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Suppression of *Meloidogyne chitwoodi* with Sudangrass Cultivars as Green Manure[1]

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Abstract: *Meloidogyne chitwoodi* race 1 reproduced on Piper sudangrass (*Sorghum bicolor* (L.) Moench), 332 (sudangrass hybrid), and P855F and P877F (sorghum–sudangrass hybrids), but failed to reproduce efficiently on Trudan 8, Trudex 9 (sudangrass hybrids), and Sordan 79, SS-222, and Bravo II (sorghum–sudangrass hybrids). *Meloidogyne chitwoodi* race 2 behaved similarly and reproduced more efficiently on Piper, P855F, and P877F than on Trudan 8, Trudex 9, or Sordan 79. The mean reproductive factor for *M. chitwoodi* races on the poorer hosts ranged from <0.1 to 0.9 under greenhouse and field conditions. *Meloidogyne hapla* failed to reproduce on any of the cultivars tested. In the laboratory, leaves of each cultivar chopped and incorporated as green manure reduced the *M. chitwoodi* population in infested soil more than unamended or wheat green manure treatments. Trudan 8, although limited to the zone of incorporation, protected this zone from colonization of upward migrating second stage juveniles (J2) for up to 6 weeks. Leaves of Trudan 8 but not roots were effective against *M. chitwoodi,* and J2 appeared to be more sensitive than egg masses. Trudan 8 and Sordan 79 as green manure reduced *M. chitwoodi* in bucket microplots under field conditions.

Key words: Columbia root-knot nematode, control, green manure, host suitability, *Meloidogyne chitwoodi, M. hapla,* northern root-knot nematode, nematode, organic amendment, potato, *Sorghum bicolor,* sudangrass, sorghum–sudangrass hybrid.

The Columbia root-knot nematode, *Meloidogyne chitwoodi* Golden et al., is a serious pest of potato, *Solanum tuberosum* L., in the Pacific Northwest. The nematode causes warts on the tuber surface and brown spots within the tubers (23). Blemished tubers may be downgraded or rejected for processing and fresh market sale. Control of this nematode is heavily dependent on soil fumigation with 1,3-dichloropropene or metham sodium (18). Because of health and environmental concerns, the continued availability of these soil fumigants is uncertain. Thus, the search for alternative measures to manage root-knot nematodes on potato and other vegetable crops has become increasingly important.

Recently, Davis et al. (3) showed that summer sudangrass and winter rapeseed as green manures may reduce disease incidence of *Verticillium dahliae* and *Rhizoctonia solani* on potato. Our studies indicate that rapeseed as green manure significantly reduces potato damage caused by *M. chitwoodi* (21). Winter rapeseed for green manure is sown late in summer and incorporated before flowering the following spring. However, growers are concerned that the hard seeds of rapeseed may germinate later and that volunteer plants will become a serious weed problem for the vegetable seed and potato industries in the region. A strong opposition also exists in the vegetable seed growing areas because of the possibility of seed contamination. Thus, sudangrass would be preferred over rapeseed as a green manure crop because it is cold sensitive and can be readily controlled with selective herbicides.

Ideally, a green manure crop should not serve as a host for the targeted nematode. Poor host status combined with the detrimental effects of green manure may reduce the nematode population to a manageable level. Information on host status of sudangrass and sorghum cultivars (*Sorghum bicolor* (L.) Moench) for *M. chitwoodi* is very limited (14).

The purpose of these studies was to evaluate the host suitability of several sudangrass and sorghum–sudangrass hybrids for *M. chitwoodi* races 1 and 2 and *M. hapla,*

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and to compare the efficiency of these cultivars as green manure to reduce *M. chitwoodi* populations in pot cultures and field microplots.

Materials and Methods

Nematode species: Isolates of *M. chitwoodi* races 1 (WAMC1) and 2 (ORMC8) and *M. hapla* (WAMH) were obtained from the Washington State University Irrigated Agriculture Research and Extension Center root-knot nematode collection (16). Egg inocula were obtained from infected tomato, *Lycopersicon esculentum* Mill. cv. Columbian by extraction with 0.5% NaOCl (7).

Host test plants: Cultivars included sudangrass cv. Piper, three sudangrass hybrids cvs. Trudan 8, Trudex 9, and 332, and five sorghum–sudangrass hybrids cvs. Sordan 79, P855F, P877F, SS-222, and Bravo II. According to Harlan and de Wet (5), all nine cultivars are in the bicolor race group of *S. bicolor*. Piper seeds were obtained locally; Trudan 8, Trudex 9, and Sordan 79 from Northrup King Co., Minneapolis, MN; P855F and P877F from Pioneer Hi Bred, Inc., Plainview TX; 332, SS-222, and Bravo II from Germain's Seeds, Fresno, CA.

Host studies

Greenhouse test: Each test cultivar listed above was tested against each nematode species and race. Columbian tomato, an excellent host for both species of nematodes, was used as a standard. Pepper, *Capsicum annuum* L. cv. California Wonder, a nonhost for *M. chitwoodi* and a host for *M. hapla,* and wheat, *Triticum aestivum* L. cv. Stephens, a nonhost for *M. hapla* and a host for *M. chitwoodi,* were also included as checks to detect contaminated nematode inocula. For each nematode isolate, 5,000 eggs (Pi) in 5 ml of water were pipetted into five holes around five 2-week-old sudangrass or sorghum–sudangrass test plants growing in 10-cm-d plastic pots. The potting medium (850 g per pot) was a methyl bromide-treated (0.3 kg/m^3) loamy sand soil (84% sand, 10% silt, 6% clay; 0.5% organic matter, pH 6.9). Treatments, replicated five times, were arranged in a randomized complete block design on a greenhouse bench. Greenhouse temperature ranged between 22 and 26 C during the experiment. Host suitability was assessed after 55 days by washing the roots free of soil, extracting the eggs (7), and calculating the reproductive factor (R_f) as follows: R_f = final egg density (Pf) ÷ initial egg density (Pi) (15). A test plant was considered a suitable host for nematode when $R_f \geq 1$; a poor host, $R_f \leq 1$ but >0.1; or nonhost, $R_f \leq 0.1$.

Microplot field test: Host status of Piper, Trudan 8 and Trudex 9 sudangrass, and P8555F, P877F and Sordan 79 sorghum–sudangrass was further evaluated in field bucket microplots (19) at the Hermiston Agricultural Research and Extension Center in Hermiston, Oregon. Pioneer P3732 field corn, a suitable host for *M. chitwoodi* (12), was included for comparison. Cultivars were arranged in five randomized complete blocks. A 2.5-liter layer of uninoculated, unfertilized soil (77% sand, 16% silt, 7% clay; 0.7% organic matter, pH 7.6) treated with methyl bromide (0.3 kg/m^3), was placed in the bottom of each 19-liter bucket. Inoculum consisting of 18,000 *M. chitwoodi* (race 1) eggs in 100 ml water was then mixed with 10 liters of soil with fertilizer (31 g NH_4NO_3 7.4 g KCl, and 10.6 g P_2O_5) added, and placed in each bucket. An additional 2.5 liters of unfertilized, uninoculated soil was added to bring total soil volume to 15 liters per bucket. Ten seeds of each cultivar were then planted in each bucket. The plants were grown for 5 months (May to October 1990) when the roots were harvested and the eggs were extracted (7). The number of second-stage juveniles (J2)/250 cm^3 soil was also determined after centrifugal-flotation extraction (9), and the total number of J2 per bucket was estimated. the Pf values were calculated by summing the number of J2 plus eggs/bucket, and R_f = Pf (eggs + J2) ÷ 18,000.

Row field test: Trudan 8 sudangrass hy-

brid, Sordan 79 sorghum–sudangrass hybrid, and P3732 field corn were evaluated for host suitability to *Meloidogyne chitwoodi* race 1 in a field study in Hermiston, Oregon. Seeds were sown on 31 May 1990 in sandy loam soil (coarse lomay mixed mesic xerollic camborthid) using four-seed hills spaced 70 cm apart in rows spaced 75 cm apart. Each host crop was replicated six times in a randomized complete block design. Each plot consisted of one row of five hills. Before planting (31 May) and at harvest (19 October), 250-cm^3 soil samples (0–40 cm deep) were taken from the middle three hills in each plot. The J2 were extracted from samples by Baermann funnel method and counted. The counts were log transformed, and means were separated by Duncan's multiple-range test. The host preference by *M. chitwoodi* was based on the number of J2 per 250 cm^3 soil.

Soil amendment-greenhouse study

Four greenhouse experiments were conducted to determine: (i) the effects on *M. chitwoodi* race 1 of nine sudangrass cultivars used as green manure; (ii) the efficiency of different plant parts used as green manures in reducing nematode population; (iii) the sensitivity of sources of nematode inocula to green manure treatments; and (iv) the depth of nematode control obtained by green manure and the duration of control within the zone of incorporation.

Finely chopped *M. chitwoodi*-infected tomato roots were mixed with a loamy sand soil (described in the greenhouse host test studies) using a cement mixer rotated for 1 minute. The infested soil was incubated for 10 days at 18 C to obtain a mixture of egg masses and J2 for the cultivar–green manure, plant parts efficiency, and depth of protection studies. In each test, 500 g of infested soil was amended with chopped (2–3 cm) leaves or roots of 2-month-old sudangrass and sorghum–sudangrass cultivars. Unamended infested soil served as control. An additional control treatment included infested soil amended with leaves of Stephens wheat. All treatments received 15 g nonfumigated field soil (starter) to facilitate decomposition of plant tissue during the incubation period. Treated soil was placed in 7.5-cm-d clay pots, incubated on a greenhouse bench for 10 days, and then planted with a 3-week-old Columbian tomato seedling. The experimental design was a randomized complete block replicated five times. The seedlings were removed after 3 weeks, the root systems were washed free of soil and stained with acid fuchsin (2), and nematodes within the roots were counted.

Data were $\log_e$ transformed before analysis of variance. Means were separated within the following four tests by Duncan's multiple-range test ($P = 0.05$). The details of the four tests are as follows:

Cultivars as green manures: In one test, 10 or 20 g of chopped leaves as green manure of Piper sudangrass, Trudan 8 and Trudex 9 sudangrass hybrids, and Sordan 79, P855F, and P877F sorghum–sudangrass hybrids were compared with the wheat and the unamended soil. In a second test, 20 g of chopped leaves as green manure of 332, SS-222, and Bravo II sorghum–sudangrass were compared with wheat amendment and with unamended soil.

Efficiency of plant parts: Twenty g of leaves, stems, or roots of Trudan 8 sudangrass hybrid were either chopped or homogenized before mixing with infested soil. Plant tissues were homogenized in 80 ml water with Sorval homogenizer (Ivan Sorval Inc., Norwalk, CT) running at high speed for 1 minute. When chopped tissue was mixed with the soil, 80 ml of water was added. Unamended infested soil, included as a control, also received 80 ml water.

Sensitivity of nematode inocula: A loamy sand soil was infested either with 2,000 freshly hatched J2 (25), or tomato root pieces with egg masses. The infested soils were immediately mixed with 20 g chopped leaves of Trudan 8 sudangrass hybrid, or unamended to serve as control. At bioassay, the nematodes were extracted (9) from a set of unamended pots, and the number of J2 or eggs + J2 in two source treatments was determined. After bioas-

say, nematode counts in corresponding unamended control treatments were used as a standard against which the percentage of nematodes killed by Trudan 8 green manure treatments was determined.

Protection of amended zone: The depth of control obtained with green manure was determined in 15-cm-high polyvinylchloride (PVC) soil columns (17), constructed by taping three PVC rings (8.25-cm-d × 5.0-cm-high) end to end. The columns were packed with soil (bulk density = 1.4 g/cm^3) infested for 10 days using chopped *M. chitwoodi*-infected tomato roots. A fourth ring, sealed on one end with 25-µm-pore nylon screen to allow nematode passage but confine amended soil, was assembled to the top of each three-ringed column. The fourth ring contained 500 g of infested soil plus 15 g starter soil into which was mixed chopped leaves of Trudan 8 sudangrass hybrid or Stephens wheat. Unamended soil served as control. The soil bulk density in this fourth ring was not determined. Five soil columns per treatment were arranged in randomized complete blocks and placed on the surface of dry soil in 10-cm-d clay pots at 18 C. The soil columns were irrigated daily with 50 ml water (1 cm) for 3 weeks, while excess water freely drained into dried soil in the pots. The wet soil in the pots was replaced with dried soil several times during the experiment. After 3 weeks, the content of each ring was bioassayed for 21 days with a Columbian tomato seedling. Tomato roots were stained, and nematodes were counted as before.

Duration of control within the zone of incorporation was evaluated by allowing J2 in unamended soil to migrate upwards in PVC columns and colonize the green-manure-amended soil above. Screen-sealed rings containing either clean soil mixed with 20 g chopped leaves of Trudan 8 sudangrass hybrid, Stephens wheat, or unamended soil were assembled to the top of three-ringed columns (15 cm high) filled with clean soil. Through a port in the bottom ring, 2,000 freshly hatched J2 were introduced into the columns. Three-week-old tomato seedlings were planted in the top rings and irrigated with 50 ml water twice daily. Excess water drained freely into dry soil contained in pots on which the columns rested. The wet soil in the pots was frequently replaced with dry soil. Three weeks after transplanting, tomato roots were gently removed, stained, and nematodes in the roots were counted. The soil–green manure mixture was returned to the top ring and reassembled on top of the columns, a new tomato seedling was planted, and 2,000 additional freshly hatched J2 were introduced. The procedure was repeated until the numbers of *M. chitwoodi* invading tomato roots in the amended soil were similar to the control.

Soil amendment–microplot study

Fifteen liters of loamy sand field soil (81% sand, 17% silt, 2% clay; 0.9% organic matter, pH 6.9) previously treated with methyl bromide (0.3 kg/m^3) were placed in 19-liter plastic bucket microplots (19) on 28 May 1991. Soil (1,000 g) infested with *M. chitwoodi* was mixed thoroughly into the top 15 cm of soil in each bucket. A single Columbian tomato seedling or 10 Trudan 8 sudangrass hybrid or 10 Sordan 79 sorghum–sudangrass hybrid seeds were planted in each bucket. Treatments were arranged in a randomized complete block design with five replicates. Sweet corn, *Zea mays* L. cv. Sweet Tooth (Ferry Morse Seed Co., Modesto, CA), and Stephens wheat were also grown in five replicates to obtain green tissue to compare with the sudangrass and sorghum–sudangrass hybrid. The buckets were weeded manually as needed and fertilized with Osmocote (14-14-14, Sierra Chemical Co., Milpitas, CA) slow release fertilizer. After 2 months, the nematode population in the soil was assessed by removing ten 2.5-cm-d soil cores from each bucket and bioassaying 500 g soil with a Columbian tomato seedling. The tops of all plants were removed at the soil line, and 450 g (equal to wheat shoot growth during the 2 months) of Trudan 8 or Sordan 79 leaves were chopped into 5-cm lengths. The chopped tissue was incorporated into the top 15 cm of soil in which tomato had grown or into soil in

which the respective plant had grown. Additional buckets in which tomato had grown received 450 g of either wheat or sweet corn leaves as control treatments, or were unamended to measure the natural decline of nematodes in simulated fallow. The buckets were kept moist for 1 month, and nematode populations were determined by bioassay as before.

Results and Discussion

Host studies

Greenhouse test: Meloidogyne chitwoodi races 1 and 2 and *M. hapla* successfully reproduced on tomato, and R_f values in three sets of experiments ranged from 9 to 75. Reproduction of *M. chitwoodi* races 1 and 2 on pepper and *M. hapla* on wheat was negligible ($R_f < 0.1$).

All sudangrass and sorghum–sudangrass hybrids tested in the greenhouse were nonhosts ($R_f < 0.1$) for *M. hapla*. Failure of *M. hapla* to reproduce on sudangrass was similar to its behavior on other grasses (4).

In the greenhouse, Piper sudangrass, 322 sudangrass hybrid, and sorghum–sudangrass hybrids P855F and P877F were suitable hosts for *M. chitwoodi* race 1 and, except for 322, were also hosts for race 2, with R_f values ranging from 1.2 to 4.7. Trudan 8 and Trudex 9 sudangrass hybrids and Sordan 79, SS-222, and Bravo II sorghum–sudangrass hybrids were poor or nonhosts for *M. chitwoodi* race 1, with R_f values ranging from <0.1 to 0.5. Trudan 8, Trudex 9, and Sordan 79 were also poor or nonhosts for race 2 with R_f values of <0.1 to 0.2 (Table 1).

Microplot field test: Reproduction of *M. chitwoodi* race 1 in bucket microplots was similar to that in the greenhouse test. Piper, P855F, and P877F had R_f values of 1.5, 6.6, and 9.5, respectively, while Trudan 8, Trudex 9, and Sordan 79 had R_f values of <0.1 to 0.9 (Table 1). *Meloidogyne chitwoodi* race 1 reproduced on P3732 field corn with R_f value of 12.4.

Row field test: Trudan 8 and Sordan 79 did not support reproduction of *M. chitwoodi* in field plots, as was the case in the greenhouse and bucket microplot tests. The number of J2 recovered from 250 cm^3 of soil from around the roots of Trudan 8 and Sordan 79 5 months after planting was 2 and 1, respectively, compared to 163 from P3732 corn.

Table 1. Reproductive factor (R_f = Pf ÷ Pi) and host status of selected sudangrass and sorghum–sudangrass hybrids for *Meloidogyne chitwoodi* races 1 (MC1) and 2 (MC2) in greenhouse, or MC1 in microplots, 55 days or 5 months after inoculation with 5,000 or 18,000 eggs per 850 g pot soil or 19 kg bucket microplot soil (Pi), respectively.

	Greenhouse				Field microplots	
	MC1†		MC2†		MC1	
Cultivar	R_f	Host status	R_f	Host status	R_f	Host status
			Field corn			
P3732					12.4	SH
			Sudangrass and sudangrass hybrids			
Piper	4.7	SH	1.2	SH	1.5	SH
332	1.3	SH				
Trudan 8	0.5	PH	<0.1	NH	<0.1	NH
Trudex 9	0.3	PH	0.2	PH	0.6	PH
			Sorghum–sudangrass hybrids			
P855F	4.5	SH	1.8	SH	6.6	SH
P877F	4.2	SH	1.8	SH	9.5	SH
Sordan 79	0.3	PH	0.2	PH	0.9	PH
SS-222	0.2	PH				
Bravo II	<0.1	NH				

R_f values are means of five replicates. Host status of each cultivar is based on $R_f \geq 1$ = a suitable host (SH); $R_f < 1$ but > 0.1 = a poor host (PH); and $R_f \leq 0.1$ = a nonhost (NH).

† *Meloidogyne chitwoodi* races 1 and 2 successfully reproduced on greenhouse grown tomatoes, and R_f values in two sets of experiments ranged from 9 to 75.

Soil amendment-greenhouse study

Cultivars as green manures: The chopped leaves of Piper sudangrass, 332, Trudan 8 and Trudex 9 sudangrass hybrids, and sorghum–sudangrass hybrids Sordan 79, P855F, P877F, SS-222, and Bravo II were soft, water soaked, and decomposing at harvest. Unlike rapeseed green manure (10), sudangrass or sorghum–sudangrass green manures did not cause phytotoxicity on bioassay tomato plants.

The mean numbers of infective nematodes in pots amended with 10 g leaves of Trudan 8 or Sordan 79 were reduced compared with those in the wheat and unamended control treatments (Table 2). Because amendment with 10 g P877F leaves reduced nematodes compared to unamended control but did not differ from the wheat treatment, the detrimental effect of P877F on nematodes was not distinguishable from the simple effects of green manure. An amendment with 20 g leaves/pot of each sudangrass or sorghum–sudangrass hybrid reduced nematodes compared to the wheat and the unamended control, although 332 and Bravo II were less effective as green manure than Trudan 8 and SS-222.

The threshold of sudangrass and sorghum–sudangrass hybrids as green manure appears to be between 10-20 g per 515 g soil (19-39 mg/g soil). This translates to 43 to 86 tonnes green manure/ha in the field based on incorporation of 15 cm deep in soil with bulk density of 1.3 g/cm^3. Significant reduction in field population of *M. chitwoodi* and potato damage was obtained by incorporating 20 tonnes of Piper/ha (21). The discrepancy between field and greenhouse observations may be related to relative nematode populations (60 ± 10 in the field versus 278 ± 55 J2/250 cm^3 in the greenhouse test), and (or) absence of egg masses, a relatively more resistant nematode propagule (11 and Table 4), in the field study.

Efficiency of plant parts: Nematode population densities were lower when leaves or stems of Trudan 8 were used as amendments than when root tissue was used. Homogenization of tissues did not alter their efficacy as a soil amendment (Table 3). We hypothesized that homogenizing would release dhurrin and glucosidase more rapidly for the reaction to produce hydrogen cyanide (HCN), similar to isothiocyanate production in rapeseed (13). Dhurrin, commonly found in sorghum and sudangrass, is hydrolyzed enzymatically to yield HCN. Jackson et al. (8) suggested that HCN was responsible for mortality of

TABLE 2. Number of *Meloidogyne chitwoodi* in tomato roots 3 weeks after planting in soil amended with 10 or 20 g leaves of wheat, sudangrass, or sorghum–sudangrass hybrids, or unamended.

Amendment source	Number of *M. chitwoodi*/tomato root		
	Test 1		Test 2
	10 g	20 g	20 g
None	984 a	129 a	767 a
Wheat	720 ab	167 a	560 a
	Sudangrass and sudangrass hybrids		
Piper	726 ab	32 b	
Trudan 8	216 cd	20 b	1 c
Trudex 9	349 abcd	14 b	
332			37 b
	Sorghum–sudangrass hybrids		
P855F	502 abc	21 b	
P877F	247 bcd	7 b	
Sordan 79	111 d	33 b	
SS-222			1 c
Bravo II			69 b

Values are means of five replicates. Nematode number for each replicate was $\log_e$ transformed before subjecting data to analysis of variance and mean separation. The means were detransformed to real numbers, and those in each column followed by the same letters do not differ at $P \leq 0.05$ according to Duncan's multiple-range test.

TABLE 3. Number of *Meloidogyne chitwoodi* in tomato roots 3 weeks after planting in soil amended with 20 g of chopped or homogenized leaves, stems, or roots of Trudan 8 sudangrass.

Amendment	Chopped	Homogenized
None	636 a	636 a
Leaves	13 b	85 b
Stems	97 b	79 b
Roots	916 a	327 a

Values are means of five replicates. Nematode number for each replicate was $\log_e$ transformed before subjecting data to analysis of variance and mean separation. The means were detransformed to real numbers, and those in rows and columns followed by the same letters do not differ at $P \leq 0.05$ according to Duncan's multiple-range test.

Culex pipiens mosquito larvae bathed in grain sorghum leaf extract. HCN is also toxic to nematodes (24). Adewusi (1) demonstrated that concentration of dhurrin was four times higher in leaves than in roots of Sordan 70, a sorghum–sudangrass hybrid. If a similar ratio of dhurrin exists in leaves and roots of Trudan 8, then the ineffectiveness of Trudan 8 roots (Table 3) may be the result of low levels of dhurrin in root tissue; this supposition remains to be proven. Also, there is evidence (6) that sudangrass leaves contain higher concentrations of dhurrin than stems. However, in our test (Table 3), the efficacy of leaves and stems as green manures in reducing *M. chitwoodi* populations was not different. At present, we are investigating the role of dhurrin in green manure on survival of *M. chitwoodi.*

Sensitivity of nematode inocula: Ten days after incubating on the greenhouse bench, 40% of the original J2-only inoculum was recovered from infested soil. In soil infested with egg masses only, the nematode population was made up of 86% and 14% J2 and eggs, respectively. Trudan 8 green manure reduced *M. chitwoodi,* regardless of inoculum sources. However, the percentage of nematodes killed in soil infested with egg masses was lower than in soil infested with J2 (Table 4). It appears that eggs in egg masses were more resistant to sudangrass green manure than were J2. Similar results were obtained with rapeseed green manure (13). Summer cropping of Trudan 8, a poor host of *M. chitwoodi,* reduced nematode population density, and by incorporating the shoots as green manure, the residual J2 population in the soil may decline more readily than eggs in egg masses on roots of a sudangrass cultivar that may be a host for the nematode.

Protection of amended zone: Trudan 8 amendment was effective only in the zone of incorporation (top 5 cm). The number of nematodes surviving below the zone of incorporation was not different from the control treatment (Table 5).

The experiment to measure upward migration showed that *M. chitwoodi* J2 migrated 20 cm upward and infected tomato roots in all treatments (Table 6). During the first 3 weeks, the numbers of infective J2 on the wheat and Trudan 8 treatments were lower than the control. After 6 weeks, no differences was observed between the wheat and control treatments, but the Trudan 8 treatment had fewer nematodes than the wheat or control. After 9 weeks, the numbers of infective J2 in the control, wheat, and Trudan 8 treatments were similar.

These results indicate that Trudan 8 amendment may not provide control of nematodes below the depths of incorporation, but suppresses nematodes only in the

TABLE 4. Number of *Meloidogyne chitwoodi* in tomato roots 3 weeks after planting in soil infested with egg masses or J2 before being amended with 20 g of chopped leaves of Trudan 8 sudangrass.

Amendment	Sources of inocula	
	Egg masses	J2
None	1350 a	350 a
Trudan 8	870 b	52 b
Percentage killed	65	85

Values are means of five replicates. Nematode number for each replicate was $\log_e$ transformed before subjecting data to analysis of variance and mean separation. The means were detransformed to real numbers, and those in each column followed by the same letters do not differ at $P \leq 0.05$ according to Duncan's multiple-range test.

TABLE 5. Number of *Meloidogyne chitwoodi* in tomato roots from three depths in soil columns amended with 20 g chopped leaves of Trudan 8 sudangrass or Stephens wheat incorporated into soil in the top (15 to 20-cm) ring.

Amendment	Amended zone	Number of nematodes at three depths (cm) below amended zone		
		0–5	5–10	10–15
None	193 a	241 a	212 a	180 a
Wheat	132 ab	191 a	440 a	357 a
Trudan 8	23 b	372 a	574 a	386 a

Values are means of five replicates. Nematode number for each replicate was $\log_e$ transformed before subjecting data to analysis of variance and mean separation. The means were detransformed to real numbers, and those in each column followed by the same letters do not differ at $P \leq 0.05$ according to Duncan's multiple-range test.

TABLE 6. Number of *Meloidogyne chitwoodi* entering tomato roots during three 3-week intervals after migrating 15 cm from unamended soil into soil amended with chopped leaves of Trudan 8 sudangrass or Stephens wheat.

Amendment	0–3 weeks	3–6 weeks	6–9 weeks
None	194 a	154 a	108 a
Wheat	40 b	40 a	120 a
Trudan 8	4 b	6 b	24 a

Values are means of five replicates. Nematode number for each replicate was $\log_e$ transformed before subjecting data to analysis of variance and mean separation. The means were detransformed to real numbers, and those in each column followed by the same letters do not differ at $P \leq 0.05$ according to Duncan's multiple-range test.

TABLE 7. Number of *Meloidogyne chitwoodi* detected in tomato roots 3 weeks after planting in 500 g soil collected from microplots before and 1 month after incorporating chopped leaves of Stephens wheat, Sweet Tooth corn, Trudan 8 sudangrass, or Sordan 79 sorghum–sudangrass hybrid into the soil.

Test plant†	Amendment source	Before amendment	After amendment
Tomato	None	6,279 a	75 a
Tomato	Wheat	5,378 a	29 ab
Tomato	Sweet corn	10,887 a	43 ab
Tomato	Trudan 8	10,764 a	10 b
Tomato	Sordan 79	8,055 a	1 c
Trudan 8	Trudan 8	308 b	1 c
Sordan 79	Sordan 79	19 c	1 c

Values are means of five replicates. Nematode number for each replicate was $\log_e$ transformed before subjecting data to analysis of variance and mean separation. The means were detransformed to real numbers, and those in each column followed by the same letters do not differ at $P \leq 0.05$ according to Duncan's multiple-range test.

† Crops were grown for 2 months in *M. chitwoodi*-infested soil before 450 g fresh leaves were chopped and incorporated in the top 15 cm soil of each microplot.

treated zone for a limited time. This effect of green manure is similar to that of the nematicide ethoprop, which does not move readily beyond the zone of incorporation and diminishes in efficacy after 6 weeks (11). This finding may explain our field observations (21) that potato tubers grown in plots amended with sudangrass or incorporated with ethoprop became infected late in the season.

Soil amendment–microplot study

The soil in which tomatoes had been grown for 2 months was heavily infested with *M. chitwoodi* before green manure treatments were applied (Table 7). Lower densities of *M. chitwoodi* were observed in buckets planted to Trudan 8 or Sordan 79, confirming that these two cultivars are less suitable hosts for *M. chitwoodi.*

In the unamended treatment, the population of *M. chitwoodi* declined by ca. 99% within 1 month and was not different from the wheat and sweet corn green manure treatments. Trudan 8 and Sordan 79 green manure, on the other hand, caused significant reduction of the nematode population densities compared to the unamended control. The greatest reduction of *M. chitwoodi* after tomato occurred in buckets that received Sordan 79 as green manure. Similarly, the number of nematodes in Trudan 8 or Sordan 79 buckets that received their own shoots as green manure was lower than in control buckets or buckets that received wheat or sweet corn amendments. The microplot studies confirmed the greenhouse observations that Sordan 79 amendment causes nematode population density to decline beyond that ascribed to the green manure effects of Stephens wheat. Inability to separate statistically the mean numbers of *M. chitwoodi* surviving the wheat amendment from those surviving Trudan 8 amendments in this experiment may be due to unforeseen sharp decline of nematodes in all treatments, including the unamended control.

The results of the host suitability and green manure studies suggest that summer cropping of Trudan 8, Sordan 79, or SS-222 will reduce the soil population density of *M. chitwoodi.* These plants have a two-fold effect in that they are poor hosts and their forage incorporated into the soil seems to have nematicidal effects. Trudan 8, a sudangrass hybrid, presumably contains a lower concentration of dhurrin than Sordan 79, or SS-222, which are sorghum–sudangrass hybrids (22). Dhurrin has been implicated in cattle poisoning if grazed improperly (20). Thus, Trudan 8 might be preferred if grown for hay production, or used for cattle grazing before incorporating as green manure.

In the present rotation scheme for potatoes in eastern Washington and Oregon, sudangrass could be planted after wheat or sweet corn. Sudangrass planted by late August may produce enough biomass to use as green manure before it is killed by autumn frost. However, sudangrass alone may not be able to adequately suppress *M. chitwoodi* populations for potato production. State inspectors downgrade or reject potato fields with 10% or more cullage. Therefore, combining green manure with a contact nematicide will probably be necessary to manage *M. chitwoodi* on potato. In a preliminary field study (unpublished), Trudan 8 green manure followed by a preplant treatment of ethoprop produced commercially acceptable potato tubers.

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