The *Journal of Cotton Science 17:80–88 (2013)*
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# AGRONOMY & SOILS

## A Scan Level Cotton Carbon Life Cycle Assessment: Has Bio-Tech Reduced the Carbon Emissions from Cotton Production in the USA?

L. Lanier Nalley*, Diana M. Danforth, Zara Niederman, and Tina Gray Teague

### ABSTRACT

**Greenhouse gas (GHG) emissions are a growing concern for agricultural producers given increased pressure from government, consumers and retail purchasers. This study addresses the changes in greenhouse gas emissions in cotton over time (using years 1997, 2005 and 2008) due to changing production methods including tillage and seed technology. Time series data in this study comes from a single farm in Arkansas with detailed records of seed used, all inputs used (e.g. fertilizers, agrochemicals, irrigation), as well as machinery and tillage type for each of over 121 fields over 11 growing seasons. Results indicate yields increased dramatically (68%) over that time, due primarily to seed technology. At the same time, agrochemical use and fuel use decreased in 2008, primarily due to Bollgard II® Roundup Ready® Flex seed technology and the resulting reduced tillage. Reduced inputs can result in lower costs for producers, as well as reduced greenhouse gas emissions. Increasing yields with reduction in input use reduces the overall greenhouse gas emissions per pound of cotton produced, resulting in benefits to producers, consumers who demand such traits, and the environment. However, due to the proliferation of glyphosate-resistant pigweed (*Amaranthus palmeri*), the decreases in greenhouse gas emissions per pound of cotton that were observed over the past decade may be reversed.**

Agriculture creates a significant source of greenhouse gas (GHG) emissions, both in the United States (U.S.), and globally (Causarano et al., 2006; Lal 2004; Nelson et al., 2009; Robertson et al., 2000). Agricultural production directly emits approximately 6.3 % of U.S. GHG emissions according to the U.S. Environmental Protection Agency (EPA) (2011). When including all the upstream and indirect emissions from production of all farm inputs, the total value is probably significantly larger. Given increased consumer awareness and demand for products with lower GHG emissions coupled with the increasing reality of a government policy to lower net GHG emissions, row crop producers in the United States may have to adjust to both consumer demands and government requirements.

Wal-Mart corporation announced a potential plan to label each of its products with a sustainability index rating and has subsequently requested that every Wal-Mart supplier provide its GHG footprint, a direct measure of climate impact (Rosenblum, 2009). In response to consumer demand for “green” products, many companies already differentiate their products with GHG emissions reductions. The sustainability index may accelerate the adoption of GHG emission lowering practices by suppliers to Wal-Mart and increase the need to lower GHG emissions throughout the supply chain, including production agriculture. Kellogg’s recent carbon footprint assessment indicated that more than half of its products’ carbon emissions are attributed to production of ingredients; hence carbon footprint reductions up to the farm level are important (Kellogg’s, 2010). Agricultural producers and processing industries may increase GHG emissions efficiency in preparation for increasing downstream pressure from industry and greater consumer demand for “green” or “sustainable” food products, as well as mitigating a potential rise in fuel prices.

One way producers and industries can reduce their GHG emissions is through the adoption of imbedded seed technologies such as hybrid rice or transgenic cotton and corn. If adoption of imbedded seed technologies results in production systems that require fewer trips across the field or fewer pesticide inputs, then it is expected that there will be reduced GHG emissions per hectare and per pound of product produced. There are two distinct ways to reduce

L.L. Nalley*, D.M. Danforth, and Z Niederman, Department of Agricultural Economics and Agribusiness, University of Arkansas, 217 Agriculture Building, Fayetteville, Arkansas 72701; T.G. Teague, Arkansas State University, University of Arkansas Agricultural Experiment Station, 245 Agriculture Building, Jonesboro, Arkansas 72467
*Corresponding author: llnalley@uark.edu

GHG per pound of product produced: (1) increase yield per hectare, holding inputs constant and (2) decrease inputs per hectare while maintaining yield. Optimally, a decrease in inputs per hectare would accompany an increase in yield per hectare. Advances in cotton breeding have simultaneously captured the benefits of both GHG reduction methods. The introduction and adoption of Bt cotton (Bollgard®; Bollgard II®; Widestrike™), and glyphosate tolerant cotton (Roundup Ready®, Roundup Ready® Flex), cotton production appears to have become less input intensive while maintaining or increasing yields.

While studies exist on GHG emissions from cotton production, there is a void in the literature on what the effect of the adoption of advanced seed technology has had on total GHG emissions per hectare and GHG emissions per kg of cotton produced. Nelson et al. (2009) summarized multiple crops (including cotton) on a county level including three tillage scenarios, but did not address yield impacts. Tillage combined and other production practices and environmental conditions can increase GHG emission by as much as 2.5 times the amount emitted from no-till (Sainju et al., 2008). Yield is a key factor in farmer production choices and is the dominant variable in assessing efficiency and sustainability of crop production (Negra et al., 2008). Nalley et al. (2012) addressed county level emissions including yield results under different tillage practices on a national scale for one year in time; however, the authors did not address the impacts of different imbedded seed technologies. The goal of this project was to develop a cradle-to-gate[1] carbon equivalent (CE) footprint of cotton using a life cycle analysis (LCA) approach to GHG emissions across the range of seed technology available to cotton producers from 1997-2008. Rather than focusing on a national or regional scale, this study analyzed a single farm of approximately 2800 hectares with numerous production methods and detailed data records. The analysis provides the CE GHG generated in production of a mass(Kg) of cotton using a range of production practices associated with different seed technologies[2]. The objectives of this project were to (1) develop a Life Cycle Inventory (LCI) for cotton production by seed type, (2) estimate GHG emissions per hectare by seed technology and (3) estimate the GHG emitted per pound of cotton produced by seed technology.

Data were obtained from one farm in Northeast Arkansas (Mississippi County) from 1997 through 2008. This farm is typical of most Midsouth cotton farms in that the 1997 crop was all conventional cotton with the gradual adoption of transgenic seed technology, specifically those traits associated with herbicide tolerance and plant expression of insecticidal toxins. By 2005 Bollgard® Roundup Ready® was widely adopted and in 2008 Bollgard II® Roundup Ready® Flex was adopted. While data from all 12 years (1997 through 2008) were reviewed, only the three representative years were used. These three years represented significant milestones in commercial availability and grower adoption of transgenic technologies in that production region. By tracking input differences by seed type, required tillage practices, and yield differences across cultivars a comparison can be made between GHG emissions and an estimated GHG differential can be calculated per hectare and per pound of lint produced. Producers select cultivars based on their input and output attributes, but as a result of adopting this imbedded seed technology a positive externality may be the reduction of GHG emissions.

## MATERIALS AND METHODS

**Life Cycle Assessment**. LCA is a systematic, cradle-to-grave approach for the analysis of products and or processes generally focusing on one or more environmental impacts. LCA assesses a product's environmental impact from resource extraction (cradle) through production, processing, transportation, use and disposal (grave) or some segment of stages in between. This systematic approach is useful for determining environmental hot-spots within a production system. In addition, this approach works well to compare the environmental impacts of two or more similar products under the same scope of analysis. This analysis included all forms of power, direct and indirect, required to produce a unit (Kg) of cotton lint. Direct emissions are those emitted from on farm activities leading to carbon dioxide or other GHG emissions, such as burning of diesel fuel in tractors or irrigation equipment, and soil

1 Cradle-to-gate analysis means looking at the process including all of the inputs leading to the production. Typically Life Cycle Analysts will cut off those impacts that are below some threshold, for example less than 1% or 5% of total impact. Cradle-to-grave analysis includes the processing, transportation, use and disposal or recycling of the product.

2 Seed technologies included: conventional; Bollgard® Roundup Ready ®; and Bollgard II® Roundup Ready Flex®

nitrous oxide ($N_2O$) emissions from application of nitrogen fertilizers. Indirect emissions are those emissions caused due to inputs used on the farm, but emitted further upstream in the supply chain, such as emissions from power plants supplying energy to produce commercial fertilizer. This analysis included $N_2O$ emissions, but assumed soil carbon to be at equilibrium and thus assumed no net soil carbon emissions or sequestration.

The scope of this LCA includes GHG emissions of agricultural inputs involved in the production of cotton (e.g. fertilizer, herbicides, pesticides, fuel, agricultural plastics and other chemicals) and stops at the placement of seed cotton into a module builder. Emissions that are generated from ginning, transport or processing of cotton are excluded and assumed to be equivalent per pound regardless of seed type. Indirect carbon emissions as a result of upstream variable input production are included but emissions from capital equipment used on-farm are excluded.

Using actual application records from a single Northeast Arkansas farm with 113 fields, an estimate of direct GHG emissions from combustion of diesel and gas, $N_2O$ emissions from N-fertilizer as well as indirect emissions from embedded carbon in agrochemical, fertilizer and fuel inputs can be obtained. As such, estimates of average emissions per hectare and per kg yield weighted by their area for three growing seasons can be elicited. Years differed primarily by cotton seed type and tillage method but irrigation type and agronomic conditions were held as constant as possible.

Fuel use was estimated for each piece of equipment using the Mississippi State Budget Generator. Based upon equipment type, accessory, speed, efficiency, and other factors, liters of diesel used per hectare were estimated for each farming application (e.g. tilling, planting, spraying, harvesting). The derived fuel amount was multiplied by the number of passes through the field for each type of application required by each seed type. In cases where there were multiple applications in one pass, such as insecticide combined with a pesticide, the fuel use was allocated in part to each type of application in order to avoid double counting. In this way, the representative emissions from each type of farm application could be estimated. Fuel use was standardized across years to assume the same tractor efficiencies. This allowed for a comparison of differences in production practices from 1997 to 2008, without including the change in machinery efficiencies over time. For example, it was assumed that the same model tractor was used for spraying in 1997 as 2005 and 2008. However, in each year, under different production methods, the number of times a field was sprayed differed.

Most fields were irrigated, however, approximately six (less than 5%) each year were not irrigated. These fields were not the same every year. Therefore, dryland area was removed to avoid bias due to different fields being irrigated by year. The large number of fields provided good variety for statistical purposes. There was limited information on quantity of water and energy used for irrigation. However, it was assumed that all fields that were irrigated were irrigated equally, regardless of seed type or production method. Thus, while irrigation may play a significant role in the overall carbon footprint, it would not have a differentiating impact with respect to different seed types or production methods. Given the fact that only one farm is being analyzed and the climatic differences (mainly rainfall) between fields in one farm should be minimal it was assumed this was a fair assumption. Thus, the rainfall and other climatic variables that dictate irrigation decisions would be roughly equivalent across all fields. Reduced tillage may lead to reduction in water demand in cotton (Karamanos et al. 2004), and thus lower the carbon footprint from water pumping. By not assuming any GHG reduction from reduced tillage, the benefits of reduced tillage are thus considered more conservative in this paper.

Carbon equivalent (CE) emission factors came from numerous sources. Diesel and gasoline combustion came from U.S. EPA (2011), while the upstream, or indirect emissions, for fuel use came from Ecoinvent 2.0 (2009). Indirect emissions from the production of nitrogen, phosphorous and potassium fertilizers came from Lal (2004) (Table 1). While the specific formulations for each fertilizer application were provided, generic N, P and K carbon emission values were used. Similarly, generic herbicide and insecticide values also came from Lal (2004). While there are numerous values for specific herbicides and insecticides, the list is not complete. Therefore, we used a generic value, based upon the active ingredient of each pesticide. We used the herbicide value for defoliant and the insecticide value for fungicides and growth regulators, as these values seemed most representative. In any case, the pesticides represented a small portion of the overall carbon footprint. The value for boron came from Ecoinvent 2.0 (2009).

**Table 1. Carbon Equivalent Values for Production Inputs**

| Input | Carbon-equivalent | | Source |
|---|---|---|---|
| Fuel | | | |
| Diesel | 0.84 | kg C/l | US EPA 2011, Ecoinvent 2.0 2009 |
| Gasoline | 0.78 | kg C/l | US EPA 2011, Ecoinvent 2.0 2009 |
| Fertilizer | | | |
| Nitrogen | 1.30 | kg C/kg | Lal, R. 2004 |
| Nitrogen N2O | 1.28 | kg C/kg | Snyder 2009, IPCC 2007 |
| Phosphate | 0.20 | kg C/kg | Lal, R. 2004 |
| Potash | 0.15 | kg C/kg | Lal, R. 2004 |
| Lime | 0.06 | kg C/kg | West and McBride 2005 |
| Herbicide | 6.30 | kg C/kg | Lal, R. 2004 |
| Insecticide | 5.10 | kg C/kg | Lal, R. 2004 |
| Fungicide | 5.10 | kg C/kg | Using Insecticide Value |
| Defoliant | 6.30 | kg C/kg | Using Herbicide Value |
| Growth Regulator | 5.10 | kg C/kg | Using Insecticide Value |

Soil nitrous oxide is a major contributor of GHG emissions from crop production (Bouwman, 1996; Del Grosso et al., 2005). While nitrous oxide emissions from nitrogen fertilizer vary widely based upon soil type, temperature, moisture, application methodology and timing, etc. (Snyder et al., 2009), we assumed 1% of the nitrogen applied to the field converted to $N_2O$ emissions, based upon IPCC Tier 1 methodology (IPCC, 2007).

Agriculture has the potential to sequester atmospheric carbon. Sequestration can occur in the root mass and woody debris if tilled back into the soil. Additionally the agricultural product itself can sequester carbon (Baker et al., 2007; Franzluebbers, 2005; Johnson et al., 2005; West and Post, 2002). Tillage methods, cropping rotations and soil type all can impact sequestration potential (Causarano et al., 2006). Nalley (2012) found that soil type played the greatest role in affecting the levels of sequestration. For this analysis, in large part due to the soil type being the same or very similar on all fields and over time, it was assumed soil carbon remained at equilibrium and so there was no net carbon sequestration or soil $CO_2$ emission.

**Yields.** Yield per hectare was provided for each field from actual on-farm data across the eleven-year period. However, given that yield in a given year depends not only upon inputs and cultivation practices, but also on environmental factors such as temperature, rainfall and pest pressure, yield was adjusted for the representative years to account for higher or lower production levels than typical. Yield adjustments were made by first fitting a regression line of average annual yield (kg lint per hectare) for the farm as a function of year, 1995 through 2009. By regressing yield per hectare as a function of time (which can be viewed as a proxy for technological change) any deviations from the mean would indicate those variables not associated with technological change, namely weather anomalies. Yields for each of the fields (95 in 1997, 121 in 2005 and 112 in 2008) for those years were then seasonally adjusted by adding the model intercept and subtracting the model slope. A model using those adjusted yields was estimated with binary variables for each of the years, constrained so that the estimates summed to 0. The estimates therefore represent the deviation of yields in each year from the seasonal trend. Those deviations were used to adjust all yields in that specific year: -20.2kg in 1997, +91.0kg in 2005 and +65.1kg in 2008. This represents a 2% yield adjustment to the actual average yield in 1997 (915 kg per hectare), a 6.6% increase to the actual average yield in 2005 (1369kg per hectare) and a 4.3% increase to the actual average yield in 2008 (1485 kg per hectare). These adjustments were relatively small, indicating that the evaluated years were typical of the yield trend observed on the farm.[3]

3 The Adjusted R-Square was 0.6 when fitting a linear form. Obviously it was not a perfect linear relationship but the yields trended up across time, most likely in a stair step form for technological changes. There was only one observation per year so this methodology did not allow the authors to estimate alternative functional forms. The field-level yields were then adjusted by the model intercept and the estimated year coefficient. A new model was estimated with the adjusted yield as a function of year dummy variables with coefficients constrained to sum to zero. The coefficient for each of the three analyzed years could then be interpreted as a difference from the yield trend and was used as a constant to adjust observed field-level yields within each of the years. A salient point is that the yield adjustments were quite small which indicated that the selected years were representative and not outliers due to uncontrolled factors such as weather.

**Production Practices**. Conventional cultivars were grown under conventional tillage in 1997. No-till and reduced tillage were used in 2005 and 2008 with the adoption of the newer seed technologies. Varieties sown in 2005 were Bollgard® Roundup Ready® and in 2008, cultivars sown were Bollgard II® Roundup Ready® Flex. Bollgard® technologies can reduce insecticide applications required to control certain caterpillar pests and Roundup Ready® technologies can reduce the number of herbicide applications and tillage operations.

Production records were available for 86 irrigated fields representing 2,181 hectares in 1997. All of the fields were planted in conventional cultivars that included BXN 47, DPL 51, DPL 5111, LA 887, SG 747, ST 373 and ST 474. While these conventional cultivars all had different attributes (seed treatments, etc.) none had the Roundup® or the Bollgard® gene associated with them. Tillage practice on all of the fields was conventional. Thus this is considered to be the baseline year given that it has the least amount of seed technology. Fuel use estimates were made for planters and pickers in addition to equipment to cut stalks, rip, hip, disc, cultivate, fertilizer application and spray (boom and hood). Carbon equivalents were computed for active ingredients in applied fertilizers (nitrogen, phosphorus, potassium, sulfur, boron), fungicides (Ridomil®), insecticides (Temik®, Guthion®, Dimethoate®, Karate®, Orthene®, Vydate®), herbicides (2-4 D, Bladex®, Fusilade®, Gramoxone®, Meturon®, MSMA, Prowl® 3.3, Roundup®, Select, Staple®), plant growth regulators (Pix®), defoliants (Def®), and boll openers (Prep®). There were no records for phosphorous (P) or potassium (K) in 2008, so an average of 1997 and 2005 was used as it is typical to use P&K and not including these would bias the results, since this decision would be made based upon soil tests and not production methods. Records were kept for each field such that GHG emissions could be calculated for each field under varying production practices.

Production records were available for 113 irrigated fields representing 2,895 hectares in 2005. Most of the planted cultivars included the Bollgard® imbedded seed technology and all were Roundup-Ready® cultivars. Cultivars included DP 444 BR, ST 4793 R, ST 4575 BR, ST 4892 BR, ST 5242 BR and ST 5599 BR. No-till was practiced on 44 fields and ridge-till was practiced on 67 fields. In most cases, a winter wheat cover crop was planted in the row middles on the ridge-till fields. The inputs associated with the wheat cover crop were also taken into account because the wheat was planted to provide a wind break and not for grain. Two fields were not classified by tillage type and were thus removed. Fuel use estimates were made for planters and pickers in addition to equipment to cut stalks, rotary hoe, hip (disk bedders), terratill (deep tillage), roll, and spray (boom and hood). Carbon equivalents were computed for active ingredients in applied fertilizers (nitrogen, phosphorus, potassium, sulfur and boron), insecticides (Ammo® 2.5, Baythroid®, Bidrin®, Capture® 2EC, Centric®, Intrepid®, Kelthane®, Orthene® 90S, Temik® 15G, Tracer®, Zeal®), herbicides (Glyfos® Xtra, glyfosate, Harmony® Extra, Ignite®, Valor®), plant growth regulators (Pix®), defoliants (Def®, Dropp®), and a boll opener (Prep®). Agrochemicals were each given a generic CE value based on their active ingredient and by functional class (Insecticides, herbicides, plant growth regulators, defoliants and boll openers).

Production records were available for 102 irrigated fields representing 2,702 hectares in 2008. Most planted cultivars included the Bollgard II® imbedded seed technology and all were Roundup Ready® Flex cultivars. Cultivars included AM 1550 B2RF, DP 901 B2RF, DP 902 B2RF, ST 4554 B2RF, ST 4664 RF, and ST 5458 B2RF[4]. No-till was practiced in 57 fields and 44 fields were ridge-tilled in fall with wheat cover crop in the row middles. One field was unclassified and thus removed. Fuel use estimates were made for planters and pickers in addition to equipment used to terra-till, prepare beds, run middles, and spray (boom). Carbon equivalents were computed for active ingredients in applied fertilizers (nitrogen, phosphorus, potassium, sulfur and boron), insecticides (Ammo® 2.5, Bidrin®, Carbine®, Portal®, Temik® 15G), herbicides (Aim®, Banvel®, Direx® 4L, Dual®, Extra Credit® 5, Glyfos® Xtra, Gramoxone Inteon®, Ignite®, Roundup Ready® Valor®), plant growth regulators (Pix®), defoliants (Dropp®, Folex®, Free Fall®), and boll openers (Super Boll®).

4 Several large farms in Northeast Arkansas were contracted by DP to grow lines for seed in 2008. DP 901 as grown on the farm in 2008 became DP 0920 and DP 902 became DP 0924 in 2009.

## RESULTS

Indicated in Table 2 is that on a carbon equivalent per hectare of production basis, which is solely a function of input usage and not yield, GHG emissions decreased over time. For example, in 2008 87% of all the fields in the study had a CE per hectare less than 550 kg compared to just 1% and 2% in 1997 and 2005, respectively.[5] Furthermore when looking at the percentage of hectares in the study with a CE under 625 kg, all area under cultivation in 2008 qualified and only 78% and 58% qualified in 1997 and 2005, respectively. These differences can be explained by the adoption of new seed technology, which altered production practices and thus input usage. This phenomenon is illustrated in Figure 1, where the amount of diesel fuel usage (a function of passes in the field to apply inputs) is decreasing over time. It is worth noting in 2005 some input usage is higher (nitrogen fertilizer and some agrochemicals) than the baseline of 1997.The fertilizer usage is a function of soil dynamics over time, price and yield potential. In so much as there is a greater yield potential with new seed technology, there may be greater demand for fertilizer. Not only has the amount of agrochemicals decreased over time, so has its variance from one field to the next. This would make intuitive sense, with conventional cotton with no Bollgard® one would have to spray only the infested fields but not others. In the interval from 1997 to 2005, the Arkansas Boll Weevil Eradication Program had essentially eliminated the boll weevil from this production area. Boll weevils were not significant pests in Northeast Arkansas as in other parts of the state because of winter kill and limited overwintering habitat, but there were reductions in insecticide use associated with eradication. Although the pest pressure was historically low in the production area, insecticide was applied for boll weevil control (as well as for secondary pest outbreaks following insecticide applications for boll weevil).

5 It should be noted that these CE/ac do not account for diesel used in irrigation which would add to total emissions. The study also omits the amount of carbon which is sequestered through cotton production that would subtract from net carbon emissions.

**Table 2. Percentage of Fields within a Given Carbon Equivalent Range Per Hectare.**

| (kg CE/ha) | 1997 | 2005 | 2008 |
|---|---|---|---|
| Less than 500 | 0 | 0 | 19 |
| 525 | 0 | 0 | 40 |
| 550 | 1 | 2 | 28 |
| 575 | 24 | 1 | 2 |
| 600 | 45 | 37 | 8 |
| 625 | 7 | 19 | 4 |
| 650 | 8 | 1 | 0 |
| 675 | 1 | 7 | 0 |
| 700 | 9 | 30 | 0 |
| 725 | 3 | 4 | 0 |

**Number of fields for 1997= 86, 2005= 113 and 2008= 106.**

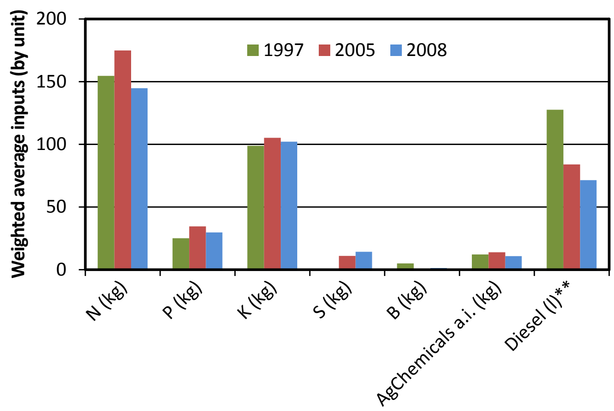


**Figure 1. Weighted Average Inputs for Production by Year**
****Fuel Use Using Standardized Equipment**

This leads to purchasing uncertainties for producers. Given the introduction of Bollgard® and Roundup Ready® cultivars as well as completion of the boll weevil eradication program, the standard deviation of agrochemical usage decreased from 3.09 (kg per hectare) to 0.39 to 0.22 from 1997, 2005, and 2008, respectively (Table 3). What is evident is that the input usage amounts and subsequent carbon equivalent per hectare are lower in 2008 than in 2005 and in 1997. This is attributable to the input saving production practices brought about by the adoption of seed technology conservation tillage with reduced number of herbicide applications and tillage passes in the field. While this in itself is encouraging news for the environment it is ignoring the gains in yield brought about by seed technological advancements. While CE per hectare is important it ignores the productivity of a field and thus how efficient a producer is at using each unit of GHG. Thus, the ratio of kg of GHG per kg of cotton is a more holistic view of GHG reduction progression through time.

Table 3 highlights the yield enhancements from 1997 to 2008. Compared to the average 1997 yields of 923 kg lint per hectare yield increased by 52% and 66% in 2005 and 2008, respectively (Table 3). This is important given the reduction in input usage from a GHG standpoint. Yielding more with less is not only advantageous from an economic standpoint but from a GHG standpoint as well. The ratio of CE per kg of cotton is a more holistic measure of GHG improvements than CE per hectare alone because it captures changes in both inputs and outputs. There are many factors that contribute to higher yields (management practices, more efficient use of inputs, climatic issues) along with advanced breeding and imbedded seed technology. Advancements of seed technology alone certainly do not account for the entire growth in yield over time, but they likely account for a large portion. Additionally, weed control advancements were accomplished simply by a post-emergence application of the Roundup herbicide on Roundup Flex cotton rather than more time-consuming tillage operation. This weed management option allowed producers to move rapidly from crop establishment to "lay by". At that point they could begin to apply irrigation, which allowed them to avoid water deficit stress in the critical period prior to first flower. It is important to note that yield potential is set by the plant structure at first flower. In a conventional tilled field, often the crop was stressed because producers were spending their time killing weeds (and sometimes by insects not controlled by BT, such as boll weevil) rather than allocating time to best management practices.

**Table 3. The Average and Standard Deviation of Yield, GHG Emissions (CE) per Hectare, CE Per Kilogram of Cotton Produced, and use of Agricultural Chemicals per Hectare.**

| | 1997 | 2005 | 2008 |
|---|---|---|---|
| **Average Yield (kg/ha)** | **923** | **1395** | **1490** |
| ***St Dev of Yield (kg/ha)*** | ***133*** | ***272*** | ***335*** |
| **Avg CE kg/ha** | **602** | **630** | **522** |
| ***St Dev CE kg/ha*** | ***41*** | ***45*** | ***34*** |
| **Avg CE kg/kg of Cotton** | **0.67** | **0.47** | **0.34** |
| ***St Dev CE kg/kg of Cotton*** | ***0.10*** | ***0.09*** | ***0.05*** |
| **Avg kg Ag Chemicals/ha** | **5.5** | **6.3** | **4.9** |
| ***St Dev kg Ag Chemicals/ha*** | ***3.09*** | ***0.39*** | ***0.22*** |

**Carbon Equivalent Per Kilogram of Cotton.** The amount of GHG (CE) to produce one pound of cotton has steadily decreased from 1997 to 2008. Again, this is a function of increased yields and decreased inputs. In 1997 (with conventional cultivars) it took approximately 0.67 kg of CE to produce one kg of cotton lint. That number decreased 29% to 0.47 kg of CE in 2005 (with Bollgard® Roundup Ready® cultivars), and decreased 49% (compared to 1997) to 0.34 kg of CE in 2008 (with Bollgard® Roundup Ready® II). Figure 2 illustrates that 99% of fields in 2008 had a CE per kg of cotton lower than 0.5 compared to 67% in 2005 and just 3% in 1997. By any standards, this is a significant reduction in the amount of GHG required in cotton production. While the absolute values of these numbers may not be precise given the exclusion of irrigation (increase CE and thus increase the CE per kg of cotton) use and carbon sequestration (decrease CE and thus decrease the CE per kg of cotton) the relative difference between the values should.[6] The precise amount of the reduction that can be attributed to imbedded seed technology warrants further work but given that the adoption of newer seed technology led farmers to change their production practices in a holistic view, a large portion of this GHG reduction can be attributed to the entire "technology package". That is, imbedded seed technology such as Bollgard® can lead to fewer foliar insecticide applications which leads to a lower GHG emissions per hectare. So, by adjusting to the new seed technology through changes in production practices four things are apparent from this study:

1. Input usage has decreased per hectare.
2. Yield has increased per hectare.
3. Because of point (1) GHG emissions per hectare have decreased.
4. Because of points (1) and (2) GHG emissions per pound of cotton have decreased.

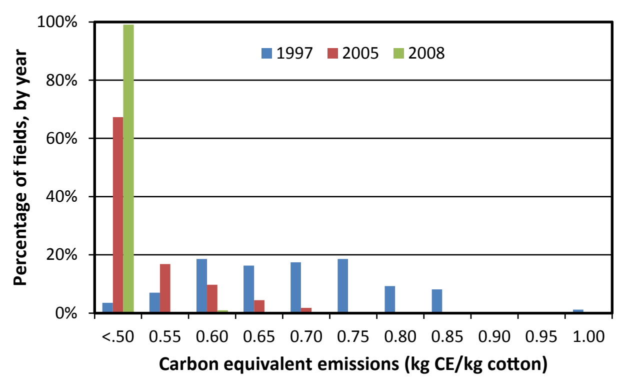


**Figure 2. Percentage of Fields within a Given Carbon Equivalent per Pound of Cotton Yielded**

6 This assumes that all acres on a farm are irrigated equally and that all cotton within a field sequesters the same amount of atmospheric carbon.

## CONCLUSIONS

Many agricultural commodity groups are becoming aware of the increased consumer, industry, and government pressure to reduce GHG emissions. It just takes one of these three entities to gain enough momentum to bring about changes in agricultural production. This study analyzes technological change in imbedded seed technology from 1997 through 2008 for one farm in Northeast Arkansas with over 100 fields of monoculture cotton. While producers did not adopt these new cotton cultivars based on their carbon emissions, they did adopt them based on their input requirements, which is directly tied to carbon emissions. That is, the producer's main motive for seed adoption is driven by profitability not GHG levels. This study concludes that while profitability is the motive, a positive externality of the adoption of imbedded seed technology (Roundup Ready®, Bollgard®, etc.) has been a reduction in GHG emissions both from a per hectare and per pound of cotton produced standpoint.

From a GHG emissions per hectare standpoint the conventional cultivars planted in 1997 averaged 81 kg of CE more than in 2008 with Roundup Ready® Bollgard II® (602 kg/ha versus 521 kg/ha ). While this is encouraging news it is not the complete story. Yields from 1997 to 2008 increased from an average of 923 kg/ha to 1490 kg/ha. By any standard this is a large gain in yield, although the total increase in yield cannot be attributable to improved seed technology alone. Given, the large increase in yield and the relatively large decrease in GHG emissions per hectare the comprehensive CE/kg of cotton ratio can be calculated and compared. The most telling conclusion form this study is that the GHG emitted, in its carbon form, to produce one kg of cotton has decreased by 49% from 1997 to 2008. While the results of this study are from only one farm, this farm is representative of the Midsouth in adoption of technology and representative of best management practices for Northeast Arkansas.

One potential issue of concern for the future is the high incidence of glyphosate resistant Palmer amaranth (*Amaranthus palmeri*). Glyphosate has been a major factor in allowing farmers to employ many conservation tillage practices, and reduce the number of trips required across the field. Given the proliferation of glyphosate resistant Palmer amaranth, producers in the Midsouth have returned to utilizing residual herbicides, and some producers have begun to reincorporate some tillage practices in pigweed control programs. Producers may still not see yield reductions, but they may see increased levels of greenhouse gas emissions per hectare because of challenges with pigweed control. Crop rotation to Liberty Link and other glufosinate resitant cotton varieties is one resistance management tactic.

## ACKNOWLEDGEMENT

The extensive farm production records used in this study were provided by David Wildy, Wildy Farms, Leachville, AR. We thank Mr. Wildy for his long term and continuing support of applied agricultural research in Arkansas. Justin Wildy and Dale Wells, Les Goodson and other Wildy family and Wildy Farms staff members are acknowledged for their assistance with access to and interpretation of the production and operations data. The authors thank the Cotton Incorporated Arkansas State Support Committee for providing funding for this study.

## DISCLAIMER

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the University of Arkansas.

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