MISSISSIPPI'S CENTENNIAL ROTATION – TWELVE YEARS OF ROTATION: EFFECT ON YIELD, NUTRIENT UPTAKE AND NUTRIENT REMOVAL

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Abstract

Long-term crop rotation studies are useful tools for studying the effects of production systems and practices across an extended time period. Studies such as the Old Rotation at Auburn University and the Morrow Plots at the University of Illinois are some of the oldest continuous research in the United States. With these studies, time (years) is the only replication and allows for evaluating trends rather than actual differences. In 2004, the Centennial Rotation was initiated on the Delta Research and Extension Center at Stoneville, MS to commemorate the 100-year anniversary of the Delta experiment station. New technologies have been introduced and adopted and can be evaluated in long-term rotations studies. As Mid-South production moved into the 21st century, cotton remained the primary crop for sandy soils. However, with the emphasis on bio-energy and bio-fuels, corn and soybean gained prominence and commodity prices increased. With increased grain prices, corn production in the Mid-south became more profitable and with a shift in infrastructure began replacing cotton on many farms. Cotton, corn, and soybean were included in the various rotational schemes in the Centennial Rotation mirroring what producers were beginning to consider. The systems in the Centennial Rotation included 2-year, 3-year, and 4-year rotations all compared to continuous cotton. At the initiation of the study a corn/soybean system was also included even though at the time this practice was not common in the Mid-south. All crops within a rotation system have been grown each year allowing for direct comparisons of crops for a given year and prices associated with that season. In certain years with high corn prices, there could be an advantage to growing corn but the field was scheduled to be planted to cotton in the rotational scheme. The fifteen "treatments" have been replicated four times with each one consisting of four 4-row subplots. The center rows have been harvested to avoid border effects. Samples taken at harvest have been used to determine harvest moisture, bushel test weigh, and seed index (seed weight) of the grain crops and lint percentage and lint yield of the cotton plots. Once yields are calculated, total plant nutrient uptake and removal was estimated based on standards. As expected the highest nutrient removal has been observed in the grain systems. For cotton over time, the lint yields have been much lower than the yield of cotton following corn. Nutrient removal for the continuous cotton system of nitrogen (N) and phosphorus (P) was 25 to 40% of the grain crop systems. Soil samples taken following harvest are used to monitor soil nutrient levels and the basis for P and potassium (K) applications. The corn crop returns far greater levels of residue to the soil than continuous cotton and should aid in the buildup of organic matter. In the 13th season, all system will be back to the same starting point as the first season and will start over. At the end of the 12th growing season, the 2-yr rotation systems have completed six cycles, the 3-yr rotations have completed four cycles, and the 4-yr rotation systems have completed three cycles.

Introduction

Crop rotation has returned to prominence after many years of continuous cotton in the Mid-south. Crop rotation has been used in farming systems for hundreds of years with modern rotations (green manures) begun as early as 1730 in England. The benefits from crop rotation can be divided into three major areas. These include: a) maintenance of crop yields; b) control of diseases, insects, weeds, and other pests; and c) prevention of soil erosion. Before the widespread use of chemical fertilizers, maintenance and/or improvement of crop yields were best accomplished by improving the base fertility of the soil where the crop was to be grown. This usually required growing a legume crop to promote nitrogen fixation or applying manure to provide additional organic nutrients. Corn/cotton rotations were used through the first three to four decades of the 20th century as animal power on the farm was extremely important. Corn was needed as feedstock for the animals. Mechanization and inorganic fertilizer materials reduced the need for some animals and crops, rotations decreased, and mono-crop agriculture gained in popularity. With today's farm policies and programs, and the freedom to choose different crop mixes, rotations have returned to prominence. Field research across the cotton producing states supported crop rotation. However, growers were reluctant to rotate because of government payments and crop rotations complicated production practices and presented extra challenges.

Early research at the Delta Branch Experiment Station, which has now been in existent for more than 100 years, revolved around crop rotation. The experiment station continues to address the original objective of the land-grant institution – that is to make agriculture a profitable enterprise. Early research included simple rotations and the use of manure on fields that had been used for cotton production. Mechanization shifted the agricultural industry from hand labor to machines and chemicals. That shift continues with the introduction and acceptance of biotechnology. The shift from rotation to mono-cultural and gradually back to rotation brings us to the 21st century. Cotton, corn, soybean, grain sorghum, and rice production recorded record yields in the past year with the aid of new technology and advancements through research. Since 2001, cotton, corn, and soybean have had record yields and record prices. Corn production has increased while cotton has decreased in response to price and profitability. Grain crops can be planted early and along with irrigation, yield stability has led to shifts in the crop mix.

The original purpose of this research project was to establish long-term rotations involving cotton, corn, and soybean with the crops to be grown with the most up-to-date technology available. The actual production inputs have changed with time as new technology has been adopted. The designed was implemented to examine the impact of rotations on the whole-farm enterprise while monitoring soil nutrients, nematodes, and other pests. Several cooperators were identified to assist in the overall management of the project in order to assure maximum utilization of the data collected. Soil samples from the main plots have been taken after the last crop was harvested and have been used to monitor changes. Following the 2015 growing season, soil samples were taken from all subplots as well.

Research Objectives:

1. Determine the effects of long-term crop rotation with respect to yield and profitability while utilizing state-of-the-art technology.
2. Assess the impact of crop rotation on the whole-farm enterprise.
3. Monitor changes in soil nutrient status, nematode numbers and types, and weed species.
4. Demonstrate the long-term need for crop rotation for the next century

Materials and Methods

The research study has included five crop rotation sequences along with continuous cotton as the base systems. All crops in a rotation sequence are grown each season thus establishing 15 distinct 'treatments' that are replicated four times. The five crop rotation sequences include 1) corn-cotton, 2) corn-cotton-cotton, 3) corn-soybean, 4) soybean-corn-cotton, and 5) soybean-corn-cotton-cotton and are summarize in Table 1. Each plot contains eight 40-in rows 200 ft in length with a minimum of four rows harvested for yield determinations. Fertility requirements are determined from soil tests each year. All cultural practices are maintained as uniformly as possible taking into consideration the technology that is available. Plots are harvested with commercial equipment adapted for plot harvests with subsamples taken from the cotton and grain plots. Grab-samples from the cotton harvest are taken during harvest and then processed through a 10-saw micro-gin to determine lint percentage and lint yields. Grain subsamples are taken during the harvest process and sealed in sterilized bags. These grain samples are then used for determining harvest moisture, bushel test weight and seed index (100-seed weight). Both bushel test weight and seed index are adjusted to a constant moisture (15.5% for corn and 13.0% for soybean).

Soil samples are taken each year with 8 to 10 cores taken from each main plot and analyzed for nutrient status, and soil acidity (liming), organic matter, and exchangeable cations. The nutrient management and pesticide regiment are adjusted as needed and as issues arise. As herbicide tolerance (weed resistance) became a problem in the area, cultivars were changed and the herbicide protocol adjusted based on the committee expertise and recommendations. All data from the systems ar4 summarized and analyzed statistically using SAS (Cary, NC) procedures.

Once yields have been determined for each crop, nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) uptake and removal are estimated based on the yields for each crop. A running summary of nutrient uptake and removal has been maintained for comparisons of nutrient removal from the various cropping systems. To date, emphasis has been placed on yields, NPKS uptake and removal. The next step is to continue the economic analysis of inputs, costs, and returns. These production inputs and returns will analyzed to determine the overall effects of rotation on whole-farm economics. The rotations have cycled through the first 12 years and will begin again in 2016.

Table 1. Cropping sequence for long-term cotton-based rotation cropping system. All crops in each sequence to be grown each year. MAFES-DREC, Stoneville, MS

CENTENNIAL ROTATION STUDY												
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
System	1	2	3	4	5	6	7	8	9	10	11	12
1	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
2	CT	CR	CT	CR	CT	CR	CT	CR	CT	CR	CT	CR
3	CR	CT	CR	CT	CR	CT	CR	CT	CR	CT	CR	CT
4	CR	CT	CT	CR	CT	CT	CR	CT	CT	CR	CT	CT
5	CT	CR	CT	CT	CR	CT	CT	CR	CT	CT	CR	CT
6	CT	CT	CR	CT	CT	CR	CT	CT	CR	CT	CT	CR
7	CR	SB	CR	SB	CR	SB	CR	SB	CR	SB	CR	SB
8	SB	CR	SB	CR	SB	CR	SB	CR	SB	CR	SB	CR
9	SB	CR	CT	SB	CR	CT	SB	CR	CT	SB	CR	CT
10	CT	SB	CR	CT	SB	CR	CT	SB	CR	CT	SB	CR
11	CR	CT	SB	CR	CT	SB	CR	CT	SB	CR	CT	SB
12	SB	CR	CT	CT	SB	CR	CT	CT	SB	CR	CT	CT
13	CT	SB	CR	CT	CT	SB	CR	CT	CT	SB	CR	CT
14	CT	CT	SB	CR	CT	CT	SB	CR	CT	CT	SB	CR
15	CR	CT	CT	SB	CR	CT	CT	SB	CR	CT	CT	SB
CT = Cotton		CR = Corn		SB = Soybean								

Results and Discussion

The first twelve years of the Centennial Rotation long-term study was completed in 2015 (100-yr rotation). Long-term cropping system rotations and long-term research are limited or non-existent in many areas of the world. The Morrow Plots (University of Illinois) and The Old Rotation (Auburn University) are some of the oldest continuous plots in the US. To celebrate the centennial anniversary of the Delta Branch Experiment Station and a new era in agricultural technology, the Centennial Rotation was initiated in 2004 at the Delta Research and Extension Center at Stoneville, MS. The "treatments" outlined in Table 1 show the first twelve years of the rotations and the crops being grown each year. The project was setup as a cotton-based system due the historic significance of cotton to this region of the US. Treatments 7 and 8 (Table 1) do not contain cotton and are included to document the long standing advantages of corn/soybean rotation. With recent shifts to grain production, this system has become quite important. The 12-yr cycle will repeat in the 13th season (2016) at which time some rotations will have completed six cycles, others four cycles, and the last system will have completed three cycles. The yield summary from the first twelve years are shown in Table 2. Cotton yields in the continuous cotton area have the overall lowest yields for cotton compared to the other systems and over the years have ranged from a low of 718 lb/acre in 2007 to a high of 1452 lb/acre in 2013 and averaged 1043 lb lint/acre. Most of the yield variation can be attributed to differences in environmental conditions, pest pressure, or other factors. During that same period, cotton following corn has ranged from 942 lb/acre in 2007 to 1952 lb/acre in 2013 with an average of 1250 lb lint/acre. Thus the rotation benefit averaged 207 lb lint/acre for an increase of 19.8%. These results are higher than those shown from earlier rotation research where the yield increase was 10 to 18% depending on soil type, location, and year. When continuous cotton yields were the highest at 1452 lb lint/acre (2013) cotton following corn the same year had yields of 1952 lb lint/acre. This 500 lb/acre difference was an increase of nearly 35% based on "rotation effect" alone. The rotation effect seems to be greater as environmental conditions favor higher cotton lint yields.

Table 2. Summary of crop yields from the Centennial Rotation Study (2004-2015). [Adjusted to standard moisture] Delta Research and Extension Center, Stoneville, MS (*SEE* Table 1 for complete yearly rotation system)

CENTENNIAL ROTATION STUDY - SUMMARY OF CROP YIELDS (LB or BU/ACRE)

Rotation System	Rotation Sequence	2004 Crop Yield	2005 Crop Yield	2006 Crop Yield	2007 Crop Yield	2008 Crop Yield	2009 Crop Yield	2010 Crop Yield	2011 Crop Yield	2012 Crop Yield	2013 Crop Yield	2014 Crop Crop	2015 Crop Yield
1	Continuous CT	1430.5	1101.8	978.9	718.5	927.6	877.6	1039.4	843.2	1076.4	1452.1	1122.1	948.7
2	CT-CR	1470.9	204.6	1185.4	200.8	1218.9	182.4	1185.6	61.6	1237.4	216.8	1221.2	217.3
3	CR-CT	201.2	1334.3	185.1	942.2	194.9	961.3	194.7	965.4	242.6	1952.1	236.1	1323.0
4	CR-CT-CT	197.2	1298.4	988.0	219.4	1314.9	975.3	201.8	982.2	1098.1	228.8	1184.0	1048.0
5	CT-CR-CT	1509.4	213.3	1202.1	866.7	206.8	984.7	1148.2	73.8	1194.3	1691.6	259.5	1421.0
6	CT-CT-CR	1525.1	1148.8	191.1	909.3	982.5	194.8	1234.7	841.9	244.7	1803.8	1192.5	221.2
7	CR-SB	193.9	57.8	199.3	78.4	205.8	73.3	207.2	52.6	241.3	58.3	241.3	42.2
8	SB-CR	60.3	212.3	62.5	208.8	56.1	205.1	65.7	101.8	42.9	232.5	56.6	221.5
9	SB-CR-CT	61.4	212.6	1206.2	75.5	197.6	994.5	70.6	113.7	1105.0	72.1	250.0	1365.2
10	CT-SB-CR	1447.5	61.5	194.6	1019.2	60.4	209.4	1199.0	47.9	244.0	1902.2	57.3	230.2
11	CR-CT-SB	195.9	1268.2	64.4	207.6	1222.3	66.3	209.0	963.0	46.6	234.2	1285.6	41.1
12	SB-CR-CT-CT	60.4	199.0	1152.6	852.2	57.5	195.9	1239.2	849.3	45.6	229.2	1255.9	1095.4
13	CT-SB-CR-CT	1402.7	52.3	191.2	929.5	978.7	69.8	208.0	1059.2	1052.8	66.9	252.8	1292.9
14	CT-CT-SB-CR	1446.6	1148.2	58.1	223.4	1240.5	929.3	66.8	105.0	1194.0	1529.9	59.5	235.9
15	CR-CT-CT-SB	200.5	1359.4	947.2	81.5	199.9	992.6	1026.1	50.4	242.3	1857.7	1069.4	46.2

NOTE: Cotton Yield reported in lb lint/acre, Corn Yield reported in bu/acre @15.5%, Soybean Yield reported in bu/acre @ 13%

In the Centennial Rotation corn yields have ranged from 62 to 243 bu/acre in corn following cotton systems (12-yr average of 195 bu/acre) and 101 to 241 lb/acre for corn following soybean (12-yr average of 206 bu/acre). When the systems are compared and included the bad year, corn following soybean had yields that averaged 11 bu/acre higher (5.6%). The 2011 yields for corn (91.2 bu/acre) were way below average due to a lack of irrigation in a timely fashion. Soybean yields in the corn/soybean rotation have ranged from 42.2 to 78.4 bu/acre with the lowest yields in 2015 (Table 2) and averaged across twelve years equal to 58.9 bu/acre. Weather problems such as hurricanes have caused some problems (lodging) but the yields have still been harvestable. Timely irrigation is a key to successful and consistent corn production as evident in 2011. Timing of the first irrigation is critical.

A main area of interest in long-term rotation studies deal with nutrient uptake and nutrient removal. Nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) uptake and removal are calculated for each of the systems each year and a running total maintained. Figure 1 shows the estimated N, P, K, and S uptake for selected crops in the Mississippi Delta while Figure 2 gives an estimate of the N, P, K, and S removal by the crops based on the yields given. For cotton, corn, and soybean, the crops take up more nutrients than are actually removed from the field. Only the grain portion of corn and soybean are removed and the seed and lint portion of cotton along with some vegetative materials. Soybean removes the largest percentage of N and K while corn removes the largest percentage of P. These values have been used to calculate nutrient uptake and removal for the crop sequences that have been grown to date. The summary of nutrient uptake is shown in Table 3 and the summary of nutrient removal is shown in Table 4. The continuous cotton system has resulted in the lowest nutrient removal for N, P, K, and S. After twelve years, the greatest N uptake and removal has occurred in the corn/soybean rotation system (Treatments 7 and 8) where each crop has been grown six times (Table 4). The two treatments are different because yields have been different from year to year. Table 5 provides a summary of nutrient removal when all systems are averaged together and across the twelve years. Much of the N that is removed in the CR/SB system comes from symbiotic N fixation when soybean is grown, Also, higher N fertilizer rates are used for corn compared to cotton. Producers should take extra steps to insure adequate fertility when shifting from cotton production to rotations with grain crops. Nutrient removal, especially N, can be 3 to 4 times higher than continuous cotton. The P and K removal rates are also highest for the CR/SB system. When examining uptake and removal, N uptake can be as much as 300 lb N/acre depending on the crop and yield. As long as the residue is returned to the soil and not burned, most of the nutrients not removed in the grain or seed can be recycled and thus reused for future crops. If residue is removed for feed stocks related to bio-energy, the available nutrient pool in the soil and organic matter can be further reduced as well.

Nutrient Uptake for Selected Crops

Crop	Yield	N	P	K	S
	bu or lb/A	------------------	lb/A	--------------------	
Corn	180	240	45	199	30
Soybean	60	314	26	170	20
Wheat	80	149	24	135	21
Cotton	1000	160	21	116	24
Rice	7000	112	26	139	12

To Convert P to P_2O_5 multiply by 2.29
To Convert K to K_2O multiply by 1.20

Figure 1. Estimated nutrient uptake for specific crops based on selected yields. Nutrient uptake values based on average results published from several sources in the southern United States and may differ from other areas.

Nutrient Removal for Selected Crops

Crop	Yield	N	P	K	S
	bu or lb/A	------------------	lb/A	--------------------	
Corn	180	162	35	43	14
Soybean	60	240	21	71	6
Wheat	80	92	19	23	5
Cotton	1000	64	12	33	6
Rice	7000	70	19	23	6

To Convert P to P_2O_5 multiply by 2.29
To Convert K to K_2O multiply by 1.20

Figure 2. Estimated nutrient removal for specific crops based on selected yields. Nutrient removal values based on average results published from several sources in the southern United States and may differ from other areas.

Table 3. Summary of total nutrient (N, P, K, S) uptake from the Centennial Rotation Study (2004-2015). Delta Research and Extension Center, Stoneville, MS.

NUTRIENT UPTAKE					N	P	K	S
	CROP SEQUENCE				Uptake	Uptake	Uptake	Uptake
Trt	YR1	YR2	YR3	YR4	(lb/acre)	(lb/acre)	(lb/acre)	(lb/acre)
1	Continuous CT				2002.7	262.9	1452.0	300.4
2	CT	CR			2648.0	428.8	2070.2	361.1
3	CR	CT			2869.4	470.8	2254.5	388.6
4	CR	CT	CT		2551.8	398.5	1967.8	354.5
5	CT	CR	CT		2607.3	398.7	1995.0	366.0
6	CT	CT	CR		2677.9	415.4	2059.8	373.3
7	CR	SB			3616.2	479.3	2452.3	335.7
8	SB	CR			3376.8	444.6	2281.6	311.7
9	SB	CR	CT		3242.3	412.7	2189.5	334.3
10	CT	SB	CR		3250.0	434.9	2260.1	355.7
11	CR	CT	SB		3030.3	405.9	2104.7	327.7
12	SB	CR	CT	CT	2718.9	362.2	1900.9	313.2
13	CT	SB	CR	CT	2933.2	386.0	2035.5	332.9
14	CT	CT	SB	CR	2915.8	378.3	2015.1	335.3
15	CR	CT	CT	SB	2948.4	390.2	2056.5	340.5

Table 4. Summary of total nutrient (N, P, K, S) removal from the Centennial Rotation Study (2204-2013). Delta Research and Extension Center, Stoneville, MS.

NUTRIENT REMOVAL					N	P	K	S
	CROP SEQUENCE				Removal	Removal	Removal	Removal
Trt	YR1	YR2	YR3	YR4	(lb/acre)	(lb/acre)	(lb/acre)	(lb/acre)
1	Continuous CT				801.1	150.2	413.1	75.1
2	CT	CR			1456.4	300.9	507.0	129.4
3	CR	CT			1607.7	333.7	546.5	142.5
4	CR	CT	CT		1331.5	271.4	495.7	119.2
5	CT	CR	CT		1319.3	266.7	510.6	118.7
6	CT	CT	CR		1383.5	281.3	521.6	124.1
7	CR	SB			2610.5	377.5	737.0	136.5
8	SB	CR			2440.1	349.3	689.5	126.3
9	SB	CR	CT		2113.6	304.4	667.8	116.2
10	CT	SB	CR		2054.8	317.0	662.2	124.4
11	CR	CT	SB		1752.1	289.4	617.2	116.1
12	SB	CR	CT	CT	1628.2	255.9	555.2	103.6
13	CT	SB	CR	CT	1772.8	273.5	601.1	109.9
14	CT	CT	SB	CR	1725.0	264.2	600.2	107.3
15	CR	CT	CT	SB	1755.0	274.3	603.6	111.3

The economic impact of crop rotations is evident in most years just from the yield standpoint. However, as the costs of inputs continue to escalate, particularly with respect to technology fees, the more important rotation becomes. The increase in herbicide-resistant weed species across the country could lead to even more emphasis on crop rotation and herbicide rotation. Glyphosate-resistance has been documented for several weed species in the growing area and has necessitated the shift back to residual herbicides for controlling weeds. Different herbicide technologies are being used to assist with this problem but crop rotation can play a major role in the future. Some of the newer soybean cultivars have yields that have lagged behind their non-biotech counterparts.

Table 5. Summary of nutrient removal for the rotation systems included in the Centennial Rotation at the Delta Research and Extension Center, Stoneville, MS. (2004 – 2015)

ROTATION SYSTEM	N Removal	P Removal	K Removal	S Removal
	(lb N/Acre)	(lb P/Acre)	(lb K/Acre)	(lb S/Acre)
Continuous Cotton	**801.1**	**150.2**	**413.1**	**75.1**
CR-CT	**1532.0**	**317.3**	**526.8**	**136.0**
CR-CT-CT	**1344.8**	**273.1**	**509.3**	**120.7**
SB-CR	**2525.3**	**363.4**	**713.2**	**131.4**
SB-CR-CT	**1973.5**	**303.6**	**649.1**	**118.9**
SB-CR-CT-CT	**1720.2**	**267.0**	**590.0**	**108.0**

Results shown are averaged across all possible combinations of each rotation system. CR-CT includes treatments 2 and 3; CR-CT-CT includes treatments 4, 5, and 6; SB-CR includes treatments 7 and 8; SB-CR-CT includes treatments 9, 10, and 11; and SB-CR-CT-CT includes treatments 12, 13, 14, and 15.

The Centennial Rotation will continue the next 12-yr phase in 2016 with plans to continue through the end of the century. Long-term rotations are meant as demonstrations of what is possible and evaluate the systems over time. In the beginning, conventional cultivars were used and shifted as the bio-technology became the adopted standard. With the recent problems associated with herbicide resistance in weeds, it became necessary to address the issue with a change in protocol and residual herbicides as well as bio-tech traits. The future will likely continue to change and the rotations will adapt. The economic implication are of the greatest importance to producers and will be the next phase of the data analysis.