High-Residue Conservation Tillage for Row Crops

The autumn 2005 issue of *Inside CEFS* offered a glimpse of the first mechanical roller-crimper in North Carolina deployed for residue management in cotton and soybean. These trials were initiated in 2003 and continued for two cropping seasons. Our goal was to evaluate weed suppression, residue management, and cotton lint and soybean yield response in a high-residue, low tillage system to determine (1) the physical effect of surface pressed, intact residue and residue orientation on early-season weed suppression using different weed control programs; (2) the relationship between residue decomposition and incident weed pressure; and (3) the impact of residue management on soybean and cotton stand establishment, growth, and yield. Further testing was done in 2005 to assess early season root zone soil moisture content in selected treatments. Readers who are not acquainted with the mechanical roller-crimper or the motivation driving this project, may review our first installment from the conservation tillage 'underground' for details. Our present purpose is to summarize results relevant to the project's objectives, as well as lay the foundation for future work in this relatively new and critical area of conservation tillage.

Methods

In autumn 2003, a winter annual rye (cv. 'Wrens Abruzzi') cover crop was drill-seeded at two locations with similar weed management histories at the NCDA Cherry Farm Research Unit in Goldsboro, NC. The primary soil type at both sites was Wickham sandy loam, classified as well-drained and moderately permeable on a 0-2% slope range. Prior to rye growth termination, the cover crop biomass was measured by sampling 0.5-m^2 steel quadrats. Rye growth was terminated mechanically, or with glyphosate (1.75 L ha^{-1}), and the standing rye residue flattened using one pass of a mechanical roller-crimper, specially built for this project by the Kelley Manufacturing Company of Tifton, GA. USA.

Full-season soybean (Pioneer 95B97) was planted with a six-row John Deere Maximerge vacuum planter calibrated to deliver 344,300 seeds ha^{-1} (8 seeds/ft) on 76-cm (30-inch) rows (12-row plots). Cotton (DP 451) was planted using a four-row planter calibrated at 119,170 seeds ha^{-1} (3.5 seeds/ft) on 96-cm (38-inch) rows (8-row plots). Weed management programs were selected to represent a range of herbicide inputs, including: (1) rye residue + no herbicide; (2) rye + glyphosate only for burndown; (3) rye + glyphosate + pre-emergent residual herbicide; (4) rye + glyphosate +pre- + post-emergent over-the-top herbicide. Pre- and post-emergence herbicide treatments for soybean (metolachlor + imazaquin pre-broadcast; bentazon + sethoxydim post-broadcast) and cotton (fluometuron pre-broadcast; MSMA post-directed) were applied at NCSU recommended rates.

No-tillage planting was performed in all plots except cotton, where a subsoil-strip till treatment was introduced. A conventional 'clean' disk tillage treatment and, a no-tillage treatment with cotton and soybean planted directly into standing rye that had been previously treated with glyphosate for growth termination, were included in both trials. All treatments were randomized before planting in complete blocks with four replications.

Weeds

Weed pressure was assessed at planting (AP), and at two weeks and four weeks post-emergence (PE) by counting the number and species of germinated weeds within three independent 0.5-m^2 steel quadrats centered on, and coincident to, the nearest plant row occurring at the terminus of alternating left and right side offsets approximately 2 m perpendicular to a diagonal transect in each plot. Total weed biomass was estimated at eight weeks PE by harvesting the above-ground biomass in the same three 0.5m^2 quadrates noted above. The biomass was oven-dried at 70° C to a constant weight. Weed count and biomass data underwent analysis of variance in the MIXED procedure in SAS. A 0.05 level of probability was adopted for testing hypotheses.

Cover Crop Residue

Residue decomposition was evaluated by placing folded, intact rye residue in 2-mm nylon mesh bags at rates equivalent to field conditions. The bags were retrieved at 2, 4, 6, 8, and 16 weeks after planting. Per cent original residue remaining in the bags was computed and the data fit to a decomposition model in SAS 9.2.

Soil Moisture

Three no-tillage treatments were selected for soil moisture testing: (1) NT—no roll + gly + pre + post herb; (2) NT— roll + gly + pre + post herb; and (3) NT — roll + no herb, and two subsoil strip-tillage treatments (1) SST + roll + pre + post herbicide; and (2) SST + roll + no herbicide. Soil was sampled to 45 cm deep in the undisturbed, untrafficked interrow in all no-tillage and disk tillage plots approximately two weeks after crop emergence using a 1.25 cm diameter steel Giddings tube. This procedure was modified for subsoil strip-tillage, where two row positions were sampled (1) tilled strip; and (2) undisturbed, untrafficked interrow. Two 45 cm long cores were taken from each plot and sectioned into 0-15, 15-30, and 30-45-cm deep increments. Two bulk density core samples 7.62 cm high x 7.62 cm diameter, were also obtained at each of the same three depths using a Uhland drive head and hammer assembly. Soil moisture content was determined gravimetrically (g H_2O/g soil) and converted to a volumetric basis (m^3 H_2O m^3 soil) using bulk density values.

Yield

Cotton and soybean were machine harvested and yield determined. Due to high weed pressure in the unsprayed cotton plots in 2005, these required hand harvesting. In this report, metric and English units for yield are given.

Results

Weeds

Overall, the rye cover crop effectively suppressed growth of winter annual weeds. However, some annual brassicas (*B. rapa*) emerged coincidentally in the rye. Consequently, weed counts at planting tended to be higher in terms of the number of weeds surviving the rolling operation, when a burndown herbicide was not applied before rolling (**Table 1**). This produced significant (p<.0001) differences in weed counts AP in two of four observations over two seasons. To test the effect of rye residue vs. herbicide on post emergence weed suppression, statistical contrasts were designed (**Table 1**). Results indicated that weed count and weed biomass were significantly greater (p<.0001) when mechanically rolled rye was substituted for herbicide. Moreover, mean weed density increased significantly over time (p<.0001), indicating that surface pressed residue along with minimal soil disturbance did not prevent weeds from germinating. Weed count and weed biomass tended to be slightly greater where strip-tillage was applied without herbicide, compared to the no-herbicide, no-tillage treatment. Summer annuals accounted for the majority of weed species in no-tillage and subsoil strip-tillage planting systems. Dominant summer annuals included at least four species of pigweed (*Amaranthus* spp.), three species of morning glory (*Ipomoea spp.*), lambs quarters (*Chenopodium album*), eclipta (*Eclipta alba*), broadleaf signal grass (*Brachiaria platyphylla*), and carpetweed (*Mollugo verticillata*). The pressed, high-density residue also posed no challenge to seedling perennials such as pokeweed (*Phytolacca americana*), and curly dock (*Rumex crispus*). Short-lived perennials like horseweed (*Conyza canadensis*) and dog fennel (*Eupatorium capillofolium*) also were unaffected by the rolling strategy.

Table 1. Mean weed count and biomass under contrasting weed management and tillage over two cotton (COT) and soybean (SOY) cropping seasons at Goldsboro, NC.

TREATMENT	CONTRAST‡	WEED DENSITY, ct m^{-2}						WEED BIOMASS, g m^{-2}	
		AP		2-WK PE		4-WK PE		8-WK PE	
		COT	SOY	COT	SOY	COT	SOY	COT	SOY
NT-ROLL NO HERB*	NO PRE	2.9	7.5	17.4	14.8	29.6	29.4	53.6	54.7
SST-ROLL NO HERB**	NO PRE	3.0	---	17.4	---	27.0	---	120.4	---
NT-ROLL+GLY§ ONLY	NO PRE	1.2	0.5	10.5	23.4	22.7	34.2	147.6	135.9
SST-ROLL+GLY ONLY	NO PRE	1.1	---	16.8	---	23.4	---	115.9	---
NT-ROLL+GLY+PRE HERB	+PRE	0.1	0	0.1	0.7	0.4	1.5	5.9	3.2
SST-ROLL+GLY+PRE HERB	+PRE	0	---	0.3	---	0.8	---	3.5	---
NT-ROLL+GLY+PRE+POST HERB	+PRE	0	0	0	0.7	1.0	0.1	1.3	0
SST-ROLL+GLY+PRE+POST HERB	+PRE	0.3	---	1.3	---	0.6	---	3.2	---
NT-NO ROLL+GLY+PRE+POST HERB	+PRE	0	0	0.1	1.0	0.2	1.3	0.1	0.3
CDT-GLY+PRE+POST HERB***	+PRE	0	0	0.9	1.8	0.2	3.3	0.3	7.2

‡Contrast of six treatments that received a pre- and/or post-emergence residual herbicide vs. four treatments without herbicide.

* **NT**=no-tillage; **SST= subsoil strip-tillage; ***CDT=clean disk tillage; § GLY=Glyphosate

Rye Residue

Rye biomass yields are summarized in **Table 2.** Decomposition of the rye residue was fitted to a single exponential model function both years. The rate of decomposition was significantly greater (p=0.0001) in 2004 compared with 2005 (**Figure 1**). The year-to-year rate of decomposition was probably influenced by differences in natural precipitation in each season.

Table 2. Rye biomass yield (Mg ha^{-1}) for two crop years and two crop studies.

YEAR	CROP	MEAN	RANGE
2004	COT	4.97	4.50-5.76
2004	SOY	7.10	6.76-8.92
2005	COT	6.56	4.75-8.51
2005	SOY	6.54	4.95-8.47

In 2004 nearly 30 inches of rain were recorded at the research station between May-September, whereas in 2005, 22 inches of rain fell during the same period. Model predictions indicated that four weeks AP approximately 67 and 78 per cent of the original residue remained on the soil surface in 2004 and 2005 respectively. In each crop and cropping season the quantity of residue produced was enough to provide 100% soil cover. Never the less, weeds began germinating <2 weeks after planting, and weed density increased progressively over the observation period (**Figure 2**). This suggests that the weed suppressive qualities of rye mulch residue are ephemeral, even when high densities are achieved[1].

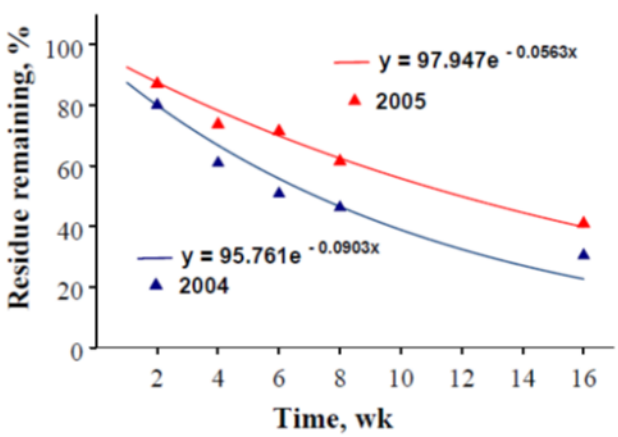

Figure 1. Rye residue decomposition beneath cotton over16 weeks.

[1] Rye (and other crop) residues contain chemicals that, when extracted and assayed in the laboratory, have been shown to inhibit weed germination via 'allelopathy'. However, when these chemicals are leached into the soil they are likely diluted and undergo rapid microbial decomposition. Hence it is difficult to separate physical vs. chemical effects when assessing weed suppression by cover crops.

Figure 2. Broadleaf signal grass emerging from beneath a thick cover of rye residue in the crop interrow. This plot received a glyphosate treatment at burndown, but no pre-emergence herbicide. Photo taken by the author 13 days after planting.

Soil Moisture

Volumetric moisture content (VMC) differed with row position (p=0.03) and soil depth (p=0.001). In general, soil moisture in the surface 15 cm was not different across treatments and row positions. Comparison of row positions in subsoil strip-tillage showed greater VMC depletion in the tilled strip vs. the undisturbed interrow. Of greater consequence was the VMC difference between treatment row position with depth (**Figure 3 and Figure 4**). In plots where herbicide was not applied, and the cover crop terminated solely by mechanical means, soil moisture was significantly depleted in the no-tillage and strip-tillage interrow position ≥ 30 cm deep, compared to where mechanical rolling was combined with a burndown herbicide to terminate cover crop growth. To express this contrast in soil moisture depletion in more practical terms: 0.185 cm^3 H_2O per cm^3 (mean interrow moisture content of the ROLL NO HERB NT—COTTON treatment, 30 to 45-cm depth; see **Figure 3** pointers), is equivalent to 30,160 gallons H_2O per acre furrow slice (AFS). On the other hand, where the cover crop was chemically killed, mean moisture content in the 30 to 45-cm depth was 0.252 cm^3 H_2O per cm^3 (mean interrow moisture content of the ROLL+GLY+PRE+POST NT—COTTON treatment; see **Figure 3** pointers), or 41,080 gallons per AFS. The difference is 10,920 gallons per AFS, or 0.40 inches of water per acre (1 acre inch = 27,154 gallons). The significance of this depletion is obvious in terms of available moisture going into the main cropping season. Since the crimping blades on the roller-crimper suppressed, but did not actually kill the cover crop immediately, it stands to reason that moisture uptake by the cover crop would still be occurring after rolling. And, since more winter annuals survived the roll/no-herbicide residue management strategy, this would tend to amplify moisture depletion in the soil profile.

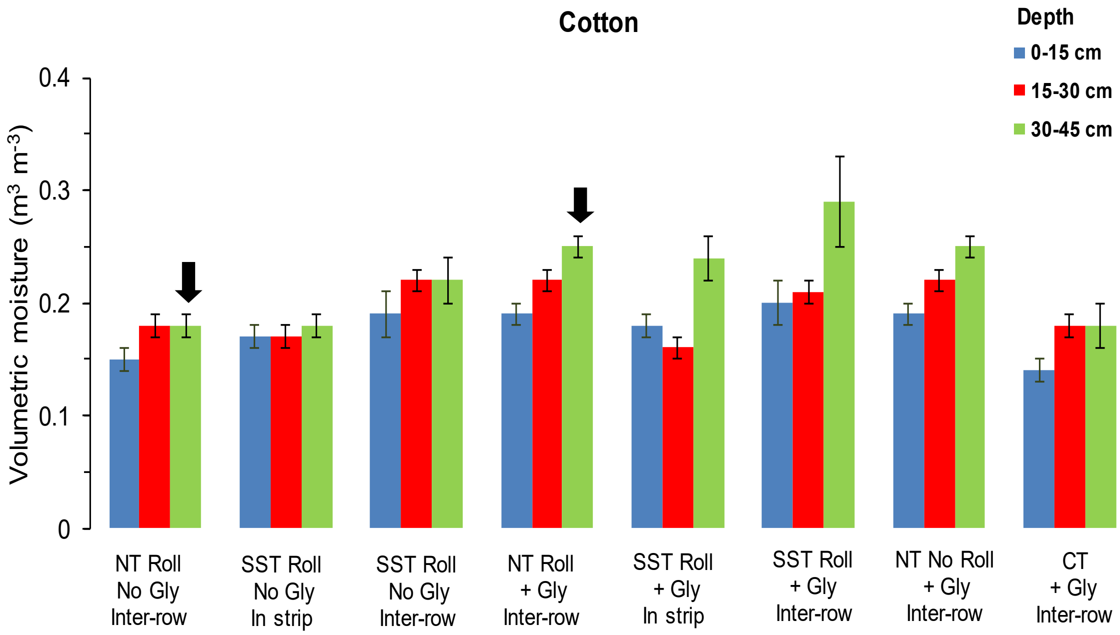

Figure 3. **Early-season soil volumetric moisture content in a cotton crop under contrasting tillage and field residue management (mean ± standard error).**

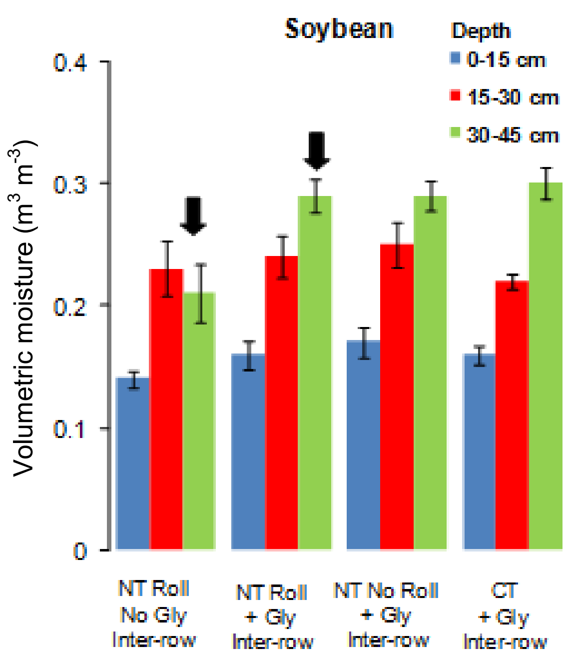

Figure 4. **Early-season soil volumetric moisture content in a soybean crop under contrasting tillage and field residue management (mean ± standard error).**

But why did the mechanically killed rye preferentially extract moisture from the deeper soil zones, rather than near the surface where the mass of small grain roots are primarily concentrated? The answer isn't clear from these data. Some evaporation from the soil surface may have been occurring, causing soil moisture to equalize more rapidly in the surficial rooting zone. The two sites had texturally dissimilar subsoil (loamy in soybeans and sandy in cotton) as noted when excavating the soil cores. But, in terms of soil moisture depletion, the response to mechanical cover crop growth termination in cotton and soybean was similar and may point to a potential downside to deploying roller-crimpers particularly under moisture-limiting conditions.

Yield

Weed management programs impacted cotton lint and soybean yield ($p<.0001$) both years. Our interpretation of these data suggests that high-density, surface pressed residue coupled with no-tillage, did not provide an effective barrier against early-season weeds equal to that of a pre-emergent residual herbicide. In general, as herbicide input was sequentially reduced, yields declined lock-step for both crops (**Table 3**). When pre- and post-emergence herbicides were included as part of the weed management program, yields of cotton lint and soybean were not significantly different between tillage system and method of residue management (roll vs. no roll). Yield response to subsoiling in cotton was inconsistent; a modest gain (+247 kg ha^{-1} lint) over no-till was noted in 2004 but none in 2005. The lack of response to sub-soiling in 2005 may have been due to early-season infection in some strip-tillage plots by *Phythium* root rot. Also, moisture was not limiting during most of the growing season in 2004, whereas in 2005 moisture was limiting only in the latter part of the season, so the overall effect of sub-soiling may have been attenuated.

Perhaps the most surprising outcome was the success we achieved planting into standing rye desiccated by glyphosate (**Figures 5** and **6**). Despite some initial reduction in stand, soybean and cotton lint yields were equal to, or better than, yield obtained by mechanical rolling both years.

Table 3. Cotton lint and soybean yield response to tillage and method of weed management for two crop years.

TREATMENT	CONTRAST‡	COTTON LINT YIELD	SOYBEAN YIELD
		Kg ha^{-1} (Lb. /Acre)	Mg ha^{-1} (Bu/Acre)
NT- ROLL NO HERB*	NO PRE	327 (292)	2.15 (32)
SST- ROLL NO HERB**	NO PRE	321 (287)	---
NT- ROLL+GLY§ ONLY	NO PRE	396 (354)	2.22 (33)
SST- ROLL+GLY ONLY	NO PRE	520 (464)	---
NT- ROLL+GLY+PRE HERB	+PRE	1014 (905)	2.49 (37)
SST- ROLL+GLY+PRE HERB	+PRE	1196 (1068)	---
NT- ROLL+GLY+PRE+POST HERB	+PRE	1270 (1134)	2.82 (42)
SST- ROLL+GLY+PRE+POST HERB	+PRE	1334 (1191)	---
NT- NO ROLL+GLY+PRE+POST HERB	+PRE	1250 (1116)	3.09 (46)
CDT- GLY+PRE+POST HERB***	+PRE	1300 (1161)	2.96 (44)

‡Contrast of six treatments that received a pre- and/or post-emergence herbicide vs. four treatments without herbicide.
***NT=** no-tillage; ****SST=**subsoil strip tillage; *** **CDT**=Clean disk tillage; § GLY=Glyphosate

Figure 5. Above, direct planting soybean into standing rye residue. At right, **Figure 6** shows soybean growing in a dense thicket of desiccated standing residue. Bean plants were a bit 'leggy' in the juvenile stage but matured normally.

What Did We Learn?

Our research group's principal goal is to examine different approaches to reducing or eliminating soil tillage, while fostering carbon enrichment to alleviate compaction, crusting, and moisture conservation in the crop root zone. Integrating tillage, residue management and pest control programs in ways that are flexible and mutually sustaining are important objectives. Following are the key take-aways from this project:

- Row crops can be successfully raised in a high-residue, low tillage system utilizing the mechanical roller-crimper.
- High-density residue and residue orientation were not as effective as herbicide in suppressing annual or seedling perennial weeds in a no-tillage or subsoil strip-tillage planting system.
- When herbicide input was reduced, there was a yield penalty regardless of tillage system.
- Mechanical cover crop rolling without glyphosate application was less effective in terminating rye growth as a glyphosate application followed by cover crop rolling.
- Variable and/or insufficient cover crop growth termination may impose soil moisture deficits on the subsequent crop, depending on effectiveness of the kill.
- Rolling and crimping cover crops is not necessary to achieve profitable returns in high residue, low tillage soybean or cotton planting systems.

Looking Ahead

Soil degradation is a problem that continues to throttle food security and agricultural progress worldwide. The principal culprits are exhaustive tillage, lack of adequate residue cover, and uncontrolled traffic in the field. Intensifying cropping systems by employing winter annual cover crops is one strategy for boosting soil carbon levels that could improve degraded agricultural soils. Other factors such as narrow row spacing also may aid in limiting opportunities for weeds by increasing competition for light, moisture, and nutrients. Future work should therefore focus on continued integration of tillage, residue management, and weed control with attention to the following points:

- Field trials of longer duration than two years are needed to evaluate the establishment effects of high residue cropping systems. Providing that timely weed control is implemented for a period during the crop establishment phase, continuous no-tillage or minimum tillage coupled with narrow row spacing and full residue cover prior to canopy closure may ultimately create a production system that relies on fewer herbicides for weed management.
- Convenience, cost, and time-saving continues to be major challenges for producers converting to high-residue cover crop systems. The present two- and four-row mechanical roller-crimpers may be adequate for small or artisanal operations; however, in order to expand adoption of the mechanical roller-crimper it will be necessary to alter its basic design to accommodate larger (eight to twelve+ row) planters as well as minimize vibration felt by the tractor operator. The present single or tandem drum arrangement of rollers cannot do this without becoming excessively massive and unwieldy. Design considerations should focus on smaller, in-row rollers that may be attached directly to the planter unit in a way similar to row cleaners and other residue management tools. In addition, if herbicides such as glyphosate are to be reduced or eliminated, the mechanical roller-crimper must be designed to completely terminate cover crop growth.
- Globally, boosting agro-productivity by increasing cropping intensity per unit of land area is an irresistible and imperative trend. High residue, low tillage is likely to impact the seasonal balance of nutrients and available soil moisture, as well as over the long term. Future work should therefore be directed toward long term assessment of profile soil moisture and nutrient stocks in diverse cropping scenarios.
- The verdict is still out over the benefits associated with rolling cover crops. Our results showed that average soybean grain and cotton lint yield over two cropping seasons did not differ significantly in response to the method of residue management. There may, however, be other merits and/or drawbacks associated with mechanically terminating cover crops that we did not perceive. We conclude that further studies evaluating the mechanical roller-crimper are needed.

Acknowledgements

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Prepared by:

Robert Walters
Department of Soil Science
North Carolina State University
CB 7619
Raleigh, NC 27695
waltersrobt@gmail.com