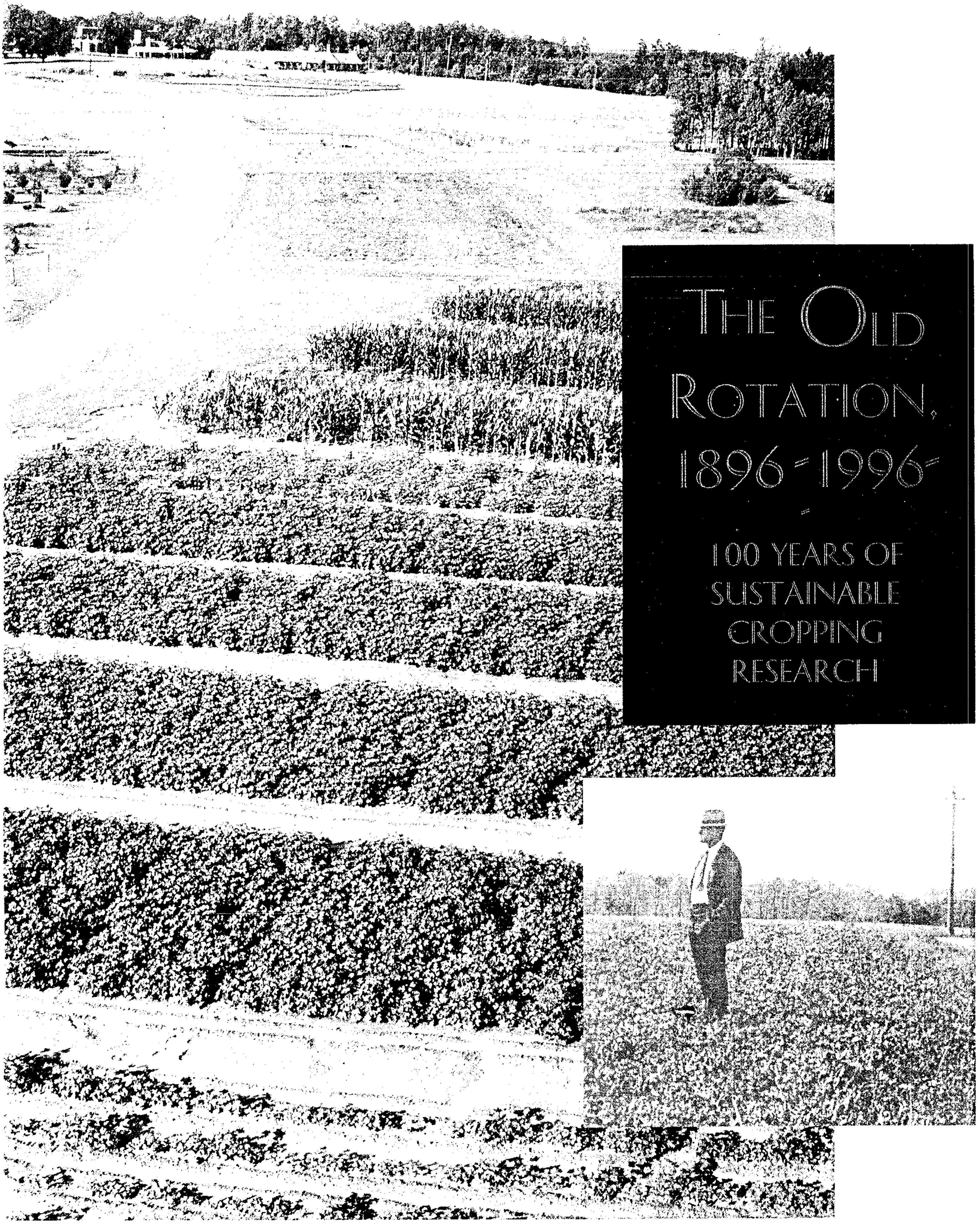

THE OLD ROTATION, 1896-1996

100 YEARS OF SUSTAINABLE CROPPING RESEARCH

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THE OLD ROTATION, 1896-1996

100 YEARS OF SUSTAINABLE CROPPING RESEARCH

FOREWORD

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One must marvel at the wisdom and foresight of those responsible for initiating the Old Rotation experiment a century ago. One must also appreciate the wisdom of those responsible for maintaining these historic plots through the years, despite the expense involved, in order that they, today, may reveal the valuable information that only such long-term experiments can provide.

We should realize that these experiments were started long before the world became concerned with the concept of sustainable agricultural production or the effects of management practices upon sustainability of crop production. Yet we have learned that such practices have significant effects, good and bad, upon the ability to maintain or improve crop productivity.

These effects may be due to different soil and crop management practices upon the incidence of diseases, insects, nematodes, and weeds, as well as the effects of chemical and physical properties of soils, water retention, soil losses through erosion, the buildup of harmful chemicals, and other concerns - all of which may impact crop productivity and sustainability. The best way to evaluate the impact of such long-term management practices is through experiments such as those of the Old Rotation.

Although these experiments have already provided very valuable information, some of which is reflected herein, they become even more valuable every passing year. With global populations increasing at the rate of 90 to 100 million people annually, the world's agriculture must provide an ever increasing flow of food and other agricultural products to sustain this rapidly growing population, And this must be done without any appreciable increases in arable lands. This means simply that existing agricultural lands must become increasingly productive.

Today many fear that our natural resource base for agriculture is deteriorating rather than improving to facilitate such needed increased productivity. If such deterioration is occurring, and there are many signs that this may be the case, we must fully understand its cause. Much of this understanding will come about through research such as that conducted through the Old Rotation plots.

As I was finishing my masters work at Auburn right after World War II, I went in to see Dr. Marion Funchess, who at the time was the dean of the School of Agriculture and director of the Alabama Agricultural Experiment Station, to get his advice on where to go to take my Ph.D. in soil science. He talked about four or five institutions, all of which had strong programs in soils, but then recommended very strongly that I go to Cornell to study with Dr. Richard Bradfield, who at that time was perhaps the preeminent soil scientist in the world. I had great respect for Dean Funchess and took his advice.

Dr. Bradfield was a wise man in many ways, and I recall one statement that he made in a seminar that has helped shape my views about agricultural research since. He said "There are many researchable topics in agriculture; some of these are problems." The Old Rotation experiment deals with major problems in agriculture that can best be addressed through such long-term efforts. I salute those who initiated these experiments as well as those who have continued them through the years.

ALABAMA'S COTTON ECONOMY, 1896-1996

THE COTTON PLANT

Cotton has a long history of use by humankind. The earliest historical records show that cotton was used to manufacture cloth before written records existed, and cotton is mentioned in Indian literature dating from 15 centuries before Christ. Heredotus (484-402 B.C.) said:

> *There are trees which grow wild there (India) the fruit of which is a wool exceeding in beauty and goodness that of sheep. The Indians make their clothes of this tree wool.*

Theophrastus (350 B.C.) also mentioned cotton cultivation in India in his letters:

> *The trees from which the Indians make their cloth have a leaf like that of the black mulberry, but the whole plant resembles the dog rose. They set them in plains arranged in rows so as to look like vines at a distance.*

During the middle ages, Europeans believed that cotton came from a kind of mystical animal-plant, and that each boll contained a little lamb and the lint in each boll was borne by that tiny lamb. Here in the "New World," the history of cotton and the history of the United States have been intertwined from the beginning. Cotton was first grown in what was to become the United States in 1607, selling for about eight cents per pound. However, native cotton plants were found by the first Spanish explorers in the 14th century in the Southwest. Cotton remained a minor crop until the invention the cotton gin in 1793. For much of the history of our nation, cotton exports have been very important and, until the end of the 19th century, the United States was the only major exporter of cotton in the world.

ALABAMA'S COTTON HERITAGE

Cotton has been produced in Alabama since before it became a state in 1819, and cotton acreage in Alabama increased steadily until the boll weevil began appearing about 1910 (Figure 1a). Since about 1930, acreage planted to cotton in Alabama has decreased. By 1982, less than 250,000 acres were planted in the state. Underlying this loss of acreage was a major change in both where cotton was produced in Alabama and the cultural and mechanical practices used to cultivate and harvest the crop.

Mitchell is Professor, Arriaga is Graduate Research Assistant, and Entry is Assistant Professor of Agronomy and Soils; Novak is Professor and Goodman is Associate Professor of Agricultural Economics and Rural Sociology; Reeves is USDA Research Agronomist and Affiliate Professor of Agronomy and Soils; Runge is Extension Program Associate and Traxler is Associate Professor of Agricultural Economics and Rural Sociology.

At the turn of the century, there were about 220,000 farms in Alabama. About 192,000 of those farms grew cotton. Half of Alabama's land resources was under cultivation. Out of a total cropland area of 20 million acres, about eight million acres were in cultivated crops, mostly cotton and corn, and the remainder was in pasture and hay. Almost all these farms had annual sales of between $100 and $1,000. In 1900, only 446 Alabama cotton farms (out of 192,000) had sales in excess of $2,500.

In 1900, Alabama ranked third in the United States in cotton production, behind Texas and Georgia. Leading cotton counties were, in descending order, Dallas (157,000 acres), Montgomery (134,000 acres), Lowndes (128,000 acres), Marengo (108,000 acres), and Bullock (103,000 acres). There were 3.2 million acres of cotton in Alabama about the time the Old Rotation was started.

At the turn of the century, more than half of the two million residents of Alabama lived on farms. There were 513,000 people over 10 years of age engaged in agriculture in Alabama. Since most Alabama farms produced cotton, and half the people in the state were farmers, much of the economic activity in the state was linked to cotton production.

The Old Rotation was listed on the National Register of Historical Places in 1988.

In the late 1800s, yields averaged about 120 to 150 pounds of lint per acre in Alabama (Figure 1a). Yields increased slowly, but in the first decade of this century, farmers in Alabama only averaged between 180 to 200 pounds per acre. From an economic perspective, it's hard to justify the nearly four million acres planted in Alabama during this period. When all costs were considered, farmers were spending about $75 to $90 on each acre of cotton grown, yielding a cost of about 25 or 30 cents per pound produced. With prices fluctuating between 15 and 25 cents (Figure 1b), most years farmers would seem to be losing money. However, cotton was the crop that was generally produced for sale off the farm, most others were mainly grown as feed for draft animals, hay, or for other on-farm purposes. Cotton provided the major source of cash. About half the cost of producing cotton was in labor for planting, cultivating, hoeing, and picking. Much of this was in the form of unpaid family labor. Farmers, their wives, and children provided the bulk of this labor. The "opportunity cost" for this labor was essentially zero. So cotton provided a way to turn family labor into cash.

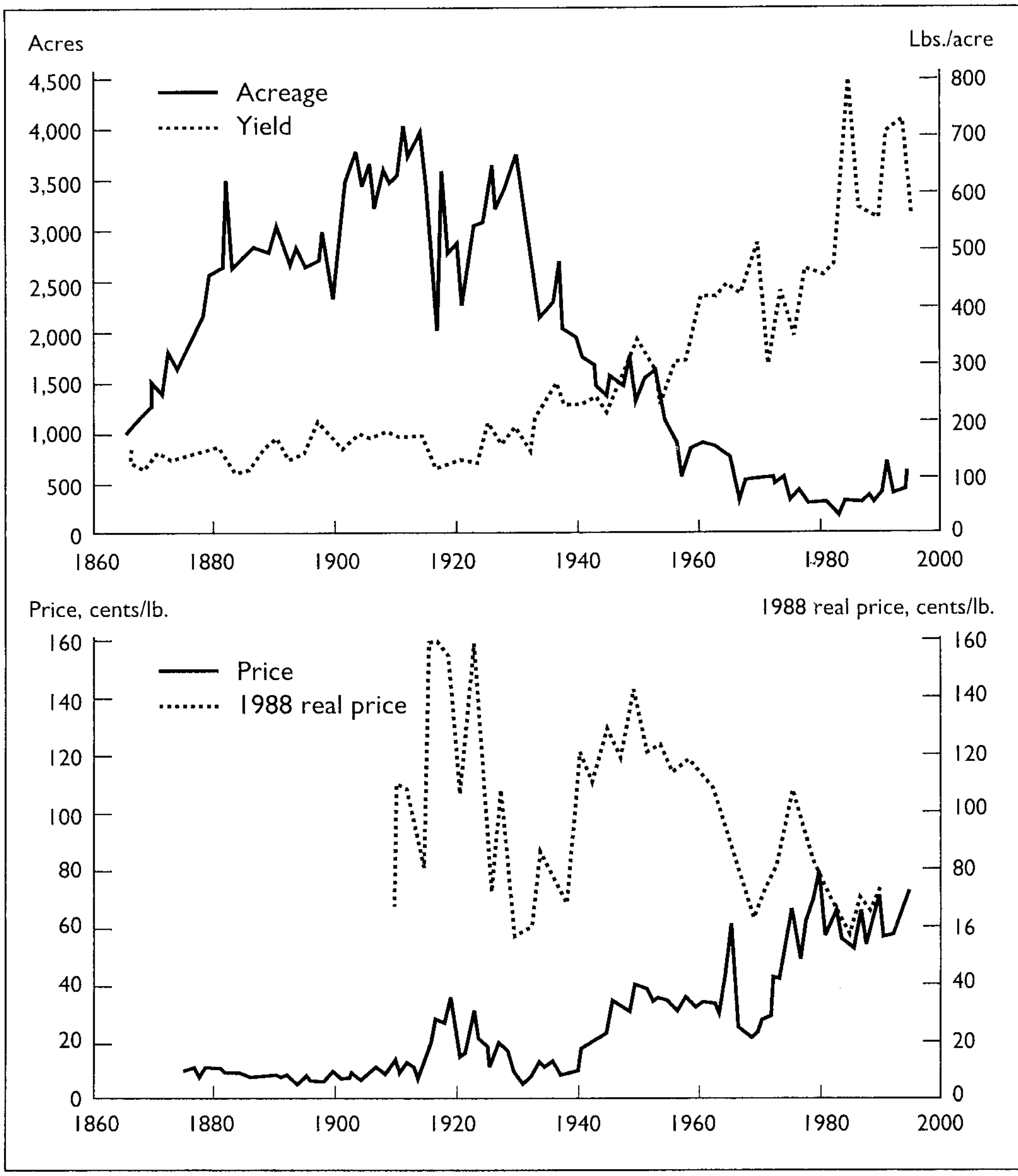


Fig. I Trends in Alabama (a) cotton acreage and yield and (b) price received by growers for lint, 1865 to 1995.

YIELDS AND ACREAGE

About 1915, the boll weevil arrived in Alabama. Yields in heavily infested fields dropped to nearly zero. The state average yield in Alabama fell to 95 pounds per acre in 1916. Although acreage decreased initially, the boll weevil did not bring about the instant demise of cotton in the state as is commonly assumed. Acreage fell about 20% at first, but increased to exceed pre-weevil numbers by 1930 as prices increased generally into the 30-cent range. Farmers were able to stay in business in spite of decreased yields.

The depression was much more devastating to farmers than the boll weevil. In 1931, the average cotton price fell to 5.6 cents per pound, and didn't recover until the second World War. During this pre-war period, Alabama lost about two million acres of cotton, with each major producing region losing about 40% of total acres between 1930 and 1940. By the end of the war, Alabama was down to about 1.5 million acres, but acreage actually increased in the 1940s in the Tennessee Valley. Between 1960 and 1970, acreage in the Wiregrass decreased from 124,000 acres to 19,000 acres. Between 1970 and 1980, acreage in the Appalachian region declined by four fifths, to about 22,000 acres.

These years were hard on the areas where mechanization, now essential in the economic production of cotton, was difficult. Cotton has migrated out of the Black Belt, once the major cotton producing region, due in part to these problems, with which farmers still are struggling. The only region of the state to retain a significant percentage of their pre-war acreage is the Tennessee Valley, which has consistently planted about 200,000 acres since 1960.

In recent years, cotton acreage has increased in Alabama, almost tripling since 1980. Alabama may soon plant 750,000 acres of cotton. Although yields have increased four-fold in good years, agriculture in the state is much more diversified than it was early in this century.

Cotton has been the most persistent of Alabama's cash crops. In 1859, the state produced 780,000 bales. In 1994 Alabama produced 726,000 bales of cotton. Cotton as a cash crop has had its ups and downs over the years, but the demand for cotton fiber has been steadily increasing for about 100 years, and the trend will likely continue. As we move into a new millennium and the second century of the Old Rotation experiment, sustainable cotton production will continue to be important to Alabama farmers.

INTRODUCTION TO THE OLD ROTATION

HISTORY

The Old Rotation is the oldest, continuous cotton experiment in the world (Steiner and Herdt, 1995) and the third oldest field crop experiment in the United States on its original site. It was placed on the National Register of Historical Places in 1988 (Am. Assoc. State and Local History, 1989). Older experiments include the Morrow Plots at the University of Illinois (c. 1876) and The Sanborn Field at the University of Missouri (c. 1888). The Magruder Plots at Oklahoma State University (c. 1892) are older, but the soil was physically moved to a new location in 1947 (Mitchell et al., 1991).

The Old Rotation was begun in 1896 by Professor John F. Duggar. In 1896, more than 3.5 million acres of cotton were planted in Alabama, but the average yield was only 130 pounds lint per acre (Figure 1a). Alabama cotton farmers planted their crop year after year on the same land. New land for clearing and cropping had almost been exhausted. Very few amendments were applied to the soil, and crop rotations and winter cover crops were a rare practice. Excessive soil erosion, declining yields, and low farm income were common. The economy of the state and the welfare of Alabamians depended upon sustainable cotton production. Some researchers suggested substituting tobacco culture for cotton. However, Professor Duggar undoubtedly believed that Alabama soils could sustain profitable yields of cotton if a crop rotation system that included winter legumes could be developed.

Corn, oat, and cowpea also were familiar crops on 19th century Alabama cotton farms. These grains and their fodder fed the draft animals that worked the fields. Corn also was a staple in the diet of the people who lived on the land. Almost as many acres of corn as cotton were planted to support the cotton cash crop. Cowpea was one of the few summer annual legumes that grew well in the South. Therefore, corn, oats, and cowpeas were logical crops to include in a crop rotation system.

OBJECTIVES

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 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.

These are the same objectives used today.

LEADERSHIP AND RESPONSIBILITIES

Duggar served as the third director of the Alabama Agricultural Experiment Station from 1903 to 1921. During this time, he continued to oversee the management of the Old Rotation. When the Department of Agronomy and Soils was established in 1919, management of the experiment became the department's responsibility. The area around the Old Rotation became known as the "Agronomy Farm." In 1977, most field crop research was moved from the Auburn University campus to the new farm at E.V. Smith Research Center near Shorter, Alabama. During the move and for several years thereafter, the logistics of managing the Old Rotation became difficult with no budget and limited equipment and personnel. Some of the yield records were lost during this period. Today, the Department of Agronomy and Soils works with staff of the Alabama Agricultural Experiment Station to maintain the Old Rotation. Agronomy and Soils faculty who have maintained the Old Rotation with the help of numerous technicians include:

Project leaders	Years
J.F. Duggar	1896-1921
E.F. Cauthen and H.B. Tisdale	1922-1929
E.L. Mayton	1929-1944
F.L. Davis	1944-1948
D.G. Sturkie	1948-1959
L.J. Chapman	1959-1963
Lex Webster	1963-1966
E.M. Evans	1966-1983
J.T. Touchton	1984-1985
C.C. Mitchell	1985-present

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 hand-written records were later found; average yields for 1896 to 1905 and from 1906 to 1915 had been published and were recovered. There are some gaps in the yield record. The most notable was in the mid-1970s when records were lost during the move from the old Agronomy Farm to the new E.V. Smith Research Center.

The only known publication that summarized all the data to date from the Old Rotation was an article by F.L. Davis (1949) in the magazine "Better Crops with Plant Food" published by the American Potash Institute. However, numerous research papers, popular articles, abstracts of professional meetings, and crop recommendations have developed from information gathered from plots in the Old Rotation.

No one is certain when it was first called the Old Rotation or who named it. A 1930 Alabama Agricultural Experiment Station bulletin contained a photo taken that year with a caption identifying it as "Old Rotation Experiment" (Bailey et al., 1930). Duggar was a coauthor of this bulletin. The 1949 article by Davis was entitled "The Old Rotation at Auburn, Alabama." The name was obviously associated with these plots by the 1940s. Davis noted in 1949 that it was ". . . probably the oldest field experiment in the United States in which cotton has been grown." A list of known publications from the Old Rotation is given in the Appendix.

EXPERIMENTAL DESIGN

Statistical analysis did not gain widespread acceptance among agricultural researchers until well into the 20th century. Therefore, the Old Rotation, like most 19th century experiments, was not replicated. Each plot was a different treatment to be observed. Yield was the only measurement recorded. In the 1950s, routine soil testing allowed quick measurements of soil pH and extractable nutrients, and these measurements were added to the records of the Old Rotation.

The Old Rotation consists of 13 plots, each 21.5 feet by 136.1 feet. A three-foot alley separates each of the plots (Figure 2). Plots are identified by numbers. Plots in rotations are essentially replicates as far as soil treatments are concerned. Today, the rotation treatments are often summarized as follows:

I. Cotton every year
- A. No legume/no N fertilizer (plots 1 and 6)
- B. Winter legumes (plots 2, 3, and 8)
- C. 120 pounds fertilizer N per acre per year (plot 13)

II. Two-year, cotton-corn rotation
- A. Winter legumes (plots 4 and 7)
- B. Winter legumes plus 120 pounds N per acre per year (plots 5 and 9)

III. Three-year rotation
- (1) Cotton-winter legumes, (2) corn-small grain for grain (60 pounds N per acre), (3) soybean (plots 10, 11, and 12)

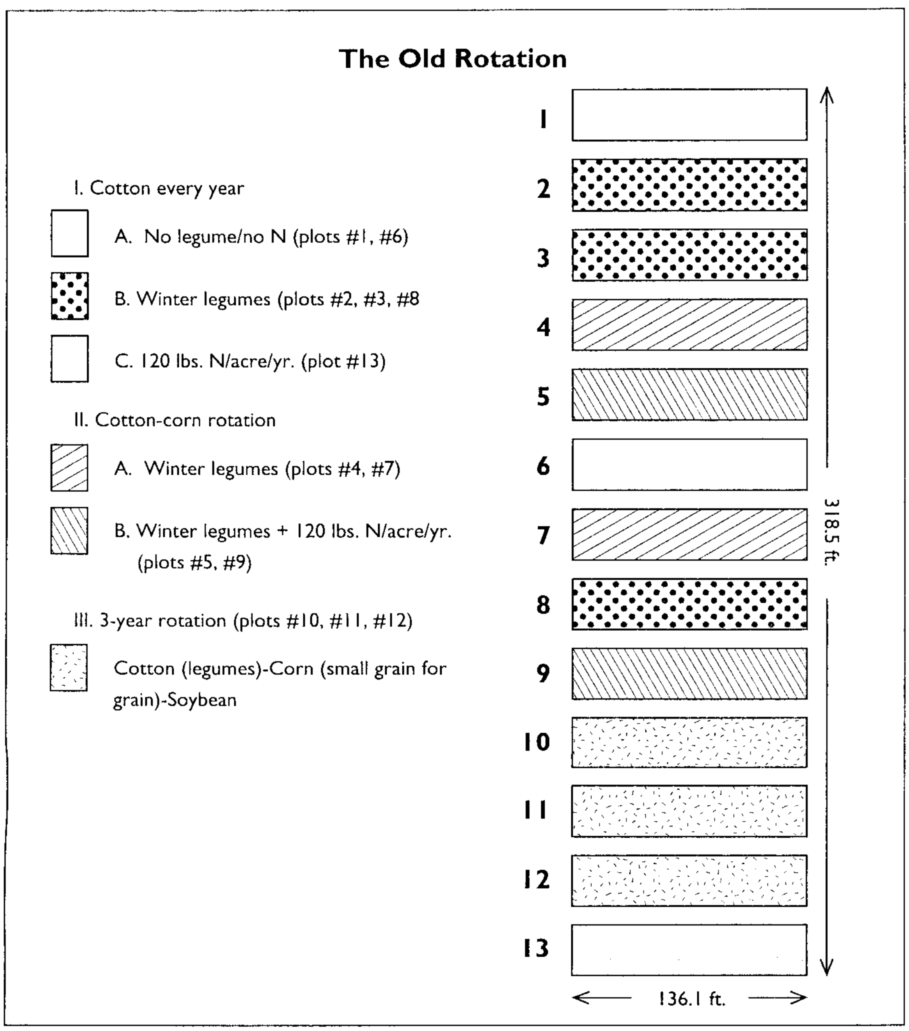


Fig. 2. Schematic of the Old Rotation and treatments used since 1956.

FERTILIZATION

All plots have received the same annual rate of phosphorus (P) and potassium (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 to 0-80-60 since 1956 (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 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 for this change was explained by Davis (1949):

> *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 pounds 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 nitrogen (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 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 134 pounds agricultural gypsum (calcium sulfate) per acre that will provide approximately 20 pounds sulfur (S) per acre per year.

Ground, dolomitic agricultural limestone is applied to each plot as needed to maintain the soil pH above 5.8. Soil sampling has been irregular and no records were kept until the 1950s. Since then, soil samples have been taken after harvest about every two years. These have been tested for pH and Mehlich-1 (dilute double acid) extractable P, K, Ca, and Mg.

TABLE 1. CROPS AND FERTILIZER RATES (POUNDS PER ACRE $N\text{-}P_2O_5\text{-}K_2O$) USED IN THE OLD ROTATION SINCE 1896

Treatment/plot	1896-1924	1925-1931	1932-1947	1948-1955	1956-Present
1	corn 0-22-19	corn 0-26-19	cotton 0-72-60	cotton 0-72-60	cotton 0-80-60
	cowpeas	vetch 0-62-0	vetch		
2	corn 0-22-19	corn 0-88-19	cotton 0-72-60	cotton 0-72-60	cotton
				vetch	vetch/clover 0-80-60
3	cotton 0-22-19	cotton 0-26-19	cotton 0-36-30	cotton 0-18-28	cotton 0-40-30
	vetch	vetch 0-62-0	vetch 0-36-30	vetch 0-18-28	vetch/clover 0-40-30
4,7	cotton 0-22-19	cotton 0-26-19	cotton 0-36-30	cotton 0-36-30	cotton 0-80-60
	vetch	vetch 0-62-0	vetch 0-36-30	vetch 0-36-30	vetch/clover 0-40-30
	corn 0-22-19	corn 0-26-19	corn 0-36-30	corn 0-36-30	corn 0-0-0
	cowpeas	vetch 0-62-0	vetch 0-36-30	vetch 0-36-30	vetch/clover 0-40-30
5,9	cotton 0-22-19	cotton 8-26-19	cotton 0-36-30	cotton 0-36-30	cotton 120-80-60
	vetch	vetch 0-62-0	vetch 0-36-30	vetch/clover 0-36-30	vetch/clover 0-40-30
	cowpeas 0-22-19	cowpea hay 0-26-19	cowpea hay 0-36-30	cowpea hay 0-36 -30	corn 120-0-0
		vetch 0-62-0	vetch 0-36-30	vetch 0-36-30	vetch/clover 0-40-30
6	cotton 0-22-19	cotton 0-88-19	cotton 0-72-60	cotton 0-72-60	cotton 0-80-60
8	(same as #3)	(same as #3)	cotton 0-72-60	cotton 0-72-60	cotton 0-80-60
			vetch	vetch	vetch/clover
10,11,12	cotton 0-22-19	cotton 0-88-19	cotton 0-36-30	cotton 0-36-30	cotton 0-80-60
	vetch	vetch	vetch 0-36-30	vetch 0-36-30	vetch/clover 0-80-60
	corn 0-22-19	corn 0-88-19	corn 0-36-30	corn 0-36-30	corn
	cowpeas/oats	oats	oats 0-36-30	oats 0-36-30	rye 60-0-0
	cowpeas 0-22-19	cowpea hay 0-88-19	cowpea hay 0-36-30	cowpea hay	soybeans
		vetch	vetch 0-36-30		
13	(same as #5)	(same as #5)	(same as #5)	cotton 0-36-30	cotton 120-80-60
				vetch 0-36-30	
				cowpea hay 0-36-30	
				vetch 0-36-30	

SITE CHARACTERISTICS AND SOILS

The site of the Old Rotation is part of a 90-acre block of land purchased by The Agricultural and Mechanical College of Alabama (now Auburn University) from I.J.B. Gay in 1884 for $1,700. The site straddles 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 53 inches (1,339 mm). Average annual temperature is 64°F (18°C) with 221 days between the last spring freeze and the first fall freeze.

SOIL SERIES

Soils in this area often have sandy Coastal Plain sediments overlying finer textured, highly weathered Piedmont soils. Although the soil at the Old Rotation site is currently identified as a Pacolet fine sandy loam (clayey, kaolinitic, thermic Typic Hapludults), a characteristic Piedmont soil, it has been called a Norfolk fine sandy loam (fine-loamy, siliceous, thermic Typic Kandiudults), a typical Coastal Plain soil. The site appears on the local soil survey as a Marvyn loamy sand (fine-loamy, siliceous, thermic Typic Kanhapludults), another Coastal Plain soil. This confusion arises because the site is on a gradual slope (2-3%) and the surface soil texture changes (Table 2). The upper part of the site (plot 1) is more characteristic of the Marvyn soil (Coastal Plain) and the lower part (plot 13) is more characteristic of the Pacolet (Piedmont).

SOIL TEST RECORDS

Because the Old Rotation experiment is primarily a crop rotation and legume N study, annual rates of P and K applied to each plot have been the same. Although the amounts applied each year have changed periodically, the amount

TABLE 2. PARTICLE SIZE ANALYSIS OF THE PLOW LAYER (0-6 INCHES) IN THE 13 PLOTS OF THE OLD ROTATION

Plot no.	Particle size: Sand	Silt	Clay	Textural class	Water available
		%			*in./in.*
1	74	16	10	sandy loam	0.06
2	70	18	12	sandy loam	0.07
3	69	19	12	sandy loam	0.07
4	68	22	10	sandy loam	0.08
5	64	24	12	sandy loam	0.09
6	66	19	15	sandy loam	0.08
7	68	20	12	sandy loam	0.08
8	70	18	12	sandy loam	0.07
9	56	21	23	sandy clay loam	0.10
10	59	21	20	sandy loam	0.10
11	64	21	15	sandy loam	0.09
12	61	21	18	sandy loam	0.09
13	58	17	25	sandy clay loam	0.10

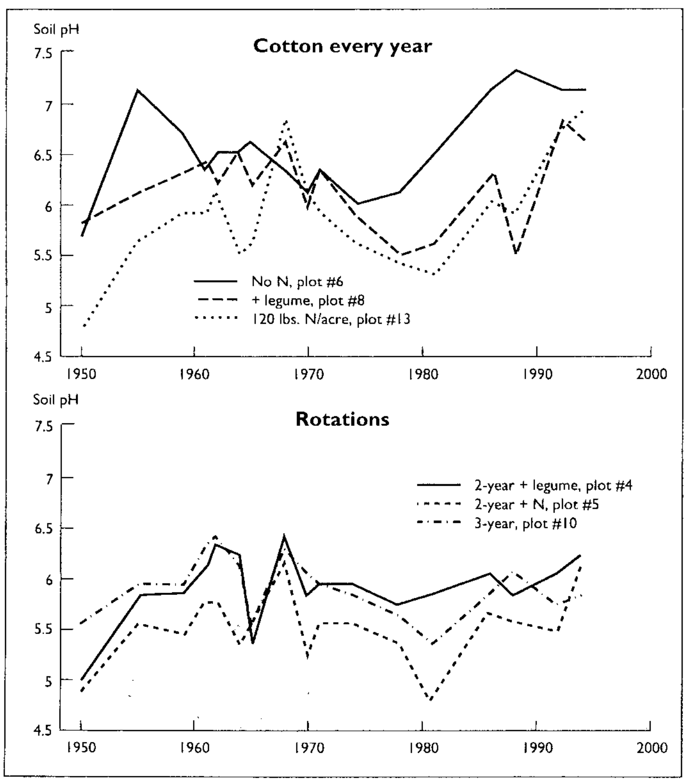


Fig. 3. Changes in soil pH since 1956 on selected plots (a) where cotton is planted every year and (b) where cotton is planted in rotation.

applied in any one year has always been the same on all plots.

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 cotton yields as a result of low N in the soil from the legume. This observation led to the split P and K fertilizer applications that continue today in some plots. However, since soil P has accumulated to high levels and soil K is in the medium range, 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."

No records of soil measurements before 1950 have been found. Since then, periodic, plow-layer soil samples have been taken for pH and Mehlich-1 (dilute double acid) extractable P and K. These are presented in figures 3-5 for selected treatments. There are statistical differences ($P<.01$) in pH and extractable P among the treatments but no difference in extractable K. In spite of an effort to lime individual plots (using finely ground, dolomitic lime-

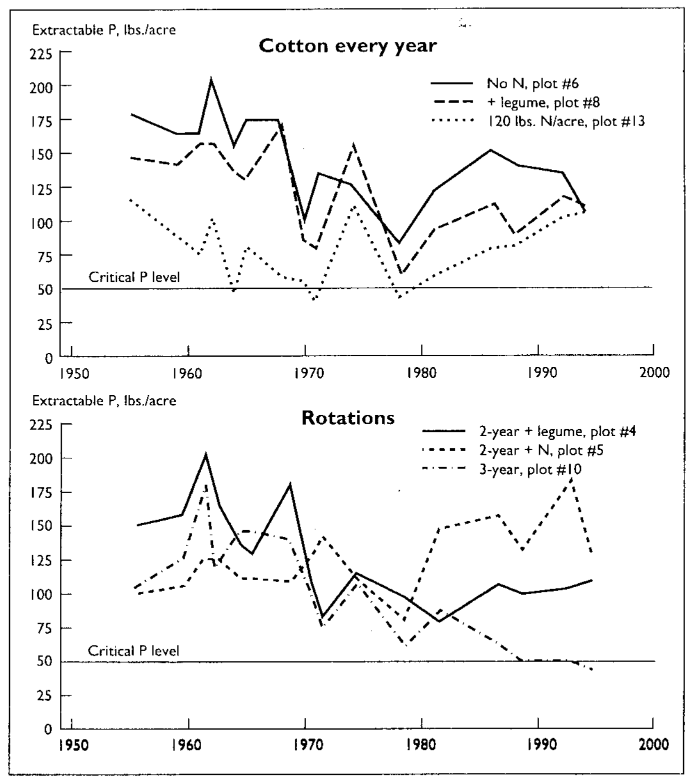


Fig. 4. Changes in Mehlich-1 extractable plow-player P since 1956 on selected plots (a) where cotton is planted every year and (b) where cotton is planted in rotation.

stone) whenever the soil pH drops below 5.8, the critical pH used in Alabama for loamy soils, the treatment receiving 120 pounds N per acre as ammonium nitrate and no winter legume has tended to have a more acid reaction than either the no N treatment or the one receiving winter legumes (vetch and/or clover) as a source of N (Figure 3a).

Extractable soil P has been consistently lower over the past 42 years in the treatment receiving only fertilizer N (Figure 4a).

TABLE 3. LONG-TERM TREATMENT EFFECTS ON SELECTED SOIL PHYSICAL MEASUREMENTS MADE IN 1994*

Treatment	Plots	Cation exchange capacity	Plow-layer N	Plow-layer C	Bulk density 0-30cm	Cone penetrometer resistance to 30 cm	Water stable aggregates
		meq/100g	%	%	*g/cm³*	*bars*	%
I. Continuous cotton							
A. No legumes	1,6	3.9	0.11	0.39	1.84	29	24
B. +legumes	2,3,8	4.7	0.14	0.75	1.85	28	38
C. 120 lb. N/acre	13	5.4	0.10	0.54	1.73	20	22
II. Two-year rotation							
A. +legumes	4,7	4.4	0.13	0.82	1.75	19	40
B. +leg./+120 lb. N/acre	5,9	5.1	0.11	1.00	1.66	20	38
III. Three-year rotation	10,11,12	4.9	0.14	1.01	1.56	19	39
Analysis of variance	*P>F*	*<0.01*	*NS*	*<0.01*	*<0.01*	*NS*	*<0.01*

*Values presented are an average of samples taken in the winter and spring of 1994.

The plot receiving 120 pounds N per acre per year since 1955 is the last plot in the experiment and is at the lowest elevation. The surface soil texture tends to be finer than that of the first few plots of the experiment (Table 2) that are more typical of Coastal Plain soils. The apparent lower P may result from the higher P fixing capacity of the finer-textured soil in this plot.

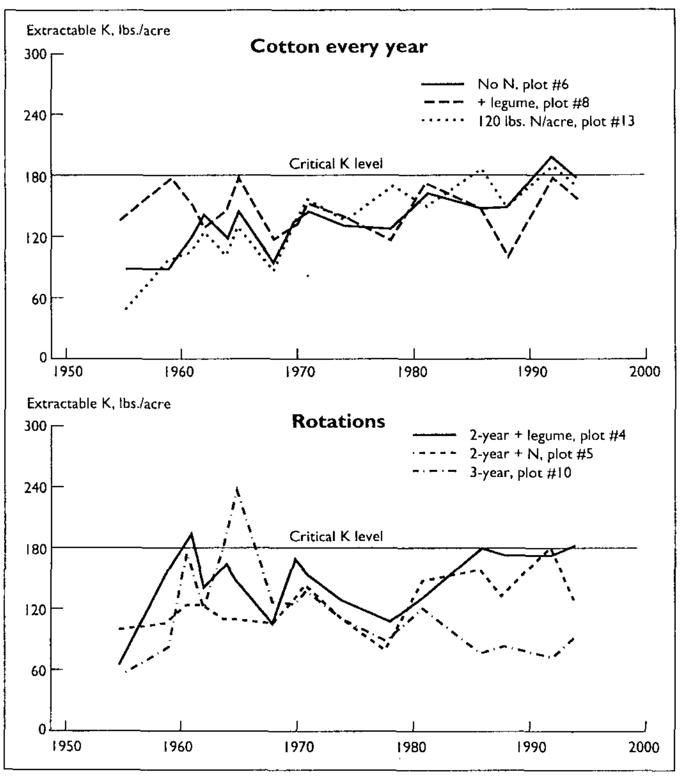


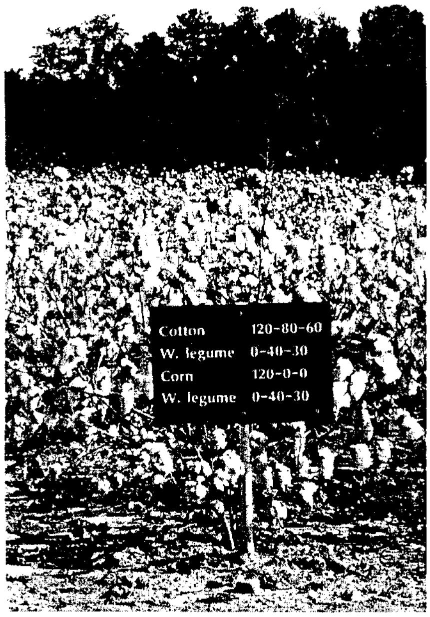
Fig. 5. Changes in Mehlich-I extractable plow-player K since 1956 on selected plots (a) where cotton is planted every year and (b) where cotton is planted in rotation.

SOIL PHYSICAL MEASUREMENTS

Apparent treatment differences in soil tilth have been observed by individuals plowing, planting, and cultivating the Old Rotation. Soil on plot 13, which has been planted to cotton every year since 1956 with only commercial N fertilization, has a history of severe crusting after planting. Poor cotton stands frequently result when rains cause crusting prior to seedling emergence. The problem has also been observed on other plots planted to cotton every year with no winter legume (plots 1 and 6). In spite of the lack of a structured, replicated, experimental design that allows use of traditional statistical analyses, some soil physical measurements suggest that the observed soil tilth problems may be due to long-term treatment effects.

In 1994, selected soil physical measurements were made on each plot during the winter and again after planting in the spring. Treatments with observed crusting problems (plots 1,6, and 13) had lower organic C, higher cone penetrometer resistance, higher bulk density, and fewer water stable aggregates (Table 3). This confirms poor soil structure and soil compaction in these treatments compared to those treatments that use winter legumes and crop rotations. More information on the relationship between soil organic matter and yield is presented in the section on Soil Organic Matter.

CROP YIELDS



CULTIVARS

Records of cultivars planted on the Old Rotation prior to the 1960s do not exist. Part of this omission was probably because the cultivars selected by the project leaders represented the best that was available based on variety trials by the Alabama Agricultural Experiment Station and those recommended by the Cooperative Extension Service. Specific varieties listed in the records are given in Table 4.

COTTON

Seasonal Variability and Long-term Trends. Improving crop yields, primarily cotton yields, has been the principal focus of the Old Rotation since its beginning. Yields were the only consistent records kept throughout the history of the Old Rotation. Seed cotton yield records from plot 3 (cotton every year with only legume N) are used to illustrate the wide yield variability expected under nonirrigated conditions as used in the Old Rotation and practiced by most Alabama growers (Figure 6). An interesting observation is that yields are rarely high for two consecutive years. Likewise, two consecutive low yielding years also are 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 that entered Alabama in 1911 and became widespread by 1914. Davis (1949) attributed this decline primarily to a P deficiency in the winter legume. The 1924 revision increased P rates from 22 to 88 pounds P_2O_5 per acre per year. The 1931 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 about 750 to more than 2,500 pounds per acre (approximately 290 to 980 pounds lint 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 cultivar was introduced in 1956. This wilt and nematode resistant variety became the variety of choice for most producers in Alabama by 1960, and was grown on the Old Rotation longer than any other cultivar.

During the late 1950s and 1960s, DDT (dichlorodiphenyl trichloroethane) was a very effective insecticide for control of boll weevils and worms. However, 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 worm and weevil control in cotton. Efforts to eradicate the boll weevil in East-

TABLE 4. SPECIFIC CULTIVARS OF COTTON, CORN, SMALL GRAIN, SOYBEAN, AND WINTER LEGUME PLANTED ON THE OLD ROTATION AS FOUND IN HANDWRITTEN RECORDS

Year(s)	Cotton	Corn	Small grain	Soybean*	Winter legume
1968-70	Auburn 56	Fla. 200A	wheat (GA 1123)	Bragg	woolypod vetch crimson clover (Autauga)
1971	Auburn 56	Funks G4949	wheat (GA 1123)	Bragg	hairy vetch crimson clover (Dixie)
1978	DPL 26	Funks G4864	rye	Bragg	hairy vetch crimson clover (Dixie)
1979	DPL 26	Funks G4864	rye (Wrens Abruzzi)	Hutton	hairy vetch crimson clover (Dixie)
1980	DPL 26	Coker 56	rye (Wrens Abruzzi)	Bragg	hairy vetch crimson clover (Dixie)
1981	DPL 26	Pioneer 3147	rye (Wrens Abruzzi)	Bragg	hairy vetch crimson clover (Dixie)
1982	DPL 41	Ring-around 1502	rye (Wrens Abruzzi)	Braxton	hairy vetch crimson clover (Dixie)
1983	DPL 41	Ring-around 1502	rye (Wrens Abruzzi)	Braxton	hairy vetch crimson clover (Dixie)
1984	DPL 41	sorghum	rye (Wrens Abruzzi)	Braxton	hairy vetch crimson clover (Dixie)
1985	DPL 41	FG 4858	rye (Wrens Abruzzi)	Braxton	vetch (Cahaba white) crimson clover (Tibbee)
1986	DPL 41	Pioneer 3320	rye (Wrens Abruzzi)	Braxton	vetch (Cahaba white) crimson clover (Tibbee)
1987-91	DPL 90	DK 689	rye (Wrens Abruzzi)	Braxton	vetch (Cahaba white) crimson clover (Tibbee)
1992	DPL 90	DK 689	wheat (Fla. 301)	Stonewall	vetch (Cahaba white) crimson clover (Tibbee)
1993	DPL 90	DK 689	rye (Wrens Abruzzi)	Stonewall	crimson (AU Robin)
1994	DPL 5690	DK 689	rye (Wrens Abruzzi)	Hutcheson	crimson (AU Robin)
1995	DPL 5690	DK 689	wheat	Stonewall	crimson (AU Robin)

*Prior to 1956, the summer legume was cowpea as a green manure crop or cowpea hay.

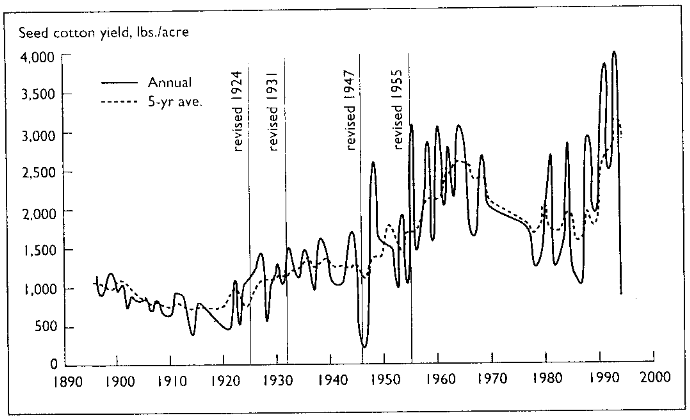


Fig. 6. Annual seed cotton yields on plot 3, 1896-1995, where only winter-legume N has been available to the cotton crop.

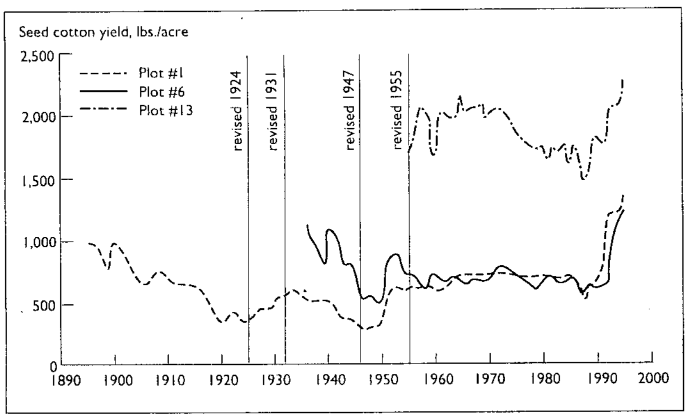


Fig. 7. Seed cotton yields on the control plots (plots 1 and 6) where neither fertilizer N nor winter-legume N has been used on cotton and where 120 pounds fertilizer N per acre per year have been applied on plot 13.

Central Alabama also began and may have partially accounted for the upward trend in yield during the past few years.

No N and No Legumes. 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 (Figure 7). Plot 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, the yield potential gradually declines over a period of 15 to 20 years 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 12 pounds per acre per year. This is approximately equivalent to available N from non-symbiotic fixation and rainfall.

Relatively higher yields since the late 1980s are found in all treatments and may be a result of favorable growing seasons. However, the 100th growing season, 1995, produced some of the lowest yields in more than 50 years. This was attributed to problems throughout the growing season including soil crusting from intensive spring rains following planting, replanting, an extreme summer drought, and increased insect pressure.

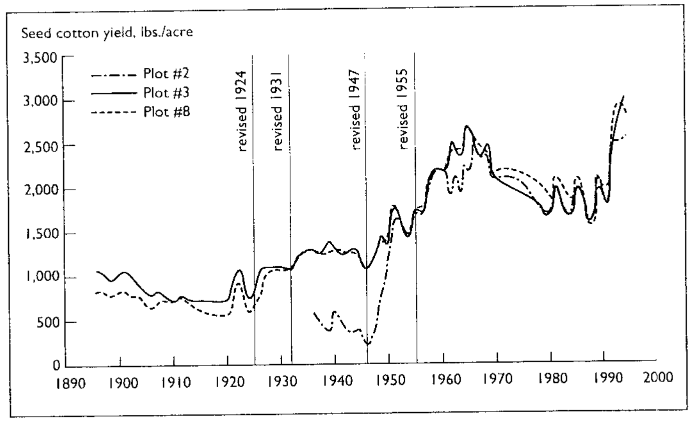


Fig. 8. Seed cotton yields on plots that have been continuous in cotton with only winter legumes as N sources. Plot 2 was in corn prior to 1932; winter legumes were added in 1948. Fertilizer P and K are applied to the legume in plot 2, to the cotton in plot 8, and split between cotton and legumes in plot 3.

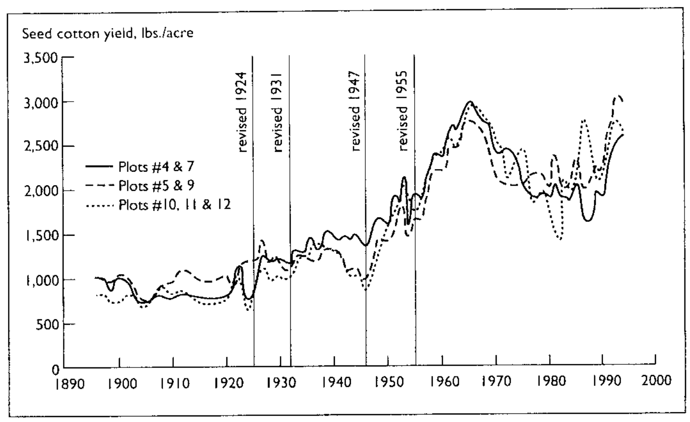


Fig. 9. Seed cotton yields on the two-year rotation with legumes (plots 4 and 7), the two-year rotation with legumes and 120 pounds N/acre/yr. (plots 5 and 9) and the three-year rotation (plots 10, 11, & 12), 1896-1995.

Winter Legumes Versus Fertilizer N. Including a winter legume as the only source of N for the cotton crop (plots 3 and 8; Table 5; Figure 8) has produced yields as high or higher than those produced from applying 120 pounds N per acre to a cotton monoculture (plot 13; Table 5; Figure 7). 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. Yields since 1956 have been similar using legume N and fertilizer N. Therefore, the choice farmers make obviously depends on costs and management. Planting and growing win-

TABLE 5. TEN-YEAR AVERAGE SEED COTTON AND CORN GRAIN YIELDS, 1896-1995

Treatment (plots)	1896-1905	1906-1915	1916-1925	1926-1935	1936-1945	1946-1955	1956-1965	1966-1975	1976-1985	1986-1995
Seed cotton yields (pounds per acre)										
I. Continuous cotton										
A. No N/no legumes (#6)	800	630	340	510	370	510	620	710	610	930
B. + legumes (#3,#8)	860	680	640	1,160	1,230	1,580	2,360	2,100	1,840	2,230
C. 120 lb. N/acre (#13)	—	—	—	—	—	—	1,960	2,040	1,630	1,860
II. Cotton-corn rotation										
A. +legumes (#4,#7)	870	750	770	1,260	1,440	1,950	2,640	2,410	1,850	2,290
B. +legumes/+N (#5,#9)*	890	950	1,150	1,190	1,170	1,680	2,500	2,030	2,170	2,560
III. Three-year rotation (#10,#11,#12)	740	804	704	1,150	1,140	1,690	2,640	2,390	2,210	2,240
Corn grain yields (bushels per acre)										
I. Continuous corn										
A. No N/no legumes (#2)	18	11	9	10	—	—	—	—	—	—
B. +legumes (#1)	19	16	18	26	—	—	—	—	—	—
II. Cotton-corn rotation										
A. +legumes (#4,#7)	18	13	15	29	34	40	69	39	33	73
B. +legumes/+N (#5,#9)*	—	—	—	—	—	—	—	**	42	96
III. Three-year rotation (#10,#11,#12)	16	13	15	29	36	47	86	68	33	107

*120 pounds N per acre added as ammonium nitrate since 1956 to cotton and corn. Prior to this, a summer legume (cowpea) was planted in rotation with cotton and winter legumes.
**Insufficient data.
Note: Corn grain yields are calculated using 56 pounds per bushel at 15.5% moisture.

TABLE 6. ESTIMATED N 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 legumes (#1;#6)	0	0	12	—
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. +legumes/+N (#5,#9)	232	240	94	20
III. Three-year rotation (#10,#11,#12)	320	60	275	72

ter legumes in a continuous cotton system requires a higher level of management, and depending upon seed, fertilizer N, and planting costs, growing winter legumes can cost more than using fertilizer N.

Recent measurements on winter legumes indicate that between 80 and 150 pounds N per acre are fixed in the above-ground portion of the legume. If most of this N is available to cotton, it will be adequate for nonirrigated cotton. A N budget for the treatments in the Old Rotation (using yield, fertilization, and crop removal estimates during the past decade) suggests that N use efficiency is the same for continuous cotton regardless of the source of N (Table 6). Nitrogen use efficiency appears higher for the three-year rotation because of the high N removal associated with soybeans and because only 60 pounds fertilizer N per acre is applied during the three-year period.

Crop Rotations. There is a definite yield advantage to rotating cotton with other crops (Table 5; Figure 9). However, the two-year cotton-winter legume-corn rotation is as beneficial as the three-year rotation. Low yields for nonirrigated 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 three-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."

CORN

In spite of historically low corn grain yields compared to midwestern states, corn has been the principle grain crop produced in Alabama. It was a staple on 19th century Alabama cotton farms because it provided food and fodder for livestock and grain for

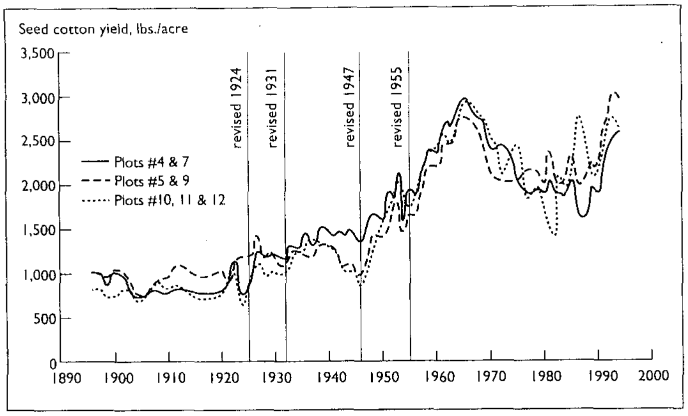


Fig. 9. Seed cotton yields on the two-year rotation with legumes (plots 4 and 7), the two-year rotation with legumes and 120 pounds N/acre/yr. (plots 5 and 9) and the three-year rotation (plots 10, 11, and 12), 1896-1995.

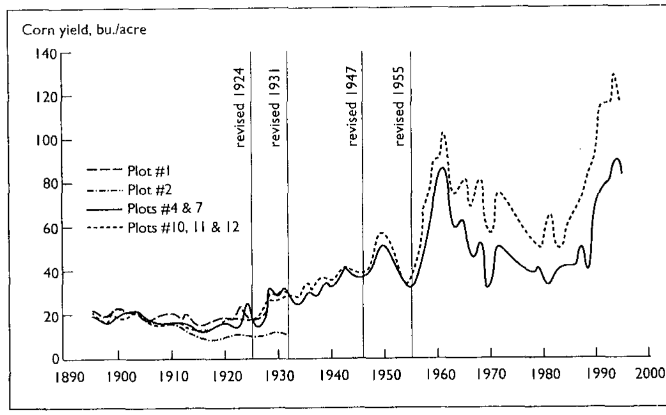


Fig. 10. Corn grain yields on selected treatments, 1896-1995.

human consumption. Corn grain yields on the Old Rotation are very similar to Alabama average yields. While grain yields have gradually increased over the 100 years of the Old Rotation, only during the past decade (1986-1995) have they increased dramatically (Table 5, Figure 10). The reason for this yield increase is not apparent. It may be a reflection of higher N fixation by the winter legume (Table 7; Figure 11), improved hybrids, and good weather during the past decade.

WINTER LEGUMES

Yield records for winter legumes were not kept prior to 1926. Many years since 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

TABLE 7. TEN-YEAR AVERAGE WINTER LEGUME (CRIMSON CLOVER AND/OR VETCH) DRY MATTER, SMALL GRAIN, AND SOYBEAN YIELD, 1896-1995

Treatment (plots)	1896-1905	1906-1915	1916-1925	1926-1935	1946-1945	1956-1955	1966-1965	1976-1975	1976-1985	1986-1995
				Winter legume (pounds dry matter per acre)**						
I. Continuous cotton										
A. No N/no legumes (#6)	—	—	—	—	—	—	—	—	—	—
B. +legumes (#3,#8)	***	***	***	1090	850	840	730	1470	***	3560
C. 120 lb. N/acre since 1956 (#13)	***	***	***	1050	520	910	—	—	—	—
II. Cotton-corn rotation										
A. +legumes (#4,#7)	***	***	***	1130	880	720	1120	1250	***	3560
B. +legumes/+N (#5,#9)*	***	***	***	1180	560	890	1100	1160	***	3550
III. Three-year rotation (#10, 11, 12)	***	***	***	1120	810	790	1040	1530	***	3960
				Small grain (bushels per acre)						
III. Three-year rotation (#10, 11, 12)	16 (oat)	***	***	***	59 (oat)	41 (oat)	50 (oat) 23 (wheat)	19 (wheat)	28 (rye) 43 (wheat)	27 (rye)
				Soybean (bushels per acre)						
III. Three-year rotation (#10, 11, 12)	—	—	—	—	—	—	34	33	38	35

*120 pounds N per acre added as ammonium nitrate since 1956 to cotton and corn. Prior to this, a summer legume (cowpea) was planted in rotation with cotton and winter legumes.
**Prior to 1985, winter legumes (clover and/or vetch) yields were recorded as green, harvest-weight only. Dry matter yields were estimated by assuming 18% dry matter. Since 1985, dry matter yields have been estimated by plot by determining moisture at harvest.
***Insufficient data.
Note: 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.

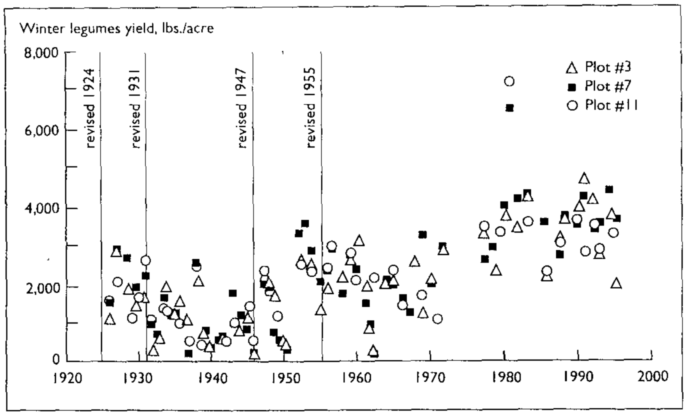


Fig. 11. Estimated dry matter yields of winter legumes in selected plots, 1926-1995.

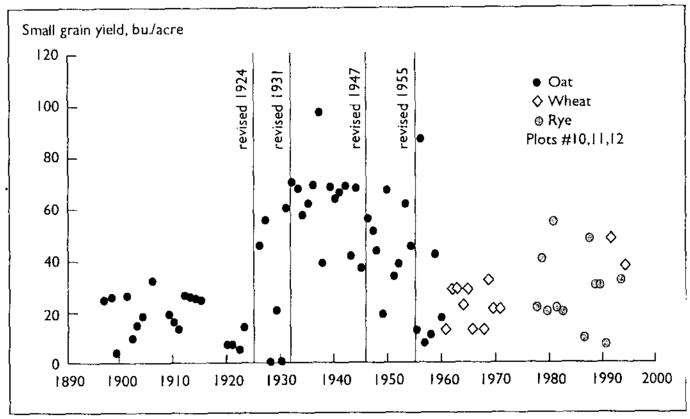


Fig. 12. Grain yields of oat, wheat, and rye, 1896-1995.

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. Apparently, this resulted in low dry matter yield estimates (Table 7; Figure 11). Data in Table 6 would suggest that dry matter yield has more than doubled since the 1960s. Improved varieties and timely fall planting have no doubt contributed to higher dry matter yields of winter legumes.

SMALL GRAIN, COWPEA, AND SOYBEAN

Small grain (oat, wheat, or rye) and either cowpea or soybean have been planted on the three-year rotation (plots 10, 11, and 12) since 1956. Prior to this time, cowpea was planted as both a summer green manure crop and a hay crop. It was one of the few summer annual legumes that was productive on the soils and climate of the deep South 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 as hay are not complete. Data available are in the Appendix. In the early 1960s, soybean became a profitable and widespread crop throughout much of the South. As a cash crop, it replaced cowpea as the summer annual legume of choice. 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 profuse grain producer, it is frequently planted as the small grain because it provides rapid fall growth, winter soil protection, early maturity, and high total biomass production. Average yields of small grain and soybeans are given in Table 7 and Figure 12.

SOIL ORGANIC MATTER

Soil organic matter (SOM) is an important indicator of soil quality because it influences soil structure, which affects soil stability and its capacity to provide water. It is also the controlling factor in nutrient cycling. Soil organic matter can affect soil productivity. The amount of SOM reflects past balances between rates of humus formation and mineralization.

Organic matter loss occurs because the rate of organic matter mineralization is greater than the annual input from plants while increases in SOM are a result of increased plant biomass and/or decreased degradation. Final amounts of soil carbon in agroecosystems are the direct result of the specific farming practices implemented on the land. Following a change in land management, SOM changes slowly with time. These changes are difficult to detect until suf-

TABLE 8. SOIL ORGANIC MATTER IN THE OLD ROTATION

	Year			
Plot	1988	1992	1994	Average
		% SOM		
1. No legume/no N	1.0	1.0	0.6	0.9
2. Winter legumes	1.7	1.7	2.0	1.8
3. Winter legumes	1.6	1.1	1.7	1.5
4. Two-year rotation/+legumes	2.0	1.8	1.9	1.9
5. Two-year rotation/+legumes/+N	2.2	1.8	1.9	2.0
6. No legume/no N since 1896	0.9	0.7	0.6	0.7
7. Two-year rotation/+legumes	1.7	1.8	1.5	1.7
8. Winter legumes	2.9	1.7	1.6	2.1
9. Two-year rotation/+legumes/+N	2.4	2.3	1.8	2.2
10. Three-year rotation	2.8	2.5	1.8	2.4
11. Three-year rotation	2.6	2.4	1.9	2.3
12. Three-year rotation	2.2	2.1	1.9	2.1
13. 120 lb. N/acre/yr.	1.4	1.8	1.5	1.6

Treatment	1988-1994 Treatment average,%
I. Cotton every year	
A. No legume/no N	0.8
B. Winter legumes	1.8
C. 120 lb. N/acre/yr.	1.6
II. Two-year rotation	
A. Winter legumes	1.8
B. Winter legumes/+120 lb. N	2.1
III. Three-year rotation	2.3

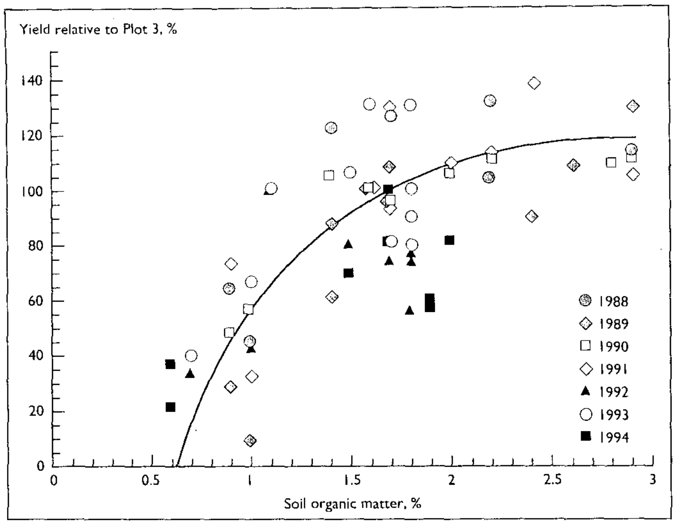


Fig. 13. Relationship between SOM and cotton yields relative to plot 3 since 1988.

ficient time has elapsed for the changes to be larger than the spacial and analytical variability in the soil (Entry et al., 1996).

No records were kept of SOM measurements on the Old Rotation before 1988. Measurements in the plow layer have been made in 1988, 1992, and in 1994 using the Walkley-Black procedure and a factor of 1.9 to convert from organic C to organic matter (Table 8).

Results of this investigation show that long-term planting of winter legumes significantly increases SOM. The two-year cotton-corn rotation with winter legumes plus N (treatment IIB; plots 5 and 9) and the three-year rotation (treatment III; plots 10, 11, and 12) had higher SOM than the other four rotations. Cotton without winter legumes (treatment IA; plots 1 and 6) had lower SOM 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 SOM also are the highest yielding plots. Increased SOM can be viewed as a consequence of improved production. However, Figure 13 suggests that SOM may also be viewed as a predictor of relative crop yield. There is a significant trend toward higher cotton yields in plots with higher SOM. Figure 13 suggests a yield plateau in the Old Rotation above 2% SOM.

Cover crops grown on cropland in the southeastern United States are beneficial because they maintain SOM, improve the physical and chemical characteristics, supply the soil with 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 years, data from the Old Rotation indicate that winter legumes increase amounts of both C and N in soil, which ultimately contribute to higher cotton yields.

MEASURING SUSTAINABILITY ON THE OLD ROTATION

DEFINING SUSTAINABILITY

A sustainable agricultural system should maintain or enhance agricultural production, protect natural resources, be economically viable, and be socially acceptable (Novak and Goodman, 1994; Pfeffer, 1992; Taylor, 1990). Cotton production in the southeastern United States has had a major influence on the economy of this region for almost 200 years. The fact that it continues to be produced as an economically viable crop suggests that cotton is a viable and acceptable component in a sustainable production system. Yet the historical record of cotton production's destruction of natural resources (soil erosion in the southern Piedmont, stream sedimentation, deforestation, etc.) leaves doubt about its sustainability as a protector of the natural resource base (Trimble, 1974). Pesticide use since the boll weevil entered the Cotton Belt in the early 1900s has added to concerns about sustainability, especially since some of the early insecticides included arsenicals and DDT, which are no longer allowed by EPA because of the health or environmental hazards they pose.

MEASURING PRODUCTIVITY

Productivity is difficult to assess because it involves more than just yield. Alabama's cotton acreage is 15-20% of what it was during peak production in 1914, yet statewide yields are five times higher (Figure 1). The nominal price of cotton has increased over the past 100 years but when adjusted for inflation, the real price has not increased. These trends make evaluating sustainability difficult.

Production indexes have been suggested as appropriate measures of change (Binswanger, 1978; Lu et al., 1979). If all quantifiable inputs and outputs are known or can be reasonably estimated from historical records, then a total factor productivity (TFP) index can be calculated. If externalities such as the cost to society from exposure to pesticides or the negative effects of sedimentation from soil erosion can be factored into TFP, then a total social factor productivity (TSFP) index can be defined and used to evaluate long-term sustainability of a production system.

Records from the Old Rotation where actual inputs and yields are known are extremely valuable for assessing productivity through the use of indexes. The advantage of using indexes is the ease with which they can be developed and compared. The primary interest in addressing the question of the sustainability of cotton production is in the effect on the movement of a total factor productivity index over time. Total factor productivity can be a more informative productivity indicator than partial measures, such as output per unit of land or output per unit of labor. The appeal of TFP is that it can be interpreted as "output per unit of input." As constituted here, this index number formula adjusts for the effect of changing input prices, so that changes in TFP can be attributed to a change in production efficiency, rather than changing market prices; a doubling of TFP implies that twice as much output is derived from each "unit" of input.

Selected treatments in the Old Rotation were used to calculate TFP and TSFP to assess the sustainability of cotton production under different management strategies.

METHODS USED

Data from three of the original 13 Old Rotation treatments were used to develop TFP indexes to compare the effect of N fertilizers and winter legumes on long-term productivity. Treatments were:

1. No N: continuous cotton with no nitrogen and no winter legume (plot 6 in Table 1);

2. Winter legumes: continuous cotton with a winter legume (crimson clover and/or vetch) used as a green manure and N source (plot 8), and;

3. N fertilizer: continuous cotton with annual application of 120 pounds N per acre (plot 13).

The first two treatments have not changed since the experiment was initiated in 1896. The third treatment was in a two-year cotton-vetch-cowpea rotation until 1955.

The types and levels of all inputs used on the Old Rotation were not recorded. Therefore, management and input practices on the Old Rotation from 1896 to the present (i.e. pest control, cultivation, labor, etc.) were assumed to be those recommended by the Alabama Cooperative Extension Service (ACES) and the Alabama Agricultural Experiment Station (AAES) for medium to large Alabama farms. Input budgets were constructed by compiling information on "typical" technologies for each era of the experiment. Prices received by farmers came from USDA records.

Except for shifts from mules and hoes to tractors and herbicides, field operations have remained fairly constant since 1896. Cotton production tools were powered by animals and humans from 1896 to 1939. A transition period from animal to tractor power occurred from 1940 to 1955. Since 1955, production has shifted from two-row (1956-70) to four-row (1970-85) to six-row (1986 to present) soil tillage and planting equipment. Marginal improvements were made in plowing, leveling, bedding, and planting equipment. Representative machinery operations for a typical cotton farm consisted of cutting stalks after harvest; flat-breaking the land using a plow; pulverizing the broken land using disk harrows, harrows and/or a drag; bedding; laying off the rows or opening furrows; planting; fertilizing; cultivating; hand thinning ("chopping" cotton); pest control; and harvesting and hauling.

From 1896 to 1959 harvesting was accomplished almost exclusively by hand picking, requiring approximately 100-114 hours per acre. During the 1960s, the cotton picker gradually replaced field hands and family harvesting labor, dramatically decreasing the labor required to produce an acre of cotton. For this analysis, it was assumed (and the historic record supports) that by 1970 100% of Alabama's cotton was mechanically harvested.

Variable costs included in the analysis accounted for seed, fertilizer, pesticides, defoliation, interest on operating capital, harvesting, ginning, and warehousing as well as for machinery operation. Fixed costs of operation included tractor and machinery depreciation, interest, insurance, and taxes. Estimated returns were to land, management, and owner-operator labor.

Ginning and labor were the other major inputs into the production process. Indexes were used to estimate ginning costs from ACES budgets. Budgets also were used to estimate labor rates and wages for the period 1978 to 1991. Alabama wage rates for 1923 to 1976 were taken from Agricultural Statistics bulletins. A United States wage rate multiplied by 57% was used as the Alabama wage rate prior to 1923.

The Tornquist approximation to the Divisia index was used in our analysis (Christensen, 1975). Divisia input, output, and total factor productivity (TFP) indexes can be calculated as:

$$(1) \quad I(X)_t = \pi_i (X_{it} / X_{i,t-1})^{(S_{it} + S_{i,t-1})/2}$$

$$(2) \quad I(Y)_t = \pi_j (X_{jt} / X_{j,t-1})^{(W_{jt} + W_{j,t-1})/2}$$

$$(3) \quad TFP_t = I(Y)_t / I(X)_t$$

where

$I(X)_t$ and $I(Y)_t$ are quantity indexes of input and output use in time t;

X_{it} is the quantity of input i;

Y_{jt} is the quantity of output j;

$S_{it} = r_{it} X_{it} / \Sigma r_{it} X_{it}$ where r_{it} is the price of input i, and

$W_{jt} = p_{jt} Y_{jt} / \Sigma p_{jt} Y_{jt}$ where p_{jt} is the price of output j.

TFP INDEXES WITHOUT EXTERNAL COSTS

In 1896, lint yield accounted for 93% of the output shares. This declined to 89% in 1991 because of the higher value assigned to cotton seed (Table 9). Nevertheless, the movement in lint yield and output index over time are very similar. The most dramatic shift in input shares since the Old Rotation began has been in decreased labor shares and increased machinery, harvesting, and ginning shares. Surprisingly, seed and fertilizer command smaller shares today than before the turn of the century.

Three distinct eras of productivity change are exhibited by the TFP series (Figure 14a). The TFP of the no-N plot eroded steadily over the first 50 years of the experiment, bottoming out in the mid-1940s at less than 40% of the 1900 level. The turn-of-the-century decline on the winter legume plot was shorter and more moderate, reaching its low point in 1921 at 70% of the 1900 level. Productivity on all three plots peaked in the middle 1960s, declined during the 1970s and appear to have leveled off in the 1980s. The TFP of all plots in 1991 is greater than when the experiment began.

TABLE 9. CHANGES IN OUTPUT AND INPUT SHARES FROM 1896 TO 1991

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

The largest single event affecting TFP was the introduction of the mechanical harvester. This was factored into the TFP calculations in 1959. This technological advancement, more than any other during the history of the Old Rotation, resulted in a decline in the input index (increase of TFP) on all three plots. Hand picking of cotton is an extremely labor intensive activity. The appearance of the cotton harvester had the effect of reducing the overall production labor requirement (per acre) by approximately 70%. The productivity decline of the 1970s is likely due to the effect of poor management when the main research farm was moved from the vicinity of the Old Rotation. Loss of DDT as a cotton insecticide also made insect control difficult during this transition period.

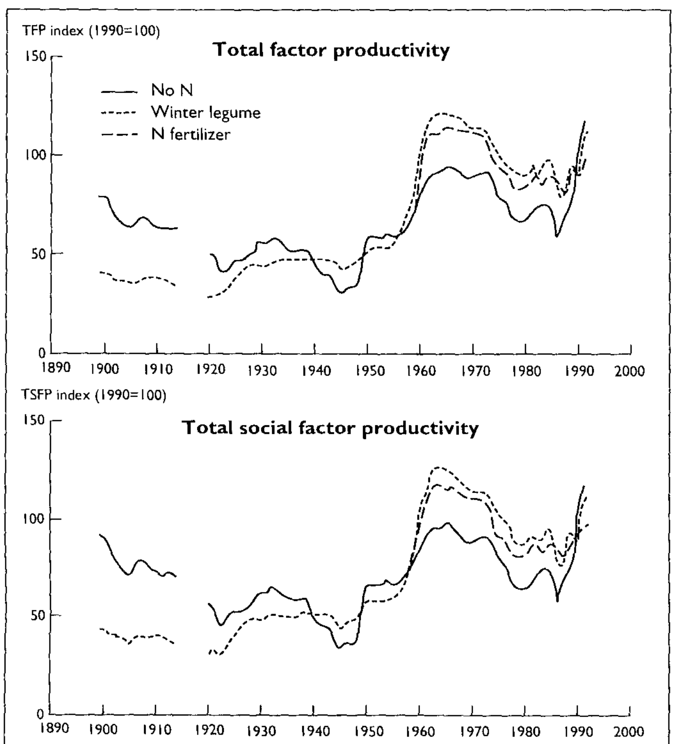


Fig. 14. (a) Total factor productivity indexes and (b) total social factor productivity (including externalities) indexes using five-year moving averages or treatments where cotton is planted every year.

TOTAL SOCIAL FACTOR PRODUCTIVITY

The TSFP indexes differ from the TFP indexes in that a societal cost is assigned to soil erosion and pesticide use (Figure 14b). The major categories of external costs of pesticide use are regulatory costs, adverse health effects, and damage to the natural environment. The actual net per acre cost (net of external benefits) of these effects is not known. The approach followed in this study is to assume external costs equal to 50% of expenditures on herbicides, insecticides, and defoliants. For soil erosion, Ribaudo's (1989) $2.34 per ton of soil loss, for annual off-site damage costs in the Southeast United States, was multiplied by an estimated average soil loss quantity.

Although casual observation indicates that erosion has occurred on the Old Rotation, a historical record of erosion does not exist for the site. Past erosion was modeled using the Erosion Productivity Index Calculator (EPIC) simulation program (Williams, 1990). EPIC simulated 96 years of soil and organic matter loss for the no N and winter legume experimental plots and 35 years of loss for the 120 pounds N per acre plot. Ten years of daily wind and rainfall data for the Auburn area were used to generate historic weather conditions. Average annual soil loss over the simulations were:

Treatment	Soil loss	Organic N loss
	tons/acre/year	lb./acre/year
No N/no legume	9.9	12
Winter legume	6.1	11
N fertilizer	7.8	16

The inclusion of external costs did not significantly affect productivity trends in any of the treatments (Figure 14b). The no-N plot indexes are not changed at all; the input indexes on the other two plots increased by an average of about 6%. Total Factor Productivity on the legume and N-fertilized plots decreased by 4% and 6%, respectively. The main conclusions from TFP calculations are unaffected. Therefore, total input use remains relatively stable over time when Ribaudo's (1989) external costs estimates are included in TFP. Significant productivity growth has occurred whether measured as conventional TFP or as TSFP. Sustainability of continuous cotton production as measured by TFP was minimally affected by externalities.

INTER-PLOT COMPARISONS

It is not possible to assess the relative performance of the three plots using either the TFP or TSFP indexes discussed above. However, the input use, output use, and productivity of the winter legume and N-fertilized treatments relative to the no-N treatment can be calculated as indexes (Cooke and Sundquist, 1991). When this was done, the relative output indexes (not shown) merely confirm that the output (yield) of the no-N and winter legume plots were similar during the early

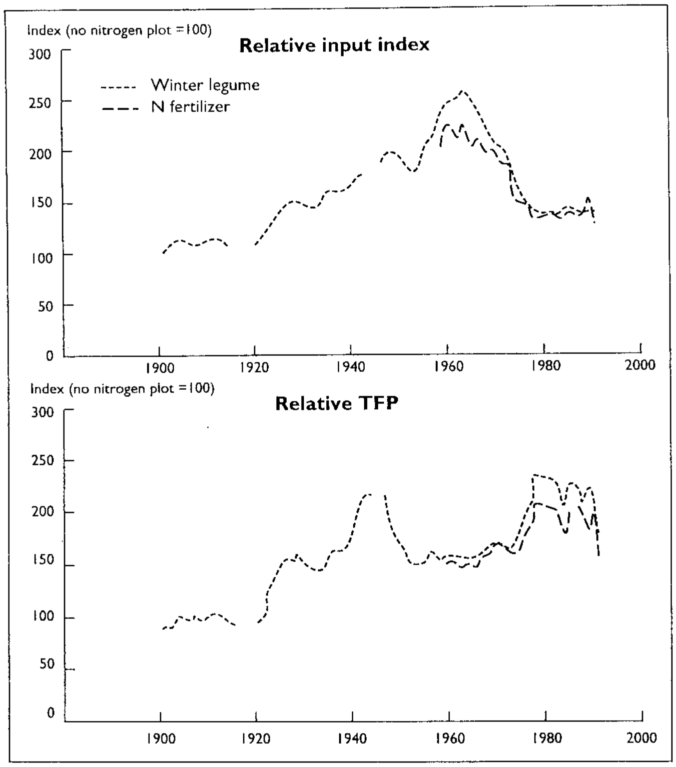


Fig. 15. Relative input (a) and TFP (b) indexes relative to the no-N treatment.

years of the experiment, but then diverged. Yield and output on the winter legume and N-fertilized plots were similar from 1955 to 1991.

The input series (Figure 15a), as expected, shows that the winter legume and fertilizer-N plots used more input than the no-N plot. However, much of this apparent input intensity is related to increased harvest costs, which were due to higher yields on the legume and N-fertilized plots. More harvest labor is needed and ginning costs are higher on an acre that yields two bales than on an acre that yields one bale of cotton.

The most informative inter-plot comparisons are obtained from the productivity measures of TFP in Figure 15b. The winter legume plot relative TFP hovers near 100 until 1920, climbs to 200 in the 1940s, declines in the 1950s through the 1970s, and climbs back to 200 in the 1980s and 1990s. The TFP of the N-fertilized plot follows a similar pattern, but is slightly below the winter legume plot in all years.

One of the most interesting findings is that there is a greater difference in relative TSFP than relative TFP. The difference is 6-8% in most years on both plots. This implies that accounting for externalities enhances the productivity advantage of the winter legume and chemical nitrogen plots. In other words, the low input system (no N), has less desirable environmental consequences than either the winter legume or N-fertilized systems. This is due to the decrease in soil erosion brought about through the higher biomass production of the winter legume and N-fertilized plots.

CONCLUSIONS

Viewed from the 97-year perspective of the Old Rotation, each of the plots fulfilled at least one criteria required for a system to be sustainable. Output per unit of input is higher in 1991 than in 1896 even when externalities are valued. Other conclusions from this study are:

(1)None of the systems show a linear trend in output or TFP over the history of the experiment. Productivity cycles are present in all three systems, despite the positive overall trend. An important focus of future research will be to attempt to explain whether these cycles are related to weather, technology, or changes in the resource base.

(2)The system that has neither an organic or a chemical source of added N is less productive than the other two systems. This system compares even more poorly when externality costs are assigned.

(3)Organic and chemical sources of N have similar productivity impacts.

(4)Soil erosion and pesticide externalities have a modest effect on measured productivity.

(5)The most dramatic single event to affect productivity was the introduction of the mechanical cotton picker. The impact of this technology is powerful enough to offset the effect of many other changes in the system.

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APPENDIX

APPENDIX TABLE 1. SEED COTTON YIELDS (POUNDS PER ACRE) BY YEAR, 1896-1935

	Plot						
Year	3	4	5	6	8	10	13
			Yields, (lb./acre)				
1896	1,134	1,088	1,050	965	898	—	—
1897	928	856	832	824	733	705	701
1898	1,075	1,051	1,226	1,032	858	763 —	
1899	1,192	1,033	805	957	733	698	1,065
1900	956	874	1,017	1,016	887	953	—
1901	1,045	1,008	1,112	794	963	901	896
1902	701	717	805	525	418	589	—
1903	836	491	452	437	772	481	437
1904	800	769	800	656	656	736	608
1905	816	821	811	829	771	805	—
1906	700	916	800	720	568	1,182	—
1907	768	792	1,039	800	814	799	959
1908	747	784	—	593	766	804	—
1909	626	550	853	557	633	841	956
1910	628	692	1,128	552	760	888	—
1911	915	979	848	715	706	754	720
1912	845	931	1,464	676	685	914	—
1913	590	783	1,011	618	571	760	1,011
1914	382	480	626	496	503	378	—
1915	789	606	816	570	571	720	601
1916-19			missing years				
1920	512	555	1,117	307	325	237	—
1921	472	392	578	227	355	499	562
1922	1,083	840	1,430	546	965	720	—
1923	515	725	1,120	152	374	909	818
1924	1,040	1,347	1,504	470	811	1,155	—
1925			missing year				
1926	1,222	1,077	1,349	395	986	987	—
1927	1,410	1,714	1,483	586	1,544	1,235	1,346
1928	602	537	621	254	633	432	—
1929	1,038	1,283	1,144	536	1,120	1,397	1,170
1930	1,240	1,346	1,206	725	1,091	866	—
1931	1,030	900	840	492	1,015	924	967
1932	1,466	1,728	1,627	636	1,356	1,332	—
1933	1,166	1,262	1,073	490	1,293	1,529	996
1934	1,096	1,123	1,183	466	1,061	1,358	—
1935	1,454	1,656	1,337	521	1,447	1,392	1,363

APPENDIX TABLE 2. SEED COTTON YIELDS (POUNDS PER ACRE) BY YEAR, 1936-1995

	Plot								
Year	1	2	3	4 & 7	5 & 9	6	8	10, 11, & 12	13
				Yields, (lb./ acre)					
1936	1,183	530	1,334	1,404	1,255	442	1,279	1,193	—
1937	1,061	590	970	1,145	1,051	516	1,058	1,291	1,135
1938	1,332	617	1,622	1,805	1,630	521	1,488	1,478	—
1939	994	559	1,390	1,594	1,186	502	1,519	1,181	1,114
1940	917	499	1,068	1,327	1,344	334	1,006	1,195	—
1941	595	235	1,049	1,193	1,097	180	977	1,111	833
1942	627	235	1,032	1,354	814	264	1,027	698	—
1943	754	365	1,459	1,594	960	430	1,435	883	794
1944	960	607	1,656	1,826	1,471	473	1,512	1,262	—
1945	151	67	811	1,140	941	74	838	1,130	355
1946	105	17	208	723	833	24	267	468	—
1947	662	461	1,603	1,903	1,404	398	1,637	1,639	626
1948	667	2,107	2,563	2,597	2,330	482	1,968	1,682	—
1949	888	1,735	1,582	1,939	1,678	559	1,766	1,985	982
1950	886	1,582	1,529	1,651	1,529	689	1,466	1,651	—
1951	989	1,502	1,498	1,798	1,651	694	1,654	1,510	691
1952	737	1,022	998	1,061	1,022	542	1,008	1,262	—
1953	696	1,793	1,836	2,158	1,793	449	1,838	1,956	785
1954	8	1,202	1,030	1,262	1,150	461	1,267	1,358	—
1955	1,121	3,000	3,026	3,161	2,534	859	2,861	2,623	1,265
1956	629	1,510	1,495	1,788	1,522	499	1,582	2,062	1,368
1957	667	1,824	1,836	2,196	2,129	586	2,052	1,968	2,054
1958	626	2,707	2,788	2,798	2,776	624	2,332	2,803	2,102
1959	556	1,735	1,652	2,077	2,102	452	1,897	2,243	1,618
1960	816	2,940	2,976	2,947	2,465	756	2,822	2,686	2,405
1961	389	217	2,039	2,534	2,366	612	2,362	2,580	1,886
1962	730	2,537	2,765	3,067	2,693	679	2,443	2,911	1,824
1963	754	2,246	2,160	2,602	2,779	684	2,412	2,885	2,006
1964	612	2,897	3,026	3,310	3,250	545	2,844	2,861	2,479
1965	456	2,714	2,849	3,408	2,995	790	2,813	3,202	1,874
1966	682	1,872	1,836	1,997	1,944	768	2,021	2,647	2,071
1967				missing year					
1968	778	1,735	1,668	2,038	1,934	610	1,846	2,268	1,853
1969	636	2,414	2,611	2,921	2,441	516	2,441	2,606	2,086
1970	669	2,210	2,243	2,551	2,012	650	2,087	2,541	1,970
1971	991	1,915	2,011	2,234	1,733	1,010	2,189	2,122	2,208
1972-77				missing years					
1978	362	1,610	1,699	1,634	1,900	439	1,882	1,634	1,361
1979	442	1,248	1,212	1,402	—	533	1,553	1,730	1,522
1980	634	1,308	1,342	1,630	1,577	655	1,622	2,210	1,594
1981	650	1,970	1,896	2,102	—	734	2,134	2,371	1,735
1982	919	2,582	2,616	2,652	2,796	907	2,712	2,755	2,333
1983	514	1,234	1,210	1,685	—	509	1,555	2,030	1,445
1984	512	1,252	1,437	1,132	1,241	631	1,143	—	860
1985	758	2,909	2,792	2,413	—	486	2,696	2,530	2,189
1986	512	945	1,217	1,329	1,292	405	972	1,206	—
1987	470	1,132	1,014	1,554	—	484	1,124	1,608	1,258
1988	726	2,033	1,597	1,670	2,105	1,016	1,815	1,670	1,960
1989	290	3,085	2,850	2,722	—	817	3,720	3,103	1,742
1990	1,125	1,888	1,960	2,069	2,178	944	2,178	2,142	2,069
1991	870	2,430	2,610	2,870	—	1,920	2,790	2,980	2,290
1992	1,633	2,790	3,775	2,790	3,410	1,270	3,050	2,870	2,110
1993	1,670	2,070	2,540	3,300	—	1,020	2,690	2,540	2,030
1994	830	3,190	3,920	2,940	2,250	1,450	3,160	2,360	2,690

APPENDIX TABLE 3A. CORN GRAIN YIELDS (BUSHELS PER ACRE) BY YEAR, 1896-1935

Year	Plot 1	Plot 2	Plot 4 & 7	Plot 10, 11, & 12
	Yields, (bu./acre)			
1896	18	16	15	—*
1897	25	20	22	15
1898	12	12	14	12
1899	18	19	18	15
1900	30	29	25	24
1901	15	18	15	14
1902	missing year			
1903	21	20	21	22
1904	21	15	17	14
1905	13	15	14	10
1906	10	13	12	14
1907	28	16	19	18
1908	15	9	16	11
1909	19	16	19	17
1910	18	12	14	15
1911	19	12	16	12
1912	22	10	13	16
1913	17	14	13	15
1914	5	2	3	2
1915	10	6	7	6
1916-19	missing years			
1920	16	9	14	17
1921	19	10	19	12
1922	17	8	12	18
1923	18	7	11	12
1924	17	8	15	18
1925	missing year			
1926	16	13	16	16
1927	27	10	23	32
1928	31	9	42	38
1929	34	9	40	25
1930	23	8	24	27
1931	17	12	22	23

* _ = missing year of data.

APPENDIX TABLE 3C. CORN GRAIN YIELDS (BUSHELS PER ACRE) BY YEAR, 1978-1994

Year	Plot 4 & 7	Plot 5 & 9	Plot 10, 11, & 12
	Yields, (bu./acre)		
1978	15	38	46
1979	41	45	57
1980	13	27	31
1981	40	45	30
1982	79	90	92
1983	27	28	36
1984	—	—	102
1985	18	18	51
1986	—	—	—
1987	69	76	111
1988	48	65	58
1989	118	137	138
1990	57	73	110
1991	—	132	148
1992	97	124	125
1993	78	122	117
1994	87	112	78

* _ = missing year of data.

APPENDIX TABLE 3B. CORN GRAIN YIELDS (BUSHELS PER ACRE) BY YEAR, 1936-1977

Year	Plot 4 & 7	Plot 10, 11, & 12
	Yields, (bu./acre)	
1932	23	26
1933	21	26
1934	27	31
1935	44	49
1936	27	2,304
1937	16	26
1938	46	42
1939	25	29
1940	41	44
1941	46	47
1942	34	38
1943	41	36
1944	24	17
1945	39	51
1946	37	47
1947	39	52
1948	76	69
1949	48	54
1950	46	54
1951	18	28
1952	26	42
1953	61	55
1954	4	14
1955	43	71
1956	50	53
1957	86	111
1958	110	109
1959	62	89
1960	83	90
1961	81	100
1962	28	47
1963	31	43
1964	90	108
1965	62	95
1966	19	50
1967	missing year	
1968	24	63
1969	25	38
1970	54	72
1971	96	118
1972-77	missing years	

APPENDIX TABLE 4. ESTIMATED DRY MATTER YIELDS (POUNDS PER ACRE) OF WINTER LEGUMES BY YEAR*

	Plot											
Year	1	2	3	4	5	7	8	9	10	11	12	13
						(Lb./ acre)						
1896-1925						missing years						
1926	2,325	—**	1,078	1,261	1,238	1,260	1,090	974	1,169	1,342	—	1,459
1927	2,268	—	2,851	2,316	1,499	2,846	2,257	2,952	789	1,969	—	1,558
1928						missing year						
1929	3,262	—	1,870	3,080	2,771	2,593	1,191	2,342	3,337	1,157	—	2,123
1930	2,182	—	1,443	2,120	1,550	1,918	1,693	1,105	1,021	1,645	—	1,155
1931	2,976	—	1,562	3,124	3,036	2,286	2,842	2,341	2,487	2,551	—	2,758
1932	—	—	264	924	569	859	1,060	813	298	993	—	556
1933	—	—	638	2,049	658	747	856	586	1,047	1,430	—	870
1934	—	—	1,922	2,259	1,649	1,598	1,175	1,075	2,031	1,384	—	774
1935	—	—	1,112	1,387	1,084	1,029	1,025	774	1,252	997	—	970
1936	—	—	1,444	1,369	1,106	1,088	1,031	904	1,676	975	—	593
1937	—	—	1,031	280	214	209	207	155	826	588	—	449
1938	—	—	2,004	3,862	2,332	2,550	3,023	2,195	2,095	2,432	—	2,277
1939	—	—	624	530	400	698	564	557	432	393	—	386
1940	—	—	410	622	346	396	381	383	556	472	—	310
1941	—	—	606	1,111	519	619	487	510	774	838	—	410
1942	—	—	662	1,328	495	837	608	621	994	739	—	352
1943	—	—	1,766	685	290	1,760	1,670	522	221	947	—	252
1944	—	—	668	1,576	716	1,008	882	864	1,012	914	—	941
1945	—	—	1,080	3,330	2,147	774	1,131	936	2,412	1,391	—	995
1946	—	—	269	2,178	2,196	320	456	788	1,872	743	—	482
1947	—	—	2,115	1,850	1,121	1,971	1,949	1,985	1,107	2,327	—	1,238
1948	—	2,939	1,921	1,094	1,242	1,890	1,755	1,355	2,381	1,818	—	1,193
1949	—	2,066	1,625	1,287	1,584	734	1,413	567	1,328	1,197	—	846
1950	—	779	486	945	909	540	373	540	990	464	—	347
1951	—	584	375	504	562	322	388	221	162	299	—	
1952	—	3,686	3,501	3,636	4,019	3,501	3,654	3,357	3,209	—	3,362	2,043
1953	—	2,408	2,453	3,101	3,209	3,659	3,506	3,582	—	2,484	3,753	2,812
1954	—	2,685	2,399	3,259	2,862	2,624	3,236	2,603	2,565	2,199	—	1,676
1955	—	1,301	1,247	2,061	1,989	2,053	1,827	2,160	2,097	—	2,624	1,517
1956	—	2,052	1,951	2,165	1,656	2,372	2,363	2,448	—	2,421	2,718	—
1957	—	2,866	2,880	3,101	3,346	2,903	3,167	3,593	3,006	2,934	—	—
1958	—	1,978	2,129	1,784	1,851	1,701	1,310	1,980	1,832	—	1,422	—
1959	—	2,066	2,520	2,903	2,300	2,655	2,264	2,223	—	2,696	2,331	—
1960	—	2,264	3,128	2,777	2,651	2,340	1,958	2,462	2,115	2,075	—	—
1961	—	1,944	1,976	1,265	1,089	1,643	1,512	2,016	1,494	—	1,152	—
1962	—	590	626	977	1,085	720	608	923	—	2,142	900	—
1963	—	234	180	207	180	158	135	171	270	185	—	—
1964	—		1,998	2,358	2,367	2,133	1,962	2,457	1,197	—	1,999	—
1965	—	2,412	2,106	1,602	1,287	2,034	2,079	1,287	—	2,448	1,701	—
1966	—	1,494	1,764	882	774	1,773	1,854	1,539	1,782	1,575	—	—
1967						missing year						
1968	—	2,016	2,426	2,673	2,894	1,301	2,061	1,895	—	1,305	1,719	—
1969	—	1,377	1,188	1,062	1,890	3,330	1,242	2,700	2,322	1,656	—	—
1970	—	1,710	2,101	1,885	1,811	1,921	1,699	2,043	1,844	—	2,176	—
1971	—	2,769	2,673	2,637	2,931	2,835	2,826	2,871	—	1,143	3,051	—
1978	—	3,285	3,231	2,889	3,276	2,664	3,699	3,744	1,458	3,438	—	—
1979	—	2,250	2,214	2,187	2,574	2,952	2,187	2,412	2,727	—	3,195	—
1980	—	3,447	3,699	2,601	2,430	4,005	3,735	3,600	—	3,411	3,519	—
1981	—	5,031	6,111	6,471	6,057	6,570	6,903	5,085	5,949	7,245	—	—
1982	—	3,744	3,339	2,601	2,817	4,095	3,924	3,726	3,339	—	—	—
1983	—	3,753	4,176	4,059	5,148	4,266	3,906	3,717	—	3,654	3,636	—
1984-85						missing years						
1986	—	1,719	2,088	1,760	2,412	3,600	977	1,784	—	2,263	2,502	—
1987	—	3,438	3,006	2,430	2,772	2,610	3,096	2,106	—	2,936	—	—
1988	—	3,402	3,618	3,582	3,618	3,816	4,590	3,618	3,654	—	—	—
1989						missing year						
1990	—	3,680	4,090	4,420	3,180	3,330	4,590	3,580	—	3,480	—	—
1991	—	3,910	4,680	5,130	5,060	4,300	5,190	4,150	5,140	2,730	—	—
1992	—	3,420	4,180	3,970	4,850	3,450	—	3,780	3,620	2,950	—	—
1993	—	3,030	2,750	2,610	3,140	3,550	3,490	3,460	2,980	5,790	—	—
1994	—	4,513	3,739	3,571	4,118	4,462	4,163	4,489	—	—	—	—
1995	—	3,040	1,910	1,880	2,800	3,520	1,790	4,460	—			

*NOTE:From 1926 to 1989 the yields were reported in a wet weight basis. The yields here reported are dry, using18% dry matter as an estimate. From 1990 to 1995 the yields were recorded dry.

** _ = missing year of data.

APPENDIX TABLE 5. YIELDS OF SMALL GRAINS (PLOTS 10, 11, AND 12) IN BUSHELS PER ACRE BY YEAR

Year	Type	Yield
		Bu./acre
1896	oat	—*
1897	oat	24
1898	oat	25
1899	oat	3
1900	oat	—
1901	oat	26
1902	oat	9
1903	oat	14
1904	oat	18
1905	oat	—
1906	oat	32
1907	oat	—
1908	oat	—
1909	oat	19
1910	oat	16
1911	oat	13
1912	oat	25
1913	oat	25
1914	oat	25
1915	oat	25
1916	oat	—
1917	oat	—
1918	oat	—
1919	oat	—
1920	oat	7
1921	oat	7
1922	oat	5
1923	oat	14
1924	oat	—
1925	oat	—
1926	oat	45
1927	oat	55
1928	oat	0
1929	oat	20
1930	oat	0
1931	oat	61
1932	oat	71
1933	oat	68
1934	oat	57
1935	oat	62
1936	oat	70
1937	oat	97
1938	oat	39
1939	oat	69
1940	oat	64
1941	oat	66
1942	oat	69
1943	oat	41

* _ = missing year of data.

APPENDIX TABLE 5, CONTINUED. YIELDS OF SMALL GRAINS (PLOTS 10, 11, AND 12) IN BUSHELS PER ACRE BY YEAR

Year	Type	Yield
		Bu./acre
1944	oat	68
1945	oat	36
1946	oat	56
1947	oat	51
1948	oat	43
1949	oat	19
1950	oat	67
1951	oat	34
1952	oat	38
1953	oat	62
1954	oat	45
1955	oat	13
1956	oat	87
1957	oat	8
1958	oat	109
1959	oat	42
1960	oat	17
1961	wheat	13
1962	wheat	28
1963	wheat	28
1964	wheat	22
1965	wheat	28
1966	wheat	13
1967	wheat	—*
1968	wheat	13
1969	wheat	32
1970	wheat	21
1971	wheat	21
1972-77	missingyears	
1978	rye	21
1979	rye	40
1980	rye	20
1981	rye	55
1982	rye	21
1983	rye	20
1984	rye	—
1985	rye	—
1986	rye	—
1987	rye	10
1988	rye	48
1989	rye	30
1990	rye	30
1991	rye	7
1992	wheat	48
1993	—	—
1994	rye	32
1995	wheat	38

* _ = missing year of data.

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Postscript

After 100 Years - The Future

The year 1996 finds Auburn University celebrating the centennial of the Old Rotation - 100 years of research condensed into a small plot of land! Much credit is due to our forefathers for their vision and wisdom in initiating long-term experiments and to their successors for continuing these experiments.

Today, the public demands immediate solutions to problems, and to establish an experiment to last 100 years would likely be deemed nonproductive and impractical. Farming today requires sophisticated management and large investments of money rather than just a way of life. Many external factors, such as government policies, environmental concerns, food safety, and public perception, must be integrated into farm management schemes. The interval from a research idea to implementation of new technology has greatly decreased. These demands have placed an added burden on the research and extension faculty.

Despite our fast-moving world, long-term research projects are as important today as the day the Old Rotation was implemented. Much can be learned from these long-term experiments about plant nutrient requirements, diseases, fertility, soil texture, compaction, etc. that may not be applicable today, but is necessary for the sustainability of agriculture in the next century.

The Old Rotation is not just historical - although there is much history in it. It was intended to establish a base of information and provide a reference point for measuring change over time. Based on the data available, it is successful.

The centennial celebration of the Old Rotation provides an opportunity for inventory and rededication. We have traditions and history, and from them facts and precepts for guidance in the future. We have gained knowledge, ability, experience, spirit, and the science and technology to expand our horizon.

What will be written of the Old Rotation in the year 2096? We can only hope that it will be said that we were as wise and diligent as our forefathers in maintaining this work and fostering long-term projects.

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