Influence of Sugarbeet Tillage Systems on the Rhizoctonia-Bacterial Root Rot Complex

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ABSTRACT

The Rhizoctonia-bacterial root rot complex in sugarbeet caused by *Rhizoctonia solani* and *Leuconostoc mesenteroides* can cause significant yield losses. To investigate the impact of different tillage systems on this complex, field studies were conducted from 2009 to 2011. Split blocks with conventional and strip tillage as main plot treatments were arranged in a randomized complete block design with four replications. Within main plots, there were seven treatments (non-inoculated check and six *R. solani* AG-2-2 IIIB strains). Regardless of tillage, the roots responded in a similar manner for fungal rot (conventional 8% versus strip 7%), bacterial rot (26% versus 34%), total rot (33% versus 41%), neighboring roots infected (1.7 roots versus 1.5 roots), distance spread (15.7 cm versus 15.0 cm), and the number of dead plants (12% versus 14%). Strains F517, F521, F551, and F552 always led to the lowest root and sucrose yield. Strip tillage resulted in 6% more root yield in 2009 ($P = 0.087$), while conventional tillage resulted in 7% and 27% more root yield in 2010 ($P = 0.063$) and 2011 ($P = 0.012$), respectively. The tillage systems influenced disease variables in a similar manner, but more studies will be needed to determine their impact on yield.

Additional Key Words: bacterial root rot, conventional tillage, *Leuconostoc*, Rhizoctonia root rot, strip tillage

Rhizoctonia root rot on mature sugarbeet caused by *Rhizoctonia solani* Kühn is a widespread disease problem (Bolton et al., 2010; Buddemeyer et al., 2004; Buhre et al., 2009; Führer Ithurrart et al., 2004; Ohkura et al., 2009; Strausbaugh and Gillen, 2009; Strausbaugh et al., 2011a). The causal pathogen, *R. solani*, is a species complex subdivided into at least 13 anastomosis groups (AG) (Sneh et al., 1991; Gonzalez et al., 2001). Strains from a number of these AG have been known to result in disease on sugarbeet roots (Windels & Nabben, 1989; Engelkes & Windels, 1996), but the AG primarily responsible for Rhizoctonia root rot on mature sugarbeet in Idaho is AG-2-2 IIIB (Strausbaugh et al., 2011a). AG-4 strains can also frequently be isolated from mature sugarbeet roots in Idaho, but they result in only a superficial rot, while the AG-2-2 IIIB strains result in a more invasive rot (Strausbaugh et al., 2011a). Based on 2004-2005 field surveys and 2007-2008 field studies, the AG-2-2 IIIB strains lead to a dry black rot on about 5 to 10% of the root mass on the outer portion of the root in Idaho with rot typically being initiated at the side of the root as opposed to the crown area (Strausbaugh and Gillen, 2009). Although *R. solani* appears to initiate the rot process, other organisms frequently invade *R. solani* lesions (Strausbaugh and Gillen, 2008). There is a strong tendency for bacterial root rot, a wet type rot, to get initiated in *R. solani* lesions by *Leuconostoc mesenteroides* subsp. *dextranicum* (Beijerinck) Garvie leading to a Rhizoctonia-bacterial root rot complex (Strausbaugh & Gillen, 2008). While the fungal rot typically is associated with only a small percentage of the root mass, the bacterial phase of the rot process can result in up to 70% or more of the root mass being destroyed (Strausbaugh & Gillen, 2009). The rot complex appears to increase in importance from south-central Idaho to southwestern Idaho (Strausbaugh et al., 2011a). The southwestern Idaho fields are planted in early March and harvested in early November because of warmer weather conditions, which also seem to favor bacterial root rot (Strausbaugh et al., 2011a). There is also more furrow irrigation in this production area compared to south-central Idaho (Strausbaugh et al., 2011a). Substantial yield losses occur in fields with the rot complex, and rotted roots also can lead to increased losses in storage and factory processing (Strausbaugh and Gillen, 2008; Strausbaugh and Gillen, 2009; Strausbaugh et al., 2011a; Strausbaugh et al., 2011b).

Rhizoctonia root rot is initiated by propagules in the soil such as sclerotia or mycelia associated with plant debris, but *R. solani* also appears to be capable of spreading from infected roots to neighboring healthy roots. Our understanding of *R. solani* spreading between sugarbeet roots in the field is poor. Also the response of Rhizoctonia root rot in sugarbeet produced under different tillage systems has not been documented.

Strip tillage has been part of crop production for sometime in rainfed areas in the mid-western United States on large seeded crops like corn and cotton (Evans et al., 2010). However, with glyphosate-resis-

tant sugarbeet cultivars becoming available in 2008, strip tillage is now being considered by growers in southern Idaho. With strip tillage, only a small band 20 to 30 cm wide is disturbed with the tillage equipment (Evans et al., 2010) and this can be done in the fall or spring. In Idaho, strip tillage has primarily been done in barley or wheat stubble, but strip tillage following other crops also is being considered. The standing stubble helps hold soil in place especially in sandy soils susceptible to wind erosion and helps protect young plants from wind damage (Evans et al., 2010). Protection from wind erosion and damage and reduced tillage costs seem to be the primary benefits driving the interest in Idaho, although other benefits, such as better moisture retention and infiltration, improved aeration, increased soil organic matter, and optimal fertilizer placement, are also important (Jabro et al., 2010; Overstreet, 2009; Stevens et al., 2011).

The shift toward conservation tillage systems has caused plant pathologists to reexamine disease development in systems with high residue levels (Babiker et al., 2011; Bockus and Shroyer, 1998; Rothrock, 1992; Strausbaugh and Windes, 2006). Because high residue levels and increased moisture retention could influence root rot potential (Bockus and Shroyer, 1998) in sugarbeet production, the impact of this change should be evaluated. Consequently, studies were conducted over three years to compare the influence of strip tillage versus conventional tillage on the Rhizoctonia-bacterial root rot complex in sugarbeet roots.

MATERIALS AND METHODS

Inoculum.

The six *Rhizoctonia solani* AG-2-2 IIIB strains [F508 (GenBank accession FJ492144), F517 (FJ492153), F521 (FJ492157), F548 (FJ492160), F551 (FJ492163), and F552 (FJ492164)] that had been characterized in previous research (Strausbaugh et al., 2011a) were used to generate inoculum. The strains had been stored on sterile barley kernels at -80°C. To create inoculum, the strains were first grown on potato dextrose agar (PDA; Becton Dickinson & Co., Sparks, MD) amended with streptomycin sulfate (MP Biomedicals, Inc., Solon, OH) at 200 mg L^{-1} for approximately 10 days. Plugs from these plates were then used to inoculate sterile barley (*Hordeum vulgare* L.) kernels that had been soaked in tap water for 24 hr and then autoclaved twice (one day apart) for 1 hr at 121°C. The inoculated barley kernels were incubated in the dark at 21°C for approximately six weeks. The kernels were then dried and ground with a Thomas Wiley Laboratory Mill model 4 (GMI Inc., Ramsey, MN) using a 1 mm screen (modified with 5 mm holes drilled into it). For strains F551 and F552 in 2009 and strain F521 in 2010, the barley kernel inoculum became contaminated with undesirable fungal growth, so data for these strains were not available.

Treatments.

The 2009 study was conducted in a field with barley stubble from a 6.187 t/ha crop. The barley crop had been harvested with a John Deere Model 7720 commercial combine (John Deere, Moline, IL) equipped with both a straw chopper/spreader and a chaff spreader while leaving the stubble approximately 10 to 15 cm high. A split block design was used where the main plot treatments were conventional and strip tillage, arranged in a randomized complete block design with four replications. The plots were eight rows 10.7 m long and 56 cm apart. Within each main block there were seven treatments (non-inoculated check and six *R. solani* AG-2-2 IIIB strains – F508, F517, F521, F548, F551, and F552). With the two main block treatments and seven within block treatments, there were a total of 14 treatments. The conventional tillage treatment consisted of fall moldboard plowing followed by spring roller harrowing, marking, and planting. The strip tillage treatment consisted of a late fall strip tillage with a 2007 Strip Cat (Twin Diamond Industries LLC, Minden, NE) and spring planting. Four of the rows in the eight-row plots were for yield and the other four were used to evaluate root rot. Only the two center rows of the yield and root rot plots were inoculated with the *R. solani* strains leaving the two outside rows uninoculated. The crowns of plants in the center rows of root rot and yield plots were inoculated at 1.2 m intervals (offset between rows by 0.6 m in case there was row to row spread) at a rate of 1.0 g of ground barley kernel inoculum per plant at the eight-leaf growth stage on 25 June 2009. The plants were hand inoculated through a 2.6 cm diameter polyvinyl chloride (PVC) tube to avoid problems with wind and unintended spread.

Field management.

The plots were planted to stand at a density of 128,099 seeds/ha with the commercial sugarbeet cultivar B-5 (consult Betaseed Inc. for actual cultivar name) on 12 May 2009. The seed were treated with fungicides Allegiance FL (15.6 g a.i. metalaxyl/100 kg seed) and Thiram 42S (250 g a.i. thiram/100 kg seed) to limit the influence of damping-off pathogens and allow for good stand establishment. The seed also was treated with Poncho Beta (60 g a.i. clothianidin and 8 g a.i. beta-cyfluthrin/100,000 seed), which served as the sole pest control treatment during the growing season. The fields were managed using standard commercial cultural practices as recommended by the Sugarbeet Grower's Guide Book (published annually by The Amalgamated Sugar Company, LLC, Boise, ID). Fertilizer (140 kg N/ha) was applied as a liquid with a drop tube next to the row at planting and glyphosate was applied as needed to control weeds at rates recommended in the guide book. The field was sprinkler irrigated with a linear move system to replace water lost by evapotransporation (ET) based on the Twin Falls AgriMet weather station (station code TWFI).

Disease evaluations.

On 1 September 2009, center rows of the root rot portion of the plots were visually evaluated for the number of dead plants. In addition, four inoculated plants were arbitrarily selected, hand dug, bisected, and visually evaluated for the percentage of root mass with fungal (dry black rot) and bacterial root rot (wet rot with various colors; caused by natural infection because no bacteria were inoculated) and spread to neighboring plants. Spread was assessed (hand dug neighboring plants) as the total number of infected plants and the distance (measured center of plant to center of plant) to the furthest infected plant within and/or across row from the inoculated planted. Fifteen of the inoculated roots from the experiment were arbitrarily selected for isolation. Isolations for *R. solani* were conducted on potato dextrose agar amended with 200 mg L^{-1} streptomycin sulfate using previously described techniques (Strausbaugh and Gillen, 2009). Isolations for *L. mesenteroides* were conducted on a semi-selective medium, glucose-yeast extract-peptone (GYP) agar (Cai et al., 1999) amended with 0.2 mg L^{-1} tetracycline and 30 mg L^{-1} vancomycin, using previously described techniques (Benkerroum et al., 1993; Strausbaugh and Gillen, 2009).

Yield.

The center two rows of the yield portion of the plots were harvested on 20 October 2009 with the aid of a mechanical topper and small plot harvester. Total yield was determined using a load cell-scale on the plot harvester. Two eight-beet root samples collected from each plot at harvest were analyzed by the Amalgamated Tare Lab in Paul, ID. Percent sugar was determined using an Autopol 880 polarimeter (Rudolph Research Analytical, Hackettstown, NJ) and a half-normal weight sample dilution and aluminum sulfate clarification method [ICUMSA Method GS6-3 1994] (Bartens, 2005). Conductivity was measured using a Foxboro conductivity meter Model 871EC (Foxboro, Foxboro, MA) and nitrate was measured using a multimeter Model 250 (Denver Instruments, Denver, CO) with Orion probes 900200 and 9300 BNWP (Krackler Scientific, Inc., Albany, NY). Estimated recoverable sucrose (ERS) yield per ton of roots was calculated using [(extraction) x (0.01) x (gross sucrose/ha)]/(t/ha) , where extraction = 250 + [[(1255.2) x (conductivity) – (15000) x (percent sucrose - 6185)]/[(percent sucrose) x (98.66 – [(7.845) x (conductivity)])]] and gross sucrose = [[(t/ha) x (percent sucrose)] x (0.01)] x (1000 kg/t).

2010 and 2011 experiments.

The experiment was repeated in 2010 following a 7.80 t/ha barley crop. The 2010 experiment was fertilized with 118 kg N/ha, planted on April 26, irrigated with solid set sprinkler irrigation system, inoculated at the eight-leaf growth stage on 28 June, evaluated for root rot on 20 September, and harvested on the 12 October. The experiment was repeated again in 2011 following a 5.38 t/ha barley crop. The 2011

experiment was fertilized with 90 kg N/ha, planted on 2 May, irrigated with solid set sprinkler irrigation system, inoculated at the eight-leaf growth stage on 22 June, evaluated for root rot on 21 September, and harvested on the 13 October.

Temperature data.

Growing degree days (GDD) using a 10°C base were calculated from data collected by the Twin Falls AgriMet station (station code TWFI). The weather station is located at 42° 32.747' North 114° 20.762' West and was within a short distance of the plots in 2009 (4.15 km), 2010 (1.41 km), and 2011 (1.29 km).

Data Analysis.

The SAS (Version 9.2, SAS Institute Inc., Cary, NC) Univariate procedure was used to test for normality of the data. The data were also evaluated using the SAS generalized linear mixed models procedure (Proc GLIMMIX). In the model statement the fixed effects were tillage, strain, and the tillage by strain interaction. The random effects were block, and the block by tillage and block by strain interactions. In the model statement, the denominator degrees of freedom were calculated using the DDFM=KENWARDRODGER option. Mean comparisons were conducted using the least squared means (LSMEANS) statement ($\alpha = 0.05$) while using the "lines" option to generate the output. Regression analysis was conducted using the SAS Proc REG procedure. When means are followed by ± x, x refers to the standard error.

RESULTS

Temperature.

For the April-May period, the GDDs (20 yr avg = 431) were 464, 295, and 260 for 2009, 2010, and 2011, respectively. Both the 2010 and 2011 growing seasons started with cool weather, but the 260 GDDs in 2011 was the lowest in the last 20 years. For the June-July period, the GDDs (20 yr avg = 1017) were 1003, 976, and 967 for 2009, 2010, and 2011, respectively. For the August-September period, the GDDs (20 yr avg = 968) were 1003, 944, and 1085 for 2009, 2010, and 2011, respectively. The 2011 growing season ended quite warm with the 1085 GDDs being the highest in the last 20 years. The total GDDs for the April through September growing season (20 yr avg = 2416) were 2470, 2215, and 2312 for 2009, 2010, and 2011, respectively.

Rhizoctonia root rot.

For the percentage of root mass associated with Rhizoctonia root rot (dry black fungal rot), the main effects can be investigated because the tillage by strain interaction was not significant in 2009, 2010, and 2011 ($P = 0.286$, 0.904, and 0.341, respectively; Table 1). In all three years, significant differences ($P < 0.001$) were observed among strains and versus the non-inoculated check (Table 1). In the non-inoculated

Table 1. Percentage of sugarbeet root mass infested with dry black fungal rot was evaluated in fields with conventional and strip tillage on roots inoculated with one of six strains of Rhizoctonia solani AG-2-2 IIIB in Kimberly, ID.

	Fungal rot (%)[‡]		
Variable[†]	**2009**	**2010**	**2011**
Strains			
F521	7 b	ND	9 a
F551	ND	10 a	8 ab
F517	10 a	9 a	8 ab
F508	5 bc	7 b	8 ab
F548	3 c	7 b	8 ab
F552	ND	10 a	5 b
Non-inoculated check	0 d	0 c	0 c
$P > F$[§]	<0.001	<0.001	0.001
Tillage			
Conventional	6	7	6
Strip till	4	7	7
$P > F$	0.001	0.846	0.255

[†] Strains of *Rhizoctonia solani* AG-2-2 IIIB. Conventional = field had been fall plowed and spring roller harrowed but not cultivated during the season. Strip tillage = a fall strip tillage was performed to prepare the seed bed. In 2009 the plots were irrigated with a linear move sprinkler system, and in 2010 and 2011 they were irrigated with a solid set sprinkler system.
[‡] Fungal rot = average percentage of root mass with dry black fungal rot in the inoculated root based on an evaluation of four locations in the disease plots. ND = no data.
[§] $P > F$ was the probability associated with the F value. Means within a column followed by the same letter did not differ significantly based on least squared means (= 0.05). The main effects can be compared because there was no strain by tillage treatment interaction in the 2009, 2010, and 2011 studies (P = 0.286, 0.904, and 0.341, respectively).

checks, no rot was observed, while in the inoculated plots, root rot ranged from 3 to 10% depending on strain and year. There were no consistent significant differences for Rhizoctonia root rot between tillage treatments, even though in 2009 conventional tillage had more (P = 0.001) rot (Table 1). The overall mean (without non-inoculated checks) root mass with Rhizoctonia root rot for conventional tillage was 7.8 ± 3.3% while under strip tillage it was 7.3 ± 3.3%. Isolations

Table 2. Percentage of sugarbeet root mass infested with wet bacterial rot was evaluated in fields with conventional and strip tillage on roots inoculated with one of six strains of *Rhizoctonia solani* AG-2-2 IIIB in Kimberly, ID.

	Bacterial rot (%)‡		
Variable†	**2009**	**2010**	**2011**
Strains			
F551	ND	37 a	53 a
F548	9 bc	21 b	41 ab
F508	14 b	16 b	36 bc
F521	13 b	ND	34 bc
F552	ND	38 a	26 bc
F517	47 a	37 a	25 c
Non-inoculated check	0 c	0 c	0 d
$P > F$§	<0.001	<0.001	<0.001
Tillage			
Conventional	18	20	25
Strip till	16	29	36
$P > F$	0.536	0.074	0.172

† Strains of Rhizoctonia solani AG-2-2 IIIB. Conventional = field had been fall plowed and spring roller harrowed but not cultivated during the season. Strip tillage = a fall strip tillage was performed to prepare the seed bed. In 2009 the plots were irrigated with a linear move sprinkler system, while in 2010 and 2011 they were irrigated with a solid set sprinkler system.

‡ Bacterial rot = average percentage of root mass with wet bacterial rot in the inoculated root based on an evaluation of four locations in the disease plots. ND = no data.

§ $P > F$ was the probability associated with the F value. Means within a column followed by the same letter did not differ significantly based on least squared means ($\alpha = 0.05$). The main effects can be compared because there was no strain by tillage treatment interaction in the 2009, 2010, and 2011 studies ($P = 0.152$, 0.126, and 0.176, respectively).

from 40 out of 45 inoculated roots tested over the three years were positive for the presence of *R. solani*. Roots not positive were nearly completely rotted and only secondary infection organisms were isolated. When comparing Rhizoctonia root rot to GDDs, there were no relationships at the 5% level.

Bacterial root rot.

For the percentage of root mass associated with bacterial root rot

Table 3. Percentage of sugarbeet root mass infested with fungal and bacterial root rot was evaluated in fields with conventional and strip tillage on roots inoculated with one of six strains of *Rhizoctonia solani* AG-2-2 IIIB in Kimberly, ID.

	Total rot (%)[‡]		
Variable[†]	**2009**	**2010**	**2011**
Strains			
F551	ND	47 a	61 a
F548	12 bc	27 b	49 ab
F508	19 b	23 b	44 bc
F521	20 b	ND	43 bc
F517	57 a	46 a	33 bc
F552	ND	48 a	32 c
Non-inoculated check	0 c	0 c	0 d
$P > F$[§]	<0.001	<0.001	<0.001
Tillage			
Conventional	24	27	31
Strip till	19	37	43
$P > F$	0.212	0.117	0.135

[†] Strains of *Rhizoctonia solani* AG-2-2 IIIB. Conventional = field had been fall plowed and spring roller harrowed but not cultivated during the season. Strip tillage = a fall strip tillage was performed to prepare the seed bed. In 2009 the plots were irrigated with a linear move sprinkler system, while in 2010 and 2011 they were irrigated with a solid set sprinkler system.

[‡] Total rot = average percentage of root mass with root rot (both fungal and bacterial) in the inoculated root based on an evaluation of four locations in the disease plots. ND = no data.

[§] $P > F$ was the probability associated with the F value. Means within a column followed by the same letter did not differ significantly based on least squared means ($\alpha = 0.05$). The main effects can be compared because there was no strain by tillage treatment interaction in the 2009, 2010, and 2011 studies ($P = 0.155$, 0.187, and 0.169, respectively).

(wet rotting tissue), the main effects can be investigated because the tillage by strain interaction was not significant in 2009, 2010, and 2011 ($P = 0.152$, 0.126, and 0.176; Table 2). In all three years, significant differences ($P < 0.001$) were observed among strains and the non-inoculated check (Table 2). In the non-inoculated checks no rot was observed, while in the inoculated roots, rot ranged from 9 to 53% depending on strain and year. The strains associated with the most rot varied between years. There were no consistent significant differ-

ences for bacterial root rot between tillage treatments, although in 2010 strip tillage was associated with more rot at the 10% level (Table 2). The overall mean (without non-inoculated checks) root mass with bacterial rot for conventional tillage was 25.5 ± 16.7%, while under strip tillage it was 34.1 ± 22.3%. Isolations from 16 out of 45 *R. solani* inoculated roots tested over the three years were positive for the presence of *L. mesenteroides*. Roots not positive for *L. mesenteroides* typically had overwhelming growth of other bacteria or yeast which could have obscured the presence of *L. mesenteroides*. When comparing bacterial root rot to GDDs, there were no relationships at the 5% level.

Total root rot.

For the percentage of root mass associated with the Rhizoctonia-bacterial root rot complex (all rotted tissues), the main effects can be investigated because the tillage by strain interaction was not significant in 2009, 2010, and 2011 ($P = 0.155$, 0.187, and 0.169, respectively; Table 3). In all three years significant differences ($P < 0.001$) were observed among strains and the non-inoculated check (Table 3). No rot was observed on roots in the non-inoculated checks, while in inoculated roots, total root rot ranged from 12 to 61% depending on strain and year. The strains associated with the most rot varied among years. There were no significant differences ($P > 0.117$) for total root rot between tillage treatments. The overall mean (without non-inoculated checks) total rot for conventional tillage was 33.4 ± 18.2%, while under strip tillage it was 41.4 ± 24.3%. When comparing total root rot to GDDs, there were no relationships at the 5% level.

Dead plants.

For the percentage *R. solani* inoculated roots that died, the main effects can be investigated because the tillage by strain interaction was not significant in 2009, 2010, and 2011 ($P = 0.130$, 0.798, and 0.354, respectively; Table 4). In all three years there were significant differences ($P < 0.040$) among strains and the non-inoculated check (Table 4). No dead plants were observed in the non-inoculated check plots, while with inoculated roots the percentage of dead plants ranged from 2 to 30% depending on strain and year. The strains associated with more dead plants varied between years. There were no consistent significant differences for dead plants between tillage treatments, but in 2010 strip tillage resulted in more dead plants at the 10% level. The overall mean (without non-inoculated checks) number of dead plants for conventional tillage was 12.2 ± 16.4%, while under strip tillage it was 14.5 ± 18.1%. When considering temperature, there were more dead plants correlated with an increase in August-September GDD ($r^2 = 0.771$, $P = 0.021$).

Neighboring infected roots.

For the number of neighboring infected roots with Rhizoctonia root rot, the main effects can be investigated because the tillage by strain

Table 4. Percentage of inoculated sugarbeet plants that died in the two center rows of plots with conventional and strip tillage when inoculated with one of six strains of *Rhizoctonia solani* AG-2-2 IIIB in Kimberly, ID.

	Dead plants (%)[‡]		
Variable[†]	**2009**	**2010**	**2011**
Strains			
F551	ND	12 a	30 a
F548	3 b	7 ab	20 ab
F508	2 b	2 b	15 bc
F521	9 b	ND	14 bc
F517	30 a	12 a	6 cd
F552	ND	13 a	4 cd
Non-inoculated check	0 b	0 b	0 d
$P > F$[§]	<0.001	0.040	0.001
Tillage			
Conventional	10	3	12
Strip till	8	8	14
$P > F$	0.513	0.073	0.692

[†] Strains of *Rhizoctonia solani* AG-2-2 IIIB. Conventional = field had been fall plowed and spring roller harrowed but not cultivated during the season. Strip tillage = a fall strip tillage was performed to prepare the seed bed. In 2009 the plots were irrigated with a linear move sprinkler system, while in 2010 and 2011 they were irrigated with a solid set sprinkler system.

[‡] Dead plants = the percentage inoculated plants that died (no green leaf area) in the two center rows of a four-row disease plot. ND = no data.

[§] $P > F$ was the probability associated with the F value. Means within a column followed by the same letter did not differ significantly based on least squared means ($\alpha = 0.05$). The main effects can be compared because there was no strain by tillage treatment interaction in the 2009, 2010, and 2011 studies ($P = 0.130$, 0.798, and 0.354, respectively).

interaction was not significant in 2009, 2010, and 2011 (P = 0.152, 0.163, and 0.257, respectively; Table 5). In all three years there were significant differences ($P < 0.023$) among strains and the non-inoculated check (Table 5). No infected plants were observed in the non-inoculated check plots, but for inoculated roots the mean number of neighboring infected roots ranged from 0.2 to 3.7 depending on strain and year. The strains associated with more infected roots varied

Table 5. The number of neighboring infected sugarbeet roots next to a root inoculated with one of six strains of *Rhizoctonia solani* AG-2-2 IIIB in conventional and strip tillage plots in Kimberly, ID.

	Neighboring infected roots[‡]		
Variable[†]	**2009**	**2010**	**2011**
Strains			
F551	ND	0.8 a	3.7 a
F548	0.7 bc	0.7 ab	3.1 ab
F552	ND	0.7 ab	2.6 bc
F521	1.7 a	ND	2.3 bc
F517	2.0 a	0.6 ab	2.0 c
F508	1.3 ab	0.2 bc	1.7 c
Non-inoculated check	0.0 c	0.0 c	0.0 d
$P > F$[§]	<0.001	0.023	<0.001
Tillage			
Conventional	1.2	0.5	2.4
Strip till	1.0	0.5	2.0
$P > F$	0.283	0.978	0.127

[†] Strains of *Rhizoctonia solani* AG-2-2 IIIB. Conventional = field had been fall plowed and spring roller harrowed but not cultivated during the season. Strip tillage = a fall strip tillage was performed to prepare the seed bed. In 2009 the plots were irrigated with a linear move sprinkler system, while in 2010 and 2011 they were irrigated with a solid set sprinkler system.

[‡] Neighboring infected roots = average number on infected plants surrounding an inoculated plants based on an evaluation of four locations in the disease plots. ND = no data.

[§] $P > F$ was the probability associated with the F value. Means within a column followed by the same letter did not differ significantly based on least squared means ($\alpha = 0.05$). The main effects can be compared because there was no strain by tillage treatment interaction in the 2009, 2010, and 2011 studies ($P = 0.152$, 0.163, and 0.257, respectively).

among years. There were no significant differences for the number of neighboring infected roots between tillage treatments. The overall mean (without non-inoculated checks) number of neighboring infected roots for conventional tillage was 1.7 ± 1.2 roots, while under strip tillage it was 1.5 ± 1.2 roots. When considering temperature, there were more neighboring infected roots correlated with an increase in August-September GDD ($r^2 = 0.962$, $P < 0.001$).

Table 6. Furthest distance to neighboring infected sugarbeet root from a root inoculated with one of six strains of *Rhizoctonia solani* AG-2-2 IIIB in conventional and strip tillage plots in Kimberly, ID.

	Distance (cm)[‡]		
Variable[†]	**2009**	**2010**	**2011**
Strains			
F551	ND	17.8 a	22.3 a
F548	9.3 b	14.4 a	21.8 a
F552	ND	17.3 a	17.7 ab
F517	17.5 a	17.1 a	13.5 b
F508	11.6 ab	8.0 b	13.2 b
F521	16.2 ab	ND	12.1 b
Non-inoculated check	0.0 c	0.0 c	0.0 c
$P > F$[§]	<0.001	<0.001	<0.001
Tillage			
Conventional	11.3	12.5	14.9
Strip till	10.6	12.4	13.8
$P > F$	0.770	0.987	0.524

[†] Strains of *Rhizoctonia solani* AG-2-2 IIIB. Conventional = field had been fall plowed and spring roller harrowed but not cultivated during the season. Strip tillage = a fall strip tillage was performed to prepare the seed bed. In 2009 the plots were irrigated with a linear move sprinkler system, while in 2010 and 2011 they were irrigated with a solid set sprinkler system.

[‡] Distance = average distance to the furthest neighboring infected root based on an evaluation of four locations in the disease plots. ND = no data.

[§] $P > F$ was the probability associated with the F value. Means within a column followed by the same letter did not differ significantly based on least squared means ($\alpha = 0.05$). The main effects can be compared because there was no strain by tillage treatment interaction in the 2009, 2010, and 2011 studies ($P = 0.967$, 0.123, and 0.535, respectively).

Distance spread.

For the distance spread to neighboring infected roots by Rhizoctonia root rot, the main effects can be investigated because the tillage by strain interaction was not significant in 2009, 2010, and 2011 ($P = 0.967$, 0.123, and 0.535, respectively; Table 6). In all three years there were significant differences ($P < 0.001$) among strains and the non-inoculated check (Table 6). For inoculated roots, the mean distance spread to neighboring infected roots ranged from 8.0 to 22.3 cm depending on strain and year. There were no significant differences for

Table 7. Sugarbeet root yield in conventional and strip tillage plots inoculated with one of six strains of *Rhizoctonia solani* AG-2-2 IIIB in Kimberly, ID.

	Root yield (t/ha)[‡]		
Variable[†]	**2009**	**2010**	**2011**
Strains			
Non-inoculated check	84.61 a	83.28 a	66.68
F508	81.59 ab	81.46 ab	64.47
F548	84.72 a	83.37 a	62.38
F551	ND	76.24 bc	61.32
F552	ND	72.82 c	60.05
F517	74.59 b	78.24 a-c	59.65
F521	74.34 b	ND	56.48
$P > F$[§]	0.044	0.007	0.550
Tillage			
Conventional	77.54	82.16	71.06
Strip till	82.40	76.32	52.05
$P > F$	0.087	0.063	0.012

[†] Strains of *Rhizoctonia solani* AG-2-2 IIIB. Conventional = field had been fall plowed and spring roller harrowed but not cultivated during the season. Strip tillage = a fall strip tillage was performed to prepare the seed bed. In 2009 the plots were irrigated with a linear move sprinkler system, while in 2010 and 2011 they were irrigated with a solid set sprinkler system.

[‡] Root yield = root yield based rows two and three of an eight-row plot. ND = no data.

[§] $P > F$ was the probability associated with the F value. Means within a column followed by the same letter did not differ significantly based on least squared means ($\alpha = 0.05$). The main effects can be compared because there was no strain by tillage treatment interaction in the 2009, 2010, and 2011 studies ($P = 0.165$, 0.759, and 0.126, respectively).

the distance spread to neighboring infected roots between tillage treatments. The overall mean (without non-inoculated checks) distance spread for conventional tillage was 15.7 ± 8.7 cm, while under strip tillage it was 15.0 ± 6.8 cm. When considering temperature, there was more spread correlated with a decrease in April-May GDD ($r^2 = 0.769$, $P = 0.022$).

Root yield.

For root yield with the Rhizoctonia-bacterial root rot complex, the main effects can be investigated because the tillage by strain interac-

Table 8. Sugarbeet estimated recoverable sucrose in conventional and strip tillage plots inoculated with one of six strains of *Rhizoctonia solani* AG-2-2 IIIB in Kimberly, ID.

	ERS (kg/ha)[‡]		
Variable[†]	**2009**	**2010**	**2011**
Strains			
Non-inoculated check	9,411 a	11,742 a	8,585
F508	9,477 a	11,464 ab	8,053
F548	9,614 a	11,559 a	7,655
552	ND	9,963 d	7,470
F517	8,329 b	10,774 bc	7,303
551	ND	10,567 cd	7,225
F521	8,343 b	ND	7,154
$P > F$[§]	0.013	<0.001	0.283
Tillage			
Conventional	8,895	11,291	8,746
Strip till	9,175	10,732	6,524
$P > F$	0.387	0.218	0.019

[†] Strains of *Rhizoctonia solani* AG-2-2 IIIB. Conventional = field had been fall plowed and spring roller harrowed but not cultivated during the season. Strip tillage = a fall strip tillage was performed to prepare the seed bed. In 2009 the plots were irrigated with a linear move sprinkler system, while in 2010 and 2011 they were irrigated with a solid set sprinkler system.
[‡] ERS = estimated recoverable sucrose at harvest. ND = no data.
[§] $P > F$ was the probability associated with the F value. Means within a column followed by the same letter did not differ significantly based on least squared means ($\alpha = 0.05$). The main effects can be compared because there was no strain by tillage treatment interaction in the 2009, 2010, and 2011 studies ($P = 0.106$, 0.691, and 0.182, respectively).

tion was not significant in 2009, 2010, and 2011 ($P = 0.165$, 0.759, and 0.126, respectively; Table 7). In 2009 ($P = 0.044$) and 2010 ($P = 0.007$), there were root yield differences among strains and the non-inoculated check (Table 7). At the 10% level, there were differences for root yield between tillage treatments in all three years. Strip tillage was associated with higher yield in 2009 ($P = 0.087$), but lower yields in 2010 ($P = 0.063$) and 2011 ($P = 0.012$). The overall mean root yield without non-inoculated checks for conventional tillage was 75.3 ± 11.0 t/ha, while under strip tillage it was 67.6 ± 16.2 t/ha. The overall mean root yield with just non-inoculated checks for conventional tillage was 82.8 ± 7.3 t/ha, while under strip tillage it was 73.6 ± 16.3 t/ha. When com-

paring root yield to GDDs, there were no relationships at the 5% level.

Estimated recoverable sucrose.

For estimated recoverable sucrose yield with the Rhizoctonia-bacterial root rot complex, the main effects can be investigated because the tillage by strain interaction was not significant in 2009, 2010, and 2011 (P = 0.106, 0.691, and 0.182, respectively; Table 8). In 2009 (P = 0.013) and 2010 ($P < 0.001$), there were sucrose yield differences among strains and the non-inoculated check (Table 8). For sucrose yield between tillage treatments, there were differences in 2011 (P = 0.019; higher with conventional), but not in 2009 (P = 0.387) and 2010 (P = 0.218). The overall mean sucrose yield without non-inoculated checks for conventional tillage was 9445 ± 1697 kg/ha, while strip tillage was 8549 ± 2146 kg/ha. The overall mean sucrose yield with just non-inoculated checks for conventional tillage was 10592 ± 1592 kg/ha, while strip tillage was 9233 ± 1931 kg/ha. When considering temperature, there was an increase in sucrose yield correlated with an increase in August-September GDD (r^2 = 0.782, P = 0.019).

DISCUSSION

In general, when comparing conventional and strip tillage, the Rhizoctonia-bacterial root rot complex responded in a similar manner for fungal rot (conventional 8% versus strip 7%), bacterial rot (26% versus 34%), total rot (33% versus 41%), neighboring roots infected (1.7 roots versus 1.5 roots), distance spread (15.7 cm versus 15.0 cm), and number of dead plants (12% versus 14%). Based on these same disease variables, all six *R. solani* AG-2-2 IIIB strains were pathogenic, because they were always significantly different from the non-inoculated check. All strains appeared to respond in a similar manner regardless of tillage type, because there were no significant tillage by strain interactions ($P > 0.10$). Although significant differences were evident at times between strains, the same ranking was not always evident in all three years. However, strains F517, F521, F551, and F552 were always ranked the lowest for root yield and recoverable sucrose. At the 10% level, strip tillage resulted in more root yield in 2009, while conventional tillage resulted in more root yield in 2010 and 2011. For estimated recoverable sucrose, no differences were observed in 2009 and 2010 between tillage treatments, but conventional tillage resulted in more recoverable sucrose in 2011.

Comparing the spread of *R. solani* in both a conventional and strip tillage system was of interest, because reduced tillage is associated with higher residue levels on the soil surface and changes in soil characteristics (Jabro et al., 2009; Jabro et al., 2010; Morris et al., 2007; Overstreet, 2009). Some of these changes in soil characteristics have been noted to influence *R. solani* (Harris et al., 2003; Kühn et al., 2009; Otten and Gilligan, 1998; Otten et al., 2004; Schroeder and Paulitz, 2008). Regardless of tillage system, the distance spread (15.7 cm in

conventional and 15.0 cm under strip tillage) and the number of neighboring roots infected (1.7 roots in conventional and 1.5 roots under strip tillage) was similar. However, year to year variation in temperature seemed to be more important than tillage system. There were more neighboring infected roots ($r^2 = 0.962, P < 0.001$) and dead plants ($r^2 = 0.771, P = 0.021$) correlated with an increase in August-September GDDs. These data support previous work showing an increase in the Rhizoctonia-bacterial root rot complex in association with warmer production areas in Idaho (Strausbaugh et al., 20011a).

Over the three year study, the root mass associated with Rhizoctonia root rot ranged from 3 to 10%, while bacterial root rot ranged from 9 to 53%. These data are in agreement with previous reports (Strausbaugh and Gillen, 2009). In a 2004-2005 field survey (Strausbaugh and Gillen, 2009), 6% of the root mass was rotted when fungi were isolated individually, but 71% and 68% of the root mass was rotted when bacteria were isolated alone or in combination with other organisms, respectively. In sugarbeet field trials in 2007 and 2008 with *R. solani* AG-2-2 IIIB strain F321, fungal rot was associated with 3 to 5% of the root mass, while bacterial rot ranged from 6 to 78% (Strausbaugh and Gillen, 2009). Thus, the severity of the Rhizoctonia-bacterial root rot complex was similar to that mentioned in previous studies (Strausbaugh and Gillen, 2009) for both grower's fields and research plots.

Establishing differences between the *R. solani* AG-2-2 IIIB strains was possible for many of the disease variables studied. However, ranking these strains from most damaging to least damaging was inconsistent among years, although strains F517, F521, F551, and F552 were associated with the lowest ranked root and sucrose yields in all three years. Because only *R. solani* was inoculated and there was no control over the naturally occurring microflora, variations in microbial communities could have caused some variation in *R. solani* strain response. In a previous study, bacteria such as fluorescent pseudomonads, *Serratia*, and *Enterobacter* collected from sugarbeet roots in Idaho could suppess *R. solani* (Lovic et al., 1993). More recently these same bacteria as well as yeast collected from sugarbeet roots in Idaho were shown to suppress *L. mesenteroides* (Strausbaugh and Gillan, 2008). Thus, establishing the response of *R. solani* strains in a natural field environment may require a better understanding of the microflora present, how the microflora responds to environmental variables such as yearly temperature variations, and how *R. solani* interacts with this microflora.

When comparing the yield variables for 2009 and 2010, there appeared to be no difference between tillage systems. Conventional tillage averaged 79.8 ± 7.2 t/ha, while strip tillage averaged 79.4 ± 7.2 t/ha. Based on GDDs, the weather was closer to 20 year average for these two years than for 2011. In 2011, there were fewer GDDs early in the growing season and more GDDs late in the growing season than in any other growing season in 20 years. With the cool start to the growing season in 2011, plants under strip tillage appeared less vig-

orous compared to those in the open, bare soil under conventional tillage. Thus, there was a 26.8% root yield reduction ($P = 0.012$) associated with strip tillage in 2011. When considering recoverable sucrose, the relationships were similar to those established with root yield. When averaged over the first two years, conventional tillage yielded 9120 ± 1403 kg/ha, while strip tillage yielded 8944 ± 1183 kg/ha. With the extreme weather swings in 2011, there was a 25.4% reduction ($P = 0.019$) in recoverable sucrose with strip tillage. In Montana, there were no differences in root yield or sucrose production between conventional and strip tillage in four out of five years from 2004 to 2008 (Evans et al., 2010). Results from most U.S. research studies show that strip tillage has not differed from conventional tillage for root and sucrose yield, but strip tillage has been superior to direct drilling in most cases (Overstreet, 2009). To develop a better understanding of the expected yield responses in Idaho, these two tillage systems will have to be studied over a longer period of time.

Because the response of disease variables was similar between tillage systems, management of the Rhizoctonia-bacterial root rot complex with similar approaches should be possible. Traditional management approaches such as crop rotation, irrigation management, in-furrow fungicide applications, and use of resistant cultivars should be applicable to both tillage systems (Barnett et al., 2011; Bolton et al., 2010; Buhre et al., 2009; Kirk et al., 2008; Kluth and Varrelmann, 2010; Windels and Brantner, 2005). Future research will need to identify better management options or optimize current options, because Rhizoctonia root rot is on the rise in Idaho and other production areas (Bolton et al., 2010; Buddemeyer et al., 2004; Buhre et al., 2009; Führer Ithurrart et al., 2004; Ohkura et al., 2009; Strausbaugh and Gillen, 2009; Strausbaugh et al., 2011a).

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DISCLAIMER

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