Conservation Tillage in Alabama's "Old Rotation"

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ABSTRACT

After 106 cropping years, Alabama's Old Rotation experiment (circa 1896) continues to document the long-term effects of crop rotation and winter legumes on sustainable cotton production in the Deep South. For 100 years the experiment was under conventional tillage. However, since 1997, all crops planted on the Old Rotation have benefited from minimum tillage. Coincidentally, record yields of all crops grown on the Old Rotation have been achieved since conservation tillage techniques have been implemented. Long-term yields suggest that winter legumes are just as effective as fertilizer N in producing optimum cotton yields. Yields are also highly correlated with soil organic matter that reflect the long-term treatments. In the past, crop rotation benefits have had a small effect on cotton yields, considering yield levels and crop value. These benefits are apparently enhanced under conservation tillage. Soil quality differences, e.g., aggregation and soil tilth, due to rotations and cover cropping are dramatic and are likely to increase under conservation tillage.

KEYWORDS

Long-term research, winter legumes, cotton, corn, sustainable agriculture, tillage

INTRODUCTION

The "Old Rotation" experiment (circa 1896) on the campus of Auburn University is the oldest, continuous cotton experiment in the world. The test was started in 1896 by Professor J.F. Duggar to test and demonstrate his theories that sustainable cotton production was possible on Alabama soils if growers would use crop rotation and include winter legumes (clovers and/or vetch) to protect the soil from winter erosion and provide nitrogen (N) for the summer crop. The Old Rotation was placed on the National Register of Historical Places in 1988.

Since the centennial cropping year of the Old Rotation (1995), major technological modifications have been implemented in managing this experiment. These include switching to genetically modified crops, almost complete elimination of insecticide use, drastically reducing herbicide use, and switching to conservation tillage instead of conventional moldboard plowing and cultivation. In 2002, another dramatic change is being monitored in the old experiment. Irrigation has been installed such that half of each plot can now be irrigated. This report will highlight yields and observations made during these transition years.

OBJECTIVES

The objectives today are very similar to Professor Duggar's original objective: to determine the effect of crop rotations and winter legumes on sustainable production of cotton in the southern United States. In addition, fertilizer P and K treatments initiated in 1925 allowed early researchers to evaluate the timing of P and K applications to cotton rotation systems. Today, the site is also used as a field laboratory for researchers, students, and visitors interested in long-term, sustainable crop production systems in the southern United States. Since conversion to conservation tillage in 1997, soil quality changes are being monitored.

METHODS

The site is at the junction of the Piedmont Plateau and Gulf Coastal Plain soil physiographic regions. The soil is identified as a Pacolet sandy loam (clayey, kaolinitic, thermic Typic Hapludults). There are 13 plots on one acre of land. Each plot is 136 feet long by 21.5 feet wide with a 3-foot alley between each plot. Originally, each plot was a separate treatment, but today treatments may be described as the cropping systems in Table 1.

Of minor interest today is the timing of fertilizer P and K. Originally, the soil was low in both P and K and the winter legume produced more biomass (and more N) with direct P and K applications. This provided more N for the following cotton crop, resulting in higher cotton yields. Today, all soils test high in P and K and there is no longer a differential

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Table 1. Description of rotation and timing of P and K application treatments for the Alabama "Old Rotation " experiment located on the campus of Auburn University.

Treatments	Plot no.	
I. Continuous cotton		
A. No legume/no fertilizer N	1, 6	
B. Winter legumes (crimson clover and/or vetch)	2, 3, 8	
Timing of P and K aoolication		
(1) Prior to planting cotton		8
(2) Fall application to winter legume		2
(3) Split application: 1/2 to cotton, 1/2 to legume		3
C. 120 lbs N acre^{-1} (as ammonium nitrate)	13	
II. Two-year cotton-corn rotation		
A. Winter legumes, no fertilizer N	4, 7	
B. Winter legumes + 120 lbs N acre^{-1}	5, 9	
Timing of P and K aoolication		
(4) Split application: 1/2 to cotton, 1/2 to legume		all 4 plots
III. Three-year rotation		
Year 1: Cotton then winter legumes	10, 11, 12	
Year 2: Corn then small grain for grain		
Year 3: Soybean then winter fallow		

response to the time of fertilizer application although the treatments continue.

All plots have received a total application of 80 lbs P_2O_5 and 60 lbs K_2O per acre per year since 1956. Fertilizer N or legume N is the only fertility variable. Lime is applied to each plot as determined by a soil test to maintain soil pH between 5.8 and 6.5. Soil samples are taken in even-numbered years.

Crop varieties

Crop varieties planted have always been those common varieties recommended and used by growers. However, since 1996, varieties planted and dates harvested reflected new, genetically modified crops that fit well with conservation tillage practices. In 1999, cotton and soybean were both Roundup Ready® varieties and corn was a Liberty Link® variety allowing weed control using only two herbicides.

Tillage

All plots were managed with conventional tillage (moldboard plow, flatbed disk or chisel, field cultivate or harrow, and cultivation for weed control) from 1896 through 1996. In 1997, all plots were switched to conservation tillage (spring paratill under the row and plant using no till planter; no mechanical cultivation). A goal was to establish reseeding crimson clover in those plots planted to winter legumes. The following management sequence is now used:

1. Early April: clip winter legumes for dry matter yield.

2. Early to late April: paratill (subsoil) cotton and corn plots; broadcast appropriate fertilizers and/or lime; strip plant corn into clover using row cleaners.

3. Late April to early May: strip plant cotton into mature clover using row cleaners and no-till planter; use Roundup® on cotton or Liberty® on corn to control emerged weeds.

4. Late May/early June: harvest small grain for grain; drill soybean into grain residue; apply Roundup or Liberty as appropriate.

5. Summer: scout cotton and apply appropriate insecticides if necessary.

6. Late August: harvest corn for grain

7. October-November: paratill and plant small grain following corn

8. Early October: harvest cotton; overseed with winter legumes if necessary (plots should have re-seeded and clover seedlings will be emerging at this time); apply fall fertilizer to appropriate plots.

9. Late October: chop cotton stalks when winter legumes are established; harvest soybean.

10. November-March: enjoy football, hunting, and basketball; write reports.

11. February: topdress small grain on plot 10, 11, or 12 with 60 lbs N acre^{-1}

RESULTS (1987 THROUGH 2001)

A New Era Begins

The near statewide cotton yield disaster in 1995 prompted Alabama farmers to quickly adopt the new Bollgard genetically modified varieties commercially available for the first time in 1996. This year also opened a century and a new era for the Old Rotation experiment. Since then, only genetically modified cotton with bollworm resistance has been planted on the Old Rotation. Interestingly, no broadcast application of insecticides have been applied to the Old Rotation since then! This contrasts with 8+ applications made annually prior to this new era. Roundup® resistant varieties were introduced in 1997 (soybean) and 1998 (cotton). Since then, only two herbicides have been used, Roundup® on cotton and soybean and Liberty® on corn, and no insecticides have been used since the 1995 season. *Genetically modified crops and conservation tillage introduced a new millenium of crop production unlike anything imagined by Professor Duggar's generation in the 1890s.*

Crop Yields

Year to year cotton yields continue to be extremely erratic due to uncontrollable environmental factors, mainly moisture. As an example, annual seed cotton yields since 1896 on plot 3 (cotton with winter legume) are plotted in Fig. 1. Interesting, rarely does one see two really bad years in a row or two very good years in a row. Year-to-year yields are extremely erratic for non-irrigated cotton. However, rarely does an exceptionally high yielding year follow another high yielding year. The same is true for low yielding years. While 1994 and 2001 were two of the highest yielding years on record; 1995 and 2000 were two of the worst. The 5-yr running average gives an indication of yield trends.

In past decades, there seemed to be a slight advantage to rotating cotton with corn or other crops. During the 1990s, this statistical advantage disappeared (Table 2). The highest numerical average (2+ bales per acre) was produced with a cotton-corn rotation using winter legumes plus N fertilizer (plots 5 & 9). Winter legumes (crimson clover) versus fertilizer N resulted in no differences in 10-yr average cotton yields from 1987 through 1996 or in the 5-year average yields since 1997.

Statistically, one should not compare yields from conventionally tilled cotton prior to 1997 and conservation tilled (no till in Table 2) because there are many more variables involved than just tillage. However, of interest is the noted increase in average yields of all crops since conservation tillage began in 1997 (Table 2). Cotton and soybean yields from the disaster year, 2000, were not included in these mean yields. Severe summer drought and late planting of cotton

Table 2. Mean crop yields on Old Rotation, 1986-2001. Cotton lint yields were calculated from seed cotton yields by assuming 38% lint. Mean values followed by the same letter are not statistically different at P = 0.10.

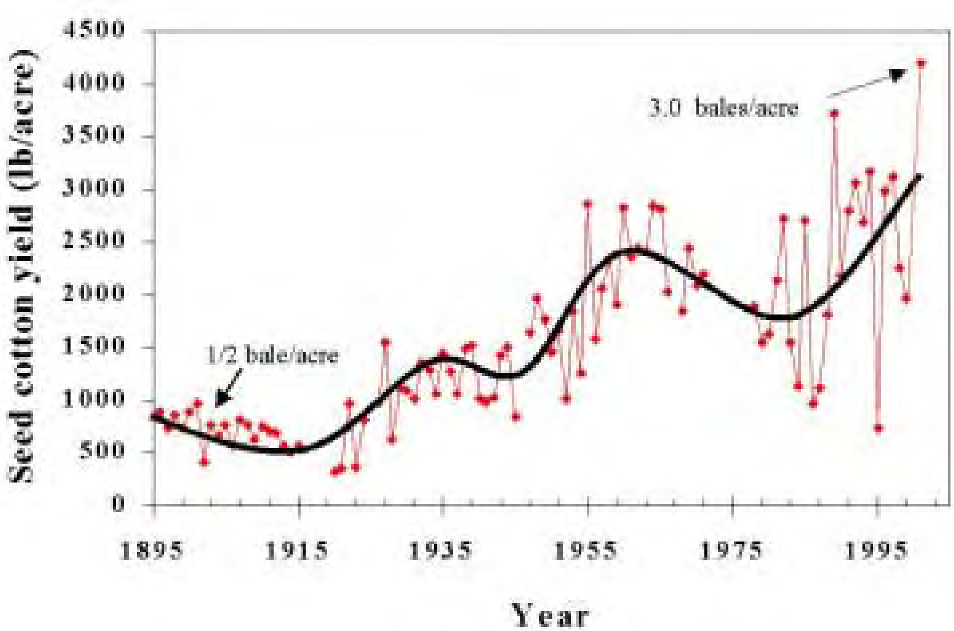
Plot	Treatment	Cotton lint yields		Corn grain yields	
		Conv. tillage 1986-95	No tillage 1996-2001	Conv. tillage 1986-95	No tillage 1997-2001
		------lbs per acre---------		--------bushels per acre--------	
1	No N	310 b	360 b	--	--
2	+ legume	770 a	1040 a	--	--
3	+ legume	850 a	890 a	--	--
4 & 7	Cotton-corn + legume	880 a	1000 a	77a	114a
5 & 9	Cotton-corn + legume + 120 N	900 a	1140 a	96a	139a
6	No N	350 b	360 b	--	--
8	+ legume	850 a	1100 a	--	--
10,11, 12	3-yr rotation	830 a	990 a	103a	127a
13	+120 N	700 a	1030 a	--	--
		Small grain (wheat or rye) --------------------------bushels per acre-------------------------			
Plot	Treatment	Conventional tillage 1986-1995		No till 1996-2001	
10,11, 12	3-yr rotation	Wheat=42 (n=2)	Rye=26 (n=6)	Wheat=76 (n=4)	Rye=23 (n=2)
		Soybean --------------------------bushels per acre--------------------------			
10,11, 12	3-yr rotation	31		40	
		Winter legume dry matter yields ------------------------lbs per acre---------------------------			
All plots	Average of all plots	3750		3080	

Table 3. Record non-irrigated crop yields on the Old Rotation.

Crop	Rank	Year	Plot	Record Yield
Cotton	1	2001†	8	1600 lbs lint acre^{-1}
	2	1994	3	1490
	3	1993	9	1270
Corn	1	1999†	11	236 bu acre^{-1}
	2	2001†	5	193
	3	1997†	5	148
Wheat (1961-present)	1	2001†	10	94 bu acre^{-1}
	2	2000†	11	81
	3	1999†	12	79
Oat (before 1960)	1	1958	--	109bu acre^{-1}
	2	1937	--	97
	3	1956	--	87
Rye (1978-present)	1	1981	--	55
	2	1988	--	48
	3	1979	--	40
Soybean (1957-present)	1	1996	12	67 bu acre^{-1}
	2	1992	--	61
	3	1983	--	55
Winter legume	1	1981	11	7250 lbs DM acre^{-1}
	2	2000†	8	6480
	3	1999†	3	6410

† Indicates conservation tillage since 1997.

Fig. 1. Yield for continuous cotton with winter legumes (plot 3) as an example of the yield trends over the 100 years of the Old Rotation.



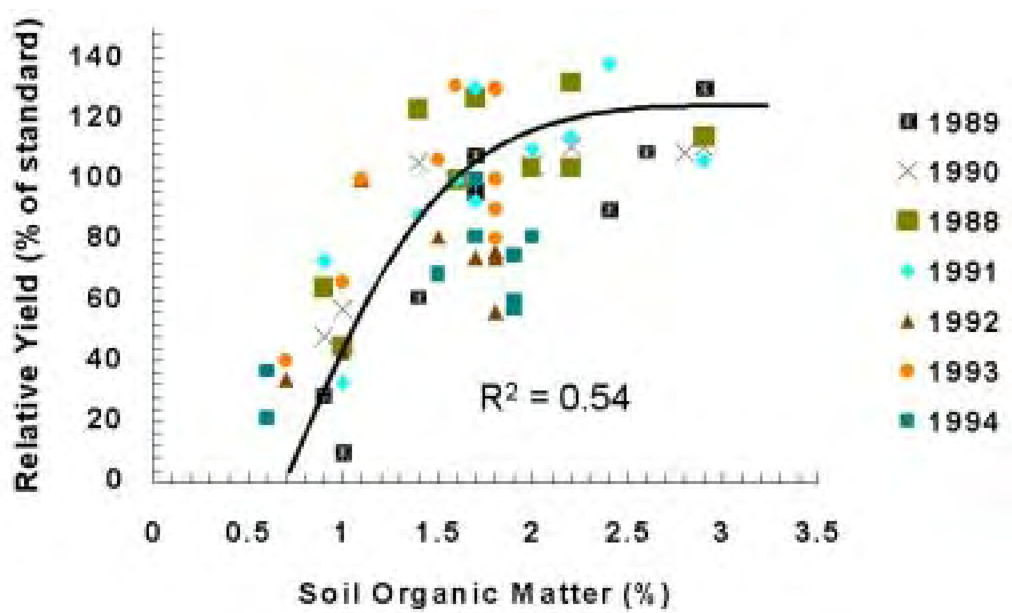
and soybean resulted in no harvestable yield in 2000.

Since switching to genetically modified crops in 1996 and conservation tillage in 1997, record yields of all crops have been produced on the Old Rotation (Table 3). A record 3 bales cotton per acre (1600 pounds lint) was produced in 2001 on a plot which has never received anything but legume N (plot 8). In 1999, a record corn grain yield of 236 bushels per acre was produced on the 3-yr rotation with only legume N. This was attributed to paratilling and residue left on the soil surface, less water runoff and more infiltration, narrow rows (30-inch rows), a high plant population, very high June rainfall during silking and pollination. Paratilling and a cool, dry spring were responsible for three consecutive record wheat yields in 1999, 2000, and 2001. The record soybean yield in 1996 (67 bushels per acre) is attributed to early planted, full-season beans planted into rye stubble and very favorable moisture during pod fill. Due to a late freeze in 1996, the rye crop was not harvested for grain which allowed for early planting of soybean. Normally, soybean is planted after grain harvest in late May or early June.

Soil Quality

Interest in sustainable agricultural systems and soil quality prompted a new look at these factors in the Old Rotation. Surprisingly, little effort has been directed over the past 100 years toward documenting the effects of the cropping systems

Fig. 2. Long-term treatments have resulted in significant differences in soil organic matter (organic C x 1.7 = soil organic matter). These differences are reflected in soil structure, water holding capacity of the plow layer, increased soil buffering capacity, e.g. increased cation exchange capacity, total mineralizable N, etc. Soil organic C was measured in 1988, 1992, and 1994 and regressed against plot yield relative to plot #3 (continuous cotton and winter legumes). There is a definite trend toward higher yields with increased soil organic matter.



on soil organic matter and its effect on yields. Soil organic matter was first measured on plots of the Old Rotation in 1988. Since then, measurements have been repeated in 1992 and 1994. As expected, the long-term treatments have had a dramatic effect on the buildup or depletion of soil organic matter. This is reflected in the yields. Yields in 1988, 1992, and 1994 were closely correlated with soil organic matter measurements (Fig. 2). In 1997, just prior to conversion to conservation tillage, additional soil physical and chemical measurements were taken to serve as a benchmark for future comparisons (Table 3). As crop rotation increased and more biomass was returned to the soil in the form of crop residue, we see increases in soil water holding capacity, hydraulic conductivity (K_{sat}), respiration, total C, total N, cation exchange capacity (CEC), and water-stable aggregates. All these indicate improvements in soil quality.

CONCLUSIONS

After 106 cropping years, the Old Rotation continues to document the long-term effects of crop rotation and winter legumes on sustainable cotton production in the Deep South. Long-term yields suggest that winter legumes are just as effective as fertilizer N in producing optimum cotton yields. Yields are also highly correlated with soil organic matter that reflect the long-term treatments. In the past, crop rotation benefits have had a small effect on cotton yields, considering yield levels and crop value. These benefits are apparently enhanced under conservation tillage. Soil quality differences, e.g., aggregation and soil tilth, due to rotations and cover cropping are dramatic and are likely to increase under conservation tillage. For more information about the Old Rotation and long-term yield records, see the references listed below or check out the web site at

http://www.ag.auburn.edu/dept/ay/cotton.htm

ACKNOWLEDGEMENT

The Old Rotation exits as the world's oldest, continuous cotton plots, and the third oldest continuous field crop experiment on the same site in the United States because of the dedication and cooperation of many individual researchers and administrators at Auburn University. The support of the Alabama Agricultural Experiment Station, Dr. John Jensen, Interim Director, and Dr. Robin Huettel, Associate Director, has been the main reason it has continued to exist. Recently, the USDA Soil Dynamic Laboratory staff and their equipment have played a major role in converting the Old Rotation to conservation tillage. Many students have collected data from the plots that add to our knowledge of soil quality changes. Most of the day-to-day

Table 4. Selected soil physical and chemical measurements made on treatments from the Old Rotation in 1997 before conversion to conservation tillage. Values followed by the same letter are not statistically different at $P = 0.10$.

Treatments	Bulk Density	Soil water	K_{sat}	Soil respiration
Continuous cotton:	----g cm^{-3}----	-----%-----	-inches min^{-1}-	lbs. C A^{-1} day^{-1}
No N/no legumes	1.66	7.69 c	0.37	22 b
+ winter legumes	1.66	7.47 b	0.43	44 ab
+120 lb. N/acre	1.73	9.40 bc	0.04	36 ab
Two-yr rotation:				
+ winter legumes	1.68	10.11 ab	0.57	60 a
+legumes/+120lb N/acre	1.62	11.67 a	0.33	45 ab
Three-yr rotation	1.65	11.47a	1.22	60 a

Treatments	Total C	Total N	C.E.C.	Water stable aggregates
Continuous cotton:	----%----	----%----	--$cmol_c$/kg--	----%----
No N/no legumes	0.50 d	0.02 c	3.1 c	49.8 b
+ winter legumes	0.84 c	0.04 ab	4.3 b	52.2 b
+120 lb. N/acre	0.87 c	0.04abc	5.6a	34.7 c
Two-yr rotation:				
+ winter legumes	0.85 c	0.05ab	4.6 b	53.2 b
+legumes/+120lb N/acre	1.09 b	0.06a	5.4a	48.9 b
Three-yr rotation	1.27a	0.05ab	5.5a	64.1a

work and maintenance is conducted by Mr. Charlie France, Research Technician, who has worked on these plots for over 40 years. The Old Rotation and other long-term experiments in Alabama are partially supported through grower checkoff funds through the Alabama Wheat and Feed Grain Committee and the Alabama Cotton Commission.

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