Conventional and Alternative Placement of Soil Insecticides to Control Sugarbeet Root Maggot (Diptera: Ulidiidae) Larvae

Mark A. Boetel, Robert J. Dregseth, Allen J. Schroeder, and Curt D. Doetkott

Department of Entomology, North Dakota State University, Fargo, ND 58105.
Corresponding author: M. A. Boetel (mark.boetel@ndsu.edu)

ABSTRACT

This field study was carried out in northeastern North Dakota from 1999 to 2002 to compare an alternative device, the spoon, with conventional band and modified in-furrow equipment for applying aldicarb, chlorpyrifos, and terbufos insecticides to control sugarbeet root maggot, *Tetanops myopaeformis* (Röder), larvae. Insecticides differed considerably in placement effects on performance, although yield differences were rare. Effects of postapplication rainfall on efficacy were insecticide- and placement-specific. Placement method had the greatest impact on performance of terbufos and chlorpyrifos, the least water-soluble insecticides tested. Spoon-applied terbufos reduced root maggot feeding injury more than conventional banded and modified in-furrow applications in two of five environments. Plots treated with spoon-applied chlorpyrifos yielded 30.8% more recoverable sucrose than those that received the insecticide as a banded application in 1999, the year of least postapplication rainfall. Aldicarb, the most water-soluble insecticide tested, was generally unaffected by placement. However, spoon-treated aldicarb plots produced 19.2% less recoverable sucrose than those receiving the material via modified in-furrow placement in 2001, the year of highest postapplication rainfall. Contrasts of root injury across all insecticides suggested that, of all placement methods tested, the spoon technique has the greatest potential to optimize granular soil insecticide efficacy for management of sugarbeet root maggot larvae.

Additional key words: *Beta vulgaris*, Insecta, insecticide application method, aldicarb, chlorpyrifos, terbufos, phytotoxicity

The sugarbeet root maggot (SBRM), *Tetanops myopaeformis* (Röder), is an economically important pest of sugarbeet (*Beta vulgaris* L.) in the north central and western United States, and in the Canadian province of Alberta. The insect is native to North America and currently ranks as the most serious insect pest of sugarbeet in the Red River Valley of North Dakota and Minnesota. Larvae are capable of causing substantial feeding injury to developing sugarbeets by rasping the root surface with oral hooks. High larval infestations can cause sufficient feeding injury to result in plant mortality, thus leading to major stand reductions and significant yield losses. Annual losses in sugarbeet yield attributed to SBRM feeding injury in the United States have been estimated at 481,000 metric tons (Theurer *et al.*, 1982). Campbell *et al.* (1998) recorded 42% lower yields from untreated control plots than from sugarbeet treated with the most efficacious root maggot insecticide treatments. Blickenstaff *et al.* (1981) observed that root maggot larvae were capable of causing up to 100% yield losses. Postemergence insecticide treatments can be applied on a prescriptive basis for SBRM management when adult activity reaches action threshold levels (Bechinski *et al.*, 1989). This is a key strategy for protecting irrigated sugarbeet fields from root maggot feeding injury. Prophylactic application of a granular soil insecticide at planting time is a common SBRM control strategy in dryland sugarbeet production (Peay *et al.*, 1969; Yun and Sullivan, 1980; Bergen, 1984; Bergen *et al.*, 1986). Typically, planter-mounted metering devices are used to regulate granular output rates. Most applications in the Red River Valley are carried out by using either banded or modified in-furrow placement techniques. Banding involves application of granules to the soil surface in 5- to 18-cm swaths over the row and ahead of planter press-wheels. Modified in-furrow placement is achieved by directing granules immediately behind the closing portion of the seed furrow to minimize insecticide contact with seed and thus, avoid potential insecticide phytotoxicity. This is an important consideration because organophosphate soil insecticides can cause phytotoxicity in sugarbeet, resulting in stunted plants, reduced biomass production, and significant stand losses (Hein and Wilson, 1995).

The spoon device is an alternative to conventional insecticide placement equipment. It was developed in Europe, but a modified version has generated interest among sugarbeet producers in the Red River Valley. The spoon is an open-faced miniature banding device that facilitates placement of a narrow swath of granules over the row with the greatest concentrations deposited laterally and immediately adjacent to the furrow rather than directly over it, thereby minimizing the likelihood of insecticide contact with seed. The objective of this investigation was to compare conventional banded and modified in-furrow placement methods with the alternative spoon device for impacts on performance of granular soil insecticides commonly used to manage the sugarbeet root maggot.

MATERIALS AND METHODS

This study was conducted in five commercial field sites near St. Thomas in northeastern North Dakota from 1999 to 2002. Study sites had the following soil types: 1) Glyndon silt loam with 3.5% organic matter and 7.8 pH in 1999; 2) Bearded silt loam with 3.3% organic matter and 8.0 pH in 2000; 3) Bearded silt loam with 5.1% organic matter and 7.9 pH in 2001; 4) Glyndon silt loam with 3.6% organic matter and 7.9 pH at site I in 2002; and 5) Glyndon silt loam with 4.9% organic matter and 7.9 pH at site II in 2002. Sugarbeet varieties used in the study were Maribo 9363 (1999 only) and Van der Have 66140 (2000 – 2002). Planting dates ranged between 10 and 21 May. Individual plots were four rows (spaced 56 cm apart) wide and 10.7 m long. The study was arranged in a randomized complete block design with four replications. Two untreated buffer rows were planted between individual plots and 7.6-m wide unplanted alleys were established between replicates at all locations.

Insecticide Applications.

Treatments included banded, modified in-furrow, and spoon placement of aldicarb (Temik 15G [granular], Bayer CropScience, Research Triangle Park, NC), chlorpyrifos (Lorsban 15G, Dow AgroSciences, Indianapolis, IN), and terbufos (Counter 15G; BASF Ag Products, Research Triangle Park, NC) insecticides applied at planting. An untreated control was included at all locations. Application rates differed slightly among insecticides used in this study. Each insecticide was applied at its maximum labeled use rate for sugarbeet (2.4, 2.2, and 2.0 kg [AI]/ha for aldicarb, chlorpyrifos, and terbufos, respectively) to reflect typical planting-time applications of these materials in dryland sugarbeet production areas affected by moderate to severe SBRM infestations. Noble™ metering units (Remcor, Inc., Howe, TX) mounted on a six-row John Deere™ (Deere & Company, Moline, IL) 71 Flex planter were used to regulate granule delivery rates, and all metering units were calibrated on the planter before treatment applications. The modified in-furrow treatment of chlorpyrifos 15G was used in this study for comparative purposes and is not recommended for use in commercial sugarbeet production due to its potential for causing plant injury.

Banded applications were directed over individual rows through Gandy™ banders (Gandy Company, Owatonna, MN) in 12.7-cm swaths ahead of the planter rear press-wheels. Modified in-furrow placement was achieved by using standard planter-equipped in-furrow delivery tubes. The modification involved orienting each tube slightly backward toward the rear press wheel to allow granule deposition into soil above the seed as the furrow closed, thus avoiding excessive insecticide contact with seed and minimizing the likelihood of insecticide phytotoxicity to sugarbeet seedlings. Effective swath width of modified in-furrow placement was approximately 5 cm with the highest insecticide concentration placed immediately over the furrow. The spoon method also employed a standard in-furrow drop tube; however, a flanged spoon-like apparatus (ca. 4.3 cm wide; galvanized steel) was attached to its terminal end (Fig. 1). A 5 mm diam. by 13 mm long steel bolt was installed at a central point near the terminal end of the spoon with two hexagonal nuts (10 mm) facing upward (inner face of spoon) to

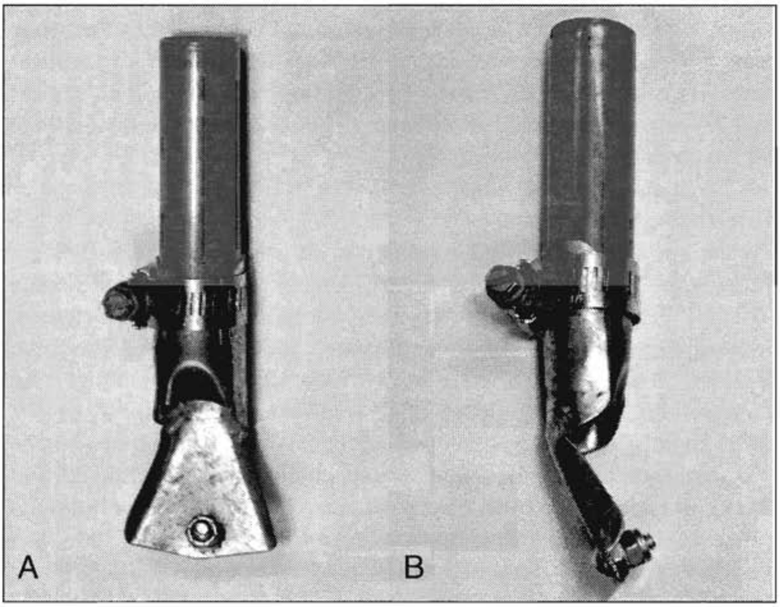

Fig. 1. Spoon placement device for applying granular soil insecticides: (A) frontal and (B) lateral view

laterally deflect falling granules and thus, prevent direct deposition of granules into the seed furrow. The tip of the tube was constricted to force granules to drop directly down the open face of the spoon, around the metal nuts, and over the row. This design resulted in the application of a miniature (5- to 7-cm wide) swath of granules to the row with the greatest insecticide concentrations falling immediately adjacent (within 2 cm) to the seed furrow rather than directly into it. Application rate recommendations on labels of most granular soil-applied insecticides are typically expressed in amount of formulated product per unit of row length. Although swath widths in our study varied because of the architecture of the placement devices, application rate within each insecticide was the same per unit row length for all placement methods compared.

Data collection and analysis.
Larval feeding injury to sugarbeet roots was assessed during late-July to mid-August of each year. Ten randomly selected roots per plot (five from each of the outer two treated rows) were dug, washed, and rated according to the 0 to 9 injury rating scale (0 = no visible feeding scars; 9 = more than 3/4 of root surface blackened with feeding scars) (Campbell *et al.*, 2000). In the fall of each year, a mechanical defoliator was used to remove sugarbeet foliage immediately before harvesting (mid- to late-September). All roots from the center 2 rows of each plot were extracted from the plot using a mechanical harvester. A harvester-mounted digital scale (Dyna-Link MSI-7200, Measurement Systems International, Seattle, WA) was used to measure pre-wash weight of all harvested roots immediately after harvesting each plot. A representative sample (12 to 18) of harvested roots was randomly collected from each plot for analysis of impurities and percent sucrose content at the American Crystal Sugar Company Quality Tare Laboratory (East Grand Forks, MN). Because edge effects on sugar concentration and quality can occur in plants near plot alleys due to reduced interplant competition, two to four roots from the end of each row were marked with spray paint after defoliation and before harvest. Those roots were excluded from sucrose content and quality analyses to avoid potential edge effects. The weight of field soil adhering to harvested roots was deducted from harvested weight to calculate sugarbeet root yield. Net extractable sucrose per hectare was estimated by multiplying root weight by sugar concentration and subtracting the loss to molasses (based on concentrations of soluble non-sucrose components).

All data were subjected to analysis of variance (ANOVA) by using the general linear models (GLM) procedure (SAS Institute, 1999). Years were not combined because our initial analyses generated significant ($P < 0.05$) treatment × year interactions; however, yield data from sites I and II in 2002 were pooled in cases where the treatment × site interaction was not significant. Single degree of freedom contrasts (Steele and Torrie, 1980) were used to examine insecticide-specific placement effects on root maggot feeding injury, sugarbeet root yield, and net extractable sucrose yield as response variables. Additional analyses on these variables, also based on GLM and contrasts, were used to assess the overall impacts of placement techniques, irrespective of insecticide used.

RESULTS

Aldicarb. *Root Injury.* Data from root injury and yield evaluations of aldicarb performance are presented in Table 1. Consistently high root maggot feeding pressure developed at all five study sites. This was evidenced by root injury rating means in the untreated control plots ranging from 7.0 to 7.28 on the 0 to 9 scale of Campbell *et al.* (2000). Although no significant differences were detected among placement methods for aldicarb applications, contrasts of root rating data from site II in 2002 revealed a trend ($P = 0.1058$) toward better root protection from spoon-applied aldicarb than from banding the insecticide.

Yield. Results for aldicarb effects on harvestable root yield were reflective of root injury rating data. Placement generally did not impart significant impacts on root yield for this insecticide. The exception was in 2001 when plots treated with the modified in-furrow application produced significantly ($P = 0.0167$) greater root yield than spoon-treated aldicarb plots. However, because root injury rating means were not statistically different between these treatments in 2001, the yield difference was probably not associated with root maggot control.

Similar to the pattern observed for sugarbeet root yield, aldicarb placement had little impact on extractable sucrose yield. In 2001, plots treated with aldicarb by using modified in-furrow placement yielded an average of 1.5 Mg/ha more ($P = 0.0025$) extractable sucrose than those that received the spoon application. The difference amounted to a 23.8% sucrose yield enhancement. Banding aldicarb also provided greater sucrose yields ($P = 0.0330$) than applying the material using spoon placement in 2001. No further statistical differences in sucrose yield were detected among aldicarb placement methods.

Chlorpyrifos. *Root Injury.* Chlorpyrifos appeared to be impacted more by placement than aldicarb. In 1999, root maggot feeding injury in

Table 1. Sugarbeet root maggot feeding injury and yield in plots treated with aldicarb 15G insecticide using modified in-furrow, spoon, and band placement, St. Thomas, ND, 1999 – 2002.

	Contrasts									
Year	**MIF[†] vs. Spoon**		***P***	**Band vs. Spoon**		***P***	**MIF[†] vs. Band**		***P***	**Check**
	Root injury (0-9)[‡]									
1999	4.22	3.38	0.1464							7.18
2000	2.32	2.53	0.6080	2.70	2.53	0.6533	2.32	2.70	0.3391	7.20
2001	1.62	1.40	0.6479	1.90	1.40	0.3139	1.62	1.90	0.5771	7.00
2002										
Site I	6.18	6.22	0.8942	6.50	6.22	0.4666	6.18	6.50	0.3905	7.00
Site II	3.02	2.85	0.6993	3.60	2.85	0.1058	3.02	3.60	0.2104	7.28
	Root yield (Mg/ha)									
1999	42.6	44.9	0.5600							27.5
2000	39.4	40.0	0.7741	37.2	40.0	0.2288	39.4	37.2	0.3548	26.9
2001	54.8	45.8	0.0167	51.6	45.8	0.1139	54.8	51.6	0.3676	45.7
2002[§]	49.8	48.2	0.4969	50.0	48.2	0.4663	49.8	50.0	0.9605	41.6
	Extractable sucrose yield (Mg/ha)									
1999	5.8	6.2	0.5199							3.6
2000	5.9	5.9	0.9855	5.6	5.9	0.5176	5.9	5.6	0.5292	3.8
2001	7.8	6.3	0.0025	7.3	6.3	0.0330	7.8	7.3	0.2863	6.0
2002[§]	6.6	6.4	0.3953	6.5	6.4	0.8073	6.6	6.5	0.5432	5.5

[†] Modified in-furrow.

[‡] Root injury ratings based on the 0 to 9 scale of Campbell *et al.* (2000).

[§] Pooled data from sites I and II due to lack of significant ($P < 0.05$) treatment X site interaction.

plots treated with spoon-applied chlorpyrifos was lower ($P = 0.0828$) than in banded plots (Table 2), and the average difference was about one full rating scale level. A trend ($P = 0.1032$) toward lower feeding injury in spoon-applied than in banded chlorpyrifos plots was also evident in 2000, and the spoon technique was superior ($P = 0.0236$) to banding the insecticide at site II in 2002. Modified in-furrow placement of chlorpyrifos resulted in greater protection from root maggot feeding injury than spoon and banded applications ($P = 0.0923$ and $P = 0.0620$, respectively) at site I in 2002.

Yield. Similar to the findings on root injury in 1999, plots treated with spoon-applied chlorpyrifos produced 30.8% more ($P = 0.0483$) extractable sucrose than those treated with the band application that year. Despite modified in-furrow applications of chlorpyrifos providing greater root protection than banded treatments in 2002, root yield was 18.5% lower ($P = 0.0853$) and extractable sucrose was 10.0% lower ($P = 0.0570$) in modified in-furrow plots than in banded plots. This provided strong evidence that chlorpyrifos can cause major negative impacts on sugarbeet yield parameters that are independent of root maggot control.

Terbufos. *Root Injury.* Although root injury sustained in the untreated control plots in 1999 was high (7.18), placement method did not have a significant impact on terbufos efficacy that year (Table 3). Root protection provided by spoon-applied terbufos was greater than modified in-furrow in 2000 ($P = 0.0314$) and in 2001 ($P = 0.0013$). Applying terbufos using spoon placement was also more effective than banding in 2001 ($P = 0.0616$) and at site II in 2002 ($P = 0.0125$). Modified in-furrow placement of terbufos resulted in less root maggot feeding injury ($P = 0.0024$) than when the insecticide was banded at site II in 2002. This finding was not repeated in other years of the experiment.

Yield. Unlike our findings for root injury in 1999, plots treated with a modified in-furrow application of terbufos produced 22.3% lower harvestable root yield ($P = 0.0550$) and 23.4% less extractable sucrose ($P = 0.0704$) than banded plots. Spoon-applied terbufos resulted in 36.1% more ($P = 0.0331$) extractable sucrose yield than modified in-furrow placement in 1999. Despite frequent differences in root injury among terbufos placement techniques, no other differences were detected in relation to sugarbeet root yield or extractable sucrose in the experiment.

Table 2. Sugarbeet root maggot feeding injury and yield in plots treated with chlorpyrifos 15G insecticide using modified in-furrow, spoon, and band placement, St. Thomas, ND, 1999 – 2002.

	Contrasts									
Year	**MIF[†] vs. Spoon**		***P***	**Band vs. Spoon**		***P***	**MIF[†] vs. Band**		***P***	**Check**
	Root injury (0-9)[‡]									
1999	6.40	5.90	0.3860	6.92	5.90	0.0828	6.40	6.92	0.3631	7.18
2000	4.00	3.80	0.6080	4.45	3.80	0.1032	4.00	4.45	0.2531	7.20
2001	5.12	4.62	0.3139	5.05	4.62	0.3907	5.12	5.05	0.8788	7.00
2002										
Site I	5.18	5.82	0.0923	5.90	5.82	0.8419	5.18	5.90	0.0620	7.00
Site II	6.30	5.85	0.3243	6.92	5.85	0.0236	6.30	6.92	0.1745	7.28
	Root yield (Mg/ha)									
1999	33.6	37.2	0.3657	30.7	37.2	0.1112	33.6	30.7	0.4715	27.5
2000	33.0	35.7	0.2508	33.2	35.7	0.2923	33.0	33.2	0.9215	26.9
2001	43.9	47.3	0.3455	44.1	47.3	0.3824	43.9	44.1	0.9431	45.7
2002[§]	37.4	42.0	0.8703	45.9	42.0	0.1180	37.4	45.9	0.0853	41.6
	Extractable sucrose yield (Mg/ha)									
1999	4.5	5.1	0.3467	3.9	5.1	0.0483	4.5	3.9	0.2735	3.6
2000	5.1	5.4	0.4279	4.9	5.4	0.2622	5.1	4.9	0.7363	3.8
2001	6.1	6.6	0.3453	6.1	6.6	0.2831	6.1	6.1	0.8938	6.0
2002[§]	5.4	5.6	0.5512	6.0	5.6	0.1845	5.4	6.0	0.0570	5.5

[†]Modified in-furrow.

[‡]Root injury ratings based on the 0 to 9 scale of Campbell *et al.* (2000).

[§]Pooled data from sites I and II due to lack of significant ($P < 0.05$) treatment X site interaction.

Table 3. Sugarbeet root maggot feeding injury and yield in plots treated with terbufos 15G insecticide using modified in-furrow, spoon, and band placement, St. Thomas, ND, 1999 – 2002.

	Contrasts									
Year	**MIF[†] vs. Spoon**		***P***	**Band vs. Spoon**		***P***	**MIF[†] vs. Band**		***P***	**Check**
	- - - Root injury (0-9)[‡] - - -									
1999	6.38	6.22	0.7934	6.88	6.22	0.2623	6.38	6.88	0.3860	7.18
2000	5.22	4.35	0.0314	4.62	4.35	0.4816	5.22	4.62	0.1311	7.20
2001	5.45	3.70	0.0013	4.65	3.70	0.0616	5.45	4.65	0.1122	7.00
2002										
Site I	5.68	5.95	0.4666	6.15	5.95	0.5956	5.68	6.15	0.2130	7.00
Site II	4.52	4.82	0.5089	6.02	4.82	0.0125	4.52	6.02	0.0024	7.28
	- - - Root yield (Mg/ha) - - -									
1999	27.5	34.0	0.1131	35.4	34.0	0.7129	27.5	35.4	0.0550	27.5
2000	34.0	32.7	0.5686	32.5	32.7	0.9521	34.0	32.5	0.5289	26.9
2001	51.7	49.1	0.4609	51.4	49.1	0.5211	51.7	51.4	0.9226	45.7
2002[§]	45.0	45.8	0.7508	45.9	45.8	0.9646	45.0	45.9	0.7175	41.6
	- - - Extractable sucrose yield (Mg/ha) - - -									
1999	3.6	4.9	0.0331	4.7	4.9	0.7163	3.6	4.7	0.0704	3.6
2000	5.0	4.8	0.6846	4.8	4.8	0.9948	5.0	4.8	0.6799	3.8
2001	6.9	7.2	0.5046	7.0	7.2	0.7246	6.9	7.0	0.7513	6.0
2002[§]	5.8	6.2	0.2343	6.1	6.2	0.7247	5.8	6.1	0.3999	5.5

[†]Modified in-furrow.

[‡]Root injury ratings based on the 0 to 9 scale of Campbell *et al.* (2000).

[§]Pooled data from sites I and II due to lack of significant ($P < 0.05$) treatment X site interaction.

Overall Placement Impacts. *Root Injury.* Contrasts of overall placement effects on protection from root maggot feeding injury (Table 4) further supported the findings relating to placement impacts on individual insecticides. Feeding injury was lower in plots treated with spoon-applied insecticides than in banded plots in 1999 ($P = 0.0472$) and 2001 ($P = 0.0349$), and at site II in 2002 ($P = 0.0006$). Spoon-treated plots also incurred significantly ($P = 0.0068$) less root injury overall than modified in-furrow plots in 2001. Modified in-furrow applications provided greater root protection than banded placement at both study sites in 2002 ($P < 0.0255$).

Yield. In 1999, spoon-treated plots produced 4.1 Mg/ha more ($P = 0.0808$) root yield than modified in-furrow plots. At site II in 2002, banded insecticides resulted in more harvestable root yield than when the materials were applied by using spoon ($P = 0.0942$) or modified in-furrow ($P = 0.0922$) placement. No further differences or trends in relation to overall placement impacts on root yield were observed.

In 1999, extractable sucrose yield from spoon-treated plots overall was statistically higher than from modified in-furrow ($P = 0.0348$) and banded plots ($P = 0.0963$). Despite the superior root yields that occurred in banded plots at site II in 2002, those differences were not reflected in extractable sucrose yield ($P > 0.1429$).

DISCUSSION

Sugarbeet root maggot larval feeding pressure was consistently high throughout this investigation. Placement-related differences in root maggot feeding injury, sugarbeet root yield, and net extractable sucrose were frequently observed, but placement effects varied among insecticides. Performance levels of chlorpyrifos and terbufos were often affected by placement method; however, aldicarb was mostly unaffected. Chlorpyrifos applied via the spoon technique resulted in less root maggot feeding injury than banding in two study years, and the same trend was evident in a third year. Plots treated with terbufos by using spoon placement also incurred less SBRM feeding injury than banded and modified in-furrow treatments in two years of the experiment.

Disparities in performance among chlorpyrifos placement methods could have been associated with water solubility. The solubility of chlorpyrifos is only 2 parts per million (ppm) (McEwen and Stephenson, 1979), whereas terbufos and aldicarb solubility values are 45 (RSC, 1986) and 6,000 ppm (Howard, 1991), respectively. The lower the solubility value, the less mobile the material is in soil water.

Table 4. Overall impact of soil insecticide placement method on sugarbeet root maggot feeding injury and sugarbeet yield parameters, St. Thomas, ND, 1999 – 2002.

	Contrasts									
Year	**MIF[†] vs. Spoon**		***P***	**Band vs. Spoon**		***P***	**MIF[†] vs. Band**		***P***	**Check**
	Root injury (0-9)[‡]									
1999	5.67	5.17	0.1393	6.90	5.17	0.0472	5.67	6.90	0.2128	7.18
2000	3.85	3.56	0.2009	3.93	3.56	0.1109	3.85	3.93	0.7836	7.20
2001	4.07	3.24	0.0068	3.87	3.24	0.0349	4.07	3.87	0.4832	7.00
2002										
Site I	5.82	6.00	0.1423	6.08	6.00	0.4013	5.82	6.08	0.0255	7.00
Site II	4.62	4.51	0.6788	5.52	4.51	0.0006	4.62	5.52	0.0017	7.28
	Root yield (Mg/ha)									
1999	34.6	38.7	0.0808	33.1	38.7	0.3739	34.6	33.1	0.3725	27.5
2000	35.4	36.1	0.6130	34.3	36.1	0.1832	35.4	34.3	0.4004	26.9
2001	50.1	47.4	0.1882	49.0	47.4	0.4273	50.1	49.0	0.5909	45.7
2002										
Site I	39.3	39.1	0.7810	39.6	39.1	0.9716	39.3	39.6	0.8083	34.3
Site II	51.4	51.5	0.9910	55.3	51.5	0.0942	51.4	55.3	0.0922	48.9
	Extractable sucrose yield (Mg/ha)									
1999	4.6	5.4	0.0348	4.3	5.4	0.0963	4.6	4.3	0.5896	3.6
2000	5.3	5.4	0.8135	5.1	5.4	0.3060	5.3	5.1	0.4277	3.8
2001	6.9	6.7	0.3355	6.8	6.7	0.6494	6.9	6.8	0.6067	6.0
2002										
Site I	5.1	5.2	0.8453	5.2	5.2	0.7155	5.1	5.2	0.8652	4.6
Site II	6.8	6.9	0.6189	7.2	6.9	0.3235	6.8	7.2	0.1429	6.4

[†]Modified in-furrow.

[‡]Root injury ratings based on the 0 to 9 scale of Campbell *et al.* (2000).

Thus, the movement of chlorpyrifos from its granular carrier and into the target zone (sugarbeet rhizosphere) is slower than the other insecticides. Water solubility also could explain the moderate impact placement had on terbufos performance and the relative lack of differences among aldicarb application methods. Aldicarb, an extremely water-soluble and soil-mobile material, moves readily in soil and is affected less by placement method. Water solubility would further explain the differences observed among insecticide placement methods in 1999. Rainfall received during the SBRM larval feeding period (June through July) in 1999 was only 10.6 cm, whereas, rainfall amounts during the same period in all other experiment years ranged from to 17.8 to 23.1 cm (Table 5). Low rainfall during the larval feeding period in 1999 would have been particularly limiting to chlorpyrifos movement in soil and thus, could have resulted in reduced efficacy, especially when the material was banded. This suggests that performance and yield differences between placement methods for chlorpyrifos and terbufos applications during 2000–2002 could have been more notable if rainfall amounts had been lower, as was the case in 1999. Optimization of chlorpyrifos performance may, therefore, require use of the spoon technique to place granules as close as practical to the target zone because the active ingredient is not likely to move far from the initial site of granule application. Findings for terbufos in 1999 were also unique compared to other years. Despite no impacts of insecticide placement on SBRM feeding injury that year, spoon-treated and banded plots yielded more recoverable sucrose than modified in-furrow plots. This suggests that terbufos impacts on yield were independent of maggot control and that the insecticide has more potential for phytotoxicity to sugarbeet plants when it is applied modified in-furrow than when banded. Because this impact was most evident in 1999, the risk of yield loss due to this apparent phytotoxicity from modified in-furrow terbufos appears to be greater in years of low postplanting rainfall. Significant

Table 5. Monthly rainfall totals, St. Thomas, ND, 1999 – 2002.

	Rainfall (cm)			
Year	**May**	**June**	**July**	**Total**
1999	1.4	8.8	1.8	12.0
2000	1.6	16.3	3.3	21.2
2001	3.4	6.4	16.7	26.6
2002				
Site I	1.0	13.4	4.4	18.7
Site II	1.0	13.3	4.5	18.8

yield differences associated with aldicarb placement were limited to 2001, the year of highest postapplication rainfall, when banded and modified in-furrow plots produced more extractable sucrose than spoon-treated plots. Banding aldicarb or applying it modified in-furrow could be slightly more advantageous than using the spoon. A plausible explanation for this is that the increased lateral distribution of aldicarb granules over the row resulting from banding may dilute the material on a volumetric basis within the sugarbeet rhizosphere, thus increasing crop safety from the highly soluble and mobile material in wet years.

The relative infrequency of yield differences among treatments during 2000–2002 could have resulted from adequate rainfall for plant development moderating the impacts of SBRM feeding injury. Although yield can be an important consideration when evaluating insecticide efficacy, our findings underscore the importance of root maggot feeding injury as a more effective criterion to characterize soil insecticide performance in protecting roots from the insect. Assessments of root maggot feeding injury will be especially important under otherwise optimal agronomic conditions that can mask yield impacts from the insect. Root ratings also validate that root maggot larvae were present and caused feeding injury to plant roots. However, as observed by Campbell *et al.* (1998), root maggot feeding injury is not always closely correlated with yield. Our data support that contention and help explain why such inconsistencies between these parameters can occur. The potential for soil insecticide phytotoxicity to sugarbeet seedlings suggests that yield data from trials carried out under low SBRM feeding pressure or in the absence of the insect should be evaluated carefully to avoid misinterpretation.

Because postplanting rainfall amounts are unpredictable, the risks associated with sugarbeet root maggot feeding injury in dryland production areas that consistently support high root maggot infestations are probably managed most appropriately by making prophylactic planting-time insecticide applications. Future development of improved host plant resistance to SBRM feeding injury, either by use of conventional breeding or transgenic technology, could potentially lead to reduced grower reliance on chemical insecticides to control this pest. However, risks associated with other soil-inhabiting insect pests of sugarbeet will likely require careful consideration and some form of protection for the fields of many growers.

It is critical to point out that the granular deflection system used with the spoon applicator in this study is an essential component of the device because it minimizes the likelihood of direct insecticide contact with sugarbeet seed during planting. Askew *et al.* (1973)

observed increases in plant injury following placement of soil insecticides in direct contact with sugarbeet seed. Hein and Wilson (1995) also demonstrated that terbufos and chlorpyrifos can be phytotoxic to sugarbeet and are capable of causing substantial plant stand reductions. Thus, major yield losses are possible if excessive concentrations of these materials are applied in direct contact with sugarbeet seed.

These results reinforce the importance of insecticide water solubility and its impact on mobility of these compounds in soil, although caution should be taken in attempting to apply these findings to all situations involving soil insecticides for root maggot management. Insecticide movement in soil and resultant performance against the target pest will often be impacted by the manner in which soil water is received. All precipitation received during this study was from natural rainfall. Placement impacts on insecticide performance in irrigated sugarbeet production could deviate from those observed in our study, especially in cases where water is supplied by using flood irrigation because laterally delivered soil water can percolate insecticide active ingredient horizontally across the soil profile and into direct contact with young sugarbeet roots.

The findings of this study demonstrate the important role placement can play in the performance of soil insecticides applied at planting time to protect sugarbeet plants from root maggot feeding injury. Because placement effects varied among the three insecticides evaluated, producers preferring to use a particular material for root maggot management should use the most consistently effective placement method for the specific insecticide chosen. Modified in-furrow and band placement appear to be consistently effective for applying aldicarb, whereas producers preferring to use terbufos or chlorpyrifos for SBRM management should consider using band or spoon placement. Overall contrasts of placement methods (insecticides combined) indicated that root protection was most consistent when the spoon device was used. Spoon placement was superior to modified in-furrow and banding in 2001, the year of highest postapplication rainfall, and spoon applications were better than bands in 1999, the year of least rainfall in this study.

The consistent SBRM control provided by spoon-applied insecticides under variable soil moisture conditions suggests that this placement method can be especially advantageous for dryland sugarbeet growers that rely on the unpredictable timing and variable amounts of rainfall that occur during the production season. Thus, applying soil insecticides for SBRM control using the spoon device may mitigate grower risk of achieving the less-than-acceptable efficacy that sometimes occurs with conventional insecticide placement. The flexibility of the spoon device for applying any of the insecticides tested in this experiment also may be desirable to growers preferring to rotate insecticide materials for SBRM management, a prudent practice for avoiding or delaying the development of insecticide-resistant root maggot strains.

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