Stacked-Gene Hybrids Were Not Found to Be Superior to Glyphosate-Resistant or Non-GMO Corn Hybrids

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Abstract

Hybrid seed corn costs rose from about $35.00/acre in 1998 to more than $100.00 by 2010 primarily because of genetic modification with multiple traits for both insect and herbicide resistance, known as gene stacking. This study compared costs, yields, net returns per acre, and yield components for ten hybrids (four stacked-gene, four glyphosate-tolerant, and two non-genetically modified organisms [GMO]) in a 2-year, furrow irrigated experiment at Stoneville, MS. The site was a Tunica clay (clayey over loamy, smectitic, nonacid, thermic Vertic Haplaquept). The stacked-gene, glyphosate-tolerant, and non-GMO hybrids did not differ in input costs, yield, or net returns per acre within a year. Yields and net returns were greater in 2011 than 2012. Drought during May and two later prolonged cloudy periods in 2012 contributed to lower stands (a reduction of 2500 plants/acre) and fewer kernels per plant (533 vs. 292 for 2011 and 2012, respectively), which reduced yields (~25%) and net returns (~50%) compared with 2011. Non-GMO hybrids had yields and net returns similar to most stacked-gene hybrids both years when insect pressure was negligible and postemergence weed control was unnecessary. Production of some non-GMO hybrids requiring preemergence herbicides should help protect against glyphosate-resistant weeds and sustain the insect resistance of Bt genotypes by providing a refuge without an economic penalty.

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Abbreviations: Bt, *Bacillus thuringiensis*; GMO, genetically modified organism.

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CHANGES IN US HYBRID CORN PRODUCTION

OVER THE PAST HALF CENTURY, corn production in the United States has undergone many genetic and agronomic changes. Development of single-cross hybrids with greater heterosis allowing higher seeding rates and earlier planting in narrower rows (from 40 inches to ≤30 inches) are the norm in most corn production areas. Increased knowledge of plant nutritional requirements, especially management of N fertilizers, development of selective herbicides for weed control, and most recently, development of transgenic hybrids in corn have all combined to increase the US national average corn grain yield from 97.0 bu/acre in 1972 to 160.4 bu/acre in 2013 (USDA-NASS, 2013).

Beginning in the late 1990s, corn hybrids began to be developed through genetic engineering, which included transgenetic traits such as specific herbicide tolerance, inclusion of delta endotoxins [Bt (*Bacillus thuringiensis*)] to impart resistance to certain insect pests, and most recently, some degree of drought tolerance. Reports in 2009 stated that Bt corn production for control of European corn borer (*Ostrinia nubilatis*) constituted 63% of the total corn acreage in the United States and resulted in considerable savings to both Bt and non-Bt producers alike as a result of that control, thus supporting the economic incentive of maintaining non-Bt refuges to sustain insect resistance in Bt genotypes (Hutchison et al., 2010). These traits are patented and result in a higher seed cost per unit due to technology fees. Seed-corn costs had risen from approximately $80.00/80,000 kernels in 1998 to as much as $320.00/80,000 kernels by 2010 (Lauer and Oplinger, 1999). Planting hybrids made with these technologies can cost in excess of $100.00/acre for the seed compared with $35.00/acre in 1998.

The process of including two or more value-added traits to a corn hybrid is known as stacking. Many of the hybrids currently being sold have at least two, and in many cases as many as four, value-added traits incorporated into their genetic makeup. Data compiled by Guanming et al. (2013) on corn grown in Wisconsin at several locations across 21 years showed that several stacked-gene hybrids had similar yields as conventional non-GMO corns. Among those hybrids that did differ, the Bt trait for resistance to European corn borer improved yields an average of 6.54 bu/acre, whereas glyphosate-tolerance and single-trait resistance to corn rootworm (*Diabrotica* spp.) had an average yield decrease of 1.57 bu/acre compared with conventional hybrids. During the 1960s virtually all seed companies warranted their hybrids against early-season stand failures and provided, at no charge, replacement seed for replanting. This policy is no longer practiced, thus making it increasingly important to exercise good seedbed preparation practices and timely planting to ensure adequate stand establishment.

The combination of rising seed costs due to stacking, rising fuel costs, fertilizer, pesticides, equipment, labor, taxes, and interest have yet to be fully analyzed for stacked-gene corn production in the Mid-South, where corn production has increased dramatically during the past 20 years. The objective of this research was to determine if stacked-gene corn hybrids could produce greater yields and net returns than non-GMO or glyphosate-tolerant hybrids when grown with irrigation in the lower Mississippi River Valley.

DETERMINING YIELD AND NET INCOME FOR TRANSGENIC AND NON-GMO CORN HYBRIDS

The experiment was conducted in 2011 and 2012 near Stoneville, MS on a Tunica clay (USDA-NRCS, 2004). Corn had been the previous crop grown before initiation of the experiment. Site preparation began the prior fall by ridging the field into 20-inch-high ridges spaced 40 inches apart. The field was sprayed with 2.0 pt/acre of Gramoxone 14 days before planting to burn winter vegetation. The day before planting, the ridges were harrowed, forming a seedbed 20 inches wide.

The experiment was planted in a randomized complete block replicated four times with a nested treatment structure consisting of three genotypes and 10 hybrids nested within each genotype. Individual plots were eight 40-inch rows 40 ft long. The 40-inch row spacing is used for cotton production and to facilitate furrow irrigation, thus making it the most common spacing used in the Mid-South. Individual hybrids were assigned at random to a plot in each replication. The hybrids selected for this experiment are listed in Table 1 along with their genotypic traits, days to maturity, and the cost (US $) per 80,000 kernels. Selection was based mainly on seed availability and reasonably similar maturity ratings. Sufficient seed was purchased at the beginning of the experiment to make at least two plantings, with remnant seed after the 2011 planting being stored at 40°F until the following season. Before planting in 2012, seed germination tests confirmed that no loss of viability had occurred during storage. Planting was accomplished with a four-row John Deere model 7100 vacuum planter (John Deere, Moline, IL). Hybrids were seeded at the rate of 36,300 kernels per acre with a 15.0% stand loss allowance for an anticipated final stand of 31,000 plants per acre. Planting dates were 7 Apr. 2011 and 29 Mar. 2012.

Lexar (*S*-metolachlor [19.0%] + atrazine [18.6%] + atrazine related products [0.39%] + mesotrione [2.44%]) was applied preemergence at the rate of 3 qt/acre. Neither glyphosate nor glufosinate were applied for postemergence weed control because of the high risk of injury to the two non-GMO hybrids. Insecticides were not applied so that the potential control of the Southwestern corn borer (*Diatraea grandiosella*) and European corn borer, which occasionally are serious pests of corn in the Mid-South, could be documented for the stacked-gene hybrids with their various Bt events. Of the rootworm species, only the Southern corn rootworm occurs in the Mid-South and has yet to be a serious pest. Also, it is not currently controlled by the available Bt events.

Liquid N fertilizer (NH_4NO_3:urea) was applied at a rate of 200 lb N/acre at growth stage V4 (Ritchie et al., 1997). The experiment was cultivated both years at growth stage V6 to provide some weed control and to clear the furrows for irrigation. No further weed control measures were necessary either year. Furrow irrigation began at growth stage V8 at a rate of approximately 1.00 acre-inch of water per irrigation using a schedule previously described (Bruns et al., 2003) in which water was applied every 10 days or 10 days after a rain event of 1.00 acre-inch or more and as shared equipment became available. Five irrigations were applied both years as shown in Table 2.

Table 1. Corn hybrids grown under furrow irrigation at Stoneville, MS in 2011 and 2012, with genotypes, maturity ratings, and purchase prices.

Hybrid†	Traits‡	Maturity	Price per 80,000 kernels
		days	$
Pioneer 31G96	HX1,LL, and RR2	117	240.90
Dekalb DKC 66-96	GENVT3Pro	116	318.00
Dekalb DKC 67-21	GENVT3Pro and RR2	117	275.00
Pioneer 31P42	HX1, LL, and RR2	119	259.90
Dekalb DKC 67-22	RR2	117	213.00
Pioneer 31P40	RR2	119	227.90
Pioneer 1615R	RR2	116	230.90
Pioneer 33N55	RR2	113	217.90
Pioneer 33N56	non-GMO	113	203.00
Pioneer 31P41	non-GMO	119	210.00

†Pioneer Hybrids, DuPont Pioneer, Johnston, IA; Dekalb Hybrids, Monsanto, St Louis, MO.

‡GENVT3Pro, Genuity VT Triple PRO RIB Complete; RR2, glyphosate–tolerant; HX1, Herculex 1 insect protection; LL, glufosinate-tolerant; non-GMO, not genetically modified (traditional genetics).

Established stands were determined by counting all of the plants growing in the two center rows of each plot at growth stage R1. Grain yields and test weights were determined by machine harvesting the four center rows of each plot with a Kincaid 8XPcombine (Haven, KS) equipped with a HarvestMaster Juniper weigh system. Kernel weight was determined by counting and weighing 100 whole kernels from a grain sample taken from each plot at harvest. Kernels per plant were estimated from the data on established stands, grain yields, and kernel weight. Production costs were estimated for each plot with a modification of a balance sheet developed for corn grain production by Iowa State University (Duffy, 2011; Table 3). Mean costs for seed, fuel, fertilizer, herbicides, irrigations, interest, labor, insurance, and land cash rent equivalent were all adjusted to prices being paid in the Mid-South at the time of the experiment (Mississippi State Univ., 2010). Net return per acre for each plot was determined based on yields and gross dollar value per acre received minus costs per acre of all inputs. Corn grain prices for this experiment were acquired from Index Mundi (2013) and based on the average price paid in September both years, which was $7.52/bu and $8.14/bu for 2011 and 2012, respectively.

Data were analyzed with the PROC MIXED procedure of the Statistical Analysis System 9.2 (SAS Institute, Cary, NC). Analyses were performed with data combined across years which were considered a fixed effect and replications (nested within year) being considered random. The ANOVAs are shown in Table 4. Means separations were done with $\text{LSD}_{\alpha = 0.10}$.

Table 2. Rainfall, irrigation, and temperature during the 2011 and 2012 corn-growing seasons at Stoneville, MS.†

2011		2012	
Rainfall	Inches	Rainfall	Inches
12 April	0.46	3–5 April	2.18
15 April	1.21	16–18 April	1.22
20–22 April	2.14	3 May	0.47
26–27 April	1.79	15 May‡	1
3–4 May	0.97	24 May‡	1
20 May‡	1	31 May	1.16
26 May	1.08	5 June	2.26
2 June‡	1	10–13 June§	4.03
10 June‡	1	22 June‡	1
22 June	1.16	3 July	1
27 June‡	1	9–16 July¶	4.51
8 July‡	1	27 July‡	1
16 July	0.97	Total	20.83
30–31 July	0.74		
Total	15.52		

†Data from Mississippi State Univ., 2010. Days ≥ 99.5°F: 2011—6 June, 7 July, 12–14 July; 2012—29 June, 21 July, 31 July.

‡Irrigation event equivalent to 1.0 inch of rainfall.

§Mean solar radiation reduced to 15.0 MJ m^2 from 28.0 MJ m^2.

¶Mean solar radiation reduced to 13.9 MJ m^2 from 26.0 MJ m^2.

ENVIRONMENT INFLUENCED YIELDS AND NET RETURN MORE THAN GENETICS

Due to an early season drought and extensive cloud cover later in 2012 that resulted in large differences between years for yield, net returns, 100-kernel weights, and kernels per plant, data are presented for the hybrid × year(genotype) interaction, and an unprotected $\text{LSD}_{\alpha = 0.10}$ was calculated for means separation. Yields, net returns per acre, 100-kernel weights, and kernels per plant of the three hybrid genotypes (stacked-gene, glyphosate-tolerant, and non-GMO) were significantly ($P \leq 0.10$) less in 2012 than in 2011 (Tables 4 and 5). Grain yields were 52.9, 40.2, and 50.1 bu/acre less in 2012 than 2011 for the stacked-gene, glyphosate-tolerant, and non-GMO classes, respectively. These data translated into reductions in net returns of $408.79, $303.29, and $377.62/acre in 2012 compared with 2011 for the respective classes of stacked-gene, glyphosate-tolerant, and non-GMO. Within each year, no significant differences were noted between the three classes for yield, net returns per acre, or 100-kernel weights. There were fewer kernels per plant on the glyphosate-tolerant hybrids in 2011 than on the other two genotypes, and on the stacked-gene genotypes than on the remaining two in 2012. Insect damage was not observed either year of the experiment in any of the plots, thus negating any advantage the stacked-gene hybrids may have had over the other two classes due to the presence of Bt traits.

Data on individual hybrids show that yields for seven hybrids were greater in 2011 than 2012 (Table 6). The

Table 3. Data used to estimate cost of production for corn hybrids grown under furrow irrigation at Stoneville, MS in 2011 and 2012.[†]

Expense	Fixed	Variable
Preharvest machinery costs	$21.40	$21.20
Seed cost (36,300 kernels/acre)		‡
Herbicide		
Gramoxone 2 pt/acre		$9.00
Lexar 3qt/acre		$40.13
Fertilizer[§]		
N 200 units/acre		
P 0 units/acre		
K 60 units/acre		
Crop insurance		$16.50
Irrigation (furrow)[¶]		
$27.57 fixed	$27.57	
$7.12/acre/inch	5 inches	$35.60
Miscellaneous		$15.00
Preinterest variable cost		‡
Interest preharvest (8 mo @ 6%)		‡
Subtotal cost		‡
Harvest cost		
Combine	$17.60	$9.90
Grain wagon	$5.70	$3.00
Hauling and handling	$7.98	$7.98
Labor 3.00 h @ $12.00	$36.00	
Land cash rent equivalent	$200.00	
Total fixed and variable costs per acre	$318.68	‡
Total cost per acre (fixed + variable)		‡

[†] Modified from Duffy (2011).

[‡] Value based on seed price of individual hybrid.

[§] N = $0.645/lb in 2011 and $0.75/lb in 2012; K = $0.60 in 2011 and 2012.

[¶] From Delta 2011 Planning Budgets Appendix Table 14 (Mississippi State Univ., 2010).

hybrids 31G96, 33N55, and DKC 67-22 (a stacked-gene and two glyphosate-tolerant hybrids, respectively) were the only three that did not differ significantly in yield between years. With respect to net return per acre, these same three hybrids along with 31P42, another stacked-gene hybrid, did not differ between years (Table 6).

In 2011 the grain yields of all stacked-gene hybrids were statistically ($P \leq 0.10$) similar. The glyphosate-tolerant hybrid 1615R was superior in yield to the other three hybrids in its classification as well as to the stacked-gene hybrid DKC 66-96. Both non-GMO hybrids in 2011 were not significantly different in yield from the other cultivars, except 33N56, which yielded more grain than 33N55 (a glyphosate-tolerant cultivar). Net returns per acre for 31G96, DKC 67-21, 1615R, and both non-GMO hybrids (33N56 and 31P41) were not significantly ($P \leq 0.10$) different in 2011. Three of the glyphosate-tolerant hybrids (DKC 67-22, 31P40, and 33N55) had lower net returns per acre in 2011 than most of the other hybrids in the experiment.

In 2012, the grain yields of 31G96, DKC 67-22, and 33N56 (stacked-gene, glyphosate-tolerant, and non-GMO hybrids, respectively) produced greater yields than the stacked-gene hybrids DKC 67-21 and DKC 66-96. No other significant differences in yield were observed that year. The net return per acre in 2012 for 31G96 was significantly greater than for five of the other hybrids representing all three hybrid classifications. On the other hand, net return per acre of the stacked-gene hybrid DKC 67-21 was significantly less than for three other hybrids (31G96, DKC 67-22, and 33N56) representing each hybrid classification.

The greater yields (seven hybrids) and net returns (six hybrids) observed in 2011 compared with 2012 are due, in part, to higher established stands that year than in 2012. Mean stands of mature plants across all hybrids were significantly ($P \leq 0.10$) less in 2012 (32,856 plants/acre) than in 2011 (35,357 plants/acre). These data translate into a 0.30% stand loss in 2011 compared with a 9.5% stand loss in 2012 from the original seeding rate of 36,300 kernels/acre. Germination tests before planting in 2012 did not reveal any loss in seed viability due to storage. A drought during the early part of the 2012 growing season (18 April to 15 May; Table 2) probably caused a reduction in stands because the root systems of some of the young plants would have been severely damaged by the vertical cracking of the drying clay soil (Wesley et al., 1994), causing the plants to die. Despite the target population of 31,000 plants/acre being exceeded both years, the nearly 2500 plants/acre difference between the 2011 and 2012 crops is estimated to have contributed a 10.8 bu/acre reduction in yield

Table 4. Type-three tests of fixed effects and covariance parameter estimates of ten irrigated corn hybrids grown on a Tunica clay at Stoneville, MS in 2011 and 2012.

			Yield (bu/acre)		Net return ($/acre)		Kernels per plant		Kernel weight (mg/100 kernels)		Test weight (lb/bu)	
Effect	Num DF	Den DF	F cal.	*P* > F	F cal.	*P* > F	F cal.	*P* > F	F cal.	*P* > F	F cal.	*P* > F
Genotype	2	54	0.2	0.8194	0.38	0.6844	1.21	0.371	0.35	0.7082	0.31	0.7336
Hybrid (genotype)	7	54	1.64	0.1445	2.09	0.0604	5.45	<0.0001	13.26	<0.0001	16.74	<0.0001
Year	1	6.33	19.91	0.0037	19.92	0.0038	37.39	0.0008	125.23	<0.0001	260.85	<0.0001
Genotype × year	2	54	0.31	0.7339	0.37	0.6952	1.58	0.2144	3.80	0.0286	0.70	0.5017
Hybrid × year (genotype)	7	54	0.59	0.7617	0.61	0.7415	0.81	0.5863	1.86	0.0947	1.60	0.1530
Components of various random effects (estimates)												
Rep (year)			111.58		6587.2		2114.78		1.0151		0.0	
Residual			1098.21		62867		9129.78		7.2631		0.7418	

Table 5. Cost, yield, net return, 100-kernel weight, and kernels per plant of stacked-gene, glyphosate-tolerant, and non-GMO corn hybrids grown under irrigation on a Tunica clay near Stoneville, MS.[†]

	Cost ($/acre)[‡]		Yield (bu/acre)[§]		Net return ($/acre)[§]		100-kernel weight (mg)[§]		Kernels/plant[§]	
Genotype	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Stacked-gene[¶]	780.59	802.43	192.7	139.8	708.42	299.63	26.8	38.7	551a[‡‡]	279b
Roundup Ready 2[#]	756.62	778.46	183.5	143.3	653.81	350.52	28.2	36.6	485b	295a
non-GMO[††]	749.11	770.95	194.8	144.7	752.66	375.04	26.4	37.9	563a	302a

[†] Means of four replications.

[‡] Data were not analyzed because costs per hybrid were not a dependent variable nor changed across replications. Higher costs in 2012 reflect increased fuel and fertilizer costs.

[§] Significantly greater ($P \leq 0.10$) for all genotypes in 2011 than comparable genotypes in 2012. Means within a column are not significantly different.

[¶] Means of four hybrids: 31G96, DKC 66-96, DKC 67-21, and 31P42.

[#] Means of four hybrids: DKC 67-22, 31P40, 1615R and 33N55.

[††] Means of two hybrids: 33N56 and 31P41

[‡‡] Means within a column followed by the same letter are not significantly different at $P \leq 0.10$.

Table 6. Cost, yield, net return, 100-kernel weight, kernels per plant, and test weights of stacked-gene, glyphosate-tolerant, and non-GMO corn hybrids grown under furrow irrigation on a Tunica clay soil in 2011 and 2012 at Stoneville, MS.[†]

	Cost ($/acre)[‡]		Yield (bu/acre)[§]		Net return ($/acre)[¶]		100-kernel weight (mg)[#]		Kernels/plant[††]		Test weight (lb/bu)[‡‡]
Hybrid	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	
Stacked-gene											
31G96	765.34	787.18	202.9 ab	157.2 a[§§]	874.05 a	582.19 a[§§]	22.8d	35.3d	698 a	371 ab	56.6b
DKC 66-96	801.72	823.56	177.4 bc	123.4 b	618.91 cde	176.71 de	28.6bc	38.1c	484 de	264 cd	57.7a
DKC 67-21	781.43	803.27	203.9 ab	123.1 b	740.17 abcd	135.45 e	26.3c	40.5bc	566 cd	221 d	53.9g
31P42	773.88	795.72	181.7 abc	140.4 ab	600.56 cde	304.19 bcde[§§]	29.6b	41.3ab	454 e	259 cd	55.2ef
Glyphosate-resistant											
DKC 67-22	752.17	774.01	175.1 bc	159.0 a[§§]	571.84 e	451.89 abc[§§]	27.9bc	39.4bc	454e	287 bcd	54.7fg
31P40	759.20	781.04	175.8 bc	130.1 ab	587.08 e	242.81 cde	32.2a	39.8bc	417e	254 cd	55.5de
1615R	760.62	782.46	210.2 a	150.4 ab	868.71 ab	399.56 abcde	26.4c	35.3d	583 bc	313 abc	55.8cd
33N55	754.48	776.32	173.1 c	133.9 ab[§§]	587.59 d	307.84 abcde[§§]	26.3c	32.1e	487 de	324 abc	56.7b
Non-GMO											
33N56	747.45	769.29	202.9 ab	157.7 a	820.83 abc	498.11 ab	23.7d	32.1e	659 ab	390 a	56.3bc
31P41	750.76	772.60	186.8 abc	131.7 ab	684.48 abcde	251.97 cde	29.1b	43.6a	468e	215 d	55.2ef

[†] Means of 4 replications.

[‡] Data were not analyzed as costs per hybrid were not a dependent variable nor changed across replications. Higher costs in 2012 reflect increased fuel and fertilizer costs.

[§] Means within a column followed by the same letter or letters are not significantly different ($s_d = 17.0$), $LSD\alpha_{=0.10} = 29.4$.

[¶] Means of gross returns($)/acre – total cost($)/acre. Means within a column followed by the same letter or letters are not significantly different ($s_d = 126.6$) at $LSD\alpha_{=0.10} = 224.00$.

[#] Means within a column followed by the same letter or letters are not significantly different ($s_d = 1.4$) at $LSD\alpha_{=0.10} = 2.4$.

[††] Means within a column followed by the same letter or letters are not significantly different ($s_d = 53.0$) at $LSD\alpha_{=0.10} = 90.2$.

[‡‡] Means of 2 years (2011 and 2012) and 4 replications. Means followed by the same letter or letters are not significantly different ($s_d = 0.14$) at $LSD\alpha_{=0.10} = 0.5$.

[§§] Means in 2011 and 2012 of the same hybrid within either yield/acre or net return/acre are not significantly different ($P \leq 0.10$).

using the grand mean for grain yield (142.2 bu/acre) and plants per acre (32,856) in 2012.

Two extended periods of cloudy weather, associated with rain events of 10 June through 13 June and 9 July through 16 July 2012 reduced mean solar radiation nearly 50%, to 15.4 MJ m^{-2} and 13.9 MJ m^{-2}, respectively, from a average level of 28.0 MJ m^{-2} during the period in June and 26.0 MJ m^{-2} during the July period (MSUES, 2013). These reductions in light would have reduced photosynthesis during the growth stages critical to corn yield (Reed et al., 1988; Elmore and Abendroth, 2006).

The early-season drought and diminished solar radiation during June 2012 reduced the estimated kernels per plant compared with those in 2011 across all hybrids (Tables 4 and 6). By growth stage V9, which in this experiment occurred by late May for all hybrids, the ear shoots were developing, and the florets on ears, both in rows per ear and florets per row, were being established. Drought stress during floret development will reduce their number, and reduced photosynthesis rates at or near anthesis will further reduce the number of kernels per plant due to the inability of the later fertilized florets near the tip of an ear to obtain sufficient photosynthate to develop grain (Reed et al., 1988). The average kernels per plant in 2011 (533) was greater than in 2012 (292) (Table 4). Because the estimated kernels per plant were determined in part using yield, no further statistical analyses were done beyond determining hybrid differences within years (Table 6). Higher corn yields are known to be associated with more kernels per plant (Elmore and Abendroth, 2006). No significant differences in kernels per plant were observed between the three hybrid classes.

In contrast, kernel weights tended to be greater in 2012 than 2011 (Table 6). The hybrid x year (genotype) interaction for these data was statistically significant ($P \leq 0.10$) but no trend was evident (Tables 4 and 6). Kernel weights ranged from 22.8 to 32.2 mg/100 kernels in 2011 and from 32.1 to 43.6 mg/100 kernels in 2012. The fewer kernels per plant produced in 2012 compared with 2011 and the law of compensatory effects regarding yield components resulted in the plants responding to the fewer sinks of developing kernels in 2012 by increasing the amounts of photosynthate deposited per kernel. This increase in kernel weight though was not enough to compensate for the loss in total kernels per plant, which along with the lower established stands of 2012 combined to result in the decreases in yield and net returns per acre previously mentioned. The kernel weights of 2012 were probably not as great as they potentially could have been due to the previously mentioned cloudy period during July, which would have reduced photosynthesis during kernel filling (Reed et al., 1988). These data confirm that despite the crop's genetic makeup, a reduced stand combined with an early-season drought and/or extended periods of cloud cover can have detrimental effects on economic return, especially with the price of today's modern corn hybrids.

Mean test weights were significantly ($P \leq 0.10$) different between the 2 years (57.4 and 54.2 lb/bu for 2011 and 2012). Significant differences among hybrids were also noted (Tables 4 and 6), though not between the three hybrid classifications (55.9, 55.7, and 55.8 lb/bu for the stacked gene, glyphosate tolerant, and non-GMO respectively). Mean test weights of the hybrids combined over both years range from 57.7 lb/bu for DKC 66-96 to 53.9 lb/bu for DKC 67–21, both stacked-gene hybrids. All test weight values were within the minimum level required for the grain to grade as No. 2 yellow, the most common grade of corn traded on the market and preferred by millers (USDA, 1996).

CONCLUSIONS

These data did not show a decisive economic benefit to growing corn hybrids with multiple genetically modified traits as part of their genotype rather than non-GMO hybrids when insects susceptible to Bt endotoxins are not present at economic levels and late postemergence weed control is not necessary. Late-season plantings that are at greater risk of being damaged by insects controlled by Bt events, and the preference of glyphosate and/or glufosinate as the herbicides of choice by the producer may make the selection of a stacked-gene hybrid a preferred choice. Planting non-GMO hybrids as an insect refuge is required and a good management practice (Guanming et al., 2013). In this study there was no economic penalty associated with the non-GMO refuge hybrids.

From the physiological standpoint, this experiment further demonstrates the deleterious effects of early-season drought and reduced solar radiation at critical growth stages on eventual yield regardless of a corn hybrid's genotype. On average, yields in 2012 were approximately 25% less and net returns per acre reduced by approximately 50% of those observed in 2011 due to stressful environmental events.

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