Economics of Weed Management Systems in Sugarbeet

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ABSTRACT

Irrigated field studies were conducted in 2004 and 2005 at the University of Wyoming Research and Extension Centers to evaluate herbicide programs and hand hoeing for weed management in sugarbeet. Preplant ethofumesate applications followed by standard-split or micro-rate herbicide programs controlled common lambsquarters (*Chenopodium album* L.) and green foxtail [*Setaria viridis* (L.) Beauv.]. Common lambsquarters control was 6% greater when four micro-rate applications were made compared with three micro-rate applications. Increasing the number of applications of either the standard-split or micro-rate herbicide programs improved green foxtail control 6 to 7% compared with lower number of applications of both programs. Common lambsquarters control was 16% greater with the standard-split rate program compared with the micro-rate program. Sugarbeet root yields were 6.97 Mg/ha greater when ethofumesate was applied preplant prior to the postemergence herbicide applications compared with postemergence herbicide programs alone. Standard-split herbicide programs resulted in 3.48 Mg/ha more root yield compared with the micro-rate herbicide program. Even with the additional cost of preplant ethofumesate, this treatment resulted in $214.92/ha higher net economic return compared with treatments where ethofumesate was not applied. The addition of hand hoeing to all herbicide treatments resulted in higher root yields and

net economic returns. Treatments that provided good weed control and resulted in high root and extractable sucrose yields performed well economically.

Additional key words: Full-rate, lay-by, grass herbicide

Sugarbeet is a high value crop requiring high annual expenditure for production. Weed management is one of the main production costs associated with sugarbeet. A large portion of this cost of production is spent establishing stands of weed-free sugarbeet. Sugarbeet is very sensitive to early weed competition because of slow canopy closure and low plant height (Scott and Wilcockson 1976). Producers often use a combination of herbicides and mechanical measures including hand labor to obtain adequate stands of weed-free sugarbeet.

Sugarbeet weed control programs generally consist of multiple herbicide applications, preemergence (PRE) followed by multiple postemergence (POST) herbicide applications or just multiple POST herbicide applications in order to provide season-long control of many annual weeds (Miller and Fornstrom 1988, 1989; Wicks and Wilson 1983). Phenylcarbamate herbicides are the foundation of these programs and are used either alone or in combination with other herbicides. The most commonly used phenylcarbamate herbicides in sugarbeet are desmedipham or a mixture of desmedipham and phenmedipham. Phenylcarbamate herbicides can cause sugarbeet injury, especially when applied as a single full-rate application (Dexter 1994). The need to reduce sugarbeet injury from phenylcarbamate herbicides resulted in the development of weed control programs that split the full-rate (standard-split rate) of the phenylcarbamates herbicides into two or three applications. Split applications reduced sugarbeet injury and improved weed control when compared with a single full-rate application (Dexter 1994). Split applications of phenylcarbamate herbicides are presently applied at the cotyledon to two-leaf stage of sugarbeet with sequential treatments applied as needed at 7 to 10 day intervals. The phenylcarbamate herbicides are commonly tank mixed with triflusulfuron and clopyralid for broad-spectrum weed control (Miller et al. 1994; Morishita and Downard 1995). Recently, growers have adopted the micro-rate program for weed control in sugarbeet. The micro-rate program involves sequential application of combinations of phenylcarbamate herbicides, triflusulfuron, and clopyralid applied at lower rates than the standard-split programs and this mixture is applied with methylated seed oil. This program was developed to reduce sugarbeet injury from standard-split herbicide applications and to reduce the herbicide input costs while maintaining weed control.

Effective season-long weed control can be accomplished when POST phenylcarbamate herbicides are used in combination with PRE herbicide such as ethofumesate (Miller and Fornstrom 1988, 1989). Incorporation into the soil by mechanical means, irrigation, or precipitation has generally improved the efficacy of PRE herbicides (Dexter 1997). Ethofumesate can also be applied POST and the efficacy of ethofumesate has often been increased when used in combination with phenmedipham, desmedipham, clopyralid, and triflusulfuron (Miller and Fornstrom 1988, 1989). Triflusulfuron is a low use rate POST herbicide that provides safe and effective control of larger weeds in sugarbeet when tank-mixed with phenylcarbamates (Morishita and Downard 1995). Clopyralid can also be tank-mixed with phenylcarbamate herbicides to broaden the spectrum of weed control in sugarbeet (Miller et al. 1994). More recently, POST applications of dimethenamid-P have been useful in providing residual control of emerging annual grasses and broadleaf weeds in sugarbeet (Rice et al. 2002).

Cultivation and/or hand hoeing are used to complement herbicide weed control programs in sugarbeet. Sugarbeet fields are often cultivated one to three times during the growing season, with an additional one to three hand hoeing operations to control escaped weeds. Herbicide treatments used prior to hand hoeing have a dramatic effect on the amount of time required to hand hoe (Dawson 1974). Hand hoeing time is a function of weed density. Miller and Fornstrom (1989) reported that herbicides reduced early-season weed populations by 33 to 97% and hoeing times by 38 to 89% compared with an untreated control. Similarly, herbicide treatments reduced mid-season weed populations by 48 to 97% and hoeing time by 48 to 88% compared with an untreated control in the same study. Over time, there has been an increased cost associated with contract hand labor for weed control in sugarbeet which has resulted in less labor and more use of herbicides and cultivation. Despite the increased cost, hand labor remains an important tool in sugarbeet weed management.

The objectives of this study were to evaluate several herbicide programs for weed control and yield in sugarbeet, and to determine the most economical herbicide program with and without hand labor.

MATERIALS AND METHODS

Field experiments were conducted at the University of Wyoming Torrington Research and Extension Center (TREC) in 2004, and the James C. Hageman Sustainable Agriculture Research and Extension

Center (SAREC) near Lingle, Wyoming in 2005 to evaluate several herbicide programs with and without hand hoeing for weed control in sugarbeet. The soil type at TREC was a Valentine fine sand (Mixed, mesic Typic Ustipsamments), and a Haverson loam (Fine-loamy, mixed, superactive, calcareous, mesic Aridic Ustifluvents) at SAREC. Soil organic matter and pH at TREC was 1.1 % and 7.8, and 1.3% and 7.9 at SAREC. Sugarbeet cultivar 'Beta 4546' was planted to stand at a seed spacing of 20 cm in 76 cm rows at a seeding rate of 168,000 seeds/ha on April 15, 2004 and April 18, 2005. The plots were sprinkler irrigated at both locations. Predominant weed species at both sites were common lambsquarters and green foxtail.

The experimental design was a randomized complete block with a split-plot arrangement and four replications. The main plots consisted of 20 herbicide treatments plus an untreated control, and the subplots consisted of the presence or absence of hand hoeing. Split plots were 3 m wide by 7.6 m long. Herbicide treatments were applied broadcast with a CO_2 pressurized knapsack sprayer delivering 180 L/ha at a pressure of 276 kPa and a walking speed of 5 km/hour. Herbicide treatments and rates are listed in Table 1. Ethofumesate was applied preplant incorporated (PPI). Two over-the-top applications of the standard-split rate were made when sugarbeet was at 2- and 4-true leaf stages of development. Three over-the-top applications of the standard-split rate were made when sugarbeet was at 2-, 4-, and 6-true leaf stages. Three over-the-top applications of the micro-rate were made when sugarbeet was at cotyledon, 2-, and 4-true leaf stages. Four over-the-top applications of the micro-rate were made when sugarbeet was at cotyledon, 2-, 4-, and 6-true leaf stages. Dimethenamid-P and clethodim were applied over-the-top in combination with the standard-split and micro-rate herbicide programs at the 6-true leaf stage of sugarbeet.

Weed control was assessed by weed species counts at both locations 14 days after the final herbicide application. Weed density was determined by counting two randomly selected areas 3 m long and 0.15 m wide in the middle two rows of each plot. Weed control was calculated by dividing the number of weeds in each plot by the number of weeds in the untreated control. Whole plots were split into two equal halves length-wise and half of each plot was hand hoed using long handle hoes. Hand hoeing was timed and was included in the economic analysis. The center row in each plot was harvested for yield using a single row sugarbeet lifter, weighed, and a sub-sample pulled for quality analysis at the Western Sugar Tare Laboratory at Scottsbluff, Nebraska.

For economic comparison, variable costs associated with weed

Table 1. Treatments, herbicides and herbicide rates at both TREC and SAREC locations.

Treatment†	Herbicides‡	Rates§
PPI fb Standard (×2)	ETH fb PDE + TRI fb PDE + CLOP	1.12 fb 0.28 + 0.018 fb 0.37 + 0.11
PPI fb Standard (×3)	ETH fb PDE + TRI fb PDE + CLOP fb PDE	1.12 fb 0.28 + 0.018 fb 0.37 + 0.11 fb 0.37
PPI fb Micro-rate (×3)	ETH fb PDE + TRI + CLOP	1.12 fb 0.09 + 0.004 + 0.02
PPI fb Micro-rate (×4)	ETH fb PDE + TRI + CLOP	1.12 fb 0.09 + 0.004 + 0.02
PPI fb Standard (×2) fb dimethenamid-P	ETH fb PDE + TRI fb PDE + CLOP fb DIM	1.12 fb 0.28 + 0.018 fb 0.37 + 0.11 fb 0.81
PPI fb Standard (×3) + dimethenamid-P	ETH fb PDE + TRI fb PDE + CLOP fb PDE + DIM	1.12 fb 0.28 + 0.018 fb 0.37 + 0.11 fb 0.37 + 0.81
PPI fb Micro-rate (×3) fb dimethenamid-P	ETH fb PDE + TRI + CLOP fb DIM	1.12 fb 0.09 + 0.004 + 0.02 fb 0.81
PPI fb Micro-rate (×4) + dimethenamid-P	ETH fb PDE + TRI + CLOP + DIM	1.12 fb 0.09 + 0.004 + 0.02 + 0.81
Standard (×2)	PDE + TRI fb PDE + CLOP	0.28 + 0.018 fb 0.37 + 0.11
Standard (×3)	PDE + TRI fb PDE + CLOP fb PDE	0.28 + 0.018 fb 0.37 + 0.11 fb 0.37
Micro-rate (×3)	PDE + TRI + CLOP	0.09 + 0.004 + 0.02
Micro-rate (×4)	PDE + TRI + CLOP	0.09 + 0.004 + 0.02
Standard (×2) + clethodim	PDE + TRI fb PDE + CLOP + CLE	0.28 + 0.018 fb 0.37 + 0.11 + 0.09
Standard (×3) + clethodim	PDE + TRI fb PDE + CLOP fb PDE + CLE	0.28 + 0.018 fb 0.37 + 0.11 fb 0.37 + 0.09
Micro-rate (×3) + clethodim	PDE + TRI + CLOP fb PDE + TRI + CLOP + CLE	0.09 + 0.004 + 0.02 fb 0.09 + 0.004 + 0.02 + 0.09
Micro-rate (×4) + clethodim	PDE + TRI + CLOP fb PDE + TRI + CLOP + CLE	0.09 + 0.004 + 0.02 fb 0.09 + 0.004 + 0.02 + 0.09
Standard (×2) fb dimethenamid-P	PDE + TRI fb PDE + CLOP fb DIM	0.28 + 0.018 fb 0.37 + 0.11 fb 0.81
Standard (×3) + dimethenamid-P	PDE + TRI fb PDE + CLOP fb PDE + DIM	0.28 + 0.018 fb 0.37 + 0.11 fb 0.37 + 0.81
Micro-rate (×3) fb dimethenamid-P	PDE + TRI + CLOP fb DIM	0.09 + 0.004 + 0.02 fb 0.81
Micro-rate (×4) + dimethenamid-P	PDE + TRI + CLOP fb PDE + TRI + CLOP + DIM	0.09 + 0.004 + 0.02 fb 0.09 + 0.004 + 0.02 + 0.81

† Standard (×2), 2 standard-split rate treatment applications; Standard (×3), 3 standard-split rate treatment applications; Micro-rate (×3), 3 micro-rate treatment applications; Micro-rate (×4), 4 micro-rate treatment applications; PPI, preplant incorporated ethofumesate application. All micro-rate treatments included MSO at 1% v/v.

‡ Abbreviation: ETH, ethofumesate; PDE, Phenmedipham + Desmedipham + Ethofumesate; TRI, triflusulfuron; CLOP, clopyralid; DIM, dimethenamid-P; CLE, clethodim; fb, followed by.

§ Rates given in kg ai/ha.

control including herbicides, herbicide application, and hand labor were calculated. All other factors such as seed, fuel, equipment, land, and cultivation costs were constant in each treatment and were not included in the analysis. Gross returns were calculated for each plot on the basis of the Western Sugar grower contract payment schedule. Price per ton was dependent on sucrose content and average price of sugar from the payment schedule. Adjustment of tare was incorporated into the calculations to more accurately reflect the payment a grower would receive. The herbicide costs were derived from data compiled by the University of Nebraska Cooperative Extension (UNCE 2004, 2005), herbicide application cost was set at a rate of \$9.88/ha and hand labor costs at a rate of \$7.50/hr. The net return was the economic return on investment in weed control.

Data were analyzed as a mixed model and subjected to ANOVA using the PROC MIXED procedure of SAS (SAS 2003) and means separated using Fisher's Protected LSD ($\alpha = 0.05$). Herbicide treatment, hand hoeing, and the interaction between these factors were analyzed as fixed effects and location was included as a random effect. Since there was no location by treatment interaction, data from TREC and SAREC were combined. Main effects of herbicide treatment and hand hoeing are presented because treatment by hand hoeing interaction was not significant. Single degree of freedom linear contrasts were used to compare groups of different herbicide treatments with respect to weed control, yield, and economic returns.

RESULTS AND DISCUSSION

Weed control

There was no herbicide treatment by location interaction with respect to weed control, so treatment data were averaged over locations for analysis. Common lambsquarters control ranged from 60 to 100% (Table 2). PPI ethofumesate followed by standard-split or micro-rate treatments provided excellent control of common lambsquarters (97 to100%) with the exception of the treatment that included three micro-rate applications, which provided only 85% control. Micro-rate treatments applied alone or in combination with clethodim or dimethenamid-P controlled common lambsquarters 60 to 80% (Table 2). Layby application of dimethenamid-P with the micro-rate program alone did not improve common lambsquarters control when compared with the micro-rate program that included PPI. Combinations of the micro-rate program with clethodim decreased common lambsquarters control when compared with combinations of clethodim with the standard-split rates. The reduction in

Table 2. Effect of herbicide treatments on the control of common lambsquarters and green foxtail, and hoeing time averaged over TREC and SAREC locations.

Treatment[†]	Weed control[‡] Common lambsquarters	Weed control[‡] Green foxtail	Hand hoeing time[§]
	%	%	h/ha
PPI fb Standard (×2)	99	100	4.07
PPI fb Standard (×3)	100	100	4.87
PPI fb Micro-rate (×3)	85	99	4.78
PPI fb Micro-rate (×4)	98	100	3.63
PPI fb Standard (×2) fb Layby	99	100	3.02
PPI fb Standard (×3) fb Layby	99	100	2.95
PPI fb Micro-rate (×3) fb Layby	99	100	3.81
PPI fb Micro-rate (×4) fb Layby	97	100	3.27
Standard (×2)	83	65	6.56
Standard (×3)	94	95	9.09
Micro-rate (×3)	60	65	9.15
Micro-rate (×4)	71	97	6.13
Standard (×2) + Grass	94	100	7.88
Standard (×3) + Grass	91	98	5.02
Micro-rate (×3) + Grass	63	94	7.85
Micro-rate (×4) + Grass	80	98	6.75
Standard (×2) fb Layby	93	83	6.19
Standard (×3) fb Layby	97	98	4.37
Micro-rate (×3) fb Layby	64	80	7.37
Micro-rate (×4) fb Layby	73	100	5.83
Weedy check	0	0	22.66
LSD (0.05)	21	16	5.35

[†] Herbicide treatments applied at cotyledon to 2-leaf stage of sugarbeet with sequential treatments applied 7 days between applications.

[‡] Weed populations were counted at both locations 14 days after the final herbicide treatment. Percentage weed control was calculated by dividing the number of weeds in each plot by the number of weeds in the weedy check.

[§] Hand hoeing time after herbicide treatment application.

control of common lambsquarters was probably due to reduced rates of phenylcarbamate herbicides used in the micro-rate treatments and not antagonism between the tank-mix of these herbicides with clethodim. Antagonism from the tank-mix of phenmedipham and desmedipham with clethodim has been reported in grass and not in broadleaf weed control (Dexter and Luecke 1995).

Single degree of freedom contrasts were conducted to determine if there were differences in weed control with the different herbicide programs (Table 3). There was no benefit to increasing the number of standard-split applications from 2 to 3 for common lambsquarters control. However, common lambsquarters control was improved by 6% when the number of micro-rate applications was increased from 3 to 4. The total amount of herbicide active ingredient applied per hectare for the standard-split treatments was higher than for the micro-rate treatments. The lower number of standard-split application did not result in as great a reduction in the amount of active ingredient applied per hectare when compared with the micro-rate treatments. This may explain the differences observed in control of common lambsquarters with the equal number of applications between the standard-split and micro-rate herbicide treatments. Standard-split treatments provided 16% greater control of common lambsquarters compared with the micro-rate treatments supporting the benefits of increased herbicide rates for management of this weed species. Use of PPI ethofumesate increased common lambsquarters control by 17% when compared with treatments where ethofumesate was not applied. Similar results were reported by Miller and Fornstrom (1989), where a PPI application of ethofumesate followed by POST herbicides were more effective than POST herbicides applied alone.

Green foxtail control ranged from 65 to 100% with the various herbicide treatments (Table 2). All treatment combinations provided more than 80% control of green foxtail, with the exception of 2 or 3 applications of the standard-split and micro-rate treatments, respectively, when PPI ethofumesate or layby dimethenamid-P was applied. Significant improvements in the control of green foxtail occurred with the increased application frequency of both the standard-split and micro-rate treatments, ethofumesate PPI, and the inclusion of clethodim as a POST treatment (Table 2). Combinations of two standard-split and three micro-rate treatments with layby application of dimethenamid-P did not improve green foxtail control when compared with combinations of these treatments with clethodim. Standard-split treatments and micro-rate treatments were not different in the control of green foxtail (Table 3). When PPI ethofumesate or POST clethodim was included in the herbicide program green foxtail control was improved by at least 5%.

The effectiveness of different herbicide treatments in determining hand hoeing time is shown in Table 2. Treatments that were less effective in controlling weeds required longer periods of time for hand hoeing. These treatments reduced weed populations, thereby resulting in reduced hoeing times. These studies illustrate that acceptable levels of common lambsquarters and green foxtail control in sugarbeet production can be achieved by increasing herbicide inputs, either through preplant followed by sequential POST treatments, increased frequency of POST applications, increased rates of POST herbicides, hand hoeing or a combination of the above.

Sugarbeet yield

No herbicide treatment by location interaction was present with respect to sugarbeet yield, so herbicide treatment data were averaged over locations for analysis. Sugarbeet root yield was closely related to weed control. Root yield and extractable sucrose yield ranged from 25 to 51 Mg/ha and 4 to 9 Mg/ha, respectively (Table 4). Ethofumesate PPI followed by four applications of the micro-rate treatment resulted in higher root and extractable sucrose yields compared with three micro-rate applications alone. Herbicide treatments did not influence sucrose concentration.

Root and extractable sucrose yields were similar when application frequency increased either in the standard or micro-rate treatments (Table 5). Root and extractable sucrose yield were 7 and 1 Mg/ha great-

Table 3. Herbicide program differences in weed control averaged over TREC and SAREC locations.

	Common lambsquarters		Green foxtail	
Comparison[†]	Difference	p>|t|	Difference	p>|t|
	%		%	
Standard (×2) vs. Standard (×3)	-2	0.4267	-6	0.0006
Micro-rate (×3) vs. Micro-rate (×4)	-6	0.0041	-7	0.0001
Standard vs. Micro-rate	16	0.0001	1	0.7108
PPI vs. No PPI	17	0.0001	10	0.0001
Layby vs. No Layby	5	0.0323	2	0.2012
Grass vs. No Grass	-6	0.0406	5	0.0230

[†] Single degree of freedom contrasts comparing differences between herbicide programs (average of all treatments that contained the herbicide program). PPI, all treatments that contained preplant incorporated ethofumesate; Layby, all treatments that contained dimethenamid-P; Grass, all treatments that contained clethodim.

Table 4. Sugarbeet root yield, extractable sucrose, and net economic return as affected by weed control treatment averaged over TREC and SAREC locations.

Treatment	Root yield	Extractable sucrose	Net return[†]
	Mg/ha	Mg/ha	$/ha
PPI fb Standard (×2)	48.1	7.9	1663
PPI fb Standard (×3)	45.8	7.5	1531
PPI fb Micro-rate (×3)	46.6	7.7	1668
PPI fb Micro-rate (×4)	42.0	6.8	1385
PPI fb Standard (×2) fb Layby	46.7	7.7	1590
PPI fb Standard (×3) fb Layby	47.9	7.9	1579
PPI fb Micro-rate (×3) fb Layby	50.8	8.3	1759
PPI fb Micro-rate (×4) fb Layby	49.2	8.1	1681
Standard (×2)	37.7	6.3	1350
Standard (×3)	43.7	7.3	1468
Micro-rate (×3)	33.6	5.4	1122
Micro-rate (×4)	37.5	6.4	1383
Standard (×2) + Grass	42.3	6.9	1451
Standard (×3) + Grass	45.8	7.7	1572
Micro-rate (×3) + Grass	36.2	6.1	1298
Micro-rate (×4) + Grass	42.6	6.9	1492
Standard (×2) fb Layby	41.9	6.9	1455
Standard (×3) fb Layby	47.0	7.6	1587
Micro-rate (×3) fb Layby	32.7	5.4	1103
Micro-rate (×4) fb Layby	40.8	6.8	1424
Weedy check	24.6	4.0	799
LSD (0.05)	14.4	2.4	589

[†] Net return was economic return on investment on weed control. Variable costs associated with weed control included herbicide, herbicide application, and hand labor. Herbicide costs were based on prevailing prices at both locations. Herbicide application cost was based on a rate of $9.88/ha, and hoeing costs were based on labor rate of $7.50/hr.

Table 5. Herbicide program differences in root yield, extractable sucrose, and net economic return averaged over TREC and SAREC locations.

Comparison[†]	Root yield		Extractable sucrose		Net return	
	Difference	**p>|t|**	**Difference**	**p>|t|**	**Difference**	**p>|t|**
	Mg/ha		**Mg/ha**		**$/ha**	
Standard (×2) vs. Standard (×3)	-1.67	0.1702	-0.28	0.1627	-28.26	0.5510
Micro-rate (×3) vs. Micro-rate (×4)	-1.52	0.2142	-0.26	0.1947	-51.93	0.2811
Standard vs. Micro-rate	3.48	0.0197	0.58	0.0174	-92.95	0.1004
PPI vs. No PPI	6.97	0.0002	1.10	0.0002	214.92	0.0018
Layby vs. No Layby	2.81	0.0563	0.45	0.0619	73.72	0.1908
Grass vs. No Grass	-1.52	0.3712	-0.27	0.4155	-31.59	0.6382

[†] Single degree of freedom contrasts comparing differences between herbicide programs (Average of all treatments that contained the herbicide program). PPI, all treatments that contained preplant incorporated ethofumesate; Layby, all treatments that contained dimethenamid-P; Grass, all treatments that contained clethodim.

er, respectively, in treatments that received ethofumesate PPI compared with those that did not receive ethofumesate PPI. A similar trend was evident with standard-split treatments compared with micro-rate treatments, with standard-split treatments resulting in increased root and extractable sucrose yields. These differences suggest obvious yield benefits from increased weed control provided by higher herbicide inputs either in the form of preplant herbicides or higher POST herbicide rates. Additionally, sugarbeet yields were improved by sequential application of dimethenamid-P as a layby treatment, although this was only marginally significant. Clethodim did not result in a significant yield increase when compared with treatments where clethodim was not applied.

There was not a hand hoeing by herbicide treatment interaction, so data were combined over herbicide treatments for analysis. Hand hoeing resulted in higher root and extractable sucrose yields compared with non-hand hoed plots; however, it had no effect on the sucrose content (Table 6). Hand hoeing was important in preventing yield losses from weed competition. These results are similar to those of Wicks and Wilson (1983), who found that sugarbeet root yields were highest in hand hoed plots and lowest in non-hand hoed plots. This suggests that hand hoeing can be an effective supplement to herbicides for weed control in sugarbeet especially for removal of large weeds that escape herbicide applications.

ECONOMIC ANALYSIS

Herbicide input costs varied among the treatments. Net returns ranged from $799 to $1759/ha. High weed pressure requires effective herbicide efficacy to optimize net production returns. Increased POST application frequency for the standard-split rate or micro-rate programs were not different from the lower number of POST appli-

Table 6. Sugarbeet root yield, extractable sucrose yield, and net return as influenced by hand hoeing averaged over TREC and SAREC locations.

Treatment[†]	**Root yield**	**Extractable sucrose**	**Net return**
	Mg/ha	Mg/ha	$/ha
Hand hoeing	45.87a[‡]	7.64a[‡]	1606.92a[‡]
No hand hoeing	38.28b	6.24b	1283.96b

† Means of all treatments with hand hoeing or no hand hoeing applied after herbicide treatment application.

‡ Least square means within a column followed by the same letter are not significantly different (α= 0.05).

cations with regard to net return (Table 5). Standard-split rate POST applications resulted in $93/ha greater net return than the micro-rate program; however, this difference was not significant. Treatments including ethofumesate PPI resulted in $215/ha increase in net return compared with treatments where ethofumesate PPI was not applied. Treatments that contained PPI applications of ethofumesate provided better weed control and resulted in higher root and extractable sucrose yields. Ethofumesate PPI reduced early-season weed competition which subsequently improved yields. The additional input cost of using ethofumesate PPI followed by either the standard-split rate or micro-rate program paid off with higher root and extractable sucrose yields resulting from better weed control. Weed infestation is the most important factor determining the most economical weed management program in sugarbeet production. Heavy weed pressure can be controlled with preplant herbicides such as ethofumesate in combination with POST standard-split rate or micro-rate applications. Standard-split rate applications had higher input costs but resulted in better economic returns because of better weed control which resulted in higher root and extractable sucrose yields.

Net returns were increased by over $300/ha from hand hoeing compared with treatments that were not hand hoed (Table 6). The additional cost associated with hand hoeing was offset by higher yields which resulted in higher net returns on investment. High weed pressures provide the highest benefit for hand hoeing while at low weed densities the decision to hoe must be based on future weed pressure and expected economic returns (Miller and Fornstrom 1989). Hand hoeing was important even with higher herbicide inputs especially for management of weed escapes late in the season. As sugarbeet growers design weed control programs, they should consider pressure from weeds which escape herbicide control before using supplemental hand hoeing.

Treatments that provided good weed control and resulted in high root and extractable sucrose yields performed well economically. Weed species such as common lambsquarters can be controlled with preplant herbicides such as ethofumesate that reduce early-season weed competition in combination with POST standard-split rate or micro-rate applications. The cost of a PPI application of ethofumesate was more than offset by the increased yield that resulted.

LITERATURE CITED

Dawson, J. H. 1974. Full-season weed control in sugarbeets. Weed Sci. 22:330-335.

Dexter, A. G. 1994. History of sugarbeet (*Beta vulgaris*) herbicide rate reduction in North Dakota and Minnesota. Weed Technol. 8:334-337.

Dexter, A. G. 1997. Weed Control Guide for Sugarbeet. http://www.sbreb.org/97/Weed/97p3.htm.

Miller, S. D. and K. J. Fornstrom. 1988. Assessment of herbicide benefits in sugarbeets (*Beta vulgaris*). J. Sugar Beet Res. 25:70-77.

Miller, S. D. and K. J. Fornstrom. 1989. Weed control and labor requirements in sugarbeets. J. Sugar Beet Res. 26:1-9.

Miller, S. D., K. J. Fornstrom, and A. Mesbah. 1994. Canada thistle control and competition in sugarbeets. J. Sugar Beet Res. 31:87-96.

Morishita, D. W. and R. W. Downward. 1995. Weed control in sugarbeets with triflusulfuron as influenced by herbicide combination, timing and rate. J. Sugar Beet Res. 32:23-35.

Rice, C. A., C. V. Ransom, and J. K. Ishida. 2002. Efficacy and sugarbeet tolerance with postemergence dimethenamid-P. J. Sugar Beet Res. 39:89-107.

[UNCE] University of Nebraska Cooperative Extension. 2004. Guide for Weed Management in Nebraska. Dept. Agronomy. EC03-130-D.

[UNCE] University of Nebraska Cooperative Extension. 2005. Guide for Weed Management in Nebraska. Dept. Agronomy. EC130.

[SAS] Statistical Analysis System. 2003. SAS Procedures Guide. Version 9.1. Cary, NC: Statistical Analysis Institute.

Scott, R. K. and S. J. Wilcockson. 1976. Weed biology and the growth of sugar beet. Ann. Appl. Bio. 83:331-335.

Wicks, G. H. and R. G. Wilson. 1983. Control of weeds in sugarbeet (*Beta vulgaris*) with hand hoeing and herbicides. Weed Sci. 31:493-499.

Wilson, R. G. 1998. Postemergence herbicide timing for maximum weed control in sugarbeet. J. Sugar Beet Res. 32:15-28.