Economic Evaluation of Glyphosate-Resistant and Conventional Sugar Beet[1]

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Abstract: Field experiments were conducted near Scottsbluff, NE, in 2001 and 2002 to compare economic aspects of glyphosate applied to different glyphosate-resistant sugar beet cultivars with that of conventional herbicide programs applied to near-equivalent, non–glyphosate-resistant conventional cultivars. Glyphosate applied two or three times at 2-wk intervals, beginning when weeds were 10 cm tall, provided excellent weed control, yield, and net economic return regardless of the glyphosate-resistant sugar beet cultivar. All conventional herbicide treatments resulted in similar net economic returns. Although the conventional sugar beet cultivars 'HM 1640' and 'Beta 4546' responded similarly to herbicide treatments with respect to sucrose content, 'Beta 4546RR' produced roots with 1% more sucrose than 'HM 1640RR'. When averaged over herbicide treatments, a producer planting Beta 4546RR could afford to pay US $185/ha more for glyphosate-resistant technology as could a producer planting HM 1640RR. When averaged over cultivars and herbicide treatments, it is estimated that a producer could afford to pay an additional US $385/ha for glyphosate-resistant technology without decreasing net return.

Nomenclature: Glyphosate; sugar beet, *Beta vulgaris* (L.) 'Beta 4546', 'Beta 4546RR', 'HM 1640', 'HM 1640RR'.

Additional index words: Herbicide-tolerant crops, technology fee, weed management, clopyralid, desmedipham, ethofumesate, phenmedipham, triflusulfuron.

Abbreviations: DES, desmedipham; fb, followed by; PHEN, phenmedipham; R_G, gross return; TRIF, triflusulfuron; Y, root yield.

INTRODUCTION

Sugar beet is an important economic crop of the state of Nebraska and the United States. Over 16,700 ha were harvested in Nebraska in 2001, resulting in sucrose production of more than 123,000 Mg (Hamlin and Groskurth 2002). In Nebraska, annual production costs can exceed US $1,400/ha (Burgener 2001). Nationwide, average net economic returns have been negative for 4 of the last 6 yr (Gianessi et al. 2002).

Weed control is a costly and necessary part of sugar beet production. In the absence of chemical weed control, the hand labor required to weed and thin sugar beet could exceed 100 h/ha (Dawson 1974). Because of the high cost of hand labor for weed removal, most weed control programs rely on several POST herbicide treatments with or without a PRE herbicide applied at planting. Cultivation and hand labor play a diminishing role in most weed control programs. In the absence of weeds, cultivation of sugar beet does not increase yield, and there is evidence that cultivation may have a negative effect on sucrose yield (Dexter et al. 1999).

Although reduced-rate herbicide applications, or microrates, reduce input costs, their efficacy can be variable. Miller and Mesbah (2000) found that broadleaf weed control was less and grass control better with microrate treatments compared with standard rate programs, and Wilson (1999) found that three microrate applications did not control redroot pigweed (*Amaranthus retroflexus* L. #[3] AMARE) or common lambsquarters (*Chenopodium album* L. # CHEAL) as well as two applications at conventional rates.

The introduction of transgenic sugar beet resistant to glyphosate could give producers the capability of broad-spectrum weed control using only one POST herbicide, applied two or more times during the growing season. One application of glyphosate is not adequate for season-long weed control in glyphosate-resistant sugar beet

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds,* Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

(Wilson et al. 2002). Two or three applications of glyphosate applied to glyphosate-resistant sugar beet controlled 95% or more of the total weed population (Guza et al. 2002; Wilson et al. 2002).

Glyphosate-resistant systems in other crops such as soybean (*Glycine max* L.) and corn (*Zea mays* L.) produce economic returns greater than or similar to those of conventional systems (Johnson et al. 2000; Nolte and Young 2002a, 2002b; Reddy and Whiting 2000). Although the cost of glyphosate is often less than conventional herbicides, input costs are sometimes greater in glyphosate-resistant systems because of an additional fee producers must pay for glyphosate-resistant seed (Johnson et al. 2000). The fee varies by crop. Because glyphosate-resistant sugar beet are not yet sold commercially, this fee has not been established. One estimate has placed the additional cost of glyphosate-resistant sugar beet seed at US $80 per unit of 100,000 seeds (Rice et al. 2001). In 56-cm rows at a seed spacing of 7.5 cm, this would equate to US $141/ha. By assembling agronomic data from several different field studies, Burgener et al. (2000) predicted that net returns would be equal between glyphosate-resistant and conventional systems if glyphosate-resistant seed costs approximately US $248/ha more than conventional seed. Forty-six percent of Burgener et al.'s figure was attributed to an increase in root yield (Y) in the glyphosate-resistant system, whereas a reduction in input costs accounted for the remaining 54%. For producers to pay such a large percentage of total weed-control costs at the time of seed purchase, financial incentive beyond a break-even scenario will be required. For this reason, Burgener et al. (2000) predicted that an additional seed cost in excess of US $123/ha will prohibit adoption of the technology. Assuming an additional cost of US $121/ha for glyphosate-resistant seed, Gianessi et al. (2002) estimated that glyphosate-resistant sugar beet would result in an average US $148/ha savings in total input costs if the technology is accepted. May (2003) approximated that farmers in the U.K. could save over US $240/ha by planting genetically modified herbicide-tolerant sugar beet, even after paying US $40/ha more for glyphosate-resistant seed. However, Gianessi et al. (2002) assume no difference in sucrose production between the two systems, whereas May (2003) only accounts for differences in yield between the two systems due to weed beet in the conventional system.

Few refereed articles have been published directly comparing economics of the glyphosate-resistant weed management system with conventionally used weed management programs applied to conventional sugar beet cultivars (May 2003). Most economic analyses of herbicide-tolerant sugar beet to date have combined data from research conducted independently, often at different locations and times (Burgener et al. 2000; Gianessi et al. 2002; May 2003). Because of decreasing profit margins faced by most sugar beet producers, it is imperative that management decisions are based on economic data generated from side-by-side comparisons. The objective of this research was to compare economic aspects of glyphosate applied to glyphosate-resistant sugar beet cultivars with that of conventional herbicide programs applied to near-equivalent conventional cultivars.

MATERIALS AND METHODS

Field studies were conducted at four sites near Scottsbluff, NE (the Scott 80 and Mitchell in 2001, and the Scott 80 and Scottsbluff in 2002). Soil at all sites was a Tripp very fine sandy loam (Typic Haplustolls) with pH of 7.6, 7.8, and 7.6 and organic matter content of 1.2, 1.0, and 0.8% at Mitchell, the Scott 80, and Scottsbluff, respectively. The experimental design was a split-plot with main plots arranged in randomized complete blocks with four replications. Twelve whole-plot factors included an untreated; glyphosate-resistant and non–glyphosate-resistant hand weeds; glyphosate applied POST once, twice, or three times; conventional weed control programs consisting of desmedipham (DES) plus phenmedipham (PHEN) plus triflusulfuron (TRIF) plus clopyralid applied POST two or three times with or without ethofumesate PRE; and a microrate treatment of DES plus PHEN plus TRIF plus clopyralid plus a methylated seed oil adjuvant applied POST three times with or without ethofumesate PRE (Table 1).

Sugar beet cultivars available with and without a glyphosate-tolerance trait were chosen. All non–glyphosate herbicide treatments were applied to conventional sugar beet cultivars ('Beta 4546'[4] or 'HM 1640'[5]), whereas glyphosate treatments were applied to glyphosate-resistant cultivars ('Beta 4546RR'[4] or 'HM 1640RR'[5]) for a total of two split-plot factors. Each conventional cultivar and its near-equivalent made up one split-plot factor. Beta 4546RR contains a transgenic event conferring glyphosate-tolerance that at the time of this publication is not registered for use in the United States. HM 1640RR contains the transgenic event 'GTSB77' and has received

[4] Betaseed Inc., 1788 Marshall Road, P.O. Box 195, Shakopee, MN 55379.
[5] Syngenta, 11939 Sugarmill Road, Longmont, CO 80501.

Table 1. Weed control treatment application rates and timings.

Treatment name	Herbicides[a]	Rate[b]	Sugarbeet growth stage[c]	Average weed height[c]
		kg/ha		cm
Hand weed			Throughout season	
PRE	Ethofumesate	1.12	PRE	0
Conventional 2	PHEN + DES + TRIF + CLOP	0.19 + 0.19 + 0.02 + 0.10	Cot, 2-4 TL	1
Microrate[d]	PHEN + DES + TRIF + CLOP	0.048 + 0.048 + 0.005 + 0.025	Cot, 2 TL, 4TL	1
Conventional 3	PHEN + DES + TRIF + CLOP	0.19 + 0.19 + 0.02 + 0.10	Cot, 2-4 TL, 4-6 TL	1
Glyphosate 1	Glyphosate	0.84		10
Glyphosate 2	Glyphosate	0.84		10
	Glyphosate	0.84		14 DAFT
Glyphosate 3	Glyphosate	0.84		10
	Glyphosate	0.84		14 DAFT
	Glyphosate	0.84		28 DAFT

[a] Abbreviations: PHEN, phenmedipham; DES, desmedipham; TRIF, triflusulfuron; CLOP, clopyralid; COT, cotyledon; 2-4 TL, two to four true-leaf; 2 TL, two true-leaf; 4 TL, four true-leaf, 4-6 TL, four to six true-leaf; DAFT, days after first treatment.

[b] Glyphosate rates are given in ae, all other herbicide rates are given in ai.

[c] When treatment was initiated.

[d] Microrate also included the addition of methylated seed oil at 1.5% by volume.

nonregulated status for use in the United States (USDA 1999).

Split plots were six rows, spaced 56 cm apart. Plot length was 9.1 m in 2001, 12.2 m in 2002. Sugar beet was planted to stand on prepared beds in mid- to late April (Table 2) at a depth of 2.5 cm and a rate of four seeds per 30 cm of row. Herbicides were applied broadcast with a tractor-mounted sprayer in 2001 and a backpack sprayer in 2002. Spray volume delivered was 195 L of water/ha at 207 kPa pressure with Tee-Jet 11002 nozzles.[6] Herbicide application dates are given in Table 2. Hand-weeded controls were kept weed free beginning on June 1, 2001, and May 15, 2002, through August 20 in both years. Plots were furrow irrigated and cultivated as needed at all locations, with the exception of Mitchell in 2001, which was not cultivated, and Scottsbluff in 2002, which was irrigated with an overhead sprinkler system. All plots were irrigated soon after planting to aid sugar beet emergence and incorporation of PRE ethofumesate.

All weeds between the center two rows in the entire length of each plot were counted approximately 14 d after final glyphosate application. Percent weed control was calculated by dividing number of weeds in each treated plot by the mean from untreated controls. Visual sugar beet injury was observed 10 to 14 d following final glyphosate application and rated on a 100-point scale, with 0 = no visible injury and 100 = death of all sugar beet plants. The center two rows of each plot were machine harvested, weighed, and analyzed for sugar content at the Western Sugar[7] tare laboratory. A separate laboratory analyzed all roots from this research to ensure that transgenic sugar beet remained out of commercial processing facilities. Yield data collected included Y and sucrose content. Gross sucrose production was calculated by multiplying the Y by the percent sucrose.

Economic returns were calculated from yield data. Gross returns (R_G) were calculated for each plot on the basis of the Western Sugar grower contract payment schedule. Price per ton is dependent on the sucrose content and the average price of sugar from the payment schedule. Gross returns were calculated with the following formula:

$$R_G = ((\text{Y-tare}) \times \%\ \text{sucrose content})P \qquad [1]$$

where

$$Y = \text{root yield in kg/ha}$$

$$P = \text{price of sugar in \$/kg}$$

An adjustment for tare was incorporated into Equation 1 to reflect more accurately the payment a grower would receive. Tare data were not available from transgenic research plots, so tare data gathered from other research plots in the same field were averaged, and the resulting value used in the calculation.

Net return is defined in this analysis as the economic return on investment and management. All costs of production other than weed control were derived from Burgener (2001) and were equal across treatments. Additional costs of hauling sugar beet roots to the pile were

[6] Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

[7] Western Sugar Corporate Headquarters, 7555 East Hampden Avenue, Suite 600, Denver, CO 80231.

Table 2. Planting, herbicide application, and harvest dates.

Treatment or operation	Timing[a]	Site: Mitchell 2001	Scott 80 2001	Scott 80 2002	Scottsbluff 2002
Plant		April 23	April 23	April 18	April 22
PRE	PRE	April 27	April 27	April 23	April 23
Conventional 2 and 3	COT	May 14	May 16	May 14	May 14
Conventional 2 and 3	2-4 TL	May 25	May 23	May 30	May 23
Conventional 3	4-6 TL	May 31	May 31	June 10	June 3
Microrate	COT	May 14	May 16	May 14	May 14
Microrate	2 TL	May 25	May 23	May 20	May 20
Microrate	4 TL	May 31	May 31	May 28	May 28
Glyphosate 1, 2, and 3	10-cm weeds	May 31	May 31	June 3	May 28
Glyphosate 2 and 3	14 DAFT	June 15	June 15	June 17	June 10
Glyphosate 3	28 DAFT	June 27	June 27	July 1	June 24
Harvest		October 3	October 4	October 5	October 4

[a] Abbreviations: COT, sugarbeet cotyledon stage; 2-4 TL, sugarbeet two to four true-leaf stage; 4-6 TL, sugarbeet four to six true-leaf stage; 2 TL, sugarbeet two true-leaf stage; 4 TL, sugarbeet four true-leaf stage; DAFT, days after first treatment.

calculated by multiplying the fresh weight by the custom charge for hauling. Weed control costs were calculated using herbicide prices listed (University of Nebraska 2002). Although all herbicide applications were applied broadcast, costs for ethofumesate and conventional rate applications of PHEN plus DES plus TRIF plus clopyralid were calculated in a 20-cm band to reflect more accurately prices associated with common grower practices. Sugar beet growers in Nebraska generally band conventional rates of sugar beet herbicides over the crop row and then cultivate to remove weeds from between the rows to save on herbicide costs. All sites except Mitchell were cultivated two to three times during the growing season. Cultivation removed weeds between the crop row, thus negating any weed control benefit of broadcasting vs. banding the herbicides. A ditching operation at the Mitchell site produced a similar effect. Because all weeds outside the calculated band area were removed mechanically, it is assumed that no weed control differences would be observed between band and broadcast applications. Because of its low cost, it is anticipated that growers will apply glyphosate broadcast to glyphosate-resistant sugar beet. Costs of production including weed management and hauling were subtracted from R_G to obtain net return for each plot.

All data were subject to ANOVA. Weed control and crop injury data were arcsine square root transformed; because no benefit from the transformation was observed, actual data are presented. No year by treatment interaction was present, so yield and economic data were averaged over years for analysis. When combining data, the MIXED procedure in SAS (2000) was used, treating year as a fixed effect and locations as random effects. Mean separation was performed using Fisher's protected LSD. Where appropriate, single degree of freedom contrasts were constructed to compare groups of glyphosate treatments with groups of conventional herbicide treatments, and the estimates associated with these contrasts are reported as break-even costs of the additional fee that will likely accompany glyphosate-resistant sugar beet seed.

RESULTS AND DISCUSSION

Weed Control and Crop Injury. No weed control treatment by cultivar interaction was present with respect to crop injury or weed control, so treatment data were averaged over cultivars for analysis. Data are presented separately by site because of differing environmental conditions and weed populations influencing crop injury and weed control (Table 3). One application of glyphosate provided variable weed control. Two or three applications of glyphosate provided at least 95% weed control at all sites except the Scott 80 site in 2002. Because of drought conditions at this site, weed populations were extremely low early in the season. Even after sugar beet had been irrigated several times to aid in emergence and stand establishment, weed density remained relatively low. However, it is important to note that because of low weed densities early in the season, a high degree of control was not necessary to avoid sugar beet yield loss. Although weed control appears to be worse at the Scott 80 in 2002 than at the other sites, most weeds present were not of economic consequence. Many weeds that were counted on July 15 germinated after the crop and did not grow above the sugar beet canopy thus avoiding sugar beet yield loss.

Three POST applications of PHEN plus DES plus

Table 3. Sugarbeet injury and weed control as influenced by weed control treatment at four sites near Scottsbluff, NE, in 2001 and 2002.

Treatment	Mitchell 2001		Scott 80 2001		Scott 80 2002		Scottsbluff 2002	
	Crop injury[a]	Weed control[b]	Crop injury	Weed control	Crop injury	Weed control	Crop injury	Weed control
	%							
Untreated[c]	5	0	20	0	0	0	0	0
Hand weed[c]	10	99	15	99	0	99	3	99
Glyphosate 1[c]	8	38	5	70	0	31	0	88
Glyphosate 2[c]	4	99	4	99	0	38	0	95
Glyphosate 3[c]	8	98	7	99	0	61	1	95
Hand weed[d]	10	99	15	99	0	99	1	99
PRE + conventional 2[d]	12	80	7	54	0	34	19	91
Conventional 2[d]	12	76	5	59	0	44	8	88
PRE + microrate[d]	7	77	6	67	0	50	12	95
Microrate[d]	5	51	3	76	0	35	8	90
PRE + conventional 3[d]	11	93	10	88	2	50	39	95
Conventional 3[d]	10	95	8	89	0	34	11	93
LSD (0.05)	6	13	5	10	1	25	12	6

[a] Rated 10 to 14 d after final glyphosate application.

[b] Control of total weed population approximately 14 d after final glyphosate application.

[c] Applied to sugarbeet cultivars HM 1640RR and Beta 4546RR. Data are averaged over cultivars.

[d] Applied to sugarbeet cultivars HM 1640 and Beta 4546. Data are averaged over cultivars.

TRIF plus clopyralid at conventional rates generally gave the greatest weed control among conventional or microrate herbicide treatments. No weed control benefit was observed by applying ethofumesate PRE before this treatment. The application of ethofumesate PRE followed by (fb) three conventional rate POST applications caused greater crop injury than POST-only treatments at the Scottsbluff site in 2002 (Table 3). Freezing temperatures on April 28 (−7 C) and May 2 (−4 C), strong winds on May 21 and 22, and ethofumesate PRE fb three POST applications of the conventional herbicides combined to cause 39% injury and a 45% reduction of leaf area (data not shown) compared with the hand-weeded control. This may be in part because of irrigation the day before freezing temperatures occurred. Greater herbicidal activity of ethofumesate in wet soils compared with dry soils has been documented previously by McAuliffe and Appleby (1981, 1984). Irrigation water saturated the soil near the surface, which would increase the concentration of ethofumesate in the soil solution (McAuliffe and Appleby 1984). Ethofumesate taken up by sugar beet roots and hypocotyls is rapidly translocated into foliage (Eshel et al. 1978). Increased herbicide in the foliage at the time of the freeze probably contributed to intensified crop response.

Hand weeding in 2001 did not begin until weeds were approximately 10 cm tall. This early-season competition in addition to injury from weed removal resulted in crop injury that was greater than expected at both locations. Hand weeding was begun earlier in 2002, thus causing less injury to the crop.

Cultivar Differences in Sucrose Content. Locations were treated as random effects, and no year by treatment interaction was present, so data were combined over locations and years for analysis. Herbicide treatment by cultivar interactions were present with respect to sucrose content, so simple effects of sucrose data are presented. The interactions resulted from differences in sucrose content between transgenic and conventional cultivars. No significant differences existed between Beta 4546 and HM 1640 with respect to sucrose content regardless of weed control treatment (Table 4). Conversely, all dif-

Table 4. Sucrose content as affected by cultivar and weed control treatment averaged over four sites near Scottsbluff, NE, in 2001 and 2002.

Treatment	Sucrose content		$P > \|t\|$[a]
	Beta 4546 or Beta 4546RR	HM 1640 or HM 1640RR	
	%		
Untreated[b]	14.32 c[d]	12.61 b	0.0001
Hand weed[b]	15.97 a	14.95 a	0.0069
Glyphosate 1[b]	15.96 a	15.06 a	0.0161
Glyphosate 2[b]	15.80 ab	14.76 a	0.0058
Glyphosate 3[b]	16.23 a	14.61 a	0.0001
Hand weed[c]	15.71 ab	15.56 a	0.6818
PRE + conventional 2[c]	15.53 ab	15.36 a	0.6382
Conventional 2[c]	15.52 ab	15.32 a	0.5889
PRE + microrate[c]	15.51 ab	14.92 a	0.1153
Microrate[c]	15.31 abc	15.14 a	0.6635
PRE + conventional 3[c]	14.84 bc	15.01 a	0.6623
Conventional 3[c]	15.34 abc	15.67 a	0.3791

[a] P values correspond to cultivar comparisons within a row.

[b] Applied to sugarbeet cultivars HM 1640RR and Beta 4546RR.

[c] Applied to sugarbeet cultivars HM 1640 and Beta 4546.

[d] Least square means within a column followed by the same letter are not significantly different (0.05).

Table 5. Cultivar differences in sucrose content averaged over four sites near Scottsbluff, NE, in 2001 and 2002.

Comparison	Difference in sucrose content	P > |t|
	%	
HM 1640RR hand weed vs. HM 1640 hand weed	−0.61	0.2832
Beta 4546RR hand weed vs. Beta 4546 hand weed	0.26	0.6450
All HM 1640RR[a] treatments vs. all HM 1640 treatments (including hand weed)	−0.44*	0.0822
All Beta 4546RR[a] treatments vs. all Beta 4546 treatments (including hand weed)	0.60**	0.0173
HM 1640RR herbicide treatments vs. HM 1640 herbicide treatments	−0.43	0.1319
Beta 4546RR herbicide treatments vs. Beta 4546 herbicide treatments	0.66**	0.0203

[a] Untreated data are not included in this analysis.

* Denotes significance (0.10).

** Denotes significance (0.05).

ferences between Beta 4546RR and HM 1640RR were significant whether treated with glyphosate, hand weeded, or no treatment was applied. This suggests the differences are not because of differential tolerance to the herbicide.

No differences were apparent between herbicide treatments within a cultivar (Table 4). When comparing hand-weeded controls, differences in sucrose content between transgenic cultivars and their near-equivalent conventional cultivars were not statistically significant (Table 5). However, when averaged over treatments, greater sucrose was produced by Beta 4546RR than Beta 4546 and a trend for lower sucrose was observed in HM 1640RR compared with HM 1640. The genetic backgrounds of Beta 4546 and Beta 4546RR are quite similar, and for all practical purposes the cultivars are equivalent with the exception of the glyphosate-tolerance trait (J. R. Stander, personal communication).[4] Because of the similar genetics of these cultivars, we conclude that greater weed control and reduced crop injury are responsible for the greater sucrose content in Beta 4546RR.

Greater weed control and reduced crop injury were also achieved in HM 1640RR when compared with HM 1640, but a trend for lower sucrose content was observed in HM 1640RR (Table 5). Approximately 75 to 87.5% of the HM 1640 genotype is shared by HM 1640RR (R. Martens, personal communication).[5] Although the cultivars are visually indistinguishable, the genetics may allow for considerable differences between the cultivars aside from glyphosate-tolerance. Sucrose production in sugar beet is inherited in a complex fashion (Schneider et al. 2002), so a 12 to 25% genotypic difference between HM 1640 and HM 1640RR could explain the trend for lower sucrose content.

Sugar beet Yield. When averaged over sites, three applications of glyphosate applied to Beta 4546RR produced greater Y than all conventional and microrate herbicide treatments except ethofumesate PRE fb the microrate and greater gross sucrose production than all conventional and microrate herbicide treatments when applied to Beta 4546 (Table 6). One application of glyphosate to Beta 4546RR produced similar gross sucrose to that of all conventional herbicide treatments applied to Beta 4546. These differences suggest obvious yield benefits from a switch to glyphosate use on glyphosate-resistant sugar beet (Beta 4546RR) from conventional sugar beet (Beta 4546) using conventional herbicides.

Three applications of glyphosate applied to HM 1640RR resulted in greater Y than ethofumesate PRE fb two or three applications of the conventional treatment, two POST applications of the conventional treatment, and the microrate without ethofumesate PRE applied to HM 1640 (Table 6). However, because of the reduced sucrose content of HM 1640RR, only the microrate and two applications of the conventional program applied to HM 1640 produced less gross sucrose than three POST applications of glyphosate applied to HM 1640RR.

Economics of Glyphosate-Resistant and Conventional Sugar beet. Glyphosate applied three times to Beta 4546RR resulted in greater gross economic return than conventional or microrate treatments applied to Beta 4546 (Table 7). Greater R_G in combination with lower treatment costs make differences in net returns between glyphosate-resistant and conventional systems substantial. Glyphosate applied two or three times to Beta 4546RR resulted in greater net return than all conventional or microrate treatments applied to Beta 4546. Two applications of glyphosate to Beta 4546RR resulted in $435/ha greater net return than any conventional or microrate treatment. All conventional and microrate treatments resulted in similar net returns as one application of glyphosate. Differences in treatment costs explain

Table 6. Root yield and gross sucrose production as affected by weed control treatment averaged over four sites near Scottsbluff, NE in 2001 and 2002.

Treatment	Beta 4546 or Beta 4546RR		HM 1640 or HM 1640RR	
	Root yield	Gross sucrose	Root yield	Gross sucrose
	kg/ha			
Hand weed[a]	53,600 ab[b]	8,500 ab	46,800 abc	7,100 abc
Untreated[a]	10,800 d	1,700 d	11,000 d	1,600 d
Glyphosate 1[a]	43,700 c	6,900 c	46,200 abc	6,900 abc
Glyphosate 2[a]	55,600 ab	8,800 ab	51,300 ab	7,500 abc
Glyphosate 3[a]	57,500 a	9,300 a	53,500 a	7,800 a
Hand weed[c]	51,400 abc	8,100 abc	48,900 abc	7,700 ab
PRE + conventional 2[c]	46,600 bc	7,200 c	44,900 bc	7,000 abc
Conventional 2[c]	44,600 c	6,900 c	41,000 c	6,300 bc
PRE + microrate[c]	49,700 abc	7,800 bc	47,800 abc	7,200 abc
Microrate[c]	47,700 bc	7,300 bc	40,400 c	6,100 c
PRE + conventional 3[c]	46,600 bc	6,900 c	43,700 bc	6,500 abc
Conventional 3[c]	44,800 c	6,900 c	45,700 abc	7,100 abc

[a] Applied to sugarbeet cultivars HM 1640RR and Beta 4546RR.

[b] Least square means within a column followed by the same letter are not significantly different (0.05).

[c] Applied to sugarbeet cultivars HM 1640 and Beta 4546.

only a fraction of the differences in net return, which are primarily because of increased sucrose production.

Gross economic returns for HM 1640 and HM 1640RR were similar between all herbicide treatments (Table 7). Differences were evident between net returns of two or three applications of glyphosate and the microrate without ethofumesate PRE and ethofumesate PRE fb three POST applications of the conventional treatment because of differences in sucrose production in combination with the lower cost of glyphosate treatments. Treatment costs explain a greater percentage of the differences in net returns between HM 1640 and HM 1640RR. It is possible that if the cost of conventional sugar beet herbicides were reduced because of competition, patent expiration, etc., the economic benefit of switching to the glyphosate-resistant HM 1640RR from HM 1640 might become negligible.

It is anticipated that an additional fee will be added to the sale price of glyphosate-resistant seed as is the case in other crops. By comparing net returns in glyphosate treatments with net returns of conventional herbicide treatments, a break-even value for this additional cost can be calculated (Table 8). A fee less than the break-even value will be assumed to benefit a producer who adopts glyphosate-resistant technology, whereas a fee greater than the break-even value would be detrimental to the adopting producer. Assuming these estimates are based on median production conditions, in 50% of the years actual break-even costs will be greater and in 50% of the years actual break-even costs will be less. To increase the probability that the technology will be profitable, the amount a producer is willing to pay should be somewhat less than the break-even cost. For each estimate, the standard error and lower limit of the

Table 7. Gross and net return as influenced by herbicide treatment and sugarbeet cultivar averaged over four sites near Scottsbluff, NE in 2001 and 2002.

Treatment	Treatment cost	Beta 4546 or Beta 4546RR[a]		HM 1640 or HM 1640RR[a]	
		Gross return	Net return[b]	Gross return	Net return[b]
	$/ha				
Untreated	0	398 e[c]	−844 d	371 b	−872 c
Glyphosate 1	35	1,680 cd	332 bc	1,646 a	292 ab
Glyphosate 2	69	2,128 ab	717 ab	1,782 a	381 a
Glyphosate 3	104	2,286 a	836 a	1,851 a	413 a
PRE + conventional 2	232	1,717 cd	164 c	1,695 a	144 ab
Conventional 2	171	1,653 cd	166 c	1,530 a	53 ab
PRE + Microrate	250	1,861 bcd	282 c	1,725 a	151 ab
Microrate	188	1,742 bcd	233 c	1,465 a	−26 b
PRE + conventional 3	319	1,619 d	−19 c	1,557 a	−74 b
Conventional 3	255	1,646 d	75 c	1,725 a	153 ab

[a] Glyphosate treatments were applied to sugarbeet cultivars HM 1640RR and Beta 4546RR while nonglyphosate treatments were applied to HM 1640 and Beta 4546.

[b] Net return defined as return to investment and management.

[c] Least square means within a column followed by the same letter are not significantly different (0.05).

Table 8. Breakeven estimates for the additional cost of glyphosate-resistant sugarbeet seed.

Comparison	Breakeven estimate	Standard error	Lower limit 90% CI[a]
	$/ha		
Averaged over cultivars			
Glyphosate vs. conventional herbicides	385*	87	245
Glyphosate 2 or 3 vs. PRE + conventional 2	432*	148	188
Glyphosate 2 or 3 vs. conventional 2	477*	148	230
Glyphosate 2 or 3 vs. PRE + microrate	371*	148	124
Glyphosate 2 or 3 vs. microrate	484*	151	232
Glyphosate 2 or 3 vs. PRE + conventional 3	633*	148	388
Glyphosate 2 or 3 vs. conventional 3	472*	148	227
Beta 4546RR vs. Beta 4546			
Glyphosate vs. conventional herbicides	479*	99	319
Glyphosate 2 or 3 vs. PRE + conventional 2	613*	168	336
Glyphosate 2 or 3 vs. conventional 2	610*	171	326
Glyphosate 2 or 3 vs. PRE + microrate	494*	168	217
Glyphosate 2 or 3 vs. microrate	546*	171	262
Glyphosate 2 or 3 vs. PRE + conventional 3	796*	168	519
Glyphosate 2 or 3 vs. conventional 3	702*	168	425
HM 1640RR vs. HM 1640			
Glyphosate vs. conventional herbicides	294*	94	141
Glyphosate 2 or 3 vs. PRE + conventional 2	252	161	−12
Glyphosate 2 or 3 vs. conventional 2	343*	161	79
Glyphosate 2 or 3 vs. PRE + microrate	245	161	−20
Glyphosate 2 or 3 vs. microrate	420*	163	148
Glyphosate 2 or 3 vs. PRE + conventional 3	472*	161	205
Glyphosate 2 or 3 vs. conventional 3	245	161	−20

[a] Abbreviations: CI, confidence interval.

* Denotes a significant comparison (0.05).

90% confidence interval are reported. By not paying more than the lower limit of the 90% confidence interval, it is assumed that the producer will be at least as profitable as the conventional system 90% of the time.

The first break-even estimate given in Table 8 corresponds to the average net return of all glyphosate treatments compared with the average net return of all conventional herbicide treatments (including microrates) when averaged over cultivars. Because one, two, and three applications of glyphosate were included in this estimate, it is considerably less than most values generated when only two or three applications of glyphosate are included. The increase in net return of two or three applications of glyphosate is greater than the cost of the extra treatments; hence, there is an increase in net return and considerable incentive for producers to apply glyphosate a second or third time. For this reason, break-even values were calculated comparing these two treatments with each conventional herbicide treatment.

If a producer usually plants the cultivar HM 1640 and uses the microrate program for weed control, it would be cost effective to switch to the glyphosate-resistant cultivar as long as the additional cost of seed was less than US $420/ha (Table 8). As a result of increased sucrose production, a producer normally planting Beta 4546 with the microrate weed management program could afford the glyphosate-resistant Beta 4546RR as long as the additional seed cost does not exceed US $546/ha. When averaged over herbicide treatments, the break-even value for HM 1640RR is US $294/ha, whereas the break-even value for Beta 4546RR is US $479/ha. If averaged over herbicide treatments and cultivars, the resulting break-even value is US $385/ha. The differences between these values serve as a reminder of the importance of cultivar selection to those who may be inclined to generalize about glyphosate-resistant technology in sugar beet. It is essential to differentiate between glyphosate-resistant sugar beet cultivars if they result in a significant difference in sucrose yield.

The results of this research emphasize the need to conduct economic analyses on data generated from side-by-side comparisons made within a single study. The large cultivar differences presented here would have likely been attributed to environmental conditions and averaged if taken from independent studies. Side-by-side comparisons are also required to discern differences in production between the two systems, which have been ignored by several previous economic analyses. The incorporation of traits into accepted cultivars can be a time-intensive process because of the biennial nature of sugar beet. The time involved is amplified when dealing with transgenic traits. In the time it takes breeders to produce a transgenic cultivar that is commercially acceptable, newer, higher-yielding conventional cultivars will have entered the market. For this reason future economic analyses should include side-by-side comparisons of locally adapted, top-yielding cultivars regardless of whether a glyphosate-resistant version of the cultivar is available.

Introduction of glyphosate-resistant sugar beet into the U.S. market would allow sugar beet producers a new weed management tool. If used properly with other best management practices, the technology will play an important role in achieving higher sucrose yields as a result of improved weed control and reduced sugar beet injury. The improved yields in addition to lower input costs will aid in increasing net economic returns to producers who adopt the technology as long as the additional seed cost is not prohibitive. The lower cost of glyphosate compared with conventional sugar beet herbicides, along with its extended window of application and wider spectrum of weed control represents a reduction in risk to producers. The differences in yield, and consequently net return and break-even values between glyphosate-resistant cultivars serve as a caution to sugar beet producers contemplating a change to glyphosate-resistant sugar beet. Because a cultivar is glyphosate resistant does not necessarily mean greater profits. Choosing a high yielding cultivar adapted to local growing conditions should still be a top priority.

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