A Historical Summary of Alabama's Old Rotation (circa 1896): The World's Oldest, Continuous Cotton Experiment

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ABSTRACT

After more than 110 yr, the Old Rotation experiment on the campus of Auburn University in Alabama continues to document the long-term effects of crop rotation and winter legume cover crops on sustainable cotton (*Gossypium hirsutum* L.) production in the southeastern United States. Long-term yields indicate that winter legumes are as effective as fertilizer N in producing maximum cotton yields and increasing soil organic carbon (SOC). Higher SOC resulted in higher crop yields. However, rotating cotton with corn (*Zea mays* L.) in a 2-yr rotation or with corn, winter wheat (*Triticum aestivum* L.), and soybean [*Glycine max.* (L.) Merr.] in a 3-yr rotation produced little long-term cotton yield advantage beyond that associated with SOC. Cotton yields without winter legumes nor fertilizer N are only slightly higher than they were 110 yr ago. Nonirrigated corn grain yields in rotation with cotton are typically low for central Alabama and appear limited by N. Yields of all crops on the Old Rotation increased with increasing rates of P and K through the 1950s. Since adoption of in-row subsoiling, high-residue, conservation tillage, and genetically modified cultivars in 1997, all crops have produced their highest, nonirrigated, recorded yields since the experiment began: 1910 kg cotton lint ha^{-1} in 2006, 14.8 Mg corn grain ha^{-1} in 1999, 6.34 Mg wheat ha^{-1} in 2001, and 4.50 Mg soybean ha^{-1} in 2004.

By the late 19th century, most of the arable land in the southeastern United States was being used for crop production, with cotton being the predominant crop. Cotton was king. Texas, Georgia, and Alabama were the leading cotton-producing states. Alabama had 1.3 million ha (3.2 million acres) of cotton in 1896 and half of its population of 2 million was directly involved in cotton farming (Hawk, 1934). Cropland not planted to cotton was planted to corn, oats (*Avena sativa* L.), and cowpea [*Vigna unguiculata* (L.) Walp.] forage. The small amount of fertilizer that was used on cropland was quickly lost along with topsoil during heavy rainfall in winter. In the southern United States, many farmers suffered under reconstruction and a sharecropping economy based on cotton production on severely degraded farmland.

In 1883, the Alabama Agricultural Experiment Station was created at the Agricultural and Mechanical College of Alabama in Auburn (now Auburn University) with the charge to improve agriculture through research (Yeager and Stevenson, 2000). In 1896, J.F. Duggar started an experiment to test his theory that sustainable cotton production was possible if growers would use crop rotations and include winter legumes (clovers and/or vetch) to protect the soil from winter erosion. Today, this experiment on the campus of Auburn University is the oldest, continuous cotton experiment in the world and the third oldest field crop experiment in the United States on the same site (Steiner and Herdt, 1993; Mitchell et al., 1991). The experiment contains 13 plots on 0.4 ha (1 acre) and has continued since 1896 with only slight modifications in treatments. The Old Rotation was placed on the National Register of Historical Places in 1988.

Our objective is to review yield trends on the Old Rotation as it relates to modern, sustainable crop production in the southeastern United States. A statement of the original objectives of the Old Rotation cannot be found in the historical records. However, the treatments themselves suggest that the objectives were to (i) determine the effect of rotating cotton with other crops to improve yields and (ii) determine the effect of winter legumes in cotton production systems. A third objective today is to maintain this experiment as a historical record of the progress made in sustainable crop production in the southeastern United States.

OLD RECORDS AND PUBLICATIONS

The original records of the Old Rotation from 1896 to 1919 were destroyed in a fire that razed Comer Agricultural Hall in 1920. However, some handwritten records were later found. Average yields for 1896 to 1905 and from 1906 to 1915 had been published as an Alabama Agricultural Experiment Station publication and were recovered. Gaps in the yield records during the mid-1970s occurred when the Alabama Agricultural Experiment Station relocated its main agronomy research farm from the site of the Old Rotation to a new center about 48 km (30 miles) away.

The first mention of the name "the Old Rotation" was in a January 1930, monthly report of the Extension Service of the Alabama Polytechnic Institute (Anonymous, 1930). Davis (1949) noted that the Old Rotation was "... probably the oldest field experiment in the United States in which cotton has been

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Published in Agron. J. 100:1493–1498 (2008).
doi:10.2134/agronj2007.0395

AJ
AGRONOMY JOURNAL
1908–2008

Abbreviations: SOC, soil organic carbon.

grown." Several publications have included data from the Old Rotation and since the experiment's centennial year in 1996, it has received increasing attention from researchers interested in sustainable crop production. However, like many historical experiments that do not fit the experimental design required by modern, peer-reviewed research journals, most results from this experiment are published in research and extension reports, nontechnical trade journals, and the popular press. The first 100 yr of this experiment was reported in detail by Mitchell et al. (1996).

METHODS

The site of the Old Rotation is on the juncture of the southern Piedmont Plateau and the Gulf Coastal Plain physiographic regions in east-central Alabama (32°36′ N, 85°36′ W). Average annual precipitation at the site is 1339 mm. Mean annual temperature is 18°C with 221 d between the last spring freeze and the first fall freeze. The soil at the Old Rotation site is identified as a Pacolet fine sandy loam (clayey, kaolinitic, thermic, Typic Hapludults).

The Old Rotation consists of 13 plots, each 6.5 m by 41.4 m, on 0.4 ha. A 1-m alley separates each of the plots. Plots are identified by numbers. Today, the rotation treatments are (i) cotton every year with (a) no legumes and no N fertilizer (Plots 1 and 6), (b) winter legumes (Plots 2, 3, 8), and (c) N fertilizer: 134 kg N ha^{-1} yr^{-1} as ammonium nitrate (Plot 13); (ii) 2-yr, cotton-corn rotation with (a) winter legumes (Plots 4 and 7) and (b) winter legumes plus 134 kg N ha^{-1} yr^{-1} as ammonium nitrate (Plots 5 and 9); and (iii) 3-yr rotation: cotton-winter legumes-corn followed by small grain for grain (67 kg N ha^{-1})-soybean (Plots 10, 11, and 12)

Winter annual legumes have always been either hairy vetch (*Vicia villosa* Roth) or crimson clover (*Trifolium incarnatum* L.) or a mixture of the two. Since 1990, only crimson clover ('AU Robin') has been planted.

The Old Rotation, like most 19th century experiments, was not replicated. Each plot was a different treatment to be observed. However, as certain cropping systems and fertilization changed over the years, some treatments actually became replicates of other treatments (Table 1). For example, Plot 1 was in corn production with either a summer legume (cowpea) or a winter legume (hairy vetch) as the only source of N from 1896 to 1931. Since then, it has been planted to cotton and treated the same as Plot 6. Yield has been the only consistent measurement recorded since 1896. Long-term yield trends are summarized using 10-yr means and means are separated using ANOVA with year × treatment interaction as the error term.

Fertilization

All plots have received the same annual rate of P and K. However, the actual rate applied has gradually increased over the years from a total annual application of 0–11–18 kg N–P–K ha^{-1} to 0–40–56 kg N–P–K ha^{-1} since 1956

Table 1. Crops and fertilizer rates (kg ha^{-1} N–P–K) used in the Old Rotation since 1896.

Plot	1896–1924	1925–1931	1932–1947	1948–1955	1956–present
1	corn 0–11–18 cowpea	corn 0–13–18 vetch 0–30–0	cotton 0–35–56 vetch	cotton 0–35–56	cotton 0–39–56
2	corn 0–11–18	corn 0–43–18	cotton 0–35–56	cotton 0–35–56	cotton vetch and/or clover 0–40–56
3	cotton 0–11–18 vetch	cotton 0–13–18 vetch 0–30–0	cotton 0–18–28 vetch 0–18–28	cotton 0–18–28 vetch 0–18–28	cotton 0–20–28 vetch and/or clover 0–20–28
4,7	cotton 0–11–18 vetch corn 0–11–18 cowpea	cotton 0–13–19 vetch 0–30–0 corn 0–13–18 vetch 0–30–0	cotton 0–18–28 vetch 0–18–28 corn 0–18–28 vetch 0–18–28	cotton 0–18–28 vetch 0–18–28 corn 0–18–28 vetch 0–18–28	cotton 0–40–56 vetch and/or clover 0–20–28 corn 0–0-0 vetch and/or clover 0–20–28
5,9	cotton 0–11–18 vetch cowpea 0–11–18	cotton 9–13–18 vetch 0–30–0 cowpea hay 0–13–18 vetch 0–30–0	cotton 0–18–28 vetch 0–18–28 cowpea hay 0–18–28 Vetch 0–18–28	cotton 0–18–28 vetch/clover 0–18–28 cowpea hay 0–18–28 vetch 0–18–28	cotton 134–40–56 vetch and/or clover 0–20–28 corn 134–0-0 vetch and/or clover 0–20–28
6	cotton 0–11–18	cotton 0–43–18	cotton 0–35–56	cotton 0–35–56	cotton 0–40–56
8	(same as Plot 3)	(same as Plot 3)	cotton 0–35–56 vetch	cotton 0–35–56 vetch	cotton 0–40–56 vetch and/or clover
10,11,12	cotton 0–11–18 vetch corn 0–11–89 cowpea and/or oat cowpea 0–11–18	cotton 0–43–18 vetch corn 0–43–18 oat cowpea hay 0–43–18 vetch	cotton 0–18–28 vetch 0–18–28 corn 0–18–28 oat 0–18–28 cowpea hay 0–18–28 vetch 0–18–28	cotton 0–18–28 vetch 0–18–28 corn 0–18–28 oat 0–18–28 cowpea hay	cotton 0–40–56 vetch and/or clover 0–40–56 corn rye or wheat 67–0-0 soybean
13	(same as Plot 5)	(same as Plot 5)	(same as Plot 5)	cotton 0–18–28 vetch 0–18–28 cowpea hay 0–18–28 vetch 0–18–28	cotton 134–40–56

(Table 1). The changes in the amounts of P and K applied were made to meet obvious fertility needs of the crops (Davis, 1949). In the 1920s, P and K were applied to both the summer crop and the winter legumes. Later, treatments were changed so that time of P and K application could be evaluated, for example, P and K were applied to either the summer crop, the winter legumes, or split. The reason behind this change was because growth of the winter legumes seemed to improve from direct P and K application resulting in higher N fixation (Davis, 1949).

In the l950s, routine soil testing allowed quick measurements of soil pH and extractable nutrients, and these measurements were added to the records of the Old Rotation. Since 1956, fertilizer N as ammonium nitrate has been applied to the cotton and corn rotation in Plots 5 and 9 at a rate of 134 kg N ha^{-1} yr^{-1} and to cotton in Plot 13 at 134 kg N ha^{-1} yr^{-1}. The small grain in Plots 10, 11, or 12 receives a topdressing of 67 kg N ha^{-1} yr^{-1} in February. No additional fertilizer N is applied to the 3-yr rotation.

From 1896 to 1931, the sources of P and K were acid phosphate (either 14% or 16% P_2O_5) and kainit (12% K_2O), respectively. In 1932, a change was made from kainit to muriate of potash (50% K_2O). In 1944, 18% superphosphate and 60% muriate of potash were used. Today, the sources of P and K are concentrated superphosphate (46% P_2O_5) and muriate of potash (60% K_2O). Since 1956, all plots have received an annual application of 150 kg ha^{-1} agricultural gypsum (calcium sulfate), which provides approximately 22 kg S ha^{-1} yr^{-1}.

Ground, dolomitic agricultural limestone is applied to each plot as needed to maintain the soil pH above 5.8. Soil sampling has not occurred on a regular schedule and as previously mentioned, no records were kept until the 1950s. Since then, soil samples have been taken after harvest about every 2 yr. Samples have been tested for pH and Mehlich-1 extractable P, K, Ca, and Mg. Soil organic carbon (SOC) measurements have been collected periodically since 1988.

Since 1997, all crops have been planted using a strip-tillage system with either an in-row subsoiler or paratill that maximizes the retention of winter cover crops or previous crop residue on the soil surface (Reeves, 1997; Reeves et al., 2005). Also in 1997, genetically modified crops have been used, which have reduced all pesticide applications. In 2003, a solid-set irrigation system was installed so half of each plot could be independently irrigated. Before this, all crops were rain fed. Only nonirrigated yields are included in this report. Irrigated yields from 2003 to 2007 have been summarized by Mitchell et al. (2008).

RESULTS AND DISCUSSION

Cotton Yields

Improving cotton yields has been the principal focus of the Old Rotation. Yields were the only consistent records kept throughout its history. Cotton lint yield records from Plot 6 (cotton every year with no N and no legumes), Plot 8 (cotton every year with only legume N) and Plots 5 and 9 (cotton-corn rotation plus winter legumes and 134 kg N ha^{-1} yr^{-1}) are used to illustrate the wide yield variability observed from year to year under nonirrigated conditions in the region (Fig. 1). This figure also illustrates the general trends in yields over the history of this experiment. All yields appear to decline slightly during the first 25 yr of the Old Rotation. This decline is generally attributed to the cotton boll weevil (*Anthonomus grandis* Boheman), which entered Alabama in 1911 and became widespread by 1914 (Smith, 2007). Davis (1949) also attributed this decline to a P deficiency in the winter legumes, which limited N available to cotton. Unlike soils in the Midwestern United States where considerable mineralizable organic N may be present, these highly weathered soils were likely very low in organic N when the experiment began, which is typical of the Ultisols that are prevalent across the region. The 1924 revision increased P rates from 11 to 43 kg P ha^{-1} yr^{-1}. The 1931 revision increased K rates from 18 to 56 kg K ha^{-1} yr^{-1}. From the mid-1920s to the mid-1960s, average seed cotton yields increased slowly as fertilizer rates increased. Large yield increases were observed in the mid-1950s on those treatments receiving commercial N fertilizer. No commercial N had been used in the Old Rotation until the 1956 revision. This is when 134 kg N ha^{-1} was applied for the first time on the 2-yr rotation (Plots 5 and 9) and the continuous cotton with no legumes (Plot 13). The small grain crop (rye [*Secale cereale* L.] or wheat [*Triticum aestivum* L.]) on the 3-yr rotation also received 67 kg N ha^{-1} as a topdress application in February. Additional cotton yield increases can be attributed to improved cultivars of cotton and better insect control. 'Auburn 56' cotton was introduced in 1956. This wilt and nematode resistant variety became widely accepted in Alabama by 1960 and was grown on the Old Rotation longer than any other single cultivar. During the late 1950s and 1960s, dichloro diphenyl trichloroethane (DDT) was an effective and widely used insecticide for control of boll weevils and other insects. Its removal from use in the early 1970s may have contributed to the temporary decline in yields during this decade. In the 1980s and 1990s, synthetic pyrethroids dominated the market for insect control in cotton. Efforts to eradicate the boll weevil in east-central Alabama began in the mid-1990s and may partially account for the upward trend in yield during the past few years (Smith, 2007). A switch in 1997 from conventional tillage (moldboard plowing, disking, harrowing, and cultivating) to high residue conservation tillage (subsoiling under the row with strip planting into cover crop residue) and the use of Roundup Ready (Monsanto Co., St.

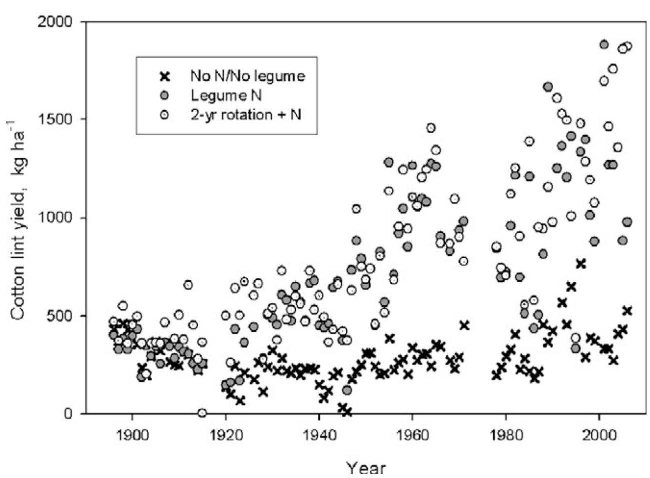

Fig. 1. Annual cotton lint yields for the no-N and no-legume treatment (Plot 6), the continuous cotton with only legume N treatment (Plot 8), and the 2-yr rotation + N treatment (Plots 5 and 9).

Table 2. Ten-year average cotton lint yields and corn grain yields on the Old Rotation, 1896–2005.

Treatment (plots)	Years† 1896–1905	1906–1915	1916–1925	1926–1935	1936–1945	1946–1955	1956–1965	1966–1975	1976–1985	1986–1995	1996–2005
	Cotton lint, kg ha^{-1}										
Continuous cotton											
No N, no leg. (6)	360ab	280d	150c	230b	170d	230e	280d	320c	270d	420d	460d
+ legumes (3,8)	380a	300cd	290b	520a	550b	710c	1060b	940b	820b	1000ab	1180bc
134 kg N ha^{-1} (13)	–	–	–	–	–	–	880c	910b	730c	830c	1310b
Cotton-corn rotation											
+legumes (4,7)	390a	340bc	340b	560a	640a	870a	1180a	1080a	830b	1030ab	1220bc
+leg., +N (5,9)‡	400a	430a	520a	530a	520b	750b	1120ab	910b	970a	1150a	1500a
3-yr rotation (10,11,12)	330b	360b	320b	510a	510b	760b	1180a	1070a	990a	1000ab	1120c
	Corn grain, Mg ha^{-1}										
Continuous corn											
No N, no leg (2)	1.21a	0.72c	0.56c	0.69b	–	–	–	–	–	–	–
+legumes (1)	1.29a	1.09a	1.16a	1.65a	–	–	–	–	–	–	–
Cotton-corn rotation											
+legumes (4,7)	1.21a	0.88 b	0.96b	1.88a	2.47a	2.67b	4.64b	2.93b	2.23c	4.58b	5.52c
+leg., +N (5,9)‡	–	–	–	–	–	–	–	§	2.79b	6.02a	8.49a
3-yr rotation (10,11,12)	1.06b	0.85b	1.02ab	1.98a	2.27a	3.27a	5.68a	4.58a	3.74a	6.71a	6.68b

† Values in the same 10-yr period followed by the same letter are not significantly different using Duncan's Multiple Range test at $P < 0.10$. Missing values (indicated by a dash) are for those periods when that particular crop was not planted in those plots.

‡ 134 kg N ha^{-1} added as ammonium nitrate since 1956 to cotton and corn. Before this, a summer legume (cowpea) was planted in rotation with cotton and winter legumes.

§ Missing data.

Louis, MO) and worm resistant (Bt) cultivars may help explain the higher yields observed over the past 10 yr.

Cotton yields on the no-N and no-legume control plots (Plots 1 and 6) have increased only slightly since the Old Rotation began (Table 2). Plot 1 was in corn during the first 40 yr of the Old Rotation. Yield trends on both these plots indicate that with no N fertilization and no legumes, the yield potential gradually declines over a period of 15 to 20 yr and then stabilizes at about half of the beginning yields. This may be a reflection of the gradual mineralization of organic N. Soil organic matter in Plots 1 and 6 is less than 1%. Nitrogen removal in the cotton lint and seed (primarily seed) from these plots is estimated to be about 13 kg N ha^{-1} yr^{-1}. This is very close to available N from nonsymbiotic fixation and rainfall (Mitchell and Entry, 1998).

Including a winter legume as the only source of N for the cotton crop (Plots 2, 3, and 8; Table 2; Fig. 1) has produced yields as high as or higher than those produced from applying 134 kg N ha^{-1} yr^{-1} to a cotton monoculture. Winter legumes were not planted on Plot 2 until 1948 (Table 1). The N-fertilized plot (Plot 13) was not added until 1956. Duggar effectively demonstrated that winter legumes could improve yields of continuous cotton during the first few years of the Old Rotation (Bailey et al., 1930). Yields since 1956 have been slightly higher using legume N compared with fertilizer N. Therefore, the choice farmers make obviously depends on costs and management. Planting and managing winter legumes in a continuous cotton system requires a higher level of management but, depending on seed, fertilizer N, and planting costs, growing winter legumes can result in yields comparable or higher than long-term use of commercial N fertilizer.

Mitchell and Entry (1998) reported that the aboveground portion of the winter legumes contributes between 90 and 168 kg N ha^{-1} in the Old Rotation. If most of this N is available to cotton, it would supply the standard recommendations of 100 to 134 kg N ha^{-1} for cotton in Alabama (Adams et al., 1994). There does not appear to be much of a yield advantage to rotating cotton with other crops when compared with continuous cotton following a winter legume, but crop rotation is beneficial compared with continuous cotton that received no N or even 134 kg N ha^{-1} (Table 2). However, the 2-yr cotton-winter legume-corn rotation produces similar yields as the 3-yr rotation.

Since converting the Old Rotation to high residue conservation tillage in 1997, the advantage of a high residue rotation with corn, winter legumes, and 134 kg N ha^{-1} is becoming apparent. Low yields for nonirrigated corn in central Alabama (National Agricultural Statistical Service, 2008) have made a cotton-corn rotation less attractive to growers than continuous cotton. Novak et al. (1990) studied risks and returns for the various Old Rotation cropping systems using data for 1980 through 1990. They concluded that."… the optimal farm plan will include a 3-yr rotation of cotton, winter legumes, corn, small grains, and soybean. The highest expected return at each target income level will result from planting the entire acreage to (this rotation). As risks are reduced, more and more of the continuous cotton with winter legume rotation will enter the farm plan."

Corn Yields

Corn has been the principal grain crop produced in Alabama in spite of low, nonirrigated corn grain yields compared with Midwestern states. It was a staple on 19th century Alabama cotton farms because it provided food and fodder for livestock and grain for human consumption (Hawk, 1934). Nonirrigated corn grain yields on the Old Rotation are similar to Alabama average yields (National Agricultural Statistical Service, 2008). While grain yields have gradually increased over the 110 yr of the Old Rotation, only during the past two decades (1986–2006) have they increased dramatically (Table 2). The reason for this yield increase is not apparent. It may be a reflection of higher N fixation by the winter legumes (Table 3), improved hybrids, and good weather during the past decade. Soil quality improvements attributed to high residue conservation tillage systems since 1997 may have also contributed to higher yields, especially on the treatments receiving winter legumes plus fertilizer N. Apparently, N deficiency is a major yield-limiting factor where only winter legumes are used for corn. The authors increased the fertilizer N rate on these treatments in 2007.

Winter Legumes

Yield records for winter legumes were not kept before 1931 and many years have missing data. In addition, harvest weights were recorded as green weight or fresh weight yield until 1985. Since 1985, all winter legume yields have been reported as dry matter yields. To calculate all yields on a dry matter basis, earlier data were converted to a dry matter basis assuming 18% dry matter in fresh herbage. This is approximately the average dry matter in herbage harvested since 1985. Since the 1950s, we have not seen differences in winter legume yields due to treatments although there are large year-to-year differences due to timing of planting, rainfall, winter damage, and time of harvest. The large increase in dry matter yields around 1980 is believed due to improved varieties of crimson clover and hairy vetch (Table 3). Since 1990, 'AU Robin' crimson clover has been used, which is an early maturing, high dry matter yielding clover developed as a winter cover crop for cotton and corn rotations. There were differences in dry matter yields of winter legumes due to fertilization before the 1960s but no differences have been observed since then (Table 3). The increase in P and K fertilization in 1956 eliminated the variable response of the winter legumes to P fertilization as discussed by Davis (1949).

Table 3. Ten-year average winter legume dry matter (DM), small grain, and soybean yields on the Old Rotation since 1926.

Cropping system	P and K applied to‡	Plot	Years† 1926–1935	1936–1945	1946–1955	1956–1965	1966–1975	1975–1985	1986–1995	1996–2005
			Winter legume (hairy vetch or crimson clover) DM kg ha^{-1}							
Continuous cotton										
+ legumes	legume	2	–	–	2300b	2040	2100	4020	3750	3850
	split	3	1590b	1150bc	1840bc	2180	2270	4250	3740	3520
	cotton	8	1640b	1120bc	2080bc	1940	2170	4550	4070	4040
Cotton-corn rotation										
+legumes	split	4	2300a	1650a	2230b	2190	2050	3880	3650	3290
	split	7	1880b	1110bc	1970bc	2090	2500	4580	4060	3240
+legume, +N§	split	5	1750b	960bc	2080bc	1990	2310	4160	3980	3130
	split	9	1610b	860bc	1920bc	2190	2470	4160	3540	3200
3-yr rotation	cotton and leg.	10	1670b	1230b	1960bc	1850	2220	3770	4960	3830
	cotton and leg.	11	1680b	1080bc	1610cd	2380	1590	4970	3360	4670
	cotton and leg.	12	–	–	3640a	1960	2590	3860	4400	3460
Cotton-vetch-cowpea hay	split	13	1520b	780c	1360d	–	–	–	–	–
P > *F*			<0.01	<0.01	<0.01	ns¶	ns	ns	ns	ns
Mean of all plots			1810	1100	2000	2080	2230	4230	3860	3550
			Small grain and soybean, kg ha^{-1}							
Oat on all plots			1570	2210	1630	1890	–	–	–	–
Rye on 3-yr rotation (Plots 10, 11, 12)			–	–	–	–	–	1850	1650	1440
Wheat on 3-yr rotation (Plots 10, 11, 12)			–	–	–	1600	1340	–	2880	4430
Soybean on 3-yr rotation (Plots 10, 11, 12)			–	–	–	2280	2230	2540	2110	2750

† Values in the same 10-yr period followed by the same letter are not significantly different using Duncan's Multiple Range test at $P < 0.10$.

‡ All fertilizer P and K applied before planting either the winter legume, cotton, or split with half to each crop.

§ 134 kg N ha^{-1} added as ammonium nitrate since 1956 to cotton and corn. Before this, a summer legume (cowpea) was planted in rotation with cotton and winter legumes.

¶ ns, not significant at $P < 0.10$.

Small Grain and Soybean

Small grain (oat, rye, or wheat) and either cowpea or soybean have been planted in the 3-yr rotation (Plots 10, 11, and 12) since 1956. Before this time, cowpea was planted as both a summer green manure crop and a forage crop. It was one of the few summer annual legumes that was productive on the soils and climate of the southeastern United States during the late 19th and early 20th century. It could be planted following a spring crop of oat or wheat or following corn in the late summer and early autumn. Yields for cowpea when turned under as a green manure crop or used for forage are not complete. In the early 1960s, soybean became widely planted throughout the region as a cash crop. Oat was produced as grain for animal feed until improved selections of wheat and rye were accepted by southern growers. Although rye is not a high grain producer, it is frequently planted as a winter cover crop because it provides rapid fall growth, winter soil protection, early maturity, and high total biomass production. Wheat has been planted as a winter cover crop in the 3-yr rotation since 1995 because of high grain yields harvested in late May, which allow for double-cropping with soybean. Since high residue conservation tillage was implemented in 1997, soybean has been drilled into wheat residue by mid-June. Average yields of small grain and soybean are given in Table 3. Growers are particularly interested in the fact that wheat grain yields have averaged 4583 kg ha^{-1} (68 bu acre^{-1}) since adopting conservation tillage. Nonirrigated, double-cropped soybean yields following wheat have averaged 2750 kg ha^{-1} (41 bu acre^{-1}).

Soil Quality and Organic Carbon

Soil organic carbon is an important indicator of soil quality. It influences soil structure, which affects soil aggregate stability and its capacity to provide plant-available water, and it is the controlling factor in nutrient cycling. Following a change in land management, SOC changes slowly with time. These changes are difficult to detect until sufficient time has elapsed for the changes to be larger than the spatial and analytical variability (Entry et al., 1996). The Old Rotation experiment has provided observations on the effect of cropping on surface layer soil organic matter changes. These have been summarized by Entry et al. (1996), Mitchell and Entry (1998), Hubbs et al. (1998), and Prieto et al. (2002).

No records were kept of SOC measurements on the Old Rotation before 1988. Measurements of SOC in the surface 0 to 15 cm were made in 1988, 1992, and in 1994 using the Walkley-Black procedure (Southern Association of Agricultural Experiment Station Directors, 1983). As expected, those treatments with higher residue inputs had higher mean SOC (Table 4).

Results of this investigation show that long-term planting of winter legumes increased SOC. The 2-yr, cotton-corn rotation with winter legumes plus N (Plots 5 and 9) and the 3- yr rotation (Plots 10, 11, and 2) had higher SOC than the other four rotations. Cotton only without winter legumes (Plots 1 and 6)

Table 4. Mean soil organic C in the surface 0 to 15 cm from samples taken in 1988, 1992, and 1994.

Crop rotation and treatment	Organic C†
	%
Cotton every year	
No winter legumes (Plots 1, 6)	0.4d
+ winter legumes (Plots 4, 7)	0.9bc
+ 134 kg ha^{-1} yr^{-1} N (Plot 13)	0.8c
2-yr rotation	
winter legumes only (Plots 4, 7)	1.0bc
winter legumes+ 134 kg ha^{-1} yr^{-1} N (Plots 5, 9)	1.1ab
3-yr rotation (Plots 10, 11, 12)	1.2a

† Mean values followed by the same letter are not significantly different at $P < 0.05$ using year × treatment as the error term.

had a lower amount of SOC than all other rotations. These results are not surprising considering the increased biomass returned to the soil from the corn, small grain, and summer legume (soybean) residue. The plots with the highest SOC are also the highest yielding plots. Increased SOC can be viewed as a consequence of improved crop production. Mitchell and Entry (1998) showed that SOC from the Old Rotation plots may also be viewed as a predictor of relative, potential crop yield. There was a significant trend toward higher cotton yields in plots with higher SOC. They suggested a yield plateau in the Old Rotation above 10 g C kg^{-1} (>2% soil organic matter). An Extension cotton survey in central Alabama in 2001 showed that 55% of fields had less than 2 g organic C kg^{-1} with a mean organic C of 3 g kg^{-1} in the surface 0 to 5 cm (Kuykendall et al., 2002). Cover crops grown on cropland in the southeastern United States build SOC, improve soil physical and chemical characteristics, supply additional N, and reduce erosion of topsoil during the high rainfall winter months. Well-adapted winter legume cover crops can replace from 90 to 120 pounds N per acre. After 99 yr, the Old Rotation indicates that winter legumes increase amounts of both C and N in soil, which ultimately contribute to higher cotton yields.

SUMMARY

Referring to information learned from the Old Rotation, Professor F.L. Davis (1949) made the following statement: "Cotton as a crop does not deplete the soil or run it down excessively. The cultural practices of leaving the soil bare through the winter and not preventing erosion are responsible for the generally low fertility level of many soils on which cotton is grown."

After more than 110 yr, the Old Rotation continues to document the long-term effects of crop rotation and winter legumes on sustainable cotton production in the southeastern United States. Long-term yields indicate that winter legumes are as effective as fertilizer N in producing maximum cotton yields. Winter legumes and crop rotations also contribute to increased soil organic matter. Higher soil organic matter results in higher crop yields. Average yields continue to increase far beyond yields that were common when J.F. Duggar established the Old Rotation in 1896. Early agronomists such as Duggar were often prophetic in their teaching and research. The following statement is attributed to Duggar: "Alabama agriculture will come unto its own when her fields are green in winter." This statement was made almost 100 yr before most farmers in the southeastern United States adopted conservation tillage systems and planted winter cover crops. More than 110 yr of yield data from the Old Rotation have verified Duggar's prophetic statement.

REFERENCES

Adams, J.F., C.C. Mitchell, and H.H. Bryant. 1994. Soil test fertilizer recommendations for Alabama crops. Agron. & Soils Dep. Ser. no. 178. Alabama Agric. Exp. Stn., Auburn Univ.

Anonymous. 1930. The "Old Rotation" Experiment. The Digest. vol. VII (4). Ext. Serv. of the Alabama Polytechnic Institute, Auburn.

Bailey, R.Y., J.T. Williamson, and J.F. Duggar. 1930. Experiments with legumes in Alabama. Bull. 232. Agric. Exp. Stn., Alabama Polytechnic Institute, Auburn.

Davis, F.L. 1949. The Old Rotation at Auburn, Alabama. *In* Better Crops with Plant Food. Reprint DD-8-49. Am. Potash Inst., Inc. Washington, DC.

Entry, J.A., C.C. Mitchell, and C.B. Backman. 1996. Influence of management practices on soil organic matter, microbial biomass and cotton yield in Alabama's "Old Rotation". Biol. Fertil. Soils 23:353–358.

Hawk, E.Q. 1934. Economic history of the South. Prentice Hall, Inc., New York.

Hubbs, M.D., D.W. Reeves, and C.C. Mitchell. 1998. Measuring soil quality on the "Old Rotation". p. 50–54. *In* T.C. Keisling (ed.) Proc. 21st Annu. Southern Conservation Tillage Conf. for Sustainable Agric., North Little Rock, AR. 15–17 July 1998. Arkansas Agric. Exp. Stn., Fayetteville.

Kuykendall, L., R.R. Beauchamp, and C.C. Mitchell. 2002. Changes in central Alabama cotton soil management, 1991 and 2001. *In* Proc. 2002 Beltwide Cotton Conf., Atlanta, GA. 8–12 Jan. 2002. National Cotton Council, Memphis, TN.

Mitchell, C.C., F.J. Arriaga, J.A. Entry, J.L. Novak, W.R. Goodman, D.W. Reeves, M.W. Runge, and G.J. Traxler. 1996. The Old Rotation, 1896–1996, 100 years of sustainable cropping research. Spec. pub. Alabama Agric. Exp. Stn., Auburn Univ.

Mitchell, C.C., K.S. Balkcom, and D.P. Delaney. 2008. Irrigation on the Old Rotation. p. 1599–1602. *In* Proc. 2008 Beltwide Cotton Conf., Nashville, TN. 8–11 Jan. 2008. National Cotton Council, Memphis, TN.

Mitchell, C.C., and J.A. Entry. 1998. Soil C, N and crop yields in Alabama's long-term 'Old Rotation' cotton experiment. Soil Tillage Res. 47:331–338.

Mitchell, C.C., R.L. Westerman, J.R. Brown, and T.R. Peck. 1991. Overview of long-term agronomic research. Agron. J. 83:24–29.

National Agricultural Statistical Service. 2008. Alabama crops. Available at www.nass.usda.gov/Statistics_by_State/Alabama/index.asp. (cited 23 July 2008; verified 28 July 2008).

Novak, J.L., C.C. Mitchell, and J.R. Crews. 1990. Economic risk and the 92-year "Old Rotation": Implications for a 250-acre farm. Cir. no. 300. Alabama Agric. Exp. Stn., Auburn Univ.

Prieto, G.S., D.W. Reeves, J.N. Shaw, and C.C. Mitchell. 2002. Impact of conservation tillage on soil carbon in the 'Old Rotation'. p. 277–282. *In* E. van Santen (ed.) Making conservation tillage conventional: Building a future on 25 years of research. Proc. 25th Annual South. Conserv. Tillage Conf. for Sustainable Agric., Auburn, AL. 24–26 June 2002. Spec. Rep. no. 1. Alabama Agric. Exp. Stn., Auburn Univ.

Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Tillage Res. 43:131–167.

Reeves, D.W., A.J. Price, and M.G. Patterson. 2005. Evaluation of three winter cereals for weed control in conservation-tillage non-transgenic cotton. Weed Technol. 19:731–736.

Smith, R.H. 2007. History of the boll weevil in Alabama, 1910–2007. Bull. no. 670. Alabama Agric. Exp. Stn., Auburn Univ., AL.

Southern Association of Agricultural Experiment Station Directors. 1983. Reference soil test method for the southern region of the United States. South. Coop. Ser. Bull. no. 289. Univ. of Georgia, Athens.

Steiner, R.A., and R.W. Herdt. 1993. A global directory of long-term agronomic experiments. Vol. 1: Non-European experiments. The Rockefeller Foundation, New York.

Yeager, J., and G. Stevenson. 2000. Inside Ag Hill: The people and events that shaped Auburn's agricultural history from 1872 through 1999. Sheridan Books, Chelsea, MI.