alone can achieve and requires residues that persist longer on the soil surface (Mirsky et al., 2012). Cover crop mixtures that integrate grasses and legumes have been known to achieve higher biomass levels in mixture than in monoculture (Clark et al., 1997; Hayden et al., 2014). By including a grass with the legume, the residue decomposition rate will also decrease; resulting in more persistent weed control (Ranells and Wagger 1996, Ruffo and Bollero 2003). For example, the addition of a cereal grain to a hairy vetch cover crop will increase biomass of the cover crop mix by more than 2000 kg ha^{-1} DM when compared to vetch monocultures (Parr et al., 2011; Reberg-Horton et al., 2012). The increased biomass of mixed cover crops can enhance the weed suppressive ability of the system (Smith et al., 2011; Teasdale and Mohler, 2000).

Soil moisture at planting, is another factor that can negatively impact early season corn growth and development. For optimum cover crop termination (i.e., minimal cover crop regrowth), the cover crops must be terminated during the critical growth stages such as: soft dough for cereal rye, and when pods are first seen on the upper five nodes of hairy vetch (Ashford and Reeves, 2003; Mischler et al., 2010; Reberg-Horton et al., 2012). Delaying cover crop termination until critical maturation can increase soil moisture losses via cover crop transpiration, thereby depleting soil moisture before spring cash crop plantings (Price et al., 2009). Davis (2010) reported reduced soil moisture post termination, in rolled-crimped treatments, when compared to burndown treatments. As a result, he discovered positive correlations between soil moisture after the cover crops were rolled-crimped with soybean [*Glycine max* (L.) Merr.] yield.

A mitigation strategy for soil moisture losses is to delay planting after rolling to allow precipitation to partially recharge soil moisture reserves. Water deficits due to winter cover crops vary widely based on soil type and winter through spring precipitation (Price et al., 2009; Reberg-Horton et al., 2012; Reeves, 1994). Staggering rolling and planting can recharge moisture in the seed germination zone but would not be sufficient for large water deficits. Waiting until later in the season to plant corn is not without its risks. Insect damage and greater water stress at pollination are concerns for growers in our region when planting is delayed (North Carolina Cooperative Extension Service, 2000). To examine whether delayed planting improves corn performance, this study was designed with three objectives in mind: (i) determine the impact of delaying planting after cover crops were rolled-crimped on soil moisture and subsequent corn performance, (ii) compare the level of weed control achieved utilizing winter P/R and HV/R mixtures as cover crop mulches, and (iii) quantify delayed planting and cover crop mixtures on corn yield.

MATERIALS AND METHODS

The effect of planting date in relationship to cover crop termination and cover crop species was tested in a 4 site-year field experiment conducted at the Center for Environmental Farming Systems in Goldsboro, NC (2011) (35.38291° N, −78.035846° W), Caswell Research Farm in Kinston, NC (2011 and 2012) (35.273206° N, −77.623816° W), and Piedmont Research Station in Salisbury, NC (2012) (35.68503° N, −80.60338° W). Locations were selected from the North Carolina Department of Agriculture Research Stations that span a broad set of climate, and soil types to North Carolina corn producers. The soil type in Goldsboro for 2011 was Wickham loamy sand (fine-loamy, mixed, semiactive, thermic Typic Hapludults) with 2 to 6% slope, Kinston for 2011 was Johns loamy sand (fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludults) with 0 to 2% slope and Kenansville loamy sand (loamy, siliceous, subactive, thermic Arenic Hapludults) with 0 to 3% slope, Kinston for 2012 was Johns loamy sand (fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Aquic Hapludults) with 0 to 2% slope and Kenansville loamy sand (loamy, siliceous, subactive, thermic Arenic Hapludults) with 0 to 3% slope, and Salisbury for 2012 was Mecklenburg clay loam (fine, mixed, active, thermic Ultic Haplualfs) with 2 to 8% slope, moderately eroded.

The experiment used a randomized complete block design with six replications, with factors consisting of the following: (i) corn planting date after cover crop termination (i.e., same day vs. approximately 2-wk after cover crops were rolled-crimped), (ii) with (PRE and POST) or without herbicide weed control (i.e., +H and–H), and iii) cover crop treatments: no-till without cover crop mulch (NT) (i.e., no cover crop), winter pea (*Pisum sativum* L. ssp. *arvense*) (P/R), and AU Early Cover hairy vetch (HV/R) both mixed with Wrens Abruzzi rye (*Secale cereal* L.). Supplemental mineral fertilizer was provided to remove potential limitations of N from the cover crops, and a herbicide treatment was included to establish weed-free control plots.

In the fall, the entire field was disked with a tandem off-set disk and leveled with a finishing harrow before planting cover crops (mid-September) to remove any existing vegetation from the prior soybean crop. Lime, P, and K were applied according to soil tests before the cover crop planting in early fall (Table 1). The plot size was four rows wide (76-cm row spacing) by 15-m long. After the seedbed was prepared in the fall (mid-September), cover crops (CC) were subsequently planted in all treatment combinations including the no-till without CC mulch plots (NT+H and NT-H) with a grain drill on a 13-cm row spacing. The winter pea and hairy vetch were planted at a rate of 28 and 51 kg ha^{-1}, respectively. Both cover crop treatments were mixed with Wrens Abruzzi rye at a rate of 56 kg ha^{-1}. Cover crops were terminated for both NT treatments in February at all 4 site-years via glyphosate (Honcho Plus, at 0.85 kg a.i. ha^{-1}, Monsanto Company, 800 N Lindbergh BLDV., ST. Louis, MO) before the cover crops reached 15 cm and had no visible residue by the time of corn planting. In early May (Table 1), the cover crop treatments (all plots) were rolled-crimped (i.e., terminated) with a 3.1 m roller-crimper (I&J Manufacturing, Gap, PA), parallel to cover crop drilling direction. The cereal rye was at soft-dough stage (Feeke's 11.2) and the legumes were at early pod set (Hoffman et al., 1993; Mischler et al., 2010).

Corn plots in the "Early Planting Date" treatments were planted immediately after rolling and approximately 2 wk after rolling in the "Late Planting Date" treatments. Certified

Table 1. Planting dates, cover crop growth stages, and percent control via roller crimper at Goldsboro, Kinston, and Salisbury, NC (2011–2012).

Site-year	Corn planting dates		Cover crop growth stage at termination			Cover crop control via roller crimper
	Early†	Late	Rye‡	Winter pea§	Hairy vetch§	
2011						
Goldsboro	2 May	23 May	11.2	third	sixth	93%
Kinston	3 May	18 May	11.2	EPS¶	sixth	80%
2012						
Kinston	7 May	14 May	11.2	EPS	EPS	92%
Salisbury	21 May	2 June	11.4	> fifth	> fifth	100%

† Rolled-crimped cover crop termination occurred once at each location during the "Early" corn planting date.

‡ Cereal rye growth stage taken at rolled-crimped cover crop termination using the Feeke's scale.

§ Legume cover crop maturity characterized as the lowest node position (from terminal node) where seed pods had formed (Mischler et al., 2010).

¶ EPS, Early pod set. North Carolina.

organic corn seed (Doebler's N631, 110-d, Jersey Shore, PA) was planted with a no-till planter (Model 7200 Max Emerge, Conservation Tillage, John Deere, Moline, IL) parallel to the roller-crimper direction at 81,504 live seed ha^{-1} for Goldsboro (2011) and Kinston (2011 and 2012), and 78,486 live seed ha^{-1} for Salisbury (2012). Corn seeding rates were adjusted for location based on recommended seeding rates for each soil type. Additional modifications to the planter were necessary at some locations due to either higher cover crop biomass levels or lodging. At the Kinston and Salisbury sites (2012), Shark Tooth row cleaners (Yetter Manufacturing, P.O. Box 358, 109 S. McDonough, Colchester, IL 62326) were employed to clear mulch ahead of the no-till coulter and v-openers of the planter units. Curvetine closers were also used (2012) to help close the row more effectively.

Crop management included the application of N fertilizer and herbicide applications. The corn crop received 180 kg N ha^{-1} consisting of split-applications of 80 kg N ha^{-1} pre-plant and 100 kg N ha^{-1} banded 4 wk after planting (WAP) as Urea Ammonium Nitrate. Having a full factorial of experimental treatments that include mulched plots which receive (+H) or do not receive a post-emergence herbicide (–H) allowed the quantification of both the impact of the mulches on weeds as well as determine crop yield loss due to weed competition. The weed-free checks received S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)-acetamide] plus atrazine [6-chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] (Metal II AT, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) and Ametryn (2-ethylamino-4-(isopropylamino)-6-(methylthio)-s-triazine(Evik DF, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419) or nicosulfuron {1-(4,6-dimethoxy-2-pyrimidinyl)-3-[3-(dimethylcarbamoyl)-2-pyridylsulfonyl]urea, 2-[(4,6-Dimethoxypyrimidin-2-ylcarbamoyl)sulfamoyl]-N,N-dimethylnicotinamide}(Accent 75 DF, DuPont, 1007 Market St., Wilimington, DE 19898) as a post-emergent herbicide depending on the weed community. Hand weeding was utilized as needed in addition to herbicide weed control to ensure weed-free conditions throughout the season in the +H plots. The two check plots that were no-till but without cover crop mulch (NT+H, and NT-H) received a glyphosate [*N*-(phosphonomethyl)glycine] (Honcho Plus, Monsanto Company, 800 N Lindbergh BLDV., ST. Louis, MO) burndown at planting thus ensuring weed-free conditions at roll-crimping and planting.

Plant and soil measurements collected throughout the season included cover crop biomass production, plant populations (i.e., corn), percent weed coverage, total weed biomass, percent soil volumetric water content, and corn yield. Following cover crop termination (i.e., same day), cover-crop biomass was harvested on an area basis (0.5 m^2) and dried at 60°C for 72 h to determine dry weight biomass production. Corn population was recorded (4 WAP) in the two center corn rows (6-linear meters total) that were also used to collect yield. Weed cover was visually rated across the entire plot for all treatments at 12 WAP on a percent basis, with no cover as 0% and complete weed coverage as 100%. Total weed biomass was collected on an area basis and dried at 60°C for 72 h to determine dry weight weed biomass at 12 WAP. Volumetric water content was measured (Fieldscout TDR 300 Soil Moisture Meter, Spectrum Technologies, Plainfield, IL 60504) to a depth of 10 cm for both planting dates at all site-years; however, due to sampling error, only the 2012 volumetric water content was reported. Using a small plot combine, corn yield was harvested from 12.2 m of the two center rows in each plot.

To determine the effects of cover crop biomass production, weed coverage and biomass, along with crop populations on corn yield, we used a mixed model analysis of variance. Preliminary analysis, across all parameters, showed significant treatment by site-year interactions; therefore, a generalized analysis was not prohibited. Each site-year was analyzed separately using proc MIXED, and within each site-year, treatments were modeled as fixed effects, and blocks as random effects (SAS Institute, 2006). Due to a lack of homogeneous variance for the percent weed cover data, an arcsine of the square root transformation was used on the dependent variable (Steel et al., 1996). For the same reason, total weed biomass data was transformed via the logarithmic transformation (Steel et al., 1996). Transformed means were back-transformed for presentation, and all means were separated using pre-planned contrasts (SAS Institute, 2006; Steel et al., 1996).

RESULTS AND DISCUSSION

Cover Crop Performance

High levels of cover crop biomass were achieved for both P/R and HV/R mixtures across all 4 site-years (Table 2). With the exception of Goldsboro (2011), cover crop biomass production did not vary between the P/R and HV/R treatments (Table 2). At Goldsboro (2011), P/R biomass was significantly higher than HV/R producing 8876 and 7781 kg ha^{-1} dry

Table 2. Cover crop biomass production at rolled-crimped cover crop termination for Goldsboro, Kinston, and Salisbury, NC (2011–2012).

Cover crop treatment	Goldsboro 2011	Kinston 2011	Kinston 2012	Salisbury 2012
	Biomass, kg ha^{-1} dry matter			
Winter pea + Wrens Abruzzi rye (P/R)	8876a†	10,661a	9050a	7192a
Cultivar AU Early Cover hairy vetch + Wrens Abruzzi rye (HV/R)	7781b	9,674a	8086a	8117a

† Within columns, means followed by the same letter are not significantly different based on pre-planned contrast at $p < 0.05$.

matter (DM), respectively (Table 2). This trend is in agreement with previous research, where P/R mixtures out-yielded HV/R mixtures by nearly 2000 kg ha^{-1} DM (Parr et al., 2011). Biomass production for both of the cover crop treatments, P/R and HV/R were in the suggested range for optimal weed suppression of 8000 kg ha^{-1} (Teasdale et al., 2012; Teasdale and Mohler, 2000). Cover crop mixtures of annual cereal grains and viny habit legumes increases the functional diversity of aboveground biomass due to the complementary canopy architectures between the bi-cultures, thus increasing the biomass production of the rolled-crimped mulch.

Soil Moisture and Crop Populations

Corn planting date after cover crop termination (i.e., same day vs. approximately 2-wk after cover crops were rolled-crimped) was not found to significantly impact soil volumetric content across all site-years (Table 3). Cover crop treatments (NT, P/R, and HV/R) significantly impacted VWC across all four sampling events at Kinston (2012), and for the 4 June sampling at Salisbury (2012)(Table 3). At Kinston (2012), greater VWC was estimated in HV/R when compared to NT and at three of the four sampling intervals when compared to P/R treatment (Table 3). Unlike the HV/R treatment at Kinston (2012), the P/R treatment did not differ in VWC when compared to the NT treatment (Table 3). There was no significant difference between the VWC measured in the P/R and NT treatments and for both the 22 May and 4 June sampling periods at Salisbury. However, during the 4 June sampling period in Salisbury, greater VWC was estimated in the HV/R treatments when compared to the NT treatment (Table 3). The differential effect of P/R and HV/R mixtures on soil moisture could be due to the difference in growth form. While both legumes have a vining habit, the HV/R mixture was more extreme and virtually every plot had lodged before rolling. The HV/R mulch was extraordinarily intertwined and the soil beneath the cover crop reside was not visible after rolling. Even though the winter pea in the P/R treatments exhibited similar, but reduced viny habit when compared to the hairy vetch in the HV/R treatments, there was considerable less lodging in the P/R treatments resulting in gaps in the mulch where soil was visible after rolling.

Corn populations were generally greater than reported from previous research that utilized heavy mulches (Mischler et al., 2010; Teasdale et al., 2012). Corn populations were reduced

Table 3. Analysis of variance and mean percent soil volumetric water content for Kinston (2012), and Salisbury (2012), as influenced by corn planting date and cover crop type.

	Kinston 2012				Salisbury 2012	
Source	7 May	10 May	14 May	1 June	22 May	4 June
	ANOVA					
Planting date (D)	ns†	ns	ns	ns	ns	ns
Cover crop (C)	***	***	**	**	ns	*
D × C	ns	ns	ns	ns	ns	ns
	Volumetric water content, v/v					
Early planting date‡						
NT+H	0.17	0.26	0.09	0.18	0.25	0.25
P/R	0.18	0.26	0.08	0.18	0.25	0.26
HV/R	0.22	0.28	0.10	0.20	0.25	0.26
Late planting date						
NT+H	0.19	0.26	0.09	0.19	0.26	0.26
P/R	0.19	0.25	0.08	0.18	0.25	0.26
HV/R	0.22	0.28	0.10	0.19	0.25	0.26
SE	0.01	0.009	0.008	0.01	0.01	0.004
	Soil volumetric water content, v/v§					
NT+H	0.180b	0.258b	0.089ab	0.182b	0.256a	0.251b
P/R	0.185b	0.258b	0.078b	0.178b	0.255a	0.257ab
HV/R	0.221a	0.280a	0.099a	0.198a	0.253a	0.261a

* Significance of *F* tests at $\alpha = 0.05$.

** Significance of *F* tests at $\alpha = 0.01$.

*** Significance of *F* tests at $\alpha = 0.001$.

† ns, nonsignificant at $\alpha = 0.05$.

‡ NT, no-till without cover crop mulch; P/R, winter pea; HV/R, cultivar AU Early Cover hairy vetch.

§ Soil volumetric water content was measured across all treatments at a depth of 12 cm for both sites and is displayed by date and treatment. Within columns, means followed by the same letter are not significantly different based on Fisher's Protected LSD test at $p < 0.05$.

relative to non-mulched plots at Kinston (2011) for the early and late planting dates, and at Kinston 2012 for the early planting date (Table 4). However, corn populations were not affected by cover crops at the other 2 site-years (Table 4). The P/R and HV/R mixtures had similar corn populations with the exception of the early planting date at Kinston (2011). The HV/R plots had reduced corn populations. This site-year (Kinston 2011) had the highest biomass and hairy vetch has been noted for causing more planter problems than other cover crops (Mischler et al., 2010). The corn planting date affected corn populations at Goldsboro (2011) and Kinston (2012). Corn populations were greater for the early planting date at Goldsboro (2011), whereas the opposite was observed for corn populations during the late planting date at Kinston (2012) (Table 4). Across the 4 site-years, Salisbury populations were least effected by both cover crop and planting date treatments (Table 4).

Soil type and conditions, along with available soil moisture, may play an important role in explaining the reductions in crop stands in the mulched plots for Goldsboro (2011) and Kinston (2012) (Table 4). One possible explanation for greater corn populations in the early-planted cover crop treatments at Goldsboro (2011) and the late-planted cover crop treatments at Kinston (2012) could be the increased soil VWC (Table 3). At Kinston (2012), the soil VWC had declined nearly half from the VWC at the early planting, and was measured below 10% on 14 May (i.e., late planting date for Kinston 2012). The drought stress was alleviated by the 1.7 cm rainfall event occurring over the night of 14 May and continuing into the following day (Fig. 1). Timely rainfall events alone do not fully explain the fluctuation in corn stand measured in the cover crop treatments.

Soil type at these locations may play an important role in establishing corn populations. Even with row cleaners mounted ahead of the planter units, there was still an increased frequency of cover crop residues hair-pinned into the seed furrow. Unlike the coarse sandy soil types at Goldsboro and Kinston (2011 and 2012), the clay loam soils at Salisbury provided a firmer planting surface; therefore, improving the slicing efficiency of the front coulter and reducing the incidence of hair-pinning (Mirsky et al., 2013). Achieving uniform crop populations will continue to be an issue in cover crop-based organic rotational no-till corn and soybean production until planter technology improves residue cutting and seed placement. These findings, along with others, (Mirsky et al., 2013; Reberg-Horton et al., 2012), highlight the need for improved no-till planting technology that can achieve proper seed placement while minimizing disturbance of the cover crop mulch.

Weed Control

Despite weed coverage estimates >60% at 3 of the 4 site-years, weed biomass estimates were <500 kg ha^{-1} (with exception of Salisbury) (Fig. 2 and 3). Considering the lack of any weed control measure other than the mulch, these weed weights are low, and in the organic context would be considered excellent (Fig. 2 and 3)(Ryan et al., 2009). The cover crop type was important in determining the weed coverage at Goldsboro (2011), Kinston (2011), and Salisbury (2012). The corn planting date had no effect on weed coverage with exception of Salisbury (2012)(Table 5). Since planting date had no effect on weed coverage at Goldsboro (2011) and Kinston (2011 and 2012), weed coverage estimates for the prior mentioned sites were presented averaged over planting date (Table 5)(Fig. 2). The weed coverage data for Salisbury (2012) was not averaged over planting date due to significant planting date by cover crop type interaction (Table 5)(Fig. 2). Even though, the corn planting date was of importance at Salisbury (2012) only, the P/R without herbicides (P/R-H) treatment had significantly greater weed coverage estimates than HV/R-H at both Goldsboro

Table 4. Analysis of variance and mean corn populations for Goldsboro (2011), Kinston (2011–2012), and Salisbury (2012), as influenced by corn planting date and cover crop type.

Source	Goldsboro 2011	Kinston 2011	Kinston 2012	Salisbury 2012
	ANOVA			
Planting date (D)	***	ns†	***	ns
Cover crop (C)	ns	***	ns	ns
D ×C	ns	ns	***	ns
Estimate				
Early planting date	69,970a	64,868a	64,869b	74,293a
Late planting date	57,119b	59,847a	79,186a	76,494a
Early planting date‡	Corn populations, plants ha^{-1}			
NT§	68,170a¶	80,868a	75,346a	74,124a
P/R	71,570a	61,532b	64,259b	77,929a
HV/R	70,169a	52,204c	55,003b	70,825a
Late planting date				
NT	56,014a	69,605a	75,888a	78,790a
P/R	56,330a	56,117b	77,929a	75,561a
HV/R	59,014a	53,818b	83,741a	75,130a

*** Significance of *F* tests at α = 0.001.

† ns, nonsignificant at α = 0.05

‡ Early planting date refers to rolled-crimped cover crop termination and planting of corn occurring on the same day. Late planting date refers to corn planting date that occurred (approximately) 2-wk after rolled-crimped cover crop termination.

§ NT, no-till without cover crop mulch; P/R, winter pea; HV/R, cultivar AU Early Cover hairy vetch, Wrens Abruzzi rye; CC, cover crops P/R and HV/R;

¶ Within columns, and by planting date, means followed by the same letter are not significantly different based on Fisher's Protected LSD test at p < 0.05.

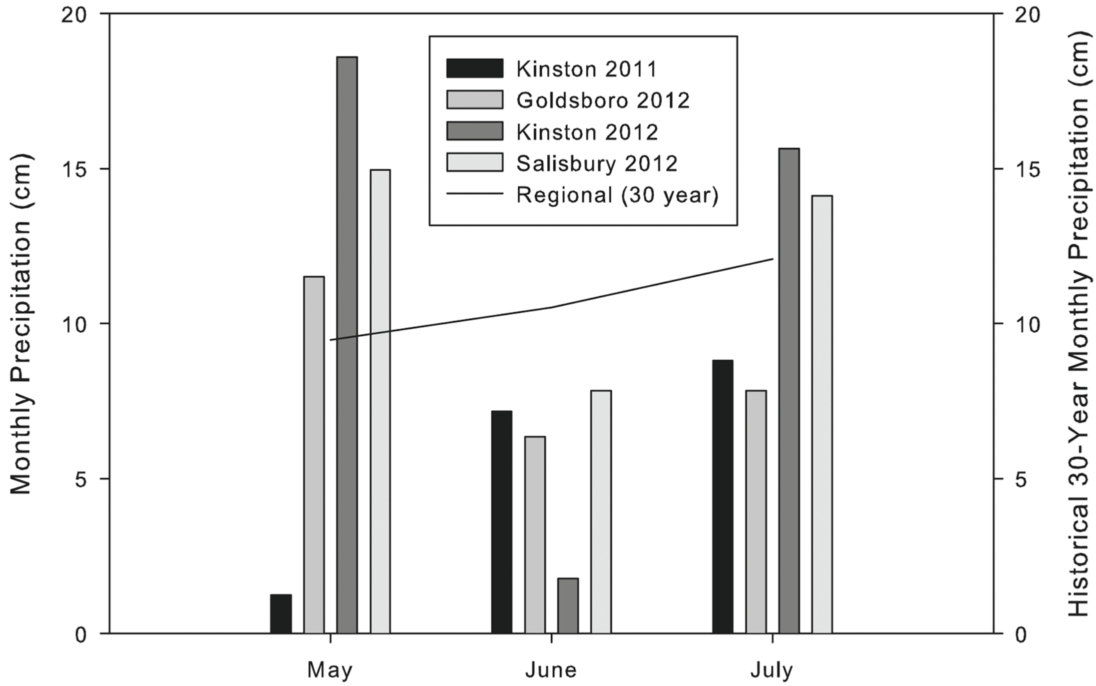

Fig. 1. Monthly precipitation (cm) and 30-yr normal for Goldsboro (2012), Kinston (2011 and 2012), and Salisbury (2012). Weather data provided by the State Climate Office of North Carolina.

(2011) and by the late planting date at Salisbury (2012)(Table 5)(Fig. 2). The lack of a corn planting date effect on weed coverage at 3 of the 4 site-years was surprising. Since the cover crops were terminated on the same day for both early and late corn planting date, it seems plausible that the late planting date plots should have greater incidence of weed coverage giving that the weeds in the late planting date had nearly 2-wk head start on the corn crop.

Weed biomass production was influenced by cover crop treatments only in 2011 at Kinston, where the pea without herbicide weed control (P-H) treatment produced significantly greater weed biomass than the HV/R-H treatment (Table 5)(Fig. 3). While not always significant at the a = 0.05, P/R-H treatment had greater weed biomass estimates for the early planting date at Goldsboro (p = 0.12), Kinston (2011;

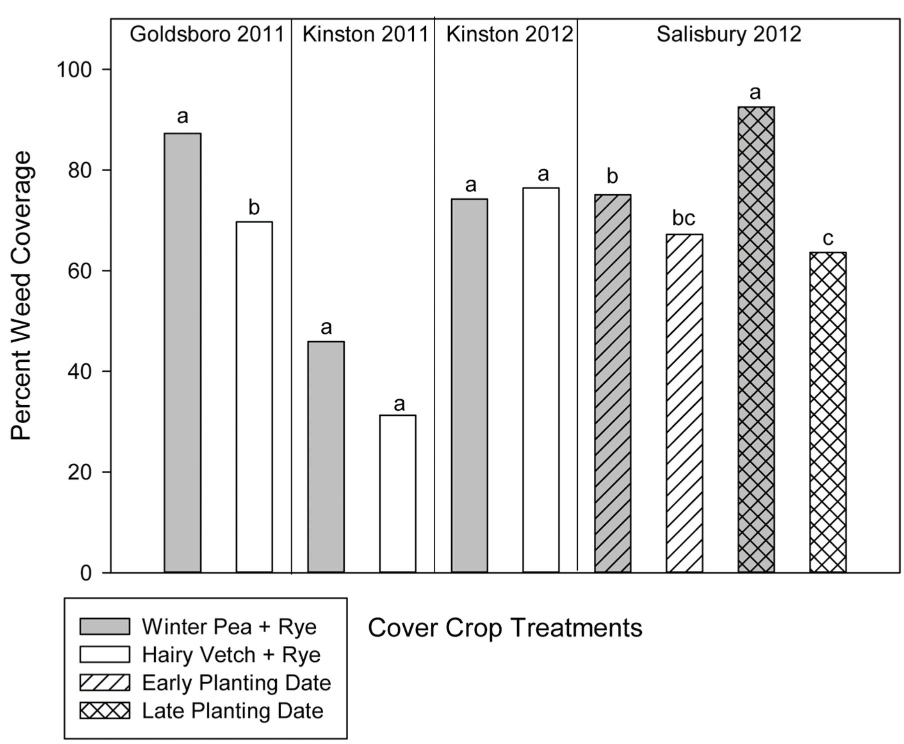

Fig. 2. Percent weed coverage in winter pea and hairy vetch cover crop treatments for Goldsboro (2011), Kinston (2011–2012), and Salisbury (2012), as influenced by corn planting date and cover crop type. Weed coverage estimates for Goldsboro (2011), and Kinston (2011–2012) are pooled over planting date. Weed-free (NT+H, P+H, and HV/R+H) and weedy check plots (NT-H) are excluded from the analysis. Means followed by the same letter are not significantly different based on Fisher's Protected LSD test at p < 0.05.

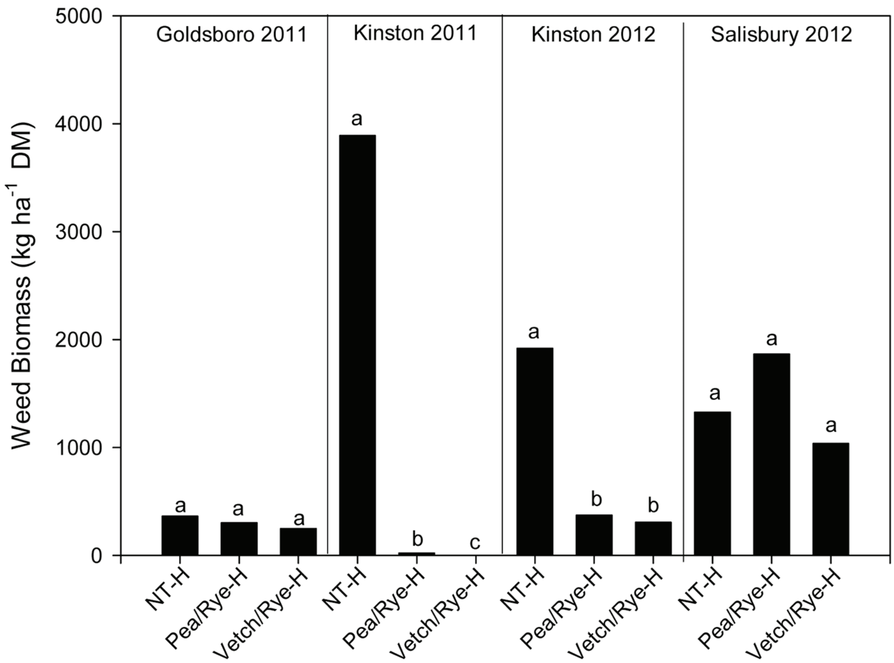

Fig. 3. Total weed biomass as influenced by site, and cover crop. Data was pooled over planting date for each site-year. Planting date did not significantly affect weed biomass. Weed biomass was collected on an area basis for all treatments by corn growth stage VT. Within site-year treatment means followed by the same letter are not significantly different based on Fisher's Protected LSD test at $p < 0.05$. Abbreviations: NT+H, no-till without cover crop mulch with herbicide weed control; P/R, winter pea; HV/R, cultivar AU Early Cover hairy vetch;-H, no herbicide weed control.

$p = 0.02$), and at the late planting date at Kinston (2012; $p = 0.19$) and Salisbury (2012; $p = 0.17$). Reduced weed suppression in the P/R cover crop treatments was surprising since the P/R treatment produced greater mulch biomass than the HV/R (Table 1). Two possible explanations for improved weed control in the HV/R treatment could be the allelopathic activity of hairy vetch (Fujii, 2001), or canopy architectural difference observed at planting that lead to less soil shading by the winter pea.

Corn Yield

Corn yield was not generalized over site-years due to significant treatment by site-year interactions; therefore, separate analysis for corn yield was performed (Table 6). Corn planting date was important in determining yield at Kinston (2012) and Salisbury (2012) (Table 6), whereas Goldsboro was the only site where cover crop treatment impacted corn yield (Table 6).

Even though weed biomass estimates were relatively low, weeds reduced corn yield at 3 of the 4 site-years; however, at Kinston (2011) there were no differences between the cover crops without herbicide weed control (CC-H) yields and the CC+H (Table 6). Weed-driven yield differential between NT+H and both P/R-H and HV/R-H treatments was most pronounced for the early planting date at Kinston (2012), and the late planting dates for both Kinston (2012) and Salisbury (2012), with approximately 2000, 1000, and 4000 kg ha^{-1}, respectively, greater corn yield in the NT+H treatments (Table 6). At Kinston 2011, corn yield was greater in the NT+H vs. CC+H treatments (Table 6). This finding was not surprising since the NT treatments at Kinston (2011) had greater crop populations for both planting dates when compared to the P/R and HV/R cover crop treatments (Table 4). The improved corn yield in the NT+H treatments relative to the corn in the cover crop treatments

Table 5. Analysis of variance of weed coverage and weed biomass in winter pea and hairy vetch cover crop treatments for Goldsboro (2011), Kinston (2011–2012), and Salisbury (2012), as influenced by corn planting date and cover crop type.

Source	Goldsboro 2011	Kinston 2011	Kinston 2012	Salisbury 2012
		Weed coverage†		
Planting date (D)	ns‡	ns	ns	**
Cover crop (C)	*	$p < 0.08$	ns	***
D × C	ns	ns	ns	***
		Weed biomass†		
Planting date (D)	ns	ns	ns	ns
Cover crop (C)	ns	**	ns	ns
D × C	ns	ns	ns	ns

* Significance of F tests at $\alpha = 0.05$.

** Significance of F tests at $\alpha = 0.01$.

*** Significance of F tests at $\alpha = 0.001$.

† Weed-free (NT+H, P/R+H, and HV/R+H) and weedy check plots (NT-H) were excluded from the analysis.

‡ ns, nonsignificant at $\alpha = 0.05$.

Table 6. Analysis of variance results of corn yield at Goldsboro (2011), Kinston (2011–2012), and Salisbury (2012), as influenced by corn planting date and cover crop type and presence, and weed control.

Source	Goldsboro 2011		Kinston 2011		Kinston 2012		Salisbury 2012	
Planting date (D)	ns†		ns		**		ns	
Cover crop (C)	*		ns		ns		ns	
Herbicide (H)	**		ns		**		**	
D × H	ns		ns		ns		ns	
D × C	ns		ns		ns		**	
C × H	ns		ns		ns		*	
D × H × C	ns		ns		ns		ns	
Contrast‡								
NT+H vs. CC+H§	ns		*		ns		$p < 0.11$	
CC+H vs. CC-H	**		ns		$p < 0.11$		**	
P/R-H vs. HV/R-H	*		ns		ns		ns	
	Early¶	Late	Early	Late	Early	Late	Early	Late
Treatments					Yield, Mg ha^{-1}			
NT+H	5.6ab#	5.5a	6.1a	5.4a	11.0a	13.3a	7.7cd	11.8ab
NT-H	–	–	–	–	6.6c	10.2b	5.6d	10.9ab
P/R+H	5.3ab	4.1ab	5.0a	4.4a	7.6bc	12.9a	14.0a	12.4a
P/R-H	3.1c	3.3b	5.3a	4.9a	6.8c	10.3b	10.1bc	6.6c
HV/R+H	6.3a	5.0ab	4.8a	5.2a	9.2ab	12.5ab	12.2ab	9.1bc
HV/R-H	4.5bc	4.5ab	4.7a	5.1a	8.0bc	11.6ab	11.2ab	8.9bc

* Significance of *F* tests at $\alpha = 0.05$.

** Significance of *F* tests at $\alpha = 0.01$.

† ns, nonsignificant at $\alpha = 0.05$.

‡ The contrast NT+H vs. CC+H evaluates the corn yield of the cover crop (CC) treatments absent of weeds as represented by NT+H. CC+H vs. CC-H assesses weed driven yield loss in the cover crop treatments. P/R-H vs. HV/R-H evaluates the weed suppression performance between the two cover crop treatments void of herbicide weed control.

§ NT, No-till without cover crop mulch; P/R, winter pea, Wrens Abruzzi rye; HV/R, cultivar AU Early Cover hairy vetch, Wrens Abruzzi rye; CC, cover crop treatments P/R and HV/R; H, weed control (i.e. plus or minus herbicide weed control);

¶ Early planting date refers to rolled-crimped cover crop termination and planting of corn occurring on the same day. Late planting date refers to corn planting date that occurred (approximately) 2 wk after rolled-crimped cover crop termination.

Within columns, means followed by the same letter are not significantly different based on Fisher's Protected LSD test at $p < 0.05$.

illustrates the challenges associated with corn production systems that incorporate the use of roller-crimped cover crop mulches.

Since the P/R and HV/R treatments produced in excess of 7000 kg ha^{-1} DM, the increased weed pressures in the non-herbicide mulch treatments were not solely a function of inadequate cover crop biomass production (Teasdale and Mohler, 2000). It is possible, that the in-row proximity of the escaped weeds illustrates the difficulties of no-till planting in high residue mulches. At each location, row cleaners were necessary to ensure proper corn seed placement, resulting in the reduction of mulch over the furrow. This, along with increased soil disturbance, favored small-seeded summer annual weeds, which highlights the need for innovative planter technologies that minimize residue disturbance while achieving good seed/soil contact.

CONCLUSION

In summary, both mixtures of hairy vetch/cereal rye and Austrian winter pea/cereal rye provided acceptable suppression of weeds and for organic no-till corn production. However, our hypothesis that delaying corn planting following cover crop termination would increase soil water content was not supported. Contrary to several study recommendations, delayed planting of corn following the termination of the cover crop had minimal effect on the recharging of the soil moisture. It is possible that gains in soil moisture achieved by delayed planting after the cover crops were rolled-crimped masked by precipitation events occurring shortly after cover crop termination and cash crop planting. Even though planting on the same day or waiting 2 wk after cover crop termination had no effect on soil volumetric water content, corn populations were greatly effected by lack of rainfall during the delay in planting period. Timely rainfall events coinciding with planting and roller-crimping date are paramount to ensuring an optimum corn stand; therefore illustrating the critical nature of scheduling roller-crimping termination and cash crop planting dates that best coincide with precipitation events. These findings indicate the need of high residue no-till planter innovations that not only minimizes hair-pinning, but also does so with minimal disturbance to the weed suppressive cover crop mulch. In addition to improved planter technology, the entomological interactions on crop performance must be assessed. Where the use of seed treatments are not available, due to organic regulations, in conjunction with high residue cover crop systems, crop performance may in fact be influenced by additional biotic stresses.

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