Open Journal of Soil Science, 2016, 6, 149-158
http://www.scirp.org/journal/ojss
ISSN Online: 2162-5379
ISSN Print: 2162-5360

Influence of Tillage and Deep Rooted Cool Season Cover Crops on Soil Properties, Pests, and Yield Responses in Cotton

Michael W. Marshall[1], Phillip Williams[2], Ali Mirzakhani Nafchi[2], Joe Mario Maja[1], Jose Payero[1], John Mueller[1], Ahmad Khalilian[2]*

[1]Edisto Research & Education Center (Edisto REC), Clemson University, Blackville, SC, USA
[2]Department of Agricultural and Environmental Sciences, Clemson University, Clemson, SC, USA
Email: marsha3@clemson.edu, pbw@clemson.edu, anafchi@clemson.edu, jmaja@clemson.edu, jpayero@clemson.edu, jmllr@clemson.edu, *akhlln@clemson.edu

How to cite this paper: Marshall, M.W., Williams, P., Mirzakhani Nafchi, A., Maja, J.M., Payero, J., Mueller, J. and Khalilian, A. (2016) Influence of Tillage and Deep Rooted Cool Season Cover Crops on Soil Properties, Pests, and Yield Responses in Cotton. *Open Journal of Soil Science*, **6**, 149-158.
http://dx.doi.org/10.4236/ojss.2016.610015

Received: September 6, 2016
Accepted: October 8, 2016
Published: October 11, 2016

Abstract

Soil compaction is a significant problem in the Southeastern USA. This compacted zone or hardpan limits root penetration below this layer and reduces potential yield and makes plants more susceptible to drought induced stresses. Soil compaction in this region is managed using costly annual deep tillage at or before planting and there is a great interest in reducing and/or eliminating annual tillage operations to lower production costs. Deep rooted cool season cover crops can penetrate this compacted soil zone and create channels, which cash crop roots, such as cotton, could follow to capture moisture and nutrients stored in the subsoil. The cool season cover crop roots would reduce the need for annual deep tillage prior to planting, increases soil organic matter, which provides greater water infiltration and available water holding capacity. Field studies were conducted for two years with three different soil series to determine the effects of tillage systems and cool season cover crops on the soil chemical and physical properties, yield responses, and pest pressure. Results showed that cool season cover crops significantly reduced soil compaction, increased cotton lint yield and soil moisture content, reduced nematode population densities, and increased soil available P, K, Mn, and organic matter content compared to the conventional no-cover crop.

Keywords

Cover Crop, Cotton, Soil Compaction, Nematodes, Soil Water Content, Tillage

1. Introduction

Chronic soil compaction is a significant problem among coastal plain soils in the

Southern USA. Although, reasons for compaction are not fully understood, it is assumed that low organic matter content and the nonexpanding clay predispose these soils to subsurface compaction [1]. The soil profile in this region is comprised of three distinct textural layers: A horizon—sandy to loamy sand, E horizon—yellowish-brown sandy to sandy clay, and Bt horizon—sandy clay loam (**Figure 1**). The E horizon has higher bulk density, lower permeability, and lower water holding capacity (less than 0.1 cm/cm) due to predominantly sandy texture with very low organic matter content (less than 1%). This compacted zone or hardpan usually occurs at a depth of 25 to 40 cm in the soil profile and ranges from 5 to 20 cm in thickness [2]. Typically, the hardpan layer limits root penetration below the plowing depth which reduces crop yield potential during drought stress conditions. For optimum crop productivity and yield, the E horizon must be broken using deep tillage so that roots can reach into the Bt horizon where water and nutrients are more plentiful [3]. Soil compaction management in the Southern USA relies heavily on the use of annual deep tillage before planting. For example, conventional tillage cotton production systems in the coastal plain region of the Southern USA require a minimum of three to five field operations at a cost of approximately $90 per hectare.

There is a great interest in minimizing the use of annual deep tillage operations to reduce costs, increase residue cover, and buildup soil organic matter. Our research has demonstrated the rapid reconsolidation of the E-horizon hardpan layer after deep tillage from one season to another in some sandy soils of South Carolina due to equipment traffic on the soils. However, the residual effects of deep tillage operations were extended for several years, using controlled equipment traffic scheme and planting directly into the previous year's subsoiler shank furrow [4].

The use of cool season cover crops is an increasingly popular sustainable farming practice that provides many benefits to the soil and subsequent summer cash crops. Cool season cover crops increase soil organic matter or soil humus, which provides greater water infiltration and available water holding capacity. Our results from a previous 4-year study [5] [6] showed that increasing soil organic matter in the sandy soils of the Coastal Plain region would significantly increase crop yields (up to 38%). We at-

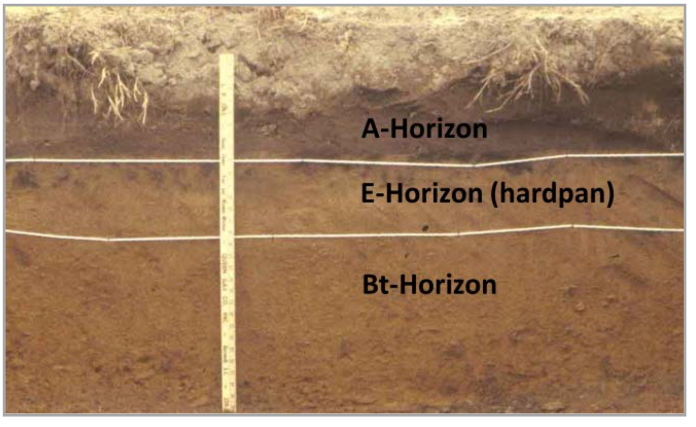

Figure 1. A typical soil profile of the coastal plain in the southern USA.

tributed the higher crop yields to improvements in chemical, biological, and physical properties of the soil. Scientists in Maryland reported that shoots of both forage radish and rye cover crops have the potential to take up significant quantities of P when these cover crops are managed for maximum dry matter production [7].

Deep-rooted cover crops may penetrate compacted soil better than fibrous-rooted species; therefore, be better adapted for use in "biological tillage" [8] [9]. Deep rooted cool season cover crops, such as rye and "Tillage Radish", can penetrate the E-horizon during the winter when soil moisture is typically higher and create and maintain channels for the cash crop roots, such as cotton, to follow and capture moisture and nutrients in the Bt horizon which is below the hardpan layer. This would reduce and/or eliminate the need for annual deep tillage (a requirement in coastal plain soils for optimizing potential crop yields), reduce fuel consumption, and increase soil organic matter and crop yields. Williams and Weil [9] reported that soybean yields were significant greater following a cool season cover crop. Cereal rye produces a thick biomass layer on top of the soil, resulting in early season water capture and storage for the summer crop. The root channels left by the terminated cover crop provided a low resistance path for the soybean roots to capture nutrients and water in the subsoil.

For agriculture to remain viable and profitable, farming practices that conserve soil, reduce crop inputs, and enhance drought resilience must be employed. Residues associated with the cool season cover crop have the potential to reduce nitrogen and other nutrient requirements in the subsequent cash summer crop [10]. For example, the terminated rye cool season cover crop released plant available nitrogen in to the soil and reduced the amount of nitrogen fertilizer required by the subsequent cotton and grain sorghum crops [11].

Nematodes cause hundreds of millions of dollars in yield losses annually to U.S. cotton, soybean, and peanut production. Each year up to 10% of all U.S. cotton production is lost to nematodes [12] [13]. Yield losses in individual fields may reach up to 50%. Nematode management relies heavily on the use of nematicides, such as aldicarb (AgLogic 15 G-$74/ha) [14] [15]. However, the most effective tool for managing nematodes (aldicarb-AgLogic 15 G) currently is only available in the southeastern USA in limited amounts. Small grain crops, including cereal rye, are good hosts or trap crops for southern root-knot and Columbia lance nematodes. The opportunity exists to use small grains as trap crops for nematodes to reduce their levels in the spring when a row crop would be planted. In a study conducted by D'Addabbo [16], wheat straw significantly suppressed populations of root-knot nematodes in the soil.

The objectives of this study were to determine the effects of tillage and deep-rooted cool season cover crop on 1) soil chemical and physical properties, 2) nematode population densities, and 3) cotton yield.

2. Methodology

Replicated tests were conducted for two years (2014 to 2015) in a production field with three different soil series: Faceville loamy sand, Fuquay sandy loam, and Lakeland sand.

Table 1 shows surface characteristics of the three different soil series. The 2.5 ha field was located near Blackville, South Carolina (Latitude 33˚20"N, Longitude 81˚19"W). At the initiation of the project, each soil series was intensively sampled using hand probes to measure the depth to the Bt horizon and the soil texture. Also, the field was mapped for variation in soil texture, using a soil electrical conductivity (EC) measurement system (Veris-3100; Veris Technologies Inc., Salina, KS, USA) [17]. Soil texture, organic matter, and moisture content were the main factors affecting EC values. The test field was then divided into three management zones based on soil series and soil EC values and 48 rectangular plots (4-rows by 18 m) were assigned in each zone, for a total of 144 plots in the test field (**Figure 2**). The following treatments were replicated 8 times in each soil series using a randomized complete block experimental design (2 × 3 factorial arrangements):

Factor A: Tillage (Deep tillage, no-till).

Factor B: Cover Crop (Rye, Tillage Radish, None).

Cool season cover crops were planted around mid-November each year, following either a deep tillage operation (about 35 cm) using a Worksaver Terra-Max (Worksaver, Inc., Litchfield, IL, USA) or no deep tillage operation. Cover crop biomass samples were collected from each plot using one meter quadrats and samples were oven dried at 60˚C for 72 hrs and weighed [18]. Cover crops were rolled using a Brillion Pulverizer equipped with Optimizer Wheels (Landoll Corporation, Marysville, KS, USA) and terminated using herbicides based on current Extension recommendations about one week before planting cotton. The cotton variety Phytogen™ 495W3RF was planted around mid-May in both years (2014 and 2015) in all experimental plots without surface or deep tillage operations using a JD 1700 vacuum planter (John Deere Company, Moline, IL, USA) equipped with row cleaners. To eliminate some problems associated

Table 1. Soil classification and surface texture of the test areas.

Soil series	Family	Sand (%)	Silt (%)	Clay (%)
Faceville	*Clayey-kaolinitic-thermic, Typic Paleudults*	78.3	9.2	12.5
Fuquay	*Loamy-siliceous-thermic, Arenic Plinthic Paleudults*	85.5	5.6	8.9
Lakeland	*Siliceous-thermic-coated, Typic Quartzipsamments*	89.5	4.2	6.3

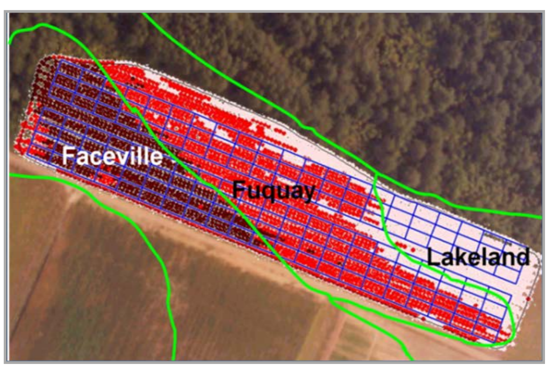

Figure 2. Soil series, EC zones, and plot arrangements of the experimental field.

with planting cotton into the terminated cover crop, due to interfere of planters/row cleaners with crop residue, the grain drill used to plant the cool season cover crop was modified by blocking seed tubes every 96 cm to create skip rows for planting cotton.

To determine the effects of different treatments on soil compaction, a microcomputer-based, tractor-mounted recording penetrometer, equipped with GPS system (**Figure 3**) was used to quantify geo-referenced soil penetration resistance during the growing season. Soil compaction values were calculated from the measured force required pushing a 3.23 cm^2 base area, 30-degree cone into the soil. Compaction data were collected 6-weeks after planting cotton and at the end of the growing season.

Twelve sets of EC-5 capacitance moisture sensors (Decagon Devices, Inc.) were installed at three depths (15, 30, and 45 cm) to determine the effects of the cover crops on soil moisture content. In each soil series, four sets were installed in no-till and deep tilled cotton plots with and without cool season cover crop. Em50R wireless radio data loggers (Decagon Devices, Inc.) were used to automatically read the sensors and store soil moisture data every hour. Also, an automatic and a manual rain gauge were installed in this field to quantify daily precipitation.

Nematode samples were collected at the initiation of these studies and at harvest each year from management zones. Sufficient soil cores (2.5-cm diameter by 20 cm deep) were collected to allow nematode assay as well as soil nutrient content, organic matter, and pH. Nematodes were extracted from soil using a combination of elutriation [19] and centrifugal sugar flotation [20]. Nematodes were identified to genus microscopically based on morphology and population densities calculated using dilution techniques.

Cotton was harvested around Mid-October, using a spindle picker equipped with an AgLeader yield monitor and a GPS unit to map changes in lint yield within and among treatments to determine the effects of cover crop and tillage treatments on cotton yields in coastal plain soils. The statistical analysis was conducted using the SAS software (Version: 9.4; SAS Institute Inc., Cary, NC, USA)

3. Results

We had an excellent cereal rye cool season cover crop in all plots except on Lakeland

Figure 3. The tractor mounted soil compaction measurement system.

sand soil series. The sand content was very high with very low water and nutrient holding capacities. The soil series had a significant effect on the amount of cool season cover crop biomass. The cereal rye biomass in test plots averaged at 550, 2528, and 5771 kg/ha in Lakeland, Fuquay, and Faceville soil series, respectively. In both years, we established tillage radish cover crop; however, due to cold winter (below −12˚C), most of the tillage radishes died. Therefore, measurements from plots with tillage radish cover crop were not included in the analysis of yield or soil health data.

The effects of cover crop and tillage on soil compaction were measured using a soil penetrometer (Figure 3). Cone index values exceeding 2 MPa limit root penetration below the compaction layer which reduces crop yields and makes plants more vulnerable to drought stress. In the no-till plots, cool season cover crop significantly reduced soil compaction (Figure 4) in the E-horizon (20 - 30 cm depth). This could be attributed to the deep-rooted cool season cover crop (cereal rye) penetrating compacted soil layers during the fall and winter when the E-horizon was relatively wet and soft. Averaged over the entire field, cone index values in cover crop plots were below the 2 MPa compaction threshold level measured at the end of the production season. In Coastal Plain soils with chronic soil compaction, this could help create and maintain open channels in the E-horizon for subsequent years. There were no significant differences in soil compaction between plots with and without cover crop when a deep tillage operation was performed at planting of the cool season cover crop. Tillage significantly reduced soil compaction compared to no-till.

Reductions in soil compaction in the E-horizon, due to the cool season cover crop, significantly increased cotton lint in the no-till plots (Figure 5). Averaged across three soil series, the yield increase was 38%. In addition, since cover crop eliminated the hardpan layer for the cotton crop, growers reduced production costs because they did not perform deep tillage ahead of planting operations. Soil series had a major effect on yield increases due to cover crop. For example, yield increase was 49%, 32%, and 22% on the Faceville loamy sand, the Fuquay sandy loam, and the Lakeland sand, respectively (Figure 6). These results were opposite to what we were expecting since the Lakeland soil had 90% sand content followed by Fuquay 85%, and Faceville 78%. We

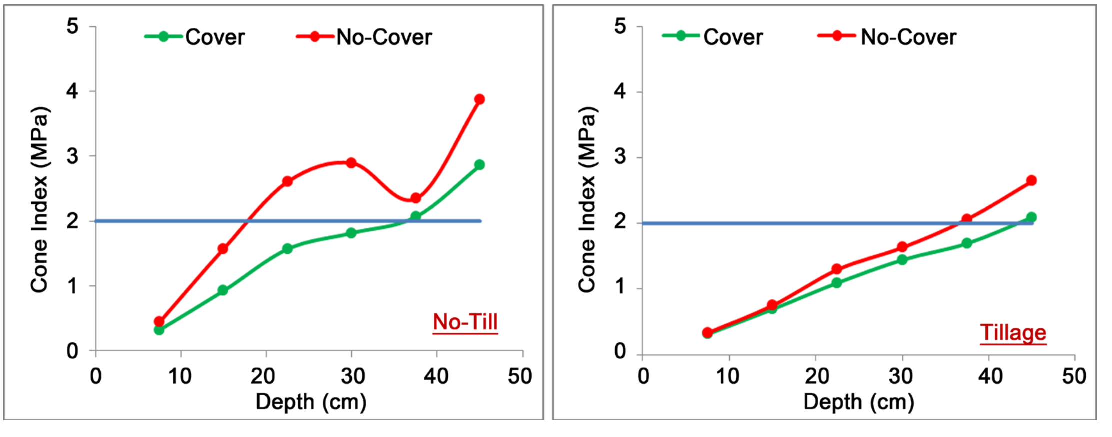

Figure 4. Effects of cool season cover crop and tillage on soil compaction.

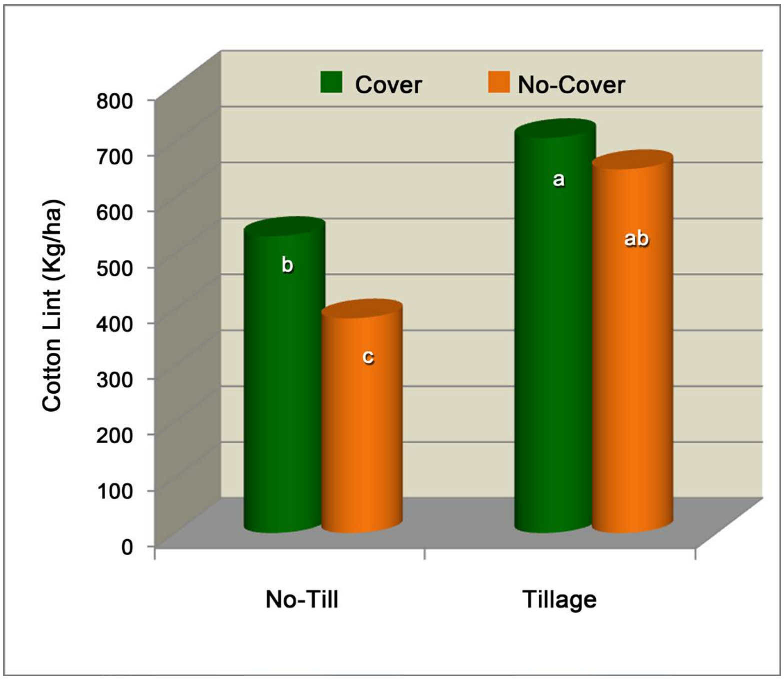

Figure 5. Effects of cool season cover crop and tillage on cotton lint.

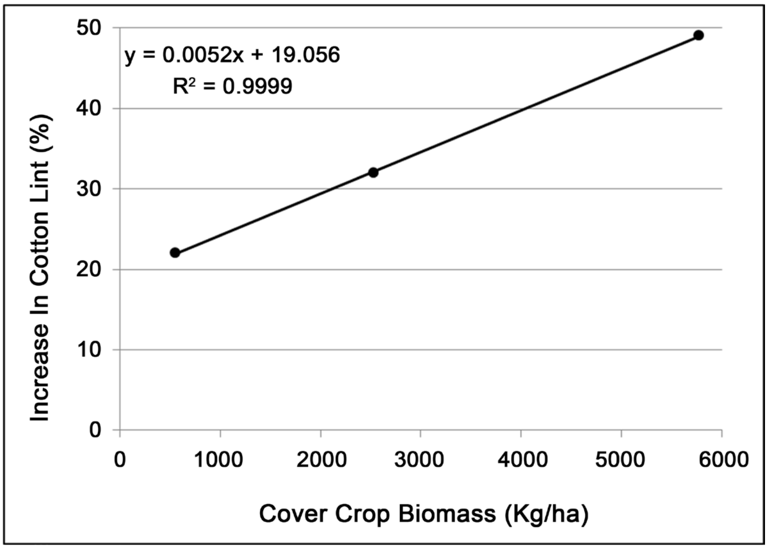

Figure 6. Effects of cover crop biomass on cotton lint yield.

were expecting that yield increase due to cover crop would be higher in lighter soil texture, since organic matter would increase soil water holding capacity and subsequently increase yield. However, biomass from cover crop rye in Lakeland soil was almost 10 fold lower than in the Faceville loamy sand soil. Therefore, there was insufficient cool season cover crop biomass produced in Lakeland soil to affect cotton lint yield. There was a strong linear correlation between cool season cover crop biomass and cotton yield increase ($R^2 = 0.999$).

Figure 7 shows an example of higher soil moisture content due to cool season cover crop in Faceville soil series in 2015. Averaged over the growing season and 3 sampling depths (15, 30, and 45 cm), cool season cover crop increased soil moisture contents by 8.5, 6.2, and 1.4 percentage points in Faceville, Fuquay, and Lakeland soils, respectively. However, in the sandy soil (Lakeland) the difference in soil moisture for the same period was not significant. This was caused by insufficient cool season crop biomass in Lakeland soil to affect soil moisture significantly. Similar results were obtained in 2014.

Cool season cover crop residue reduced the prevalence of weeds in the cotton plots and required fewer herbicide applications compared with the conventional system with no-cover (Data not shown). Cool season cover crop positively impacted soil properties by significantly increasing soil available P, K, Mn, and organic matter content by 17%, 26%, 33%, and 46%, respectively, at cotton harvest (Table 2).

Small grain crops (such as cereal rye) are good hosts or trap crops for southern root-knot and Columbia lance nematodes. In 2015, the cereal rye cool season cover crop reduced population densities of root-knot nematodes by 66% and 82% in tilled and no-till plots, respectively. In addition, galling index for the same treatments was reduced by 34% in tilled plots and 31% in no-till plots without a nematicide application.

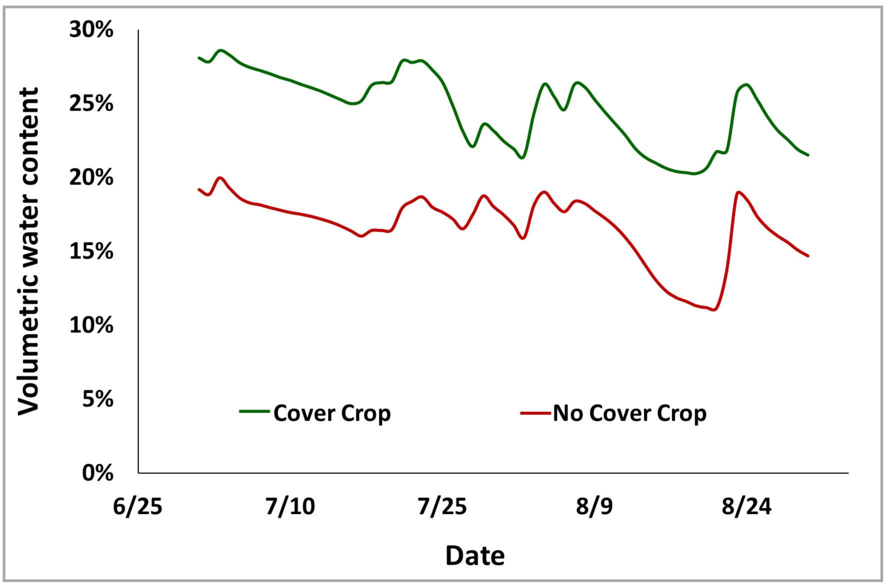

Figure 7. Effects of cool season cover crop residue on soil moisture content.

Table 2. Effects of cool season cover crop on soil available P, K, Mn and soil OM (2014).

	Tillage		No-Till	
	Cover	No-Cover	Cover	No-Cover
P (kg/ha)	264 a	215 b	247 a	211 b
K (kg/ha)	194 a	133 b	167 a	130 b
Mn (kg/ha)	33 a	25 b	31 a	24 b
OM (%)	1.41 a	0.87 b	1.42 a	0.97 b

4. Conclusion

Replicated field studies were conducted for two years with three different soil series to determine the effects of tillage and cool season cover crops on soil chemical and physical properties, crop responses, and pest pressure. These results showed that surface soil texture had a significant effect on the amount of cool season cover crop biomass produced by cereal rye. In no-till plots, cool season cover crop significantly reduced soil compaction in the E-horizon (20 - 30 cm depth). Averaged over the entire field, the cone index values in the cool season cover crop plots were below the 2 Mpa compaction threshold measured at the end of the production season. Reductions in soil compaction due to the cool season cover crop, significantly increased cotton lint yield in the no-till plots (38%). There was also a strong linear correlation between cool season cover crop biomass and cotton lint yield increase. The cool season cover crop positively impacted soil properties by significantly increasing soil available P, K, Mn, and organic matter content. It also, increased soil moisture content by about 10 percentage points. The cover crop significantly reduced population densities and galling index of root-knot nematodes without a nematicide application.

Acknowledgements

Technical Contribution No. 6465 of the Clemson University Experiment Station. This material is based upon work supported by NIFA/USDA, under project number SC-1700498. The authors also acknowledge the funding support of the SC-NRCS-CIG programs and the Clemson Public Service Activities.

Disclaimer

Mention of a trade name does not imply endorsement of the product by Clemson University to the exclusion of others that might be available.

References

[1] Siemens, J.C., Hoeft, R.G. and Pauli, A.W. (1993) Soil Compaction and Its Management in Soil Management. Deere & Company, Moline.

[2] Gorucu, S., Khalilian, A., Han, Y.J., Dodd, R.B. and Smith, B.R. (2006) An Algorithm to Determine the Optimum Tillage Depth from Soil Penetrometer Data in Coastal Plain Soils. *Applied Engineering in Agriculture*, **22**, 625-631. http://dx.doi.org/10.13031/2013.21993

[3] Khalilian, A., Hood, C.E., Palmer, J.H., Garner, T.H. and Bathke, G.R. (1991) Soil Compaction and Crop Response to Wheat/Soybean Interseeding. *Transactions of ASAE*, **34**, 2299-2303. http://dx.doi.org/10.13031/2013.31871

[4] Khalilian, A., Jones, M., Sullivan, M. and Frederick, J. (2004) Comparison of Strip Tillage System in Coastal Plain Soils for Cotton Production. *Proceedings of the Beltwide Cotton Conferences*, San Antonio, 5-9 January 2004, 803-810.

[5] Khalilian, Williamson, A.R.E., Sullivan, M.J., Mueller, J.D. and Wolak, F.J. (2002) Injected and Broadcast Application of Composted Municipal Solid Waste in Cotton. *Applied Engineering in Agriculture*, **18**, 17-22. http://dx.doi.org/10.13031/2013.7704

[6] Khalilian, A., Sullivan, M.J., Mueller, J.D., Shiralipour, A., Wolak, F.J., Williamson, R.E. and

Lippert, R.M. (2002) Effects of Surface Application of MSW Compost on Cotton Production—Soil Properties, Plant Responses and Pest Management. *Compost Science & Utilization*, **10**, 270-279. http://dx.doi.org/10.1080/1065657X.2002.10702089

[7] White, C.M. and Weil, R.R. (2011) Forage Radish Cover Crops Increase Soil Test Phosphorus Surrounding Radish Taproot Holes. *Soil Science Society of America Journal*, **75**, 121-130. http://dx.doi.org/10.2136/sssaj2010.0095

[8] Chen, G. and Weil, R.R. (2010) Penetration of Cover Crop Root through Compacted Soils. *Plant and Soil*, **331**, 31-43. http://dx.doi.org/10.1007/s11104-009-0223-7

[9] Williams, S.M. and Weil, R.R. (2004) Crop Cover Root Channels May Alleviate Compaction Effects on Soybean Crop. *Soil Science Society of America Journal*, **68**, 1403-1409. http://dx.doi.org/10.2136/sssaj2004.1403

[10] Sainju, U.M. (2002) Long-Term Effects of Tillage, Cover Crops, and Nitrogen Fertilization on Organic Carbon and Nitrogen Concentrations in Sandy Loam Soils in Georgia, USA. *Soil & Tillage Research*, **63**, 167-179. http://dx.doi.org/10.1016/S0167-1987(01)00244-6

[11] Sainju, U.M. (2006) Tillage, Cover Crops, and Nitrogen Fertilization Effects on Soil Nitrogen and Cotton and Sorghum Yields. European Journal of Agronomy, **25**, 372-382. http://dx.doi.org/10.1016/j.eja.2006.07.005

[12] Blasingame, D. and Patel, M.V. (2005) Cotton Disease Loss Estimate Committee Report. 2005 Proceedings of the Beltwide Cotton Conferences. National Cotton Council of America, Cordova.

[13] Koenning S.R., Overstreet, C. and Noling. J.W. (1999) Survey of Crop Losses in Response to Phytoparasitic Nematodes in the United States for 1994. *Journal of Nematology*, **31**, 587-618.

[14] Starr J.L., Koenning, S.R. and Kirkpatrick, T.L. (2007) The Future of Nematode Management in Cotton. *Journal of Nematology*, **39**, 283-294.

[15] Koenning S.R., Kirkpatrick, T.L. and Starr, J.L. (2004) Plant-Parasitic Nematodes Attacking Cotton in the United States: Old and Emerging Production Challenges. *Plant Disease*, **88**, 101-113. http://dx.doi.org/10.1094/PDIS.2004.88.2.100

[16] D'Addabbo, T. and Sasanlli, N. (1997) Suppression of Meloidigyne Incognita by Combinations of Olive Pomace or Wheat Straw with Urea. *Nematologia Mediterranea*, **25**, 159-164.

[17] Lund, E.D., Christy, C.D. and Drummond, P.E. (1999) Practical Applications of Soil Electrical Conductivity Mapping. In: Stafford, J.V., Ed., *Precision Agriculture* "99-*Proceedings of the* 2*nd European Conference on Precision Agriculture*, Denmark, 11-15 July 1999, 771-779.

[18] ASAE Standard S358.2 (DEC93) Moisture Measurement—Forages, 2012.

[19] Byrd, D.W., Barker, K.R., Nusbaum, C.J., Griffin, W.E., Small, R.H. and Stone, C.A. (1976) Two Semi-Automatic Elutriators for Extracting Nematodes and Certain Fungi from Soil. *Journal of Nematology*, **8**, 206-212.

[20] Jenkins, W.R. (1964) A Rapid Centrifugal-Flotation Technique for Separating Nematodes from Soil. *Plant Disease Reporter*, **48**, 692.