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Greenhouse Gas Emissions Labeling for Produce: The Case of Biotech and Conventional Sweet Corn

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Abstract

Agriculture's significant global contribution to greenhouse gas (GHG) emissions has spurred consumer and retailer mitigation interest. Biotechnology, designed to enhance the marketable portion of yield via improved disease, weed and pest management with the same or lower use of inputs, is thus well positioned to gain from producer and consumer concerns about GHG emissions. Compared to conventional sweet corn, identical lines embedded with insect control showed statistically significant higher marketable yield and no effect to lesser insecticide application. Pending seed cost and consumer acceptance of biotechnology, this should enhance returns for producers and allow marketing of multifold, consistent declines in GHG per ear.

Keywords: greenhouse gas emissions, sweet corn, agriculture, biotechnology

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Introduction

Agriculture has been reported to be a significant source of GHG emissions, both in the US and globally (Causarano et al. 2006; Robertson et al. 2000; Lal 2004; Nelson et al. 2004). The US EPA (2009) estimated that approximately 6.3 percent of US GHG emissions come directly from agricultural production. From a life cycle perspective, however, the total value is probably significantly larger, since the life cycle approach accounts for the inputs used on farm as well as the emissions from the production of said inputs.

Comprehensive U.S. climate change legislation had never been closer to law than the House passage of the Waxman-Markey bill in 2008. Despite the death of the bill in the Senate, the White House, the United States Department of Agriculture (USDA), and the Environmental Protection Agency (EPA) continue to support carbon reduction initiatives. Perhaps more importantly, agricultural producers face increasing demand to reduce GHG emissions associated with crop production from consumers, non-governmental organizations, and from the retailers of their product. Eco- and carbon-labeling is on the rise; 34 carbon footprint labels existed globally in 2009 and the number is increasing (Baddeley 2011). One survey found that 56.3% of US consumer respondents and 64.4% of UK respondents desired climate impact information on their products (Bolwig and Gibbon 2010). While US consumer demand lags that of UK and Europe as a whole, agricultural producers that supply to global markets can expect to face increasing pressure from abroad regardless of US demand or regulations.

Walmart has announced a potential plan to label each of its products with a sustainability rating and has subsequently requested that every Walmart supplier provide its GHG footprint, a direct measure of climate impact.[1] The Carbon Trust, a not-for-profit entity in the UK, has already labeled over 2,800 products for carbon emissions (Bolwig and Gibbon 2010). Tesco, the British-based supermarket chain, has begun carbon labeling some of its products and intends to expand efforts to all 70,000 of its products (Bridges 2008). Both Japan and France have trial governmental programs in place for carbon labeling (Baddeley 2011). At the same time, the International Standards Organization (ISO) has been developing an international standard (ISO 14067) on carbon footprinting (Baddeley 2011). This will make it easier to create a common footprint value and label, which may reduce consumer confusion and uncertainty, and increase demand for low carbon products. With all of these efforts coming from different segments, one can expect that there will be growing pressure from numerous angles to reduce carbon emissions for agricultural products.

Producers are experiencing GHG polices at the field level as well. For example, since 2007, the California Rice Commission (CRC) has worked with the Environmental Defense Fund (EDF) to reduce the methane emissions associated with California rice production. As a result, a list of management practices that can reduce methane emissions are under review by the American Carbon Registry and the Verified Carbon Standard to allow California rice producers to participate in voluntary carbon offset markets. Also, Kellogg's, a large purchaser of U.S. rice, is working with Louisiana rice producers in various pilot programs aimed at increasing sustainability of

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[1] See http://walmartstores.com/Sustainability/9292.aspx for more information on Wal-Mart's "Sustainability Index."

rice destined for use in Kellogg's products.[2] Large purchasers of commodities are now directly working with industries or cooperatives to source commodities that have a "green advantage" so they can use them to market their goods as such.

Use of biotech sweet corn (Seminis® or Performance Series™ Sweet Corn, abbreviated as PSSC here) to enhance GHG efficiency in agricultural production is potentially an effective way to lower GHG emissions per acre and per unit of output for sweet corn production. Fresh sweet corn provides an interesting case study for biotech vs. GHG interactions because of: 1) the high reliance on insecticides to combat ear worms and other similar pests; 2) the high incidence of down grading and waste in fresh corn markets due to insect damage; 3) PSSC's embedded insect control lessening damage and reducing or eliminating the need for insecticide applications which can lower GHG emissions per acre while maintaining or increasing marketable yield per acre. Greenhouse gas emissions from insecticides make up only a small percentage of total greenhouse gas emissions from production, and so a reduction in pesticides will have a relatively small impact on total greenhouse gas emissions. Nevertheless, a reduction in pesticide use carries many other significant environmental benefits. Thus, if marketable yield remains constant or increases and GHG emissions per ear decrease then the ratio of marketable ear per unit of GHG emitted declines.

Field corn has been analyzed in depth from a life cycle perspective (Kim and Dale 2003; Landis et al. 2007; Shapouri et al. 2002; West and Marland 2002). Greenhouse gas emission estimates ranged from a low of 157 lbs Carbon Equivalent (CE)/ac (West and Marland 2002) to a high of 616 lbs CE/ac (Kim and Dale 2003). However, relatively little literature exists with respect to sweet corn production and its effects of different production practices on life cycle and GHG impacts. While comparisons can be made between sweet corn and field corn on a per acre basis, the two are very different products and are hard to compare on a per unit basis. Field corn kernels are stripped at the field, and measured by the bushel in dry weight which can have ear worm damage. Sweet corn is harvested and boxed by the ear. Worm and pest damage only affects the kernels damaged in field corn, whereas with sweet corn, a small damage to the ear percentage-wise may result in complete wastage and thus reduced marketable yield. Therefore the seed stock used and the pesticides used vary from field corn to sweet corn.

Production practices (irrigation, tillage, cropping systems, and fertilization) can affect GHG generation by as much as a factor of 2.5 (Sainju et al. 2008). In addition, seed variety and technology affect the level of inputs required, as well as the effectiveness of such inputs on yield and yield loss. Marketable yield, the portion of ears harvested that is deemed marketable, is a key factor in producer production choices and is the dominant variable in assessing efficiency and sustainability of crop production (Negra et al. 2008).

The objectives of this study were thus to 1) conduct a life cycle inventory from pre-plant tillage to harvest to arrive at estimates of the carbon-equivalent (CE) GHG emissions of production practices for conventional vs. PSSC sweet corn as adapted to the main sweet corn producing regions across the U.S.; 2) to showcase the relative contribution to total GHG emissions of

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[2] See http://deltafarmpress.com/rice/sustainability-rice-farming-lsu-agcenter-kellogg-co-collaborate for full information.

insecticides, fungicides and herbicides (agro chemicals), fuel use for production and irrigation, and finally fertilizer including N_2O emissions from fertilizer application; 3) determine the impact of reducing the number of insecticide applications on marketable yield; and 4) quantifying CE per acre and per ear of sweet corn along with GHG uncertainty as affected by weather related differences in irrigation and number of insecticide applications. Results should provide marketing insights for retailers and producers considering the adoption of PSSC about what to expect in terms of GHG footprint per ear.

Data and Methodology

Locations and Trials

Data from university and private farm field trials that were performed at 10 locations in the Southeast and Midwest during the fall of 2009 continuing through the summer of 2010 were provided by Monsanto. These locations included two locations in Wisconsin (Cambridge and Verona), Florida (Felda and University of Florida at Belle Glade), Illinois (Hinckley and University of Illinois at Urbana), two locations in Georgia (University of Georgia at Leesburg and Tifton), Mississippi (Leland), North Carolina (Maxton) and Ohio (Ohio State University at Fremont). Corn was planted seasonally, such that there were spring or fall harvest seasons, primarily in the southern locations, and a summer harvest season for the northern locations. At Felda, Florida, corn was harvested in both the spring and the fall. Hinckley, Illinois, University of Illinois, Ohio State, and Cambridge were not included due to lack of production input data. Maxton was excluded as irrigation was terminated prematurely.

Experimental Design

Ultimately, for purposes of statistical comparison, the locations were segregated into two trials, a "variety trial" and a "regional trial." The variety trial consisted of four season/location combinations: Felda Fall, Felda Spring, UGA Fall at Leesburg, and Mississippi Fall. The main effect for the variety trial was insecticide use, with treatment levels varying from either zero applications (ZERO), to once every 48 hours (FULL) after tasseling, or once every 96 hours (HALF) after tasseling. The sub-effects were sweet corn hybrid (Obsession® vs. Passion®) and seed technology (conventional – (CONV) vs. biotech – (PSSC)). The data for these locations were balanced with two replicates for a total of 96 yield observations.

The "regional trial" consisted of three locations and two seasons (UGA Spring at Tifton, UFL at Belle Glade Spring and Verona Wisconsin Summer). The regional trials were arranged as split plots with the main effect of insecticide and sub-effect of seed technology. Passion® was the only variety used in the regional trials. This set of experiments was replicated four times but the data set was not balanced since the HALF insecticide treatment was not performed at Wisconsin. 64 yield observations were analyzed for these comparisons.

Herbicides

All seed was treated with Cruiser 250 which provides protection against pythium and fusarium fungal diseases using fludioxonil, mefenoxam, and azoxystrobin as well as secondary soil insect pests using thiamethoxam, excluding rootworm and billbug. All locations had Bicep II Magnum (s-metolachlor and atrazine) applied as a pre-plant herbicide. Some locations used only Impact (topramezone) as a post-plant herbicide, while other locations (Felda, Maxton, Leesburg, Leland) also tested Roundup on the biotech seeds given their herbicide tolerance to glyphosate as well as no post-emergent herbicides on the conventional seeds. Only yield data using Impact as a herbicide was used in this study to ensure appropriate comparison between conventional and biotech seed as Roundup would lead to plant injury for the conventional seed and herbicide effects were not the primary goal of this study.

Marketable Ears

Data collected included yield, as well as input use. Yield measures included total ears from harvested area, marketable ears, marketable ears husked (out of 10 ear subsample), ears with worm damage (out of 10 ear subsample), and ears with poor pollination (out of 10 ear subsample). In addition, data included ear diameter and ear length as well as plants harvested per plot. Marketable yield per acre was calculated as total ears harvested multiplied by percentage of ears without worm damage divided by plants harvested and then multiplied by the targeted 23,000 plant population per acre. The percentage of ears without worm damage was taken as a subsample of 10 ears selected at random from each trial plot. Data was also collected on ears with low pollination, but because the purpose of this biotech seed technology is primarily to prevent worm damage, and because poor pollination is not the target of this seed technology, it was deemed irrelevant in this study. Further, consumer rejection of corn is more likely due to worm damage than due to poor pollination.

Ear Size

Sensitivity tests were performed to see if using ear diameter and ear length in the yield calculations made significant differences in the results. The range of differences when using diameter and length resulted in approximately 5% differences in total yield expressed in terms of volume rather than ears. However, seed technology, variety, and insecticide effects were much greater, in some cases by an order of magnitude. Therefore, given the complexity of the formula, with little added benefit, length and diameter measurements were not used in the yield calculations.

Fertilizer and Irrigation

Inputs monitored were nitrogen (urea and ammonium nitrate), phosphate, and potassium. In addition, all insecticides, herbicides and fungicides were included based upon available information from field trials and included quantification of active ingredients of insecticides and the number of trips across the field for application of all inputs. Seeding rate was standardized to achieve a target plant density of 23,000 plants per acre at harvest. Irrigation amounts applied, expressed in acre-inches (ac-in), were determined based upon ranges from production budgets available from state extension specialists and by budgets provided by Monsanto.

It was assumed that irrigation was applied to maximize yield. Because rainfall varies from year to year, and the year under study may have been above or below average, irrigation quantities for each location were simulated using a triangular distribution. Minimum, most likely, and maximum values for these distributions were verified by phone with state specific sweet corn specialists. Florida primarily uses furrow irrigation while the other states primarily use center pivot irrigation. Each method requires different levels of energy for water delivery (Tables 1 and 3).

Table 1. Inputs for each production practice and location (quantities per acre).

		UF FL Spring	**Felda FL Spring**	**Felda FL Fall**	**GA Fall**	**WI**	**MS**
Nitrogen: Urea	lb	200	200	200	0	0	0
Nitrogen: Ammonium Nitrate	lb	0	0	0	113	150	160
Phosphorus	lb	150	150	150	65	25	50
Potash	lb	300	300	300	65	40	80
Fungicide	oz	17.8	0.0	0.0	0.0	1.4	4.5
Insecticide	oz	4.1, 3.1, 0	17.8, 16.7, 0	53.4, 25.9, 0	87, 49, 0	0.9, *, 0	73.2, 44.7, 0
Applications[*]	#	7, 4, 0	5,3,0	15, 8, 0	19, 11, 0	4, *, 0	19, 13, 0
Herbicide	oz.	19.9	0.2	0.2	78.3	22.2	27.0
Applications	#	2	1	1	3	2	3
Diesel Field Prep	gal	7.1	7.1	7.1	7.1	8.2	8.2
Diesel - Harvesting	gal	1.8	1.8	1.8	1.8	1.8	1.8
Irrigation Furrow[**]	ac-in	5.0	10.0	10.0	0.0	0.0	0.0
Irrigation Center Pivot[**]	ac-in	0.0	0.0	0.0	7.0	5.0	7.0

Notes:[*]The Wisconsin data had no *HALF* treatment. *FULL* and *HALF* insecticide application treatments refer to applications every 48 and 96 hours post tasseling, respectively. The *ZERO* treatment was the control with no insecticide applications.

[**] Values based upon estimates from Monsanto Production Budgets.

Plot vs. Field Yields

As stated above, field trial sites were only approximately 120 sq. feet and therefore did not use large machinery. However, for the sake of analysis, we assumed that yields and non-fuel inputs would be representative of larger scale production. While the plot yields may differ from those found in larger fields, the relative differences across production method (level of insecticide application) and seed technology should be similar. Although a gap between experimental and actual yields exists, Brennan (1984) wrote, “The only reliable sources of relative yields are cultivar trials” (182). Hence, the desired comparisons of conventional vs. PSSC seed stock across location and insecticide should be valid.

Equipment and Fuel Use

Further, to estimate fuel use associated with actual on-farm production, actual field operations needed to be estimated. The Mississippi State Budget Generator (MSBG) provides estimates of fuel use based upon specified equipment operating under specific production conditions. While similar equipment was assumed to be used across most sites, some exceptions are noteworthy. All sites used a mule train (30ft working width and 80% field efficiency) and trailer (16ft length to hold crates of harvested sweet corn deemed marketable by the pickers) pulled by tractors (2WD 75 HP) at 1.5 miles per hour for harvesting. Harvesting was thus estimated to require 1.77 gallons of diesel per acre for tractor, trailer and mule train.

Sweet corn fields located in Florida and Georgia are generally larger and therefore use larger 8 row rather than 4 row equipment for fieldwork, planting, and spraying. This results in more efficient use of fuel. Therefore different equipment was modeled for Florida and Georgia. Florida and Georgia were modeled with 130 to 170 HP MFWD tractors with wider implements (20ft to 24ft and 8 rows) for fieldwork whereas the other states were modeled using 2WD 75 HP tractors with smaller width implements (7 to 10ft and 2 to 4 rows). Fuel for fieldwork, not including spraying or harvesting was estimated at 7.09 gallons of fuel per acre for Florida and Georgia, and 8.16 gallons per acre for the other states using the Mississippi State Budget Generator (McLaughlin and Spurlock 2012). Sprayers were all assumed to be 47 HP, 30 foot, 110 gallon capacity units. Field efficiency was modeled at 55%, 65%, and 75% efficiency, and at field speeds of 9, 12, and 15 mph to arrive at a range of diesel fuel use for insecticide applications. This resulted in a median diesel fuel usage per chemical application of 0.076 gallons per acre, with a range of 0.061 to 0.101 gallons of diesel per acre.

Direct vs. Indirect Emissions

The carbon footprinting analysis put forth in this study included both direct and indirect GHG emissions of agricultural inputs involved in the production of commodities up to placing the ears into the packing boxes (e.g. fertilizer, herbicides, insecticides, fuel, agricultural plastics, and other chemicals). Excluded are the emissions generated during refrigeration, transport, or processing of a commodity that occur after the farm gate, as these would be the same regardless of production system chosen. Also excluded from this study are embedded carbon emissions as a result of upstream production of equipment and tools used on-farm for agricultural production up to the farm gate. Direct emissions are those that come from farm operations such as combustion of diesel by tractors and irrigation equipment. Indirect emissions, on the other hand, are emissions generated off-farm as a result of the manufacturing of inputs used on the farm. Examples are GHG emissions from the use of natural gas in commercial fertilizer production (Wood and Cowie 2004).

Carbon-Equivalent (CE) Emissions Factors

CE factors come primarily from EcoInvent v2.2 using the IPCC 2007 100-year methodology (EcoInvent IPCC 2007). These values estimate the emissions over the whole life cycle of the input, including production, transportation, delivery, and use. For diesel fuel, this includes both the production as well as the combustion of the fuel on farm. For nitrogenous fertilizers, this includes both the production as well as the direct and indirect emissions of N_2O, a potent greenhouse gas resulting from the application of nitrogen fertilizer to the soil (Table 2). Irrigation CE values are estimated using the amount of fuel required to pump an acre-inch of water using a diesel pump, with different values for gravity-fed furrow irrigation (0.98 gal/ac-in) and center pivot irrigation (1.63 gal/ac-in). These values come from an average fuel use required to pump an acre-inch as determined by state production budgets in Arkansas, Mississippi, and Louisiana[3].

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[3] It is assumed that water is pumped from 100ft at a 5 percent drive loss. The value assumes a 75 percent pump efficiency.

Table 2. Carbon equivalent emissions (lbs CE emitted/Input used) for fertilizer (per lb of elemental N, P or K), fuel (per lb and per ac-inch) and insecticides (lbs CE per lb of a.i.).

Description	**lbs CE / lb**
Corn Seed	0.53
N	
Urea Upstream	*0.90*
Urea Indirect	*0.43*
Urea Total	1.33
Ammonium Nitrate	2.33
N_2O Emissions	1.69
P	0.55
K	0.14
Fuel	
Diesel Upstream (per gallon)	*0.99*
Diesel Combusted (per gallon)	*6.05*
Diesel Total (per gallon)	7.04
Irrigation Furrow (calculated based on fuel use per ac-in)	6.90
Irrigation Center Pivot (calculated based on fuel use per ac-in)	11.46
Fungicides (common name)	
Manzate 200F (mancozeb)	1.44
Quadris (azoxystrobin)	2.89[**]
Headline (pyraclostrobin)	2.89[**]
Herbicides (common name)	
Atrazine (atrazine)	2.56
Dual Magnum II (s-metolachlor)	2.40
Round Up (glyphosate)	2.88
Impact (topramezone)	2.80[**]
Razincane	2.80[**]
Prowl (pendimethalin)	1.55
Bicept II Magnum (atrazine – 33.7%, s-metolachlor – 26.1%)	2.49
Callisto (mesotrione)	2.80
RUP (sodium methyl dithiocarbamate)	1.44
Avaunt (indoxacarb)	
Belt (flubendiamide)	4.55[**]
Baythroid (cyfluthrin)	2.89
Karate (lambda-cyhalorthrin)	4.79
Lannate (methomyl)	4.79
Mustang Max (zeta-cypermethrin)	2.76
Warrior (lambda-cyhalorthrin)	4.79
Tilt (propiconazole)	4.79
Silencer (lambda-cyhaolthrin)	4.55[**]
Brigade (bifenthrin)	4.79
Radiant (spinetoram)	4.79
Steward (indoxacarb)	4.55[**]

[*] Data source is EcoInvent v2.2 for all entries except indirect urea and N_2O emissions (IPPCC, 2007) and diesel combustion (USEPA, 2011).

[**] Specific chemical was not tracked separately in EcoInvent v2.2 and hence a chemical average for all fungicides, herbicides and insecticides was used. Under insecticides pyrethroid compounds were averaged at 4.79 lbs CE/lb of a.i.

Soil and Nitrogen Effects

Soil nitrous oxide (N_2O) emissions stemming from the application of nitrogen fertilizer have been identified as a major contributor to GHG emissions from crop production (Bouwman 1996; Smith 1997; Yanai 2003; Del Grosso et al. 2005; Snyder et al. 2009). The IPCC 2007 Third Assessment Report conversion factor of 298 units CO_2 emitted per unit N applied is commonly used and based on a one percent emissions loss from nitrogen application. This amounts to 1.28 lbs of carbon equivalent CE emissions per pound of elemental nitrogen applied. Additionally N_2O is emitted indirectly from volatilization of N as well as leaching and runoff of managed soils. Total direct and indirect emissions of N_2O result in an estimated 1.69 lbs of CE per pound of nitrogen applied. There is large variation in N_2O release depending upon timing, region, and method of application of nitrogen as well as climatic and soil conditions (Snyder 2009). A process based model used to estimate N_2O emissions by location and all of the other factors might be appropriate in some studies. Given that the goal of this study was to look at relative differences in carbon equivalent emissions within and not across locations based upon the specific production methods, and holding fertilizer application constant, the emissions factor approach was deemed appropriate.

Simulation of Variability

Due to variations in climatic and agronomic conditions, variability analysis was performed to account for different weather scenarios. That is, in an abnormally wet year, irrigation will be curtailed and thus so would the GHG emissions per acre of production associated with irrigation equipment. Conversely, in a dry year, irrigation will increase resulting in higher GHG emissions. Also, under different pest pressures, producers may choose to apply more or less insecticides. A triangular distribution with an upper and lower boundary was applied to both irrigation (ac-in) and insecticide applications. Uncertainty analysis was performed using Microsoft Excel @Risk software (Palisade) with defined distributions shown in Table 3. These simulations were performed to provide a minimum, maximum, and mean GHG estimate per acre under varying production and climatic conditions.

Statistical Methods

To perform comparisons of mean yields of marketable ears per acre between conventional sweet corn, treated at conventional levels of insecticide or current common practice, with their biotech counterparts, treated at varying levels of insecticide ranging from zero to full levels, least significant differences across these treatment combinations were calculated using the GLM procedure in SAS software (SAS 2004) with location/season as a random effect at the 10% level of statistical significance. Random effects for location and production season were chosen rather than fixed effects to be able to generalize across the production region.

Table 3. Values for Monte Carlo smulation using triangular distributions on irrigation water use and number of insecticide applications.

Location	**Irrigation/Insecticide Treatment**[*]	**Min**	**Most Likely**[**]	**Max**
University of Florida	ac-in	5	5	16
	FULL	0	7	24
	HALF	0	4	24
Felda Spring	ac-in	5	10	16
	FULL	5	5	24
	HALF	0	3	24
Felda Fall	ac-in	5	10	16
	FULL	0	15	24
	HALF	0	8	24
University of Georgia	ac-in	5	7	14
	FULL	4	19	19
	HALF	4	11	15
Wisconsin	ac-in	3	5	6
	FULL	4	4	10
Mississippi	ac-in	5	7	14
	FULL	4	19	19
	HALF	4	13	19

Notes:[*] Irrigation refers to number of acre-inches of water applied usually with 2 to 2.5" applied each time. Insecticide treatment refers to the number of passes applied. The *FULL* and *HALF* treatments refer to applications every 48 and 96 hours post tasseling, respectively.

[**] Note that use of the triangular distribution does not imply that observations cannot fall outside the specified range, but rather that expert opinion was used to elicit a likely range of observations.

Results

Carbon Equivalent per Acre by Location and Source

Figure 1 summarizes location differences across the three insecticide management practices on a per acre basis. While regional differences exist as expected, the difference in per acre emissions across insecticide management practice are quite small given small application of active ingredient of insecticide per acre as well as low fuel use per acre for application of insecticide. Figure 1 also provides a breakdown of the total carbon footprint by source and includes the simulated range of water and insecticide use by presenting 95% error bars. Note that agricultural chemicals applied included insecticide, herbicide, and fungicide; thus, footprint from agricultural chemicals does appear in the graph under the zero insecticide management practice. Overall, fertilizer use dominates carbon footprint at each location and does not vary by seed technology or insecticide management practice.

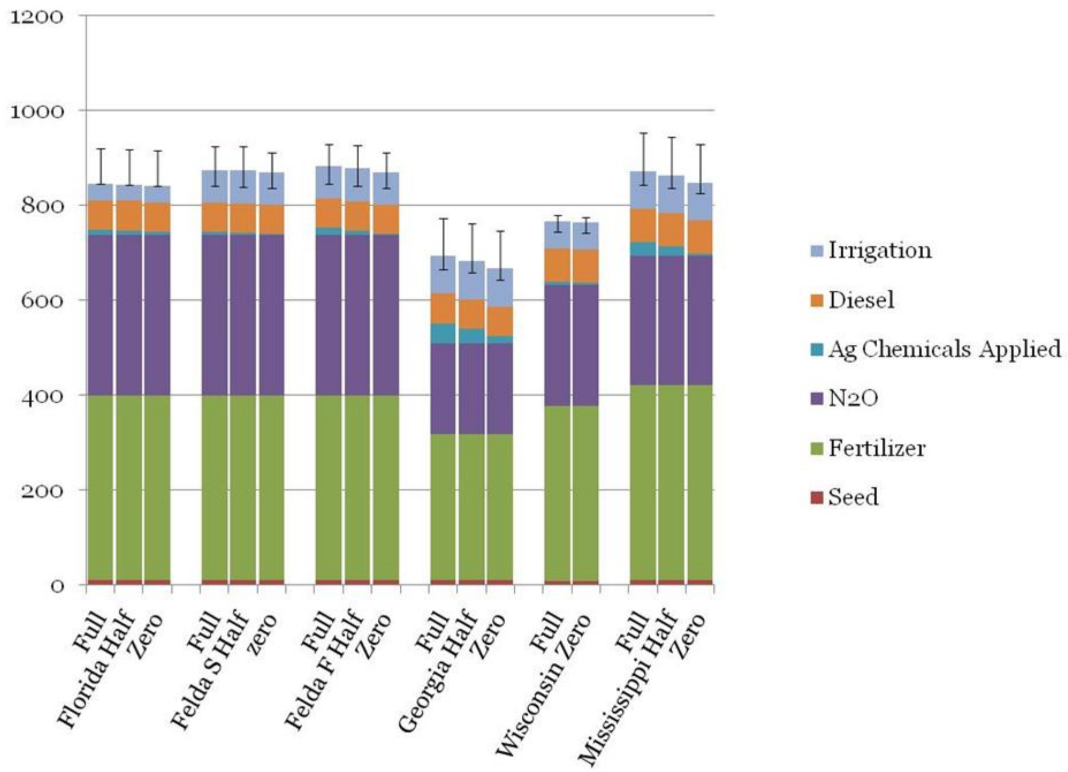

Figure 1. Carbon Emissions (lbs) per acre by location and insecticide application with simulated range of irrigation water and insecticide use for both conventional and biotech seed stock.

Yield

Marketable yields showed vast differences across practices in both regional and variety trials (Table 4). There were strong numerical differences across locations as well as differences by seed technology, variety, and insecticide.

Table 5 shows F- and p-values of the treatment effects and their interactions on marketable ear yield per acre for the variety and regional trials. Use of biotech had a statistically significant effect on its own at $p < 0.05$ in the variety trials. Also, the two-way interaction of variety × seed technology was statistically significant at $p < 0.1$. The top half of Table 6 shows marketable yield comparisons by variety. Use of PSSC seed technology was superior to conventional seed. Insecticide and variety effects, however, were not statistically significant. This suggests that producers choosing PSSC seed should be able to use less insecticide without a yield penalty regardless of variety chosen. Even though statistically speaking, effects in Table 5 for the regional trials were only marginal (insecticide ($p=0.174$) and insecticide × seed technology ($p = 0.183$)), the bottom half of Table 6 shows a similar trend in results as portrayed for the variety trials in the top half of the table. PSSC seed performs better than conventional with no significant differences across number of insecticide applications. Note that the lack of the *HALF* insecticide treatment at Wisconsin partially explains the drop in yield for that treatment under the PSSC column in the table.

Note further, that using no insecticides at all lead to higher yields than when the crop was sprayed with insecticide at full frequency. Excessive plot traffic with spraying equipment can lead to soil compaction and plant damage and is offered as an explanation for those results.

Table 4. Marketable yields from regional and variety trials by location/season, seed technology (*CONV* vs. PSSC), insecticide treatment (*FULL*, *HALF* or *ZERO*), and variety (*Passion®* vs. *Obsession®*).

Variety			**Passion®**		**Obsession®**	
Seed Technology			*CONV*	PSSC	*CONV*	*PSSC*
Trial	**Location/ Season**	**Insecticide**	----- Avg. Marketable Ears per Acre -----			
Variety Trials	Felda Fall	*FULL*	20,700	22,395	18,938	23,000
		HALF	17,020	23,000	19,550	23,034
		ZERO	17,405	21,722	18,430	20,639
	Felda Spring	*FULL*	9,702	17,731	2,355	15,559
		HALF	3,335	16,560	6,149	13,747
		ZERO	931	20,034	9,200	15,206
	Georgia Fall	*FULL*	10,551	19,406	12,267	18,662
		HALF	9,156	19,974	14,203	21,467
		ZERO	-	20,639	1,150	20,289
	Mississippi Fall	*FULL*	5,339	12,963	10,007	18,236
		HALF	7,240	11,962	8,050	12,624
		ZERO	3,424	17,500	4,273	12,078
Regional Trials	Florida Spring	*FULL*	14,826	14,475		
		HALF	11,002	11,463		
		ZERO	13,311	21,948		
	Georgia Spring	*FULL*	15,331	19,176		
		HALF	1,382	16,885		
		ZERO	-	13,644		
	Wisconsin Summer	*FULL*	3,758	25,666		
		ZERO	-	26,400		

Table 5. Analysis of variance results on marketable ear yield with location/season combination as random effect for variety trials at Mississippi, Florida and Georgia as well as regional trials at Florida, Georgia and Wisconsin.

		Degrees of Freedom		**F-**	**p-**
Trial	**Effect**	Num.	Denom.	**value**	**value**
Variety Trials	Insecticide	2	6	2.12	0.201
	Variety	1	3	0.64	0.482
	Insecticide × Variety	2	6	0.28	0.768
	Seed Technology	1	3	20.29	0.020
	Insecticide × Seed Technology	2	6	2.52	0.161
	Variety × Seed Technology	1	3	9.49	0.054
	Insecticide × Variety × Seed Technology	2	6	2.86	0.134
Regional Trials	Insecticide	2	3	0.11	0.450
	Seed Technology	1	1.99	4.32	0.174
	Insecticide × Seed Technology	2	3	3.15	0.183

Table 6. Mean marketable ear yield comparisons by variety and seed technology for variety trials and by insecticide and seed technology for regional trials.

Trial	**Variety/Insecticide**	**Seed Technology** # of obs.	*CONV*	*PSSC*
			---- Avg. Marketable Ears per Acre ----	
Variety Trials[*]	Obsession®	24	10,381	17,878
	Passion®	24	8,734	18,657
Regional Trials	*FULL*	12	11,305	19,772
	HALF	8	6,192[**]	14,174
	ZERO	12	4,437[***]	20,664

Notes: [*] $LSD_{0.10} = 6{,}436$ – to compare *CONV* with PSSC for a particular variety.

$LSD_{0.10} = 4{,}727$ – to compare *CONV* with PSSC of one variety with *CONV* with PSSC of another variety.

[**] Three of the eight yield observations had zero yield (Georgia).

[***] Eight of the twelve yield observations had zero yield (Georgia and Wisconsin).

Overall, these results suggest that the common practice of insecticide use to combat against ear worm damage is difficult given potential daily deposition of eggs near the top of the ear and subsequent hatching and migration of larvae under the husk where insecticides can't reach. The use of biotech alleviates this issue and, more importantly, statistically significantly so at all level of insecticide use and across variety. Results for the second set of locations (Florida - Spring, Georgia - Spring and Wisconsin - Summer) or the regional trial where varietal differences between Passion® and Obsession® were not performed demonstrated less significant statistical results for yield comparisons. These results may be a function of greater range of pest pressure expected as the region has greater north-south variation. Also, at Georgia, reduced and zero levels of insecticide-use programs lead to a large number of complete yield losses due to pest damage in the conventional treatments which substantially reduced variation of yield in a particular treatment which significantly lowers degrees of freedom. A similar issue occurred at Wisconsin where *ZERO* insecticide programs under the conventional treatment led to complete yield losses. Recall also that the Wisconsin location did not have a *HALF* insecticide treatment, leading to a more unbalanced data set. These zero observations greatly reduced variation and made statistical comparisons in an already small sample set difficult.

The same statistical analysis was also performed for CE footprint per ear of marketable yield. Table 7 shows the analysis of variance for both sets of experiments. Varietal differences were not significant but the levels of insecticide and seed technology were for the variety trials. Similar to the yield results, lesser statistically significant results were found for the regional trials. This lack of significance may again be partially a function of the zero yield observations as discussed above. Further, zero yield observations that were included as data points in the analysis above, could not be analyzed in the CE footprint per ear information as carbon footprint per acre cannot be divided by zero yield. Hence the number of observations dropped from 96 to 92 for the variety trials and from 48 to 41 for the regional trials.

Table 7. Analysis of variance results on C.E. per ear with location/season combination as random effect for variety trials at Mississippi, Florida and Georgia as well as regional trials at Florida, Georgia and Wisconsin.

Trial	**Effect**	**Degrees of Freedom** Num.	Denom.	**F-value**	**p-value**
Variety Trials	Insecticide	2	6.41	4.07	0.072
	Variety	1	3.05	0.84	0.676
	Insecticide × Variety	2	5.95	1.06	0.403
	Seed Technology	1	3.04	5.71	0.096
	Insecticide × Seed Technology	2	6.19	3.77	0.085
	Variety × Seed Technology	1	2.98	3.31	0.167
	Insecticide × Variety × Seed Technology	2	5.05	1.14	0.390
Regional Trials	Insecticide	2	0.02	16.28	0.932
	Seed Technology	1	0.81	3.98	0.339
	Insecticide × Seed Technology	2	0.98	0.49	0.712

Given the results of Table 7, means comparisons were performed by insecticide level and use of *PSSC* seed but are not shown in the top half of Table 8, as no statistically significantly differences were revealed. This is likely a function of the impact of zero-yield observations as well as the small number of replications. Also, since the degree of use of insecticide level does not appreciably change the carbon footprint per acre (Figure 1), dividing by statistically significant yield differences did not automatically also yield statistically significant CE per ear results. Nonetheless, the magnitude of change is large and always lower for PSSC seed than its conventional counterpart. Performing the analysis using location/season combinations as a fixed effect may prove to show some additional statistically significant results on carbon footprint per ear but these results would not be generalizable to the region and hence were not performed here.

Table 8. Mean carbon footprint per ear across location / season combination by insecticide level and seed technology for variety trial and regional trials.

Trial	**Insecticide**	**Seed Technology** # of obs.	*CONV (carbon footprint per ear)*	# of obs.	PSSC *(carbon footprint per ear)*
Variety Trials	*FULL*	16	0.161	16	0.048
	HALF	16	0.134	16	0.054
	ZERO	12	0.255	16	0.046
Regional Trials	*FULL*	12	0.112	12	0.044
	HALF	5	0.187	8	0.062
	ZERO	4	0.070	12	0.040

Comparison of carbon footprint per ear means in the regional trial in bottom half of Table 8 also shows only numerical differences. Values using PSSC seed are consistently smaller than for conventional seed, and while the conventional values were lower in the regional trial when compared to the variety trials, the average values for the PSSC seed showed less variation in carbon footprint per ear numbers. This suggests that use of PSSC seed may add more consistency to carbon footprint per ear numbers as marketable yields are less prone to complete loss due to insect pests. Finally, as in the yield results, a lack of statistically significant differences across insecticide levels when using PSSC seed suggests that producers may safely switch from a conventional insecticide program to the *HALF* and/or *ZERO* application levels without affecting carbon footprint per ear.

Conclusions

Agricultural production in the United States has experienced increased demand from private industry and consumers to reduce GHG emissions associated with crop production and will likely receive similar attention from the government. The availability of varietal and technology-specific emissions data is thus tantamount for decision makers to provide either economic incentives for GHG mitigation or to determine ramifications of GHG mitigation regulations.

With this in mind, increased marketable yields of PSSC sweet corn compared to its conventional counterpart were primarily responsible for multifold reductions in GHG per ear for PSSC sweet corn. These effects persisted across variety (Obsession® and Passion®) as well as by insecticide application (*FULL*, *HALF* and *ZERO*). Marketable yield differences between conventional and PSSC seed technologies were significant and lead to a significant reduction of ears left in the field due to insect damage. Hence, the same number of acres of sweet corn will produce more marketable sweet corn with PSSC seed than conventional seed.

The relative contribution that various production inputs make toward total CE emissions per acre was also analyzed. The CE per acre differences were relatively small for reductions in insecticide use when compared to emissions from other sources, such as fuel and fertilizer input use, as well as soil N_2O emissions from nitrogen application. In essence, this fortified the finding that marketable yield improvements enhance CE emissions, albeit per ear rather than per acre, the most. While not statistically significant across region and production environment, two to threefold reduction in CE per ear using PSSC seed are expected to aid consumer acceptance of PSSC vegetables and provide agricultural policy makers with information about the value of biotechnology related to GHG mitigation.

Insignificant differences in marketable yield across all levels of insecticide use for PSSC seed supports further benefits of biotechnology. Using a combination of PSSC seed and likely one to three insecticide applications to control other pests not covered by the PSSC technology provides marketable yield greater than achievable with the current practice of full insecticide applications using conventional seed. This provides environmental benefits in the sense that both GHG emissions per acre and, more importantly, per ear, can be lowered. Lower input use coupled with higher yields could also potentially provide monetary benefits to producers, pending the cost of PSSC seed and consumer acceptance of PSSC sweet corn.

CE per acre and CE per ear results suggest that in combination with changes in yield across location some relocation of sweet corn production may be likely. Those locations that can markedly increase their yields because of improved earworm and other insect pest control by using PSSC seed, while at the same time reducing insecticide use, may see growth. Texas seems to be a logical place for this growth of sweet corn with imbedded seed technology due to its heat and high humidity, leading to high pest pressure, combined with large populations with high demand for sweet corn. Collection of additional data at the larger field level, at locations currently not producing sweet corn, will most likely support these findings and make them stronger by providing added statistical significance. This should allow for making producer recommendations under alternative seed cost and marketable ear price scenarios.

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