ALABAMA'S "OLD ROTATION"
100 YEARS OF COTTON RESEARCH

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Abstract

Alabama's "Old Rotation" (c. 1896) is the oldest, continuous cotton experiment in the world and the third oldest continuous field crop experiment in the same location in the United States. It was placed on the National Register of Historical Places in 1988 and is celebrating its centennial this year. It is the only surviving, 19th century experiment that demonstrates the beneficial effects of rotating cotton with other crops and including winter legumes as a source of nitrogen. Where no N is included in a rotation, low cotton and corn yields continue to decline for 15 to 20 years until a relatively stable, low yield is reached. Annual N removed in cotton seed and lint (12 lb/acre/yr) is approximately that which would be expected to be available from atmospheric deposition and non-symbiotic fixation. Including a winter legume cover crop (crimson clover and/or vetch) has produced long-term yields equal to or greater than those achieved from applying 120 lb. N/acre/yr as ammonium nitrate to non-irrigated cotton. There is little yield advantage to long-term rotations for cotton, but there may be some risk advantages. Sustainable productivity research conducted using long-term records from the Old Rotation has shown that (1) continuous cotton production is sustainable, (2) output per unit of input is higher today than when the experiment began, (3) long-term productivity occurs in unexplained cycles, and (4) the most important technological advancement in sustainable cotton production was the introduction of the mechanical cotton harvester.

Introduction

In the late 19th Century, the entire economy of most southern states centered around cotton production. As new land became scarce, protecting old land and producing more profitable crops on this land became the only recourse for most growers. They didn't coin the now popular phrase "sustainable", but, in effect, that is what growers wanted--a cotton production system that reduced risk, was profitable and productive, and at the same time protected their natural resource base and was socially acceptable.

With limited inputs available for 19th Century cotton farms, early agricultural experiments with cotton in the South focused on management practices that could sustain production and be easily implemented. Turn-of-the-century experiment station publications in Alabama, Georgia, South Carolina and other southern states are filled with reports of the beneficial effects of rotating cotton with grain crops as feed for livestock and including winter legumes as a cover crop to protect the soil from erosion and provide much needed nitrogen (N) for the cotton and/or corn.

The only one of these old experiments to survive is Alabama's "Old Rotation". It was started in 1896 by Professor J.F. Duggar at the Alabama Polytechnic Institute (now Auburn University). Today, this experiment is the oldest, continuous cotton experiment in the world and the third oldest field crop experiment on the same location in the United States (Steiner and Herdt, 1995; Mitchell et al., 1991). A statement of the objectives or purposes of the Old Rotation cannot be found in the historical records. However, the treatments themselves suggest that the objectives of the experiment were to (1) *determine the effect of rotating cotton with other crops to improve yields and (2) determine the effect of winter legumes in cotton production systems.* In addition, today the Old Rotation provides a field laboratory for students and campus visitors interested in long-term sustainable, crop production systems in the southern U.S. It also provides a source of soil and plant material for allied greenhouse and laboratory research in soils, entomology, plant pathology, etc.

In 1988, the Old Rotation was listed on the National Register of Historical Places (Am. Assoc. State and Local History, 1989). The purpose of this paper is to review the contributions of the Old Rotation during its centennial year.

Methods

Experimental Design

The Old Rotation consists of 13 plots, each 21.5 feet by 136.1 feet. A 3-foot alley separates each of the plots (Fig. 1). Plots are identified by numbers. Plots in rotations (4 & 7, 5 & 9, and 10, 11, 12) are essentially replicates as far as soil treatments are concerned. Although there have been changes over the past 100 years in some of the treatments, many remain the same. Today, the rotation treatments are often summarized as shown in Fig. 1.

Statistical analysis did not gain widespread acceptance among agricultural researchers until well into the twentieth century. Therefore, the Old Rotation like most 19th-century experiments was not replicated. Each plot was a different treatment to be observed. However, some changes over the years have created replication of cropping system treatments. Yield was the only measurement recorded. 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.

Cotton or corn is planted in mid to late April after turning under the winter legume. Six rows are planted in each plot using conventional tillage which has included subsoiling

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1387-1390 (1996)
National Cotton Council, Memphis TN

under the row in recent years. Popular, recommended cultivars are planted. In the 3-yr rotation (plots 10, 11, and 12), the small grain (either rye, wheat, or oat) is harvested for grain in late May to early June. Before 1956, cowpea was grown as the summer legume. Since 1956, soybean has been double-cropped with the small grain. The small grain is planted in early October following corn harvest and soil preparation. Winter legumes (crimson clover and/or vetch) are either seeded into the standing cotton stalks immediately after cotton harvest in October and covered using a cultivator or broadcast following a light disking after the cotton stalks are cut.

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 0-22-19 pounds N-P_2O_5-K_2O per acre per year in 1896 to 0-80-60 since 1956. The changes in the amounts of P and K applied were made to meet obvious fertility needs of the crops (Davis, 1948). In the 1920s, P and K was applied to both the summer crop and the winter legume. Later, treatments were changed so that time of P and K application could be evaluated, e.g. P and K were applied to either the summer crop, the winter legume or split. The reason behind this change was explained by Davis (1948):

> *Of primary interest is the small but gradual decline in yields of both corn and cotton during the early years of the experiment. This decline was due to the small amount of growth made by the winter legumes. (The P and K) applied annually to the summer crops did not provide sufficient phosphorus for the winter legumes. When 400 lbs. per acre of 16% superphosphate were applied in the fall, the vetch immediately began to make good growth and adequate tonnage of green matter. The subsequent yields of both corn and cotton, i.e. after 1923, show the effects of the increased growth of the winter legumes.*

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 120 pounds N per acre per year, to cotton in plot 13 at 120 pounds N per acre per year, and to the small grain in plots 10, 11, or 12 as a topdressing of 60 pounds N per acre. 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 was 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 134 pounds agricultural gypsum (calcium sulfate) per acre per year which will provide approximately 20 pounds S per acre per year. Ground, dolomitic agricultural limestone is applied to each plot as needed to maintain the soil pH above 5.8.

Yield Records

Improving cotton yields have been the principal focus of Old Rotation since its beginning. Yields were the only consistent records kept throughout the history of the Old Rotation. Even with careful record keeping, data from some years are missing. When Comer Agricultural Hall burned in 1920, all of the original yield records were lost. Fortunately, most were recovered from publications except for those unpublished years just prior to the fire (1916-1920). In the mid-1970s, the main agricultural research station was moved from Auburn University's campus where the Old Rotation was located to the new E.V. Smith Research Center. Apparently, during this transition the year-to-year records were lost. These are the primary gaps in yield records from the Old Rotation.

Soil Series

Soils in this area often have sandy Coastal Plain sediments overlying finer textured, highly weathered Piedmont soils. The soil at the Old Rotation site is currently classified as a Pacolet fine sandy loam (clayey, kaolinitic, thermic Typic Hapludults).

Results and Discussion

Cotton Yields

Davis (1949) discussed many of the crop growth problems encountered on the Old Rotation during its first 50 years. Most of these, particularly K deficiencies, resulted from low applications of K fertilizers and removal of cowpea hay. Phosphorus deficiencies in the winter legume often led to low dry matter production and low yielding cotton due to less N in the soil from the legume. This observation led to split P and K fertilizer applications which continue today. However, since both soil P and K have accumulated to high levels, deficiencies are no longer observed and there are no cotton yield differences due to split P and K applications. Using data from the Old Rotation, Davis (1949) pointed out that *". . . cotton as a crop does not deplete the soil or run it down excessively. The cultural practices of leaving the land bare through the winter and of not preventing erosion are responsible for the generally low fertility level of many soils on which cotton is grown."*

Seed cotton yield records from plot 3 (cotton every year with only legume N) are used to illustrate the wide yield variability expected under non-irrigated conditions as used in the Old Rotation and practiced by most Alabama growers (Fig. 2). An interesting observation is that rarely do we observe two consecutive years with very high yields. Likewise, two consecutive low yielding years are also rare. Five-year running average yields seemed to decline slightly during the first 25 years of the Old Rotation. No doubt some of this decline was due to the boll weevil which entered Alabama in 1911 and became widespread by 1914. Davis (1949) attributed this decline primarily to a P deficiency in the winter legume. The 1925 revision increased P rates from 22 to 88 pounds P_2O_5 per acre per year. The 1932 revision increased K rates from 19 to 60 pounds K_2O per acre per year. From the mid-1920s to the mid-1960s, average seed cotton yields on plot 3 crept upward from around 750 to over 2500 pounds per acre. Some of this increase can be attributed to improved soil fertility practices, but improved cultivars of cotton and better insect control also contributed. 'Auburn 56' cotton was introduced in 1956. This wilt and nematode resistant cultivar became the variety of choice for most producers in Alabama by 1960, and was grown on the Old Rotation longer than any other single cultivar. During the late 1950s and 1960s, DDT was a very effective insecticide for control of boll weevils and worms. However, its removal from use in the early 1970's may have contributed to the temporary decline in yields during this decade. In the 1980s and 1990s, synthetic pyrethroids dominated worm and weevil control in cotton. Efforts to eradicate the boll weevil in east-central Alabama also began which may have partially accounted for the upward trend in yield during the past few years.

Five-year running average yields on the control plots (plots 1 and 6) are about the same today as they were when the Old Rotation began (Fig. 3). Plot no. 1 was in corn during the first 40 years of the Old Rotation. Yield trends on both these plots indicate that with no N fertilization and no legumes, yields gradually decline over a period of 15 to 20 years and then stabilize at about half of the beginning yields. This may be a reflection of the gradual mineralization of organic N. Organic matter ranges from less than 1% in plots 1 and 6 to more than 2% in the 3-yr rotation. There has been a significant orrelation between soil organic matter and yield since 1988 (Fig. 4). Nitrogen removal in the cotton lint and seed (primarily seed) from the "no-N" treatments (plots 1 and 6) is estimated to be about 12 pounds per acre per year. This is probably equivalent to available N from non-symbiotic fixation and rainfall (Table 1). Relatively higher yields since the late 1980s are found in all treatments and may be a consequence of favorable growing seasons. Perhaps during high-yielding years, more N is fixed during summer thunderstorms. However, the 100th growing season, 1995, produced some of the lowest yields in over 50 years. This was attributed to problems throughout the growing season including soil crusting from excessive spring rains, replanting, summer drought, and insect pressure.

Legume Nitrogen

Including a winter legume as the only source of N for the cotton crop (plot 3; Fig. 2; Table 2) has produced yields as high or higher than those produced from applying 120 pounds N per acre to a cotton monoculture (plot 13; Fig. 3; Table 2). The N-fertilized plot (plot 13) was not added until 1956. During the early years of the Old Rotation, Professor Duggar effectively demonstrated that winter legumes could improve yields of continuous cotton. Since yields are the same using legume N and fertilizer N, the choice farmers make obviously depends on costs and management. Planting and growing winter legumes in a continuous cotton system requires a higher level of management and, depending upon seed, fertilizer N, and planting costs, higher costs than using fertilizer N. Measurements of N fixed by winter legumes suggest that between 80 and 150 pounds N per acre is fixed in the above-ground portion of crimson clover and vetch by mid bloom in the spring; we used an average value of 116 in Table 1. Since most of this N is available to the cotton during the growing season, it is adequate for non-irrigated yields in Alabama.

Rotations

There is a definite yield advantage to rotating cotton with other crops (Table 2). However, the 2-year cotton-winter legume-corn rotation is as beneficial as the 3-year rotation (Fig. 5). Low yield for non-irrigated corn in Central Alabama 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-year rotation of cotton, winter legumes, corn, small grains, and soybeans. 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.*

Total Factor Productivity & Sustainability

Trying to measure the sustainability of cotton production using long-term yield records from the Old Rotation has presented a challenge. However, Traxler et al. (1995) used records of all inputs and outputs by year to develop an index of sustainability called *total factor productivity* or TFP index. Simply described, this index is a mathematical calculation of the value of all outputs divided by the value of all inputs by year. Therefore, an index above 1 suggests higher output per unit of input. If this index increases over time, the system may be considered increasing in productivity and therefore, more sustainable. Fig. 6 presents the TFP index relative to the 1990 index. Comparing the 3 continuous cotton treatments, Fig. 6 suggests that all three systems satisfy at least one criteria of sustainability; the output per unit of input is higher today than it was 100 years ago. Table 3 compares the input and output shares in 1896 with those of 1991. The greatest changes have been a dramatic decrease in labor costs and an increase in harvesting and ginning costs. We also see productivity cycles in all 3 systems that are difficult to adequately explain. Organic N systems (winter legumes) and N-fertilized systems have similar productivity impacts and are both much more productive than the low-input, no-N system. Externalities such as the negative effects of pesticide use on environmental health or the offsite effects of soil erosion can be factored into the TFP equation to produce a *total social factor productivity (TSFP)* index. The TSFP index (not shown) suggests that soil erosion and pesticide externatlities as used in the Old Rotation have only a modest effect on measured productivity (Traxler et al., 1995). The most dramatic single event to affect productivity was the introduction of the mechanical cotton picker. The impact of this technology when implemented in the 1960s was powerful enough to offset the effect of many other changes in the system.

Conclusions

Alabama's "Old Rotation" experiment has effectively demonstrated for 100 years that continuous, non-irrigated cotton production can be sustainable. However, increases in long-term sustainability seem to be related to unpredictable technological advances such as the introduction of the mechanical cotton picker in the 1960s. While rotations reduce risks, the cotton yield increase from this practice is small. Winter legumes (crimson clover and/or vetch) protect the soil during the winter and can provide all the N needed for a non-irrigated summer cotton or corn grain crop. Non-irrigated cotton yields vary dramatically from year to year, but rarely do two exceptionally bad years or two exceptionally good years follow each other. The "Old Rotation" will continue to provide living documentation of the long-term effects of cropping systems and N sources on cotton production in the southeastern U.S.

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Table 1. Estimated nitrogen budget for cropping systems in the "Old Rotation".

Treatment/plots	N available Legume	N available Fertilizer	N removed	N use efficiency
	----------lb/acre/rotation---------			----%----
I. Continuous cotton				
A. No N/no leg. (#1,#6)	0	0	12	>100
B. Winter legumes (#3,#8)	116	0	38	33
C. 120 lb. N/acre (#13)	0	120	40	33
II. Cotton-corn rotation				
A. +legumes (#4,#7)	232	0	80	35
B. +leg./+N (#5,#9)	232	240	94	20
III. 3-year rotation (#10,#11,#12)	320	60	275	72

Table 2. Ten-year average crop yields on the Old Rotation, 1986-1995.

Treatment/plots	Seed cotton	Corn grain	Winter legume	Soybean	Small grain
	-lb/ac-	-bu/ac-	-lb/ac-	-bu/ac-	-bu/ac-
I. Continuous cotton					
A. No N/no leg. (#6)	930 d	-----	-----	-----	-----
B+ legumes (#3,#8)	2230ab	-----	3560	-----	-----
C. 120 lb. N/acre (#13)	1860 c	-----	----	-----	-----
II. Cotton-corn rotation					
A. +legumes (#4,#7)	2290ab	73 b	3560	-----	-----
B. +leg./+N (#5,#9)	2560a	96a	3550	-----	-----
III. 3-year rotation (#10,#11,#12)	2240ab	107a	3960	35	27(rye) 43(wheat)

Values followed by the same letter are not significantly different using Duncan's Multiple Range test at P<0.10.
Note: Corn grain yields are calculated using 56 pounds per bushel at 15.5% moisture; oat, wheat, and rye grain yields are calculated using 32, 60, and 56 pounds per bushel, respectively; soybean yields are calculated using 60 pounds per bushel at 13% moisture. Winter legume yields are the oven-dry weights of the above-ground herbage during peak bloom when the legume is plowed under.

Table 3. Changes in output and input shares from 1896 to 1991 (from Mitchell et al., 1996)

	1896	1991
	--%-	--%-
Output shares		
Seed	7	11
Lint	93	89
	100	100
Input shares		
Seed & fertilizer	19	10
Pesticides	2	11
Harvesting/ginning	28	40
Labor	34	6
Variable machinery	14	10
Fixed machinery	2	19
	100	100

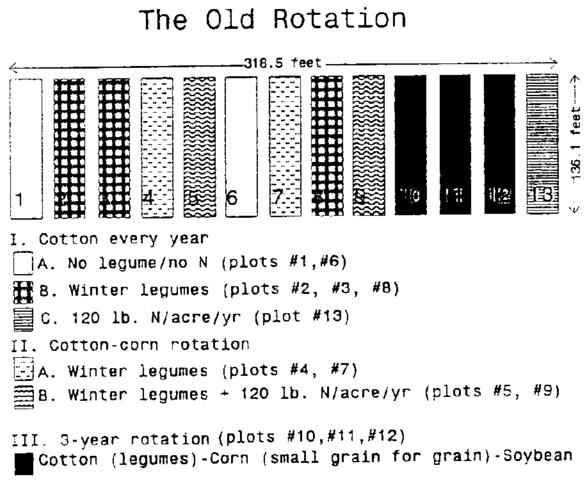

Fig. 1. Schematic of treatments used in the Old Rotation since 1956. Since 1896, the cropping sequence has significantly changed only on plots 1, 2, and 13.

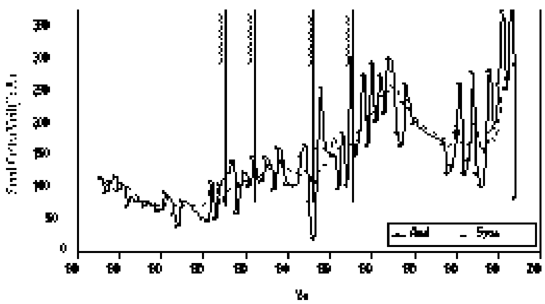

Fig. 2. Annual and 5-yr running average seed cotton yields on plot 3 which has been in a continuous cotton-winter legume treatment since 1896. Yields from this plot illustrate the large year-to-year variation in non-irrigated cotton yields in Central Alabama and the general increase in yields over the past 100 years.

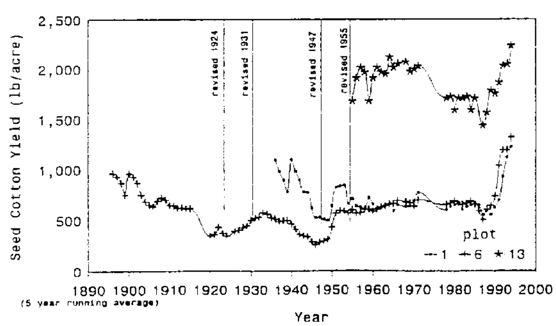

Fig. 3. Plot 6 has been in continuous cotton with no N fertilizer and no legume for 100 years. Plot 1 was included in this treatment in 1948. Where no N is included in the treatment, yields range from 250 to 1000 pounds of seed cotton per acre per year, about the same as when the experiment began. Since 1956, plot 13 has been in continuous cotton with only fertilizer N.

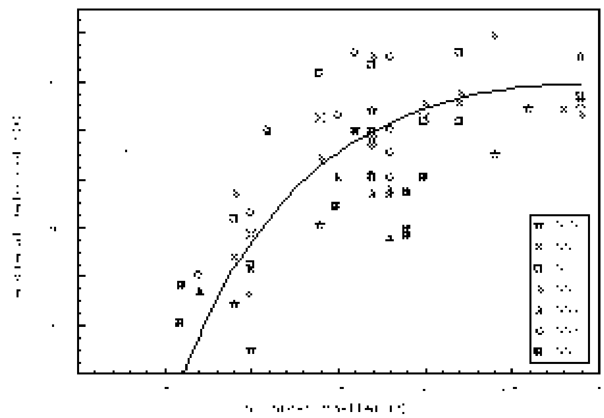

Fig. 4. Since 1988 when soil organic matter measurements were first taken, a good correlation has been established between seed cotton yields and soil organic matter. Because many of the treatments rely solely on N mineralization from organic sources, this relationship is not surprising, but may have implications for growers with low soil organic matter.

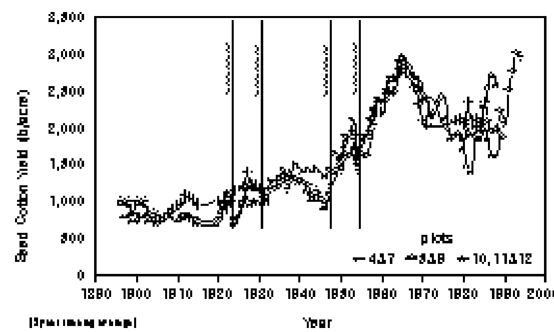

Fig. 5. Long-term cotton yields have been very similar for the 2-yr rotations (plots 4, 7, 5, and 9) and the 3-yr rotations (plots 10, 11, and 12) and only slightly higher than continuous cotton with winter legumes (Fig. 2).

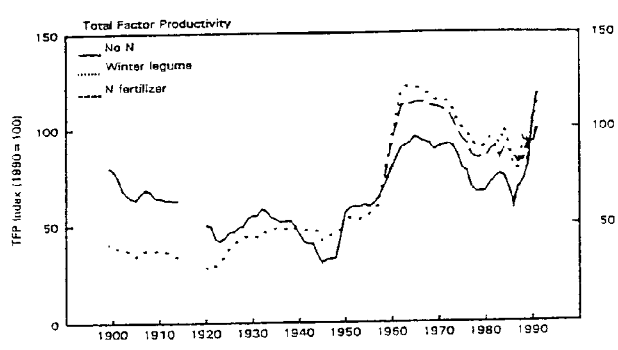

Fig. 6. Total factor productivity indexes for the 3 continuous cotton treatments (cotton planted every year) relative to 1990's index. The large increase in relative TFP around 1960 was due to the introduction of the mechanical cotton picker (from Traxler et al., 1995).