THE VALUE OF ROTATIONS – LESSONS LEARNED FROM THE FIRST TWELVE YEARS OF THE MISSISSIPPI CENTENNIAL ROTATION

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Abstract

Many lessons are to be learned from long-term crop rotation studies. They are useful tools for studying the effects of production systems and practices across changing environments. 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 and continue to provide useful information. In these studies, time (years) has been the only replication that allows for evaluating trends rather than actual differences. To recognize the celebration of the centennial anniversary of Mississippi's first experiment station, the Centennial Rotation was established in 2004 on the Delta Research and Extension Center at Stoneville, MS. New technologies continue to be introduced, adopted by producers, and need to be evaluated over time. As Mid-South production moved into the 21st century, cotton remained the primary crop for sandy soils. However, with an emphasis on bio-energy and bio-fuels, corn and soybean gained prominence and commodity prices increased. Irrigation systems were being installed and water was relatively cheap. 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. Although monoculture cotton was common in the area, it was not a suitable practice for the grain crops. To optimize yields and profits, crop rotation was needed and had been used all over the country. Cotton, corn, and soybean were included in the various rotational schemes in the Centennial Rotation mirroring what producers were beginning to consider and adopt for their operations. 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 Centennial Rotation, a corn/soybean rotation system was also included even though at the time this cropping sequence was not very common in the Mid-south. Often in years with high commodity prices, there could be an advantage to growing corn or soybean, but the field was scheduled to be planted to cotton in the rotational scheme or some other crop. Therefore, 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. While one should expect differences related to the environment, the averages across the systems are relevant. The fifteen "treatments" included in the study have been replicated four times with each one consisting of four 4-row subplots that help evaluate the natural variability occurring within each main plot. The center rows of each subplot 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 can be 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. Crop prices have varied greatly during the first 12 years of the Centennial Rotation. To measure the value of the crops being grown, average marketing year prices or the loan rate was used to calculate value based on yields. Actual cotton prices have ranged from \$0.410 to \$0.977 per pound while the loan price has been set at \$0.525 (2004-2008) or \$0.520 (2009–2015). Both corn and soybean prices for the marketing year has exceeded the loan price and ranged from \$2.22 to \$6.94 for corn and \$5.92 to \$14.50 for soybean. By using the prices for each year, one can calculate the average value of the crop each year and then summarize the total value of the rotation system. The total value of continuous cotton was set at \$8,266 while the corn/cotton rotation (6 years corn + 6 years of cotton) had a value to \$9,774. The next step will be to now go back and look at annual cost of production to determine the net value of the rotation system. 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: Overall Study

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 are summarized and analyzed statistically using SAS (Cary, NC) procedures.

Table 1. Cropping sequence for long-term cotton-based rotation cropping system. All crops in each sequence o 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

Once yields were determined for each crop, nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) uptake and removal were 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. Crop prices have been summarize in Table 2 and shows both marketing years commodity prices as well as loan rate for the crops. In calculating the crop value, the higher value was used.

Table 2. Summary of commodity price and loan rates for cotton, corn, and soybean for the Mid-south from 2004 to 2015. Information from National Agricultural Statistics Service (2015 is estimated)

CROP	MARKETING YEAR											
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
	Commodity Price/Loan Rate											
Cotton	0.410	0.461	0.450	0.576	0.481	0.655	0.791	0.977	0.761	0.815	0.658	0.590
Cotton LR	0.525	0.525	0.525	0.525	0.525	0.520	0.520	0.520	0.520	0.520	0.520	0.520
Corn	2.43	2.22	2.84	3.68	4.63	3.72	4.37	6.23	6.94	5.05	4.30	3.80
Corn LR	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
Soybean	6.20	5.92	6.23	8.36	9.29	9.24	10.40	12.00	14.50	13.20	11.00	9.15
Soybean LR	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Information obtained from National Agricultural Statistic Service (NASS)

The next step in the evaluation process 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.

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 3. 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 3. 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.

In dealing with lessons to be learned from the Centennial Rotation, one must understand that nutrient removal is also important in determining the impact of the cropping system on the farm operation. As crops are removed, nutrients, especially, nitrogen (N), phosphorus (P), Potassium, (K), and sulfur (S) are removed with the harvested yield. While nutrient uptake is far greater than removal, what is removed is what must be accounted for. The total crop removal of N, P. K, and S has been summarized in Table 4 for each of the rotation systems. If one should begin to remove additional nutrients such as corn stalks for bio-energy uses, then the nutrient removal would be even greater. By introducing grain crops into the systems, nutrient removal can be doubled or greater depending on the frequency of cotton in the system verses the grain crops. There are differences in totals for the same systems (Example: Treatment 3 vs Treatment 4) that reflects differences in the crop yield from year to year.

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

To evaluate the economic impact of crop rotations, one must first determine the value of the crop being grown relative to the cost of growing the crop. To determine the value of the crop in this study, the values in Table 2 have been multiplied by the yields in Table 3. The higher value of loan rate was used for cotton in 2004-2006 to estimate the value of the crop. These calculations were made in a spreadsheet with the totals for each cropping sequence illustrated in Figure 1. The value of the system ranged from $8,266 for the continuous cotton system to a high of $9,774 in the cotton/corn rotation system. The actual values for the CT-CR compared to the CR-CT systems were $8,894 and $10,654, respectively (Figure 1). Those two values for the same system illustrates how different the value has been with varying prices for each year and the importance of having the both crops grown in the same year.

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.

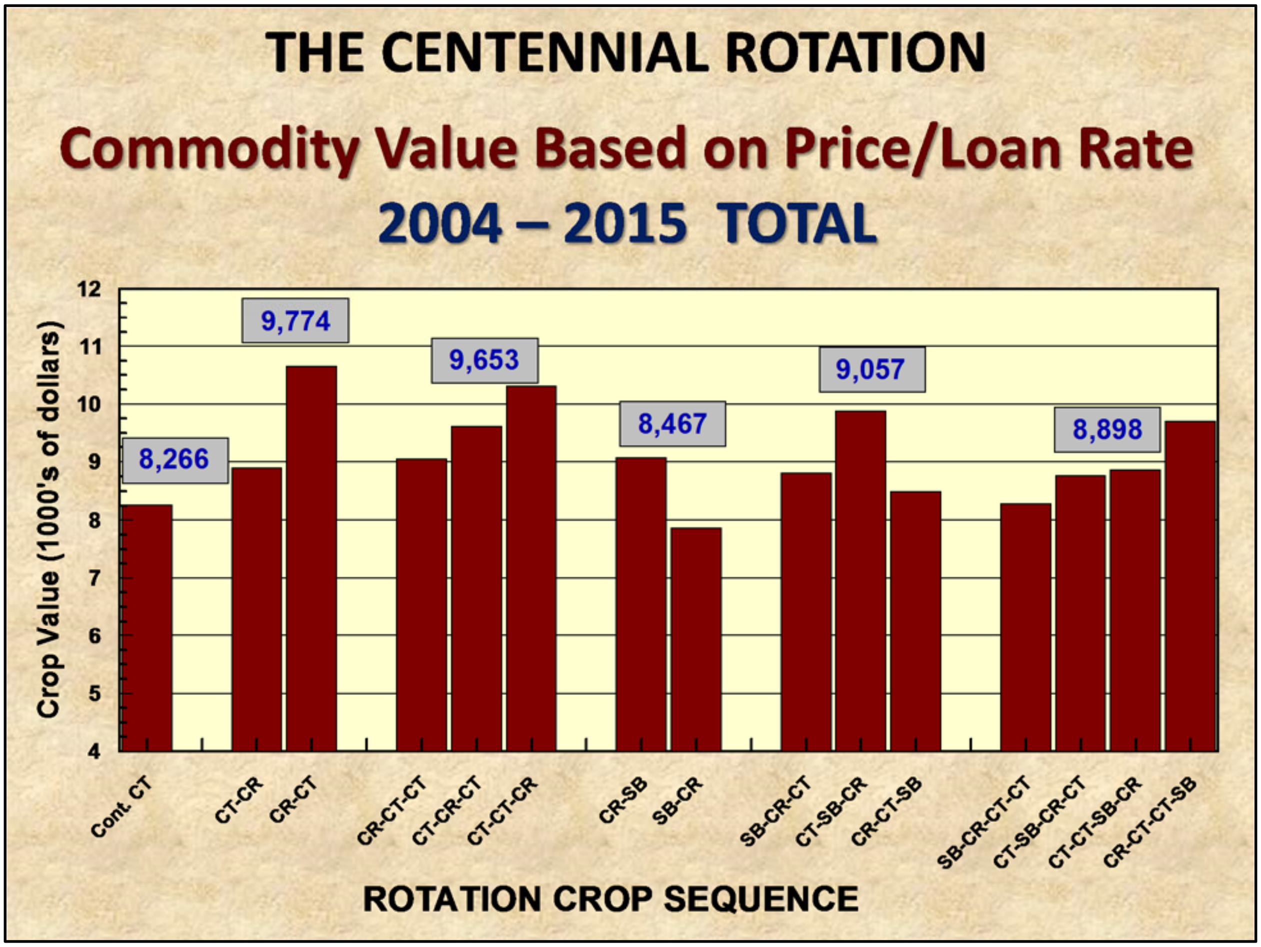

Figure 1: Summary of twelve years (2004 to 2015) of crop rotation systems value based on average marketing year prices or loan rates (higher of the two) and crop yields for specific rotation systems in the Centennial Rotation.

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.

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 implications are of the greatest importance to producers and will be the next phase of the data analysis. Annual cost of production can vary greatly from year-to-year depending on changes in the costs of inputs and the amount of inputs needed for a particular year. As an example, insect pressure may vary greatly across years as one particular insect may be difficult to control while insect pressure could be light in other years. Further economic evaluations will be forthcoming in the very near future.