Cullars Rotation: The South's Oldest Continuous Soil Fertility Experiment

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Long-term fertility research with major crop rotations provides valuable nutrient management information in addressing sustainable production. The South's oldest fertility experiment is located in Auburn, Alabama. It continues to illustrate the benefits of balanced plant nutrition and fertilizing for the needs of the crop rotation.

Alabama's "Cullars Rotation" experiment (established in 1911) was placed on the National Register of Historical Places in 2003 as the oldest continuous soil fertility experiment in the South. Along with its nearby predecessor on the National Register, "The Old Rotation," which started in 1896, these experiments contain the oldest cotton research plots in the world. Both are located on the campus of Auburn University in east-central Alabama.

Treatments on the Cullars Rotation dramatically demonstrate the long-term effects of fertilization and the lack of specific nutrients on non-irrigated crop yields over a 95-year period. The Cullars Rotation is one of the few sites where controlled nutrient deficiencies can be observed on five different crops during the course of a year (cotton, crimson clover, corn, wheat, and soybean). The experiment preserves a site for monitoring nutrient accumulation and loss and soil quality changes and their effects on long-term sustainability of an intensive crop rotation system.

Agronomics and Experimental Design

The Cullars Rotation (website: http://www.ag.auburn.edu/agronomy/cullars.htm) was designed primarily to study the long-term effect of potassium (K) fertilization, lime, and other nutrients on a 3-year rotation which included cotton, corn, small grain, and summer legumes (cowpeas or soybeans). Research

View of experiment looking toward the east with plots A, B, and C on the right.

on this site led to the discovery of K deficiency in cotton, which had been referred to earlier as "cotton rust" (Atkinson, 1891, 1892). Today, the experiment is a 3-year rotation of: 1) cotton followed by crimson clover, 2) corn harvested for grain and followed by winter wheat, and 3) soybeans double-cropped after the small grain is harvested. The soil is a Marvyn loamy sand (fine-loamy, siliceous, thermic Typic Kanhapludults) in the Coastal Plain physiographic region.

Treatments and plot layout. The study included 11 soil treatments with three crops in the 3-year rotation. In 1914, an additional three treatments (designated A, B, and C) were added to include the effect of winter legumes in the rotation. Plot size is 20 x 99 ft., with a 2-ft. border between each plot and 20 ft. between each tier (block).

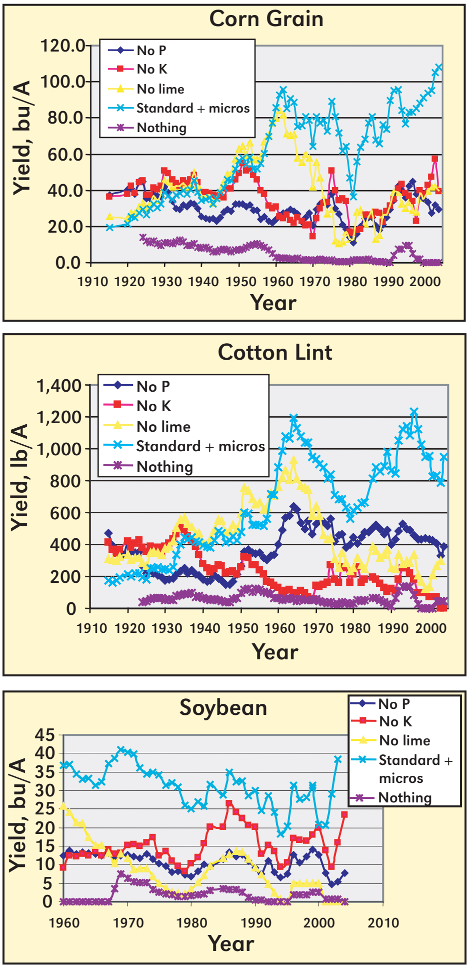

Figure 1. Long-term yield trends on selected treatments for cotton, corn grain, and soybean on the Cullars Rotation, 1911-2004. Each point is a 5-year running average. (Standard + micros is "Plot 10" in **Table 2**)

Tillage and other cultural practices. All crops were conventionally tilled with moldboard plowing, disking, and regular cultivation until 1997, and all crops have been grown with minimum tillage and transgenic cultivars since. Cotton and corn are planted directly into previous crop residue in narrow rows (30-in. rows) after paratilling or in-row subsoiling. Soybeans are drilled into wheat residue in June using a no-till drill. Since 1996, few insecticides have been applied for insect control, primarily because of the cotton boll weevil eradication program and the advent of Bollgard® technology. All crops are machine-harvested, although cotton and corn yield estimates are made by hand-harvesting portions of each plot.

Fertilization. In the early years of the Cullars Rotation, sources of plant nutrients were blood meal for nitrogen (N), superphosphate (0-18-0) and rock phosphate for phosphorus (P), and kainit (0-0-12) for K. In the last few years, P as concentrated superphosphate (0-46-0), K as muriate of potash (0-0-60), sulfur (S) as gypsum, and a micronutrient mix containing boron (B), zinc (Zn), manganese (Mn), copper (Cu), and iron (Fe) have been applied to the designated treatment plots in split applications in the spring prior to planting cotton and in the fall just prior to planting small grain. Nitrogen as ammonium nitrate (34-0-0) is applied to designated plots just prior to planting cotton and corn and as a side-dress application. The small grain is top-dressed with 60 lb N/A in late February. Fertility treatments and recent soil test results are presented in **Table 1**.

The Yield Record

Few research areas exist in the U.S. where one can see such dramatic deficiencies of plant nutrients on one site. Particularly dramatic are the plots where no soil amendment has been applied since 1911 (treatment C), the "no K" plots (treatment 6), the "no lime" plots (treatment 8), and the "no P" plots (treatment 2). Deficiencies sometimes appear on the other treatments, but are less dramatic. In general, cotton is most sensitive to low soil K in this experiment while corn, soybean, and small grain are most sensitive to low soil P (**Table 2**). Cotton and soybean seem to be more sensitive to the acid soil (pH=4.7 in 2004) in the no lime treatment than other crops in the rotation. All plots except treatment 8 (no lime) and treatment C (nothing) receive an application of ground, dolomitic limestone whenever the surface soil pH

Table 1. Treatments and mean soil pH and Mehlich-1 extractable plant nutrients and rating from 0 to 6 in. soil samples taken November 2004 on the Cullars Rotation. Particularly relevant values are shaded.

	Treatments[1]					Soil	Soil-test rating and Mehlich-1 extractable nutrients[2]			
Plot	Description	N	P	K	S	pH	P	K	Mg	Ca
							----------- mg/kg -----------			
A	No N/+legume	0	✔	✔	✔	6.1	VH 63	M 46	H 28	423
B	No N/no legume	0	✔	✔	✔	6.0	VH 57	M 44	H 23	330
C	No soil amendments	**0**	**0**	**0**	**0**	5.2	L 5	L 21	L 6	73
1	No winter legumes/ + N	✔	✔	✔	✔	6.2	H 46	M 52	H 33	371
2	No P	✔	0	✔	✔	6.2	VL 3	M 34	H 31	285
3	Standard fertilization, no micronutrients	✔	✔	✔	✔	6.1	VH 51	M 42	H 37	395
4	4/3 K	✔	✔	✔	✔	6.2	VH 81	M 47	H 38	525
5	Rock phosphate	✔	✔	✔	✔	6.0	EH 200	M 47	H 30	732
6	No K	✔	✔	0	✔	6.3	EH 101	VL 13	H 43	541
7	2/3 K	✔	✔	✔	✔	6.2	VH56	M 37	H 34	826
8	No lime	✔	✔	✔	✔	4.7	VH 68	L 26	L 3	200
9	No S	✔	✔	✔	0	6.2	VH 90	M 50	H 46	1,100
10	Standard fertilization + micronutrients (Zn,Cu, Mn, Fe, & B)	✔	✔	✔	✔	6.3	VH 85	M 66	H 36	953
11	1/3 K	✔	✔	✔	✔	6.1	VH 67	L 28	H 32	680

[1]Standard lime and fertilizer treatments: limed to pH 5.8 to 6.5; 100 lb P_2O_5/A per 3-yr rotation; 270 lb K_2O/A per 3-yr rotation; 90 lb N/A on cotton; 120 lb N/A on corn; 60 lb N/A topdress on small grain; 40 lb sulfate-S/A applied as gypsum to cotton and small grain.

[2]Rating based upon cotton on sandy soils (C.E.C. < 4.6 meq/100 grams); VL=very low; L=low; M=medium, H=high (desirable range); VH=very high; EH=extremely high (Adams et al., 1994).

drops below 5.8. Although B fertilization of cotton and reseeding clover, and Zn fertilization of corn are routinely recommended by Auburn University's Soil Testing Laboratory (Adams et al., 1994), no crop demonstrated a significant response to micronutrient fertilization in the period 1995-2004. Mean yields of cotton, corn, soybean, and small grain from 1995 through 2004 seem to reflect the long-term trends (**Table 2, Figure 1**).

Long-term trends, as illustrated by the 5-year running average yields in **Figure 1**, show periods of yield increases and dramatic decreases. Because this is a non-irrigated experiment, short-term droughts and other weather-related disasters during the growing season can have dramatic effects on yields. Year-to-year yield variability is high. The downward yield trends in the late 1970s and early 1980s reflect management problems when technical assistance was not available to address the day-to-day management of these plots. Nevertheless, the relative yields of the different fertility treatments remained about the same.

In the last 10 years of the study (1995-2004), the yield losses when P was not applied (compared to standard fertilization...lime, N,P,K,S...with micronutrients) were 57, 66, 69, 61, and 73% for cotton, corn, soybean, wheat, and clover, respectively.

When K was not applied, the yield losses were 95, 59, 40, 33, and 37% for cotton, corn, soybean, wheat, and clover, respectively.

Table 2. Mean crop yields on the Cullars Rotation, 1995-2004.

Plot	Treatment	Cotton lint, lb/A	Corn grain, bu/A	Soybean grain, bu/A	Wheat grain, bu/A	Clover dry matter, lb/A
A	No N/+legume	840 (88)	76 (78)	32 (91)	22 (41)	2870 (86)
B	No N/no legume	790 (83)	53 (54)	31 (89)	17 (31)	—
C	No soil amendments	20 (2)	1 (1)	1 (3)	0 (0)	0 (0)
1	No winter legumes/ + N	970 (102)	95 (97)	32 (91)	51 (94)	—
2	No P	410 (43)	33 (34)	11 (31)	21 (39)	910 (27)
3	Standard fertilization, no micronutrients	970 (102)	93 (95)	33 (94)	50 (93)	2940 (88)
4	4/3 K	850 (89)	88 (90)	32 (91)	50 (93)	2840 (85)
5	Rock phosphate	840 (88)	94 (96)	33 (94)	55 (102)	3080 (92)
6	No K	50 (5)	40 (41)	21 (60)	36 (67)	2090 (63)
7	2/3 K	920 (97)	101 (103)	32 (91)	54 (100)	3270 (98)
8	No lime, pH=4.9	200 (21)	39 (40)	2 (6)	14 (26)	560 (17)
9	No S	870 (92)	90 (92)	32 (91)	55 (102)	2480 (74)
10	Standard fertilization + micronutrients	950 (100)	98 (100)	35 (100)	54 (100)	3330 (100)
11	1/3 K	720 (76)	95 (97)	33 (94)	52 (96)	2700 (81)

Values in parentheses represent percentage of yield compared to "standard fertilization + micronutrients." Standard lime and fertilizer treatments: limed to pH 5.8 to 6.5; 100 lb P_2O_5 /A per 3-yr rotation;270 lb K_2O /A per 3-yr rotation; 90 lb N/A on cotton; 120 lb N/A on corn; 60 lb N/A topdress on small grain.

These results clearly illustrate the importance of adequate P and K fertilization. The data also indicate that adequate fertilization raises crop yields and sustains crop yields. The yield data in **Table 2** and **Figure 1** show that with adequate liming and fertilization, and proper management, cotton production is sustainable. **These results dispel the fallacy that cotton production harms soil productivity.**

Coincidentally, record crop yields have been recorded on the Cullars Rotation since 1996 when we switched to genetically modified varieties, and in 1997 when we switched to conservation tillage:

- 1996: 1,580 lb/A of cotton lint/A (3+ bales) on plot 7
- 1996: 75.1 bu/A of soybeans on plot 10
- 1999: 161 bu/A of corn on plot A
- 1999: 63.5 bu/A of wheat on plot 9
- 2000: 64.7 bu/A of wheat on plot 5
- 2001: 70.0 bu/A of wheat on plot 11
- 2004: 1,930 lb/A of cotton lint (almost 4 bales) on plot 1

These record yields are attributed to: 1) favorable growing seasons, 2) adoption of deep tillage to disrupt traffic pans, 3) conservation tillage which allows better moisture infiltration, higher water holding capacity, and cooler soils, 4) higher plant populations, 5) timely planting, 6) better weed control, especially through the new genetically modified varieties, and 7) less insect problems as a result of the boll weevil eradication program and the new Bollgard® cotton varieties.

Potassium movement and accumulation in soil profile (Figure 2). Soil samples taken in incremental depths to 48 in. from the K-variable treatments reveal that large quantities of K accumulate in the upper soil profile in this loamy sand with a cation exchange capacity (CEC) near 3.0 meq/100 grams. Potassium depletion occurs, especially in the top 24 in. of the soil profile, with inadequate K fertilization. Leaching occurs below the surface with the higher K rates as indicated by the Mehlich-1 extractable K levels. Routine, plow-layer soil sampling reflects soil test K increases associated with higher K fertilization rates. Note that the application of sulfate-S (as gypsum) appeared to increase K leaching.

Summary

The Cullars Rotation experiment continues to document long-term trends in non-irrigated crop yields and soil changes due to variable rates of P, K, S, micronutrients, and lime. It provides a valuable and accessible teaching tool for monitoring crop nutrient deficiencies. It also is a source of uniform soil with variable fertility conditions for allied studies. No other such resource exists in the Coastal Plain of the southern U.S. BC

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Acknowledgment

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For more about the Cullars Rotation visit this website: >www.ag.auburn.edu/agronomy/cullars.htm<.

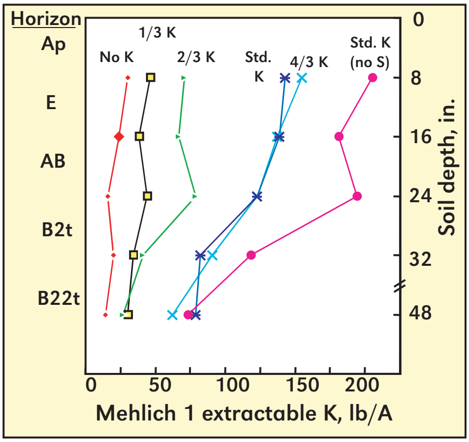

Figure 2. Soil profile K after 90 years of K fertilization, averaged across crop treatments. (Data points for each sampled depth increment are at the bottom of each in the graph. Depth increments are 8 in. except for the 16 in. increment from 32 to 48 in.)

Literature Cited

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TOOLBOX

PKalc Software Checks Nutrient Balance

"Toolbox" is a feature on the PPI/PPIC website which holds free downloadable software tools for improved nutrient management. One useful tool is called PKalc (v.1.13), a simple balance calculator which helps users determine if phosphorus (P) and potassium (K) nutrient additions are keeping up with removal by crops.

PKalc and other programs can be accessed for free at:

>www.ppi-ppic.org/toolbox> BC