Comparative Nematicidal Control of *Heterodera schachtii* on Sugar Beet as Affected by Soil Temperature and Soil Type

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ABSTRACT

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Aldicarb at 4.5 kg a.i./ha and terbufos at 9.0 kg a.i./ha were most effective in increasing sugar beet root yields in *Heterodera schachtii* infested soil at population densities (Pi) of 2.8 and 4.9 eggs/cm^3 of soil. They became less effective at Pi of 7.2 and 12.9 eggs/cm^3 of soil, and there was a negative correlation between root yields and Pi. Root yields from aldicarb (4.5 kg a.i./ha) applied 7.6 cm and 15.2 cm from the seed at time of planting did not differ significantly ($P < 0.05$). The greatest root yields from aldicarb at 9.0 kg a.i./ha was obtained when it was applied 15.2 cm from the seed; it was phytotoxic when applied at a distance of 7.6 cm. Terbufos was most effective when applied 7.6 cm from the seed. Root yield increases from oxamyl was moderate to poor and a rate of 9.0 kg a.i./ha was comparable to aldicarb only at the low Pi (2.8 eggs/cm^3 of soil). The distance of oxamyl from the seed did not affect the degree of control. Aldicarb applied in a 13-cm-row band was most effective at a rate of 4.5 kg a.i./ha, because it was phytotoxic at 9.0 kg a.i./ha in a 13-cm band. Another experiment examined the nematicidal activity of aldicarb and terbufos with 1,3-dichloropropene (1,3-D), and how the nematode-nematicide-plant relationship is affected by soil temperature and soil type. The 1,3-D treatments effectively controlled *H. schachtii* and increased sugar beet root yields at Pi of 3.9, 7.7, and 12.8 eggs/cm^3 of soil at soil planting temperatures of 6, 12, and 18 C. Aldicarb and terbufos effectively controlled Pi of 3.9 eggs/cm^3 of soil at the three soil temperatures, but were less effective than 1,3-D in controlling *H. schachtii* at the higher Pi. Root yields from the 1,3-D treatments were significantly ($P < 0.05$) greater in sandy loam and loam soils than in a clay loam soil. Aldicarb and terbufos were less affected by soil type than was 1,3-D.

Additional keywords: nematode population density, sugar beet cyst nematode

The sugar beet cyst nematode, *Heterodera schachtii* Schmidt, is one of the most important plant pathogens affecting sugar beet growth and production decisions in the western United States. Because of the debilitating effects of the nematode on plant growth, scientists continually strive to develop better control tactics, including more effective use of nematicides. Studies on the control of *H. schachtii* with the use of volatile and nonvolatile nematicides are well documented (6,9-12,14,16). However, nematode activity and chemical control are affected by certain edaphic factors, such as soil moisture and soil temperature, as well as differences in nematicide chemical properties (5,7,8,13,17).

As part of a continuing effort to determine the most efficacious method of controlling *H. schachtii*, microplot studies were made to determine 1) the differential nematicidal activity of the nonvolatile nematicides aldicarb, terbufos, and oxamyl; and 2) the relationship between *H. schachtii* population densities (Pi) and soil temperature and type on the differential activity between a volatile nematicide, 1,3-dichloropropene (1,3-D), and aldicarb and terbufos.

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MATERIALS AND METHODS

All studies were conducted at Logan, UT in 3.0 × 4.3 m microplots in a sandy loam soil (73% sand, 17% silt, 10% clay; pH 7.8) unless otherwise indicated. The following procedure and cultural practices were used in all experiments.

Nematode population densities (Pi) were determined by 1) collecting soil samples with a 2.38-cm-diameter oakfield probe, to a depth of 30 cm, on 30-cm centers (140 cores per plot), 2) extracting cysts with an elutriator (4), 3) separating cysts from soil debris by an alcohol flotation method (15), and 4) crushing cysts in water in a Potter Elvehjem Type tissue grinder and counting the eggs. Standard management practices were followed in all studies. Microplot fertility was determined by the Utah State Testing Laboratory, Logan, UT, and fertilizer was added to bring fertility levels to that used in commercial sugar beet production (110 ppm of potash, 60 ppm of nitrates, 20 ppm of phosphates) immediately before planting. A commercial sugar beet selection, 'Tasco AH-14', was used. No herbicides were used and the plots were hand-weeded. Plots were irrigated with a sprinkler irrigation system. Water (2.5–3.0 cm) was applied immediately after planting, and irrigations were made as deemed necessary. Plants were hand-thinned to a stand (30-cm spacings) 28 days after planting. The sugar beet rows were bedded immediately after thinning and continually cultivated until the beet canopy covered the rows.

Replicated plant root samples, one per 20 cm of each row, were harvested at thinning time and stained in hot lactoglycerol (1:1:1, lactic acid:glycerol: distilled water) and acid fuchsin, to determine nematodes per seedling. Thermographs recorded soil temperatures at a 15-cm depth, and plants in each experiment were grown for approximately 1,154 degree-days with a base temperature of 8 C regardless of planting time (2,8), unless stated otherwise. Data from all experiments were analyzed by an analysis of variance and a linear regression analysis.

Effects of chemical application method on nematode control. Aldicarb, terbufos, and oxamyl were evaluated on *H. schachtii* mean Pi (eggs/cm^3 of soil) of 2.8 with a range of 2.2–3.3, 4.9 with a range of 4.1–5.6, 7.2 with a range of 6.4–7.8, and 12.9 with a range of 11.4–13.1. Each nematicide was evaluated at rates of 4.5 and 9.0 kg a.i./ha, and applied at time of planting with a chisel injector that placed the chemicals 7.6 and 15.2 cm to the side of the seed at a depth of 7.6 cm. Soil temperature at time of planting was 13 C. Because of differences in chemical solubility (terbufos, 15 ppm; aldicarb, 6,000 ppm; oxamyl, 280,000 ppm) (1), aldicarb and oxamyl were applied to one side of the seed and terbufos was applied in equal rates to both sides of the seed. The seed was planted on 56-cm centers. Treatments, including nontreated controls, were replicated six times. Sugar beets were harvested after 143 days' growth, and root yields were determined and converted to metric tons/ha.

A similar study, on adjacent microplots, concerned the effects of row banding of the three nematicides on control of *H. schachtii*. Mean Pi (eggs/cm^3 of soil) were 4.9 with a range of 4.2–5.8, 8.2 with a range of 7.5–9.0, and 13.4 with a range of 12.6–14.8. Chemical application rates were 4.5 and 9.0 kg a.i./ha. Aldicarb and oxamyl were applied 2.5 cm deep in a 13-cm band and terbufos was applied 2.5 cm deep in a 25-cm band. All were centered directly over the row and covered with 3.0–4.0 cm of soil. Seeds were planted in the center of the band to a depth of 2.0 cm. (Due to differences in chemical solubility, preliminary studies had shown that maximum nematode control was obtained at these band widths.) Treatments, including nontreated controls, were replicated six times. Soil temperature at time of planting was 15 C. Plots were harvested after 139 days' growth.

Relationship of population densities and planting soil temperature to nematode control. Chemical control of *H. schachtii* with 1,3-D, aldicarb, and terbufos was studied in microplots at nematode mean Pi (eggs/cm^3 of soil) of 0.0, 3.9 with a range of 3.4–4.2, 7.7 with a range of 7.2–8.0, 12.8 with a range of 12.3–13.2, and 16.6 with a range of 16.1–16.9. To accommodate early spring planting, 1,3-D was applied the previous fall (6 October) on 30-cm centers, at a depth of 30 cm, at soil temperature of 16 C, with a chemical injector handgun at a rate of 168 kg/ha. Aldicarb and terbufos were applied at rates of 4.5 and 9.0 kg/ha, respectively, at time of planting. Planting dates in the several plots varied to achieve soil temperatures of 6, 12, and 18 C at a soil depth of 15 cm at planting. Aldicarb was applied 7.6 cm deep and 7.6 cm to one side of the center of the row. Terbufos was applied in equal amounts (4.5 kg a.i./ha) to each side of the row at similar distances and depths used for aldicarb. Treatments, including nontreated controls, were replicated six times. Plants were grown for a period of 1,258 degree-days (2,8), with a base temperature of 8 C, regardless of time of planting.

Interaction of soil type and population density on nematode control. The influence of different soil types on chemical control of *H. schachtii* with 1,3-D, aldicarb, and terbufos was studied. Soil types were sandy loam soil (73% sand, 17% silt, and 10% clay; pH 7.8); loam soil (43% sand, 45% silt, 12% clay; pH 8.2); and clay loam soil (27% sand, 31% silt, 42% clay; pH 7.8). Experimental procedures were similar to that described for 1,3-D and nonvolatile nematicide applications, but sugar beet seeds were

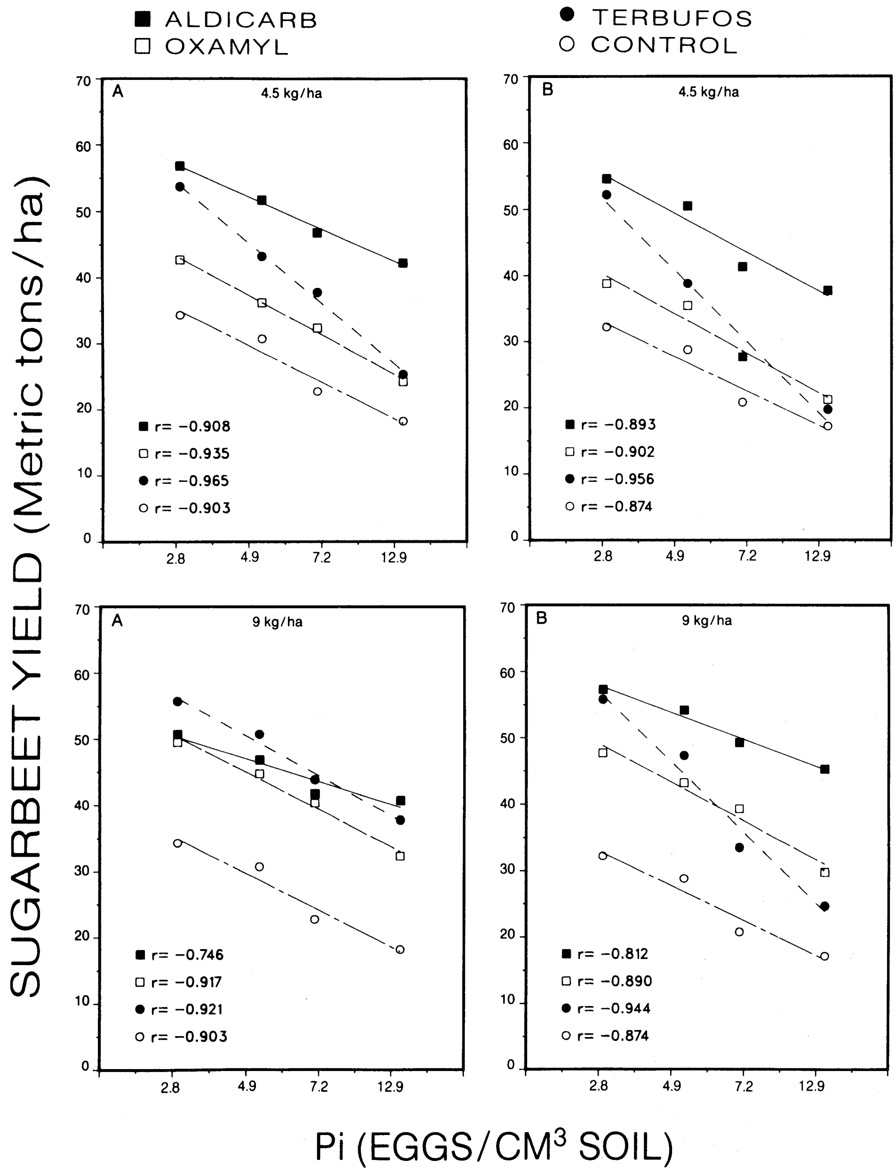

Fig. 1. Effect of method of application of nonvolatile granular nematicides on sugar beet root yields as affected by nematicidal application to control *Heterodera schachtii.* **(A)** Nematicides applied 7.6 cm deep and 7.6 cm to the side of the seedbed at time of planting. (4.5 kg/ha = 1.7; 9.0 kg/ha = 1.8.) **(B)** Nematicides applied 7.6 cm deep and 15.2 cm to the side of the seedbed at time of planting. (4.5 kg/ha = 1.9; 9.0 kg/ha = 2.0.) Aldicarb and oxamyl applied to one side of seedbed; terbufos applied to both sides. ANOVA LSD ($P < 0.05$).

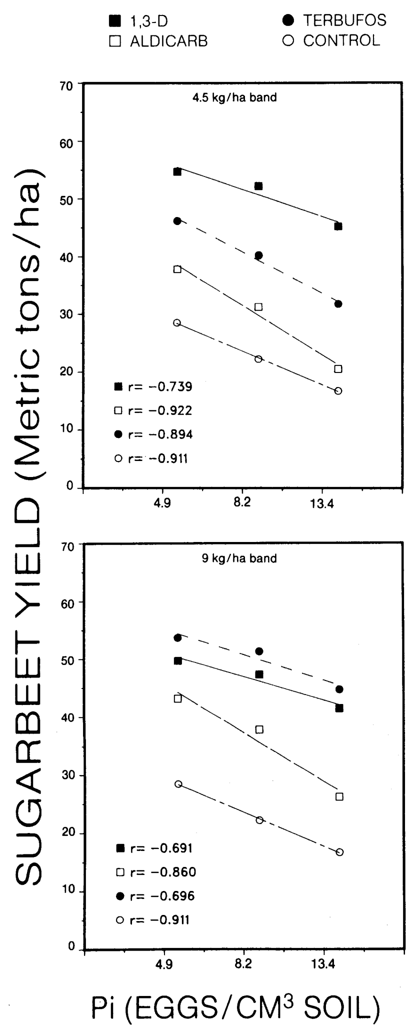

Fig. 2. Effect of method of application of nonvolatile nematicides on sugar beet root yields as affected by nematicidal applications to control *Heterodera schachtii.* Aldicarb and oxamyl applied 2.5 cm deep in a 13-cm band; terbufos applied 2.5 cm deep in a 25-cm band. ANOVA ($P < 0.05$). (4.5 kg/ha = 2.1; 9.0 kg/ha = 2.4.)

planted 5 May when soil temperature at a depth of 15 cm was 18 C. Mean nematode Pi (eggs/cm^3 of soil) were 4.2 with a range of 3.9–4.5 and 13.1 with a range of 12.7–13.5. Treatments, including non-treated controls, were replicated six times. Plants were harvested on 16 October, after 134 days' growth and 1,258 degree-days with a base temperature of 8 C (2,8).

RESULTS

Effects of chisel application spacing on nematode control. There was a direct relationship between nematode control (determined by sugar beet root yield), nematicide, and nematode Pi. (Fig. 1). Aldicarb and terbufos, at rates of 4.5 and 9.0 kg a.i./ha, respectively, effectively ($P < 0.05$) increased root yields at low nematode Pi. Application of 9.0 kg a.i./ha of aldicarb, however, was phytotoxic to sugar beet when placed 7.6 cm from the seed, thus reducing root yields.

There were significant differences ($P < 0.05$) in root yields between nematicide treated and nontreated control plots and a greater yield response with nematicide treatments as the Pi increased. Terbufos was effective only at the high Pi, when 9.0 kg a.i./ha was placed close to the seed at planting. Aldicarb was effective at the lower rate (4.5 kg a.i./ha) in all instances, except when the chemical was placed at a distance of 15.2 cm from the seed and the nematode Pi was high.

Oxamyl was less effective than aldicarb or terbufos at both 4.5 and 9.0 kg a.i./ha chemical rates, but yields were better than the nontreated control ($P < 0.05$). Oxamyl became less effective ($P < 0.05$) as the nematode Pi increased, but its effectiveness did not vary with placement.

Effects of row-band application of nonvolatile nematicides on nematode control. There were significant differences ($P < 0.05$) between sugar beet root yields in nematicide treated and nontreated control plots, and there was a direct relationship between sugar beet root yields, nematicide, and nematode Pi when the chemical was applied in a band over the seedbed (Fig. 2). All nematicides were less effective at the high Pi of 13.4 eggs/cm^3 of soil. Aldicarb was phytotoxic in a 13-cm band at 9.0 kg a.i./ha, and maximum root yields resulted from 4.5 kg a.i./ha at low to moderate *H. schachtii* Pi. Terbufos was less effective in controlling *H. schachtii*, and only the higher rate (9.0 kg a.i./ha) of terbufos was comparable to the lower rate (4.5 kg a.i./ha) of aldicarb at all nematode Pi ($P < 0.05$). Oxamyl was less effective than either aldicarb or terbufos as described herein.

Interaction of population density and planting soil temperature on nematode control. Soil temperature at time of planting affected the nematicidal control of *H. schachtii* and sugar beet root yields (Fig. 3). The 1,3-D provided the most effective *H. schachtii* control, and the greatest sugar beet root yields. The 1,3-D treatment effectively controlled all nematode Pi at planting temperatures of 6 C, as determined by sugar beet root yields, but became less effective at the high nematode Pi as soil temperature increased. Aldicarb and terbufos controlled *H. schachtii* at the low Pi, but were less effective than 1,3-D at moderate

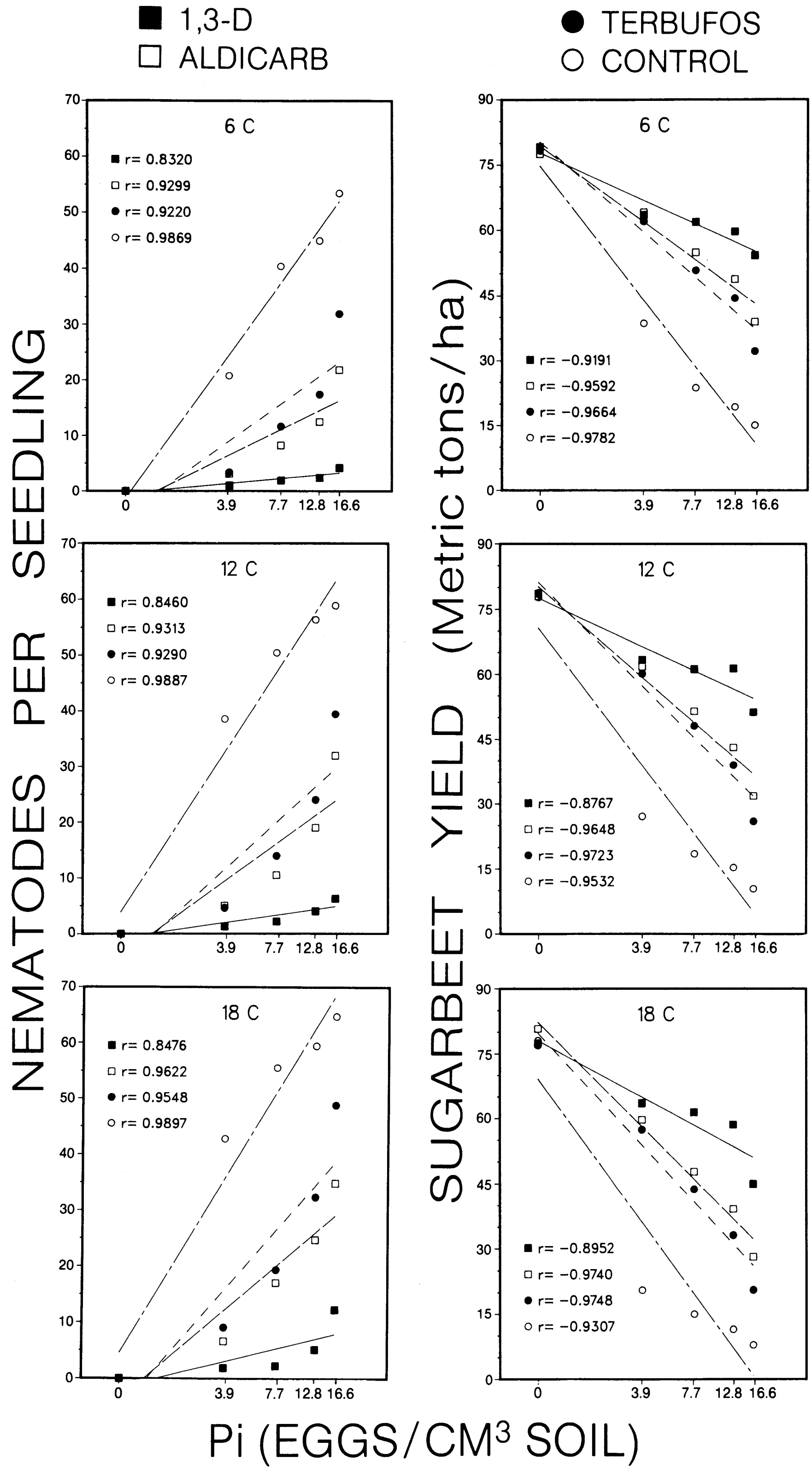

Fig. 3. Effect of soil population density (Pi) and soil temperature on J2 invasion of sugar beet seedling and root yields as affected by nematicide applications to control *Heterodera schachtii*. ANOVA LSD ($P < 0.05$). J2 invasion, 6 C = 1.1; 12 C = 1.2; 18 C = 1.2. Root yields, 6 C = 1.5; 12 C = 1.5; 18 C = 1.6.

to high Pi. Sugar beet root yields were negatively correlated to soil planting temperature and nematode Pi, and invasion of sugar beet seedlings by *H. schachtii* juveniles (J2) was inversely related to sugar beet yields.

Sugar beet root yields from nematicide-treated, nematode-infested plots did not approach those from noninfested plots ($P < 0.05$). Root yields from 1,3-D treated plots, depending on the nematode Pi, ranged from 14.8 to 33.0 metric tons/ha below that from noninfested control plots. Comparable differences were 17.6 and 50.0 metric tons/ha for aldicarb and 16.7 and 57.4 metric tons/ha for terbufos. There were no differences ($P < 0.05$) in yields from noninfested control plots and noninfested chemically treated plots.

Influence of soil type on chemical nematode control. The soil fumigant (1,3-D) effectively controlled *H. schachtii* at all Pi in sandy loam soil and loam soil, but was less effective ($P < 0.05$) at both nematode densities in clay loam soil (Fig. 4). Aldicarb and terbufos were as effective as 1,3-D at a low Pi in all three soil types. Aldicarb gave better nematode control than terbufos in clay loam soil ($P < 0.05$). Aldicarb and terbufos were less effective than 1,3-D in controlling nematodes at a high Pi in sandy loam or loam soils ($P < 0.05$). There were no differences in 1,3-D and aldicarb control at high nematode density in clay loam soil, and both were better than terbufos ($P < 0.05$). Invasion of sugar beet seedlings by *H. schachtii* J2 was inversely related to sugar beet root yields.

DISCUSSION

Results of this study confirm the important relationship between nematode population densities (Pi) and soil temperature at the time of planting on the host-parasite relationship between *H. schachtii* and sugar beet (5,7,8,14). All chemicals showed good nematicidal activity under some conditions. However, differences in the effectiveness of volatile and nonvolatile nematicides became more evident with changes in the nematode Pi and environmental

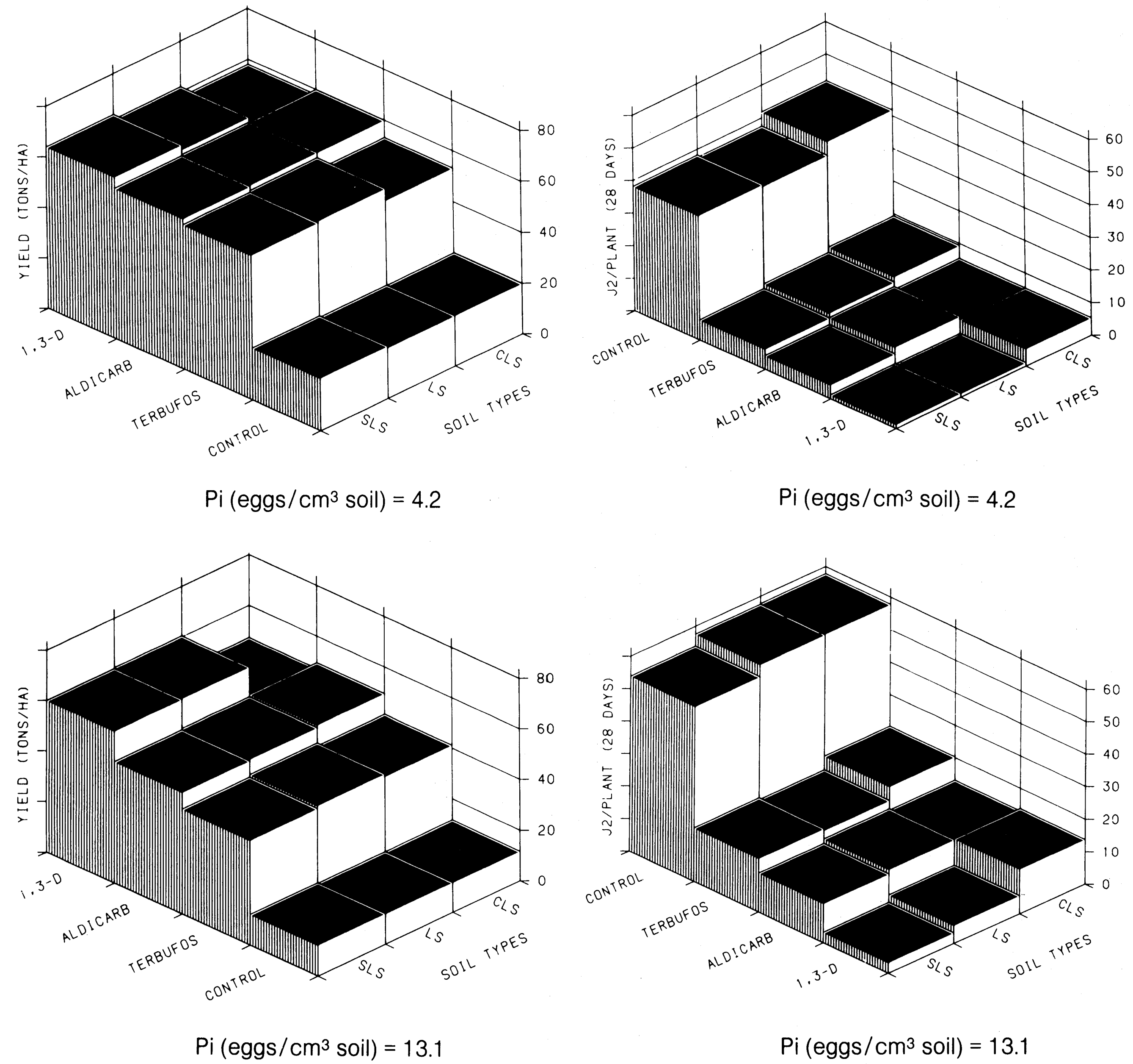

Fig. 4. Effect of soil type and soil population density (Pi) on J2 invasion of sugar beet seedling and root yields as affected by nematicide applications to control *Heterodera schachtii*. SLS = Sandy loam soil; LS = loam soil; CLS = clay loam soil. ANOVA LSD ($P < 0.05$). J2 invasion, Pi at 4.2 = 2.7; Pi at 13.1 = 4.3. Root yields, Pi at 4.2 = 3.6; Pi at 13.1 = 5.2.

conditions. The 1,3-D may be classified as an offensive nematicide that diffuses through the soil killing nematodes and eggs on contact, and reducing the nematode population to a level obtained with a successful rotation program. Aldicarb, terbufos, and oxamyl fit the role of defensive nematicides that protect the sugar beet seedling from invasion by the hatching J2. Differences in nematicidal control are affected by differential rate of kill of the nematode Pi and subsequent protection through a period of initial plant growth; 1,3-D is more effective than the nonvolatile nematicides as the Pi increases because of its ability to destroy the egg while still in the cyst. The effectiveness of aldicarb, terbufos, and oxamyl can be attributed partly to relative nematicidal activity, but differences in solubility are apparently also important. The low solubility of terbufos may account for the best control occurring when the chemical was placed to both sides of the seed at a distance of 7.6 cm. The opposite is true for oxamyl; control is excellent immediately after application, but the high solubility apparently results in rapid loss of residual and nematicidal activity when chemical activity is critical for root protection (5,7). The solubility of aldicarb contributes to its effectiveness. It is sufficiently soluble to give the essential control and still maintain residual activity over a period necessary for plant growth. These results agree with a previous report outlining the behavior of aldicarb and oxamyl in the soil (3).

One disadvantage of using 1,3-D is its inability to effectively control *H. schachtii* in heavy clay soils. Although it may be effective at low Pi, it loses some of its effectiveness at higher population levels.

Sugar beet root yields from nematode-infested, chemically treated plots were lower than those from noninfested plots, and the nematicides became less effective as the Pi increased. Therefore, regardless of the effectiveness of a chemical, it can not compensate for sound agronomic practices, including crop rotation, that prohibit or limit nematode infestation of the soil.

This study confirms findings of other investigations (6,9,12) and explains why a chemical application may be effective under certain field conditions and not under others. This information should contribute to a better understanding of the nematicide-nematode-plant relationship and result in the adoption of improved nematode control procedures. It is important to have an understanding of the nematode biology (5,7,8) and the physical limitations of the control methodology in order to achieve optimum crop yields.

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