Effect of Temperature on Virulence of *Rhizoctonia solani* and Other *Rhizoctonia* on Potato

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ABSTRACT

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Pathogenicity of 47 isolates from various geographical locations and host plants representing 11 of the 12 known anastomosis groups of *Rhizoctonia solani* and 12 isolates representing other multinucleate and binucleate species of *Rhizoctonia* was determined on sprouts and roots of emerging potato plants at 10, 15.5, and 21.1 C. Isolates of *R. solani* AG-3 killed significantly more sprouts than any other group. Isolates of most groups killed no sprouts. Whereas isolates of *R. solani* AG-3 and AG-5 damaged sprouts significantly more than other groups, most damage to roots was caused by isolates of *R. solani* AG-8 and AG-3. Other isolates, including those representing other anastomosis groups of *R. solani*, *R. oryzae*, *R. zeae*, and binucleate *Rhizoctonia* caused a minimal amount of damage to sprouts and roots. Isolates of *R. solani* AG-3 heavily damaged sprouts at 10, 15.5, and 21.1 C but caused significantly more damage at 10 C. Isolates of AG-3 also damaged roots at all three temperatures. Isolates of AG-5 damaged sprouts at 15.5 and 21.1 C but caused minimal damage to roots. Isolates of AG-8 caused heavy damage to roots but minor damage to sprouts at all three temperatures. It is apparent that at cool temperatures isolates of *R. solani* AG-3 are more virulent. At warmer temperatures, isolates of AG-8, AG-5, and perhaps, representatives of other groups of *Rhizoctonia* may be more important in the etiology of Rhizoctonia disease of potato. We know of no previous reports of AG-8 in association with potato plants, but these data indicate its potential to be a very damaging pathogen.

Rhizoctonia solani Kühn (teleomorph, *Thanatephorus cucumeris* (Frank) Donk) is the causal agent of Rhizoctonia disease, or black scurf, of potato (*Solanum tuberosum* L.). Rhizoctonia disease is known to occur wherever potatoes are grown. Reductions in quality and yield attributable to Rhizoctonia disease commonly occur where cool, moist environmental conditions prevail (4,10,11,21) but are less common, or may not occur, where warmer, drier environmental conditions are the norm (13,16,26).

R. solani is divided into subgroups based on hyphal anastomosis. Hyphal anastomosis is a manifestation of somatic, or vegetative, incompatability between isolates (2). Hyphae of isolates representing the same anastomosis group (AG) can anastomose with one another, whereas isolates representing different AGs generally do not react with one another. Currently, there are 12 AGs known (9,19,20), and most appear to be isolated populations within the species *R. solani* (2,19). Some isolates of certain groups will anastomose with members of some other AGs, including AG-BI (the "bridging isolate" group) (17), AG-8, AG-6, AG-3, and AG-2; but most isolates, including members of AG-1, AG-4, AG-5, AG-7, and AG-9 anastomose only with members of their own group.

Isolates of AG-3 often are identified as the principal cause of Rhizoctonia disease of potato (4,10,21), although recent investigators have called attention to pathogenicity against potato in isolates of AG-4 (3,14) and AG-5 (5). In addition, representatives of other AGs of *R. solani* also have been associated with diseased potato plants, including AG-1, AG-2-1, AG-2-2, and AG-9 (1,8,11,12). We know of no reports where isolates of AG-8 are associated with potato plants.

A comparison of the pathogenicity of representatives of different AGs of *R. solani* against potato has not been made. In this study, we have assembled a collection of isolates representing most AGs of *R. solani* and have challenged sprouting potato seed pieces with each. Isolates of other multinucleate and binucleate *Rhizoctonia* also are included in this study. Additionally, in view of the role of temperature in the development of Rhizoctonia disease (7,22,23,24,25), the pathogenic capability of each isolate was observed at three temperatures.

MATERIALS AND METHODS

A total of 59 isolates of *Rhizoctonia*, including 47 isolates of *R. solani*, three isolates of binucleate *Rhizoctonia* (teleomorph, *Ceratobasidium*), and nine isolates of other multinucleate *Rhizoctonia* (teleomorph, *Waitea circinata* Warcup & Talbot) were included in this study. All anastomosis groups of *R. solani* are represented in this collection, except AG-10 (20). Isolates are listed by group and geographic origin in Table 1.

Pathogenicity was determined on potato sprouts growing from seed tubers (cultivar Russet Burbank) in a sand-soil mixture. Washed builder's sand was mixed with a silt loam soil in a 2:1 (v/v) ratio, then pasteurized by heating in an electric cooker to approximately 80 C for two 30-min periods separated by a cooling period. Seed tuber pieces weighing 45–60 g were cut immediately before planting and placed on a 10-cm layer of soil near the bottom of 6- × 25-cm black plastic tubes. Seed tubers had been surface disinfested before cutting by immersing for 2 min in a 1.85% aqueous solution of formaldehyde. Seed pieces were covered with approximately 2 cm of the sand-soil mix, and inoculum was placed approximately 2 cm above the seed.

Inoculum consisted of five agar disks, 7 mm in diameter, cut from the growing edge of the appropriate fungal colony. Fungi were cultured on rehydrated Difco potato-dextrose agar (PDA), and colonies were approximately 5 days old at inoculation. The inoculum layer was covered with 7–10 cm of the sand-soil mix. Control treatments receiving sterile disks of PDA also were included. Tubes then were placed in dark growth rooms at 10, 15.5, or 21.1 C. Water was applied to the soil as needed and plants were harvested after control treatments had emerged. Soil moisture is known to affect the severity of Rhizoctonia disease (15). Therefore, care was taken to maintain soil moisture at a consistent and moderate level.

TABLE 1. Sources, geographic origins, and providers of isolates of *Rhizoctonia solani*, *R. zeae*, *R. oryzae*, and other multinucleate and binucleate *Rhizoctonia* used in this study

Isolate	Group[a]	Geographic origin	Source	Collector and/or provider
R. solani				
CS-Ka	1-1A	Japan	*Oryza sativa*	S. Kuninaga
SFBV-1	1-1B	Japan	*Beta vulgaris*	S. Kuninaga
43	1-1C	Canada	*Pinus resinosa*	N. A. Anderson
F56L	2-1	Alaska	*Solanum tuberosum*	Carling & Leiner
HV-1	2-1	Japan	*O. sativa*	A. Ogoshi
R123	2-1	Japan	*Raphanus sativus*	S. Kuninaga
B60	2-2-IIIB	Japan	*B. vulgaris*	S. Kuninaga
RH-16	2-2-IV	Japan	?	S. Kuninaga
RI-64	2-2-IV	Japan	*B. vulgaris*	A. Ogoshi
M8	3	Alaska	*S. tuberosum*	Carling & Leiner
W14L	3	Alaska	*S. tuberosum*	Carling & Leiner
ST-11-6	3	Japan	*S. tuberosum*	A. Ogoshi
R542	3	Japan	?	A. Ogoshi
M69	3	Alaska	*S. tuberosum*	Carling & Leiner
KHP37	3	Alaska	soil	Carling & Leiner
L38	3	Alaska	*S. tuberosum*	Carling & Leiner
M39	3	Alaska	*S. tuberosum*	Carling & Leiner
DP329	3	Alaska	soil	Carling & Leiner
L32	3	Alaska	*S. tuberosum*	Carling & Leiner
PO5	3	North Dakota	*S. tuberosum*	R. W. Stack
P32	3	North Dakota	*S. tuberosum*	R. W. Stack
P114	3	North Dakota	*S. tuberosum*	R. W. Stack
Chr-3	4-I	Japan	*Chrysanthemum morifolium*	S. Kuninaga
AH-1	4-I	Japan	*Arachis hypogaea*	S. Kuninaga
RR5-2	4-II	Japan	*B. vulgaris*	S. Kuninaga
UHBC	4-II	Japan	*B. vulgaris*	S. Kuninaga
P16	4-?[b]	North Dakota	*S. tuberosum*	R. W. Stack
P26	4-?	North Dakota	*S. tuberosum*	R. W. Stack
P35	4-?	North Dakota	*S. tuberosum*	R. W. Stack
ST-6-1	5	Japan	*S. tuberosum*	A. Ogoshi
Rh184	5	Japan	*B. vulgaris*	S. Naito
T441	5	Japan	?	J. R. Davis
P18	5	North Dakota	*S. tuberosum*	R. W. Stack
P80	5	North Dakota	*S. tuberosum*	R. W. Stack
P116	5	North Dakota	*S. tuberosum*	R. W. Stack
NKN2-1	6 GV	Japan	soil	S. Kuninaga
HAM1-1	6 I	Japan	soil	S. Kuninaga
NTA3-1	6 I	Japan	soil	S. Kuninaga
1556	7	Japan	soil	S. Kuninaga
1529	7	Japan	soil	S. Kuninaga
811	8	Australia	*Triticum aestivum*	S. M. Neate
C1	8	Washington	*Hordeum vulgare*	E. N. Bassett
H1	8	Oregon	*T. aestivum*	E. N. Bassett
S9R1	9	Alaska	soil	Carling & Leiner
V12M	9	Alaska	*S. tuberosum*	Carling & Leiner
S21	9	Alaska	soil	Carling & Leiner
AI1-4	BI	Japan	soil	S. Kuninaga
R. zeae				
N10-1	WAG-Z	Japan	*Cerastium caespitosum*	A. Ogoshi
C504	WAG-Z	Japan	?	A. Ogoshi
590	WAG-Z	Japan	?	A. Ogoshi
R. oryzae				
161	WAG-O	Washington	?	E. N. Bassett
231	WAG-O	Washington	*T. aestivum*	E. N. Bassett
541	WAG-O	Japan	?	A. Ogoshi
Rhizoctonia sp.				
Z1	?[b]	Alaska	soil	Carling & Leiner
Z16	?	Alaska	soil	Carling & Leiner
Z41	?	Alaska	soil	Carling & Leiner
Rhizoctonia (binucleate)				
s12-12	E	Alaska	soil	Carling & Leiner
t4-6	H	Alaska	soil	Carling & Leiner
s9-9	C	Alaska	soil	Carling & Leiner

[a]Some anastomosis groups of *R. solani* are subdivided based on colonial morphology, pathogenicity, thiamine requirement, or DNA homology. A detailed discussion of the system of intraspecific group (ISG) designation is presented by Ogoshi (19).
[b]Group or subgroup has not been determined.

Harvests were made 23 days after planting at 21.1 C, 30 days at 15.5 C, and 37 days at 10 C. Roots and shoots were washed free of soil and pathogenicity was determined separately on roots and shoots. Damage was categorized numerically for sprouts as follows: 0 = no damage, no lesions; 1 = minor damage, one to several lesions less than 5 mm long; 2 = intermediate damage, lesions greater than 5 mm long, and girdling of some sprouts; 3 = major damage, large lesions, girdling, and death of most sprouts; 4 = all sprouts killed. Roots were related as follows: 0 = no damage, no lesions or rot; 1 = minor damage, one to several lesions less than 5 mm long; 2 = intermediate damage, lesions greater than 5 mm long, some roots girdled, and much dead tissue; 3 = major damage, lesions large, and most root tissue dead; 4 = all roots rotted and dead, or no roots present.

Four replicates of each treatment were placed in a randomized complete block design in each growth room. The experiment was repeated once with similar results. Data were analyzed by analysis of variance and means were separated with Duncan's multiple range test. Data presented in this report are from the second run of the experiment.

RESULTS

Data collected on virulence of the 59 isolates at 10 C are summarized by group in Table 2. Reactions of potato plants to the various groups of fungal isolates are presented as the number of sprouts per plant killed or injured, and as damage to sprouts and roots. At 10 C, a significantly higher number of killed and injured sprouts and a significantly higher level of damage to roots and sprouts were associated with two AGs of *R. solani*: AG-3 and AG-8. More than one sprout per plant was injured by isolates of *R. solani* AG-3 and AG-8, and isolates of AG-3 killed an average of 0.9 sprouts per plant. Damage to roots and shoots caused by isolates of AG-8 and AG-3 was significantly greater at 10 C than that caused by any other group. Additionally, isolates of AG-3 caused significantly more damage to shoots than isolates of AG-8.

As temperatures increased from 10 to 21.1 C, the amount of damage to roots and sprouts caused by most groups tended to increase (Table 3). At 21.1 C, damage to sprouts caused by isolates of AG-3 and AG-5 was significantly more than any other group. Somewhat less damage to sprouts was caused by isolates of AG-4, AG-1, *R. oryzae*, and AG-8. Isolates of AG-8 and AG-3 caused significantly more damage to roots at 21.1 C than the other groups, although the trend toward more damage at the higher temperature was apparent in many other groups.

The reaction of potato plants to selected groups at 10, 15.5, and 21.1 C is presented in Table 4. Isolates of *R. solani* AG-3 killed more sprouts at 10 than at 15.5 or 21.1 C. Overall damage to sprouts also was highest at 10 C, but the number of injured sprouts and damage to roots was highest at 15.5 C. Isolates of AG-4 killed no sprouts at any of the three temperatures, and caused minimal damage to sprouts and roots. Some damage to sprouts due to infection by isolates of AG-5 was observed in the 15.5 and 21.1 C treatments. Root damage due to infection by isolates of AG-5 was minimal and not significantly different among the three temperatures.

Isolates of AG-8 killed no sprouts; overall damage to sprouts was minimal and did not vary among temperatures (Table 4). However, root damage caused by isolates of AG-8 was extensive and was comparable to the damage due to infection by isolates of AG-3.

Groups other than AG-3, AG-4, AG-5, and AG-8 caused minimal or no damage to sprouts and roots of potato. Reactions of potatoes to isolates of *R. oryzae* at three temperatures (Table 4) are representative of these minimally virulent to nonpathogenic groups; the damage to sprouts and roots that did occur was observed at the higher temperatures.

DISCUSSION

Isolates of AG-3 caused significantly more damage to potato sprouts and killed significantly more sprouts per plant than any other group of isolates evaluated in this study. This supports earlier reports (4,6,9) that have identified isolates of AG-3 as the more aggressive pathogens to potato among groups of *R. solani* and related species.

Isolates representing other AGs of *R. solani* have been implicated in the Rhizoctonia disease of potato, most notably AG-4 (3,14) and AG-5 (5). Anguiz and Martin (3) isolated AG-4 more frequently than AG-3 from potato plants with symptoms of Rhizoctonia disease in several production areas in Peru. Isolates of AG-4 were collected in greater numbers in warm environments at low elevations, whereas isolates of AG-3 were recovered more commonly from plants growing in the cool environments at high elevations. They found that isolates of AG-3 and AG-4 caused damping-off in potato seedlings grown from true seed in Peru, and isolates of AG-4 generally were more virulent than isolates of AG-3 on roots of potato plants grown from tuber pieces.

In North Dakota, Gudmestad et al (14) recovered isolates of *R. solani* AG-4 and AG-5 from diseased potato plants in fields that previously had not been cropped to potatoes. Other fields

TABLE 2. Reaction of sprouts and roots of emerging potato plants to *Rhizoctonia solani* and other multinucleate and binucleate *Rhizoctonia* at 10 C

Group designation	No. of sprouts/seed piece: Killed	Injured	Damage assessment[y]: Sprouts	Roots
R. solani				
AG-1	0.0 b[z]	0.1 b	0.1 c	0.0 b
AG-2	0.1 b	0.3 b	0.3 c	0.2 b
AG-3	0.9 a	1.1 a	2.8 a	1.5 a
AG-4	0.0 b	0.0 b	0.0 c	0.0 b
AG-5	0.0 b	0.2 b	0.2 c	0.2 b
AG-6	0.0 b	0.0 b	0.0 c	0.0 b
AG-7	0.0 b	0.0 b	0.0 c	0.0 b
AG-8	0.0 b	1.1 a	1.1 b	2.1 a
AG-9	0.0 b	0.3 b	0.2 c	0.1 b
AG-BI	0.0 b	0.0 b	0.0 c	0.0 b
R. zeae	0.0 b	0.0 b	0.0 c	0.0 b
R. oryzae	0.0 b	0.0 b	0.0 c	0.0 b
Waitea (AK)	0.0 b	0.0 b	0.0 c	0.0 b
Binucleate	0.0 b	0.3 b	0.3 c	0.1 b
Control	0.0 b	0.0 b	0.0 c	0.1 b

[y] Damage assessment for sprouts and roots made on a five-position scale where 0 = no damage, no lesions and 4 = all sprouts (or roots) dead.
[z] Numbers in columns followed by same letter are not significantly different according to Duncan's multiple range test at $P = 0.05$.

TABLE 3. Reaction of sprouts and roots of emerging potato plants to *Rhizoctonia solani* and other multinucleate and binucleate *Rhizoctonia* at 21.1 C

Group designation	No. of sprouts/seed piece: Killed	Injured	Damage assessment[y]: Sprouts	Roots
R. solani				
AG-1	0.0 b[z]	0.9 abc	1.3 bc	0.1 d
AG-2	0.0 b	0.6 bcde	0.6 cde	0.6 cd
AG-3	0.3 a	1.1 ab	2.3 a	1.8 a
AG-4	0.0 b	1.0 ab	1.4 b	0.0 d
AG-5	0.1 b	1.3 a	2.2 a	0.0 d
AG-6	0.0 b	0.0 f	0.0 e	0.0 d
AG-7	0.0 b	0.8 abc	0.7 bcde	1.2 b
AG-8	0.0 b	0.8 abcd	1.0 bcd	2.0 a
AG-9	0.0 b	0.7 bcd	0.7 bcde	0.7 c
AG-BI	0.0 b	0.3 cdef	0.0 e	0.0 d
R. zeae	0.0 b	0.2 def	0.2 e	0.0 d
R. oryzae	0.0 b	0.7 bcd	1.2 bc	0.6 cd
Waitea (AK)	0.0 b	0.6 bcdef	0.4 de	0.2 cd
Binucleate	0.0 b	0.3 cdef	0.3 de	0.2 cd
Control	0.0 b	0.1 ef	0.1 e	0.0 d

[y] Damage assessment for sprouts and roots made on a five-position scale where 0 = no damage, no lesions and 4 = all sprouts (or roots) dead.
[z] Numbers in columns followed by same letter are not significantly different according to Duncan's multiple range test at $P = 0.05$.

in North Dakota with a history of potato production yielded isolates of AG-3 and AG-5, but not AG-4. Pathogenicity studies indicated isolates of AG-3 and AG-4 caused similar damage. However, damage due to infection by isolates of AG-4 apparently was confined primarily to the roots, whereas damage due to isolates of AG-3 was observed only on subterranean plant parts other than roots.

Gudmestad et al (14) and Bandy (5) indicated that isolates of AG-5 were mildly virulent on potato. We have confirmed this mild to moderate virulence, most of which was confined to sprouts and occurred at 15.5 and 21.1 C (Table 4). We also confirm minimal damage associated with isolates of various other AGs of *R. solani* previously reported in association with potato plants or tubers, including AG-1, 2-1, 2-2, and 9 (1,8,11,12), as well as isolates of related species, including binucleate *Rhizoctonia*, *R. oryzae*, *R. zeae*, and other representatives of the genus *Waitea*.

However, our observations of pathogenicity in isolates of AG-4 do not agree with earlier reports of Anguiz and Martin (3) and Gudmestad et al (14). Interestingly, included among the seven isolates of AG-4 in our study were three isolates from the study of Gudmestad et al (14). In pathogenicity tests in North Dakota, these three isolates parasitized the feeder roots of inoculated plants and caused extensive damage. In our study, we have shown that isolates of AG-4, including the three isolates from North Dakota, were, at most, mildly virulent on sprouts and essentially nonpathogenic on roots, with all pathogenic activity occurring at the higher temperatures. Our observations also contrast with those of Anguiz and Martin (3) who reported that isolates of AG-4 from potato plants in Peru were pathogenic on potato seedlings from true seed and roots of plants grown from seed tubers.

A recurring question relates to the relationship between temperature and severity of Rhizoctonia disease of potato. Generally, severity has been reported to increase as temperature decreases to 10 C. Richards (22) indicated that damage to potato plants by *R. solani* was severe at temperatures from 9.4 to 24.4 C and most severe from 12.2 to 18.2 C. Richards measured disease severity at temperatures up to 30.3 C, but disease severity declined rapidly above 21.4 C. Hide and Firmager (15) reported slight damage at 5, but severe damage at 10 and 15 C. Also, Richards (22,23) observed damage specific to shoot tips was greatest at 12 C.

Sanford (24) reported that disease was equally severe at 17 and 23 C, temperatures noticeably higher than those reported by Richards (22,23). Where the temperature ranges overlap, our data with *R. solani* AG-3 match quite closely with data of Richards (22) and Hide and Firmager (15). Possible explanations for the aggressivity at higher temperatures observed by Sanford (24) include the specific type (AG) of *R. solani* used (Sanford's inoculum may have included AG-5, AG-8, or other AGs of *R. solani*), and inoculum level. Bolkan et al (7) reported that inoculum level can affect the relationship between temperature and the damage caused by *R. solani*.

Difference in temperature is one possible explanation for differences in virulence of isolates of AG-4 among these studies. The pathogenicity studies in North Dakota were done in a greenhouse where soil temperatures may have exceeded the highest (21.1 C) in our study (N. C. Gudmestad, *personal communication*). We have shown an increase in damage to sprouts as the temperature was increased to 21.1 C. Isolates of *R. solani* AG-4 generally are favored by warmer temperatures, and it is possible that greater damage to sprouts and roots would occur at temperatures above 21.1 C. Another notable difference between our study and that of Gudmestad et al (14) was time of inoculation. We inoculated before any sprout or root development, whereas Gudmestad et al (14) inoculated established plants.

An unanticipated observation in our study was the level and nature of virulence among isolates of AG-8. A pathogen on wheat, barley, and other small grains (18,20), AG-8 has not been reported previously in association with or as pathogenic on potato plants. However, we have shown that isolates of AG-8 can be as damaging to potato roots as isolates of AG-3. Although damage associated with isolates of AG-8 was not restricted to roots, the relative amount of damage to sprouts was significantly less than that due to infection by isolates of AG-3 or AG-5. Currently, it is not known if isolates of AG-8 are capable of causing reductions in potato yield in the field. Also, it is not known if AG-8 occurs naturally in major potato production areas. Additional studies in the field with greater numbers of isolates will be necessary to establish the geographical distribution of AG-8, and to confirm its pathogenic capacity on potato.

Isolates of *R. solani* AG-3 caused more damage to developing potato sprouts and roots than the other multinucleate or binucleate isolates of *Rhizoctonia* evaluated in this study. Also, isolates of AG-3 were more pathogenic at 10 and 15.5 than at 21.1 C, whereas isolates of other groups generally were more pathogenic at the higher temperatures. In warmer climates, isolates of AG-5, AG-8, and possibly AG-4, may be etiologically more important than isolates of AG-3. In potato-growing regions where cool soil temperatures prevail, such as Alaska, Maine, eastern Canada, and the United Kingdom, isolates of AG-3 probably will be the principal cause of Rhizoctonia disease of potato.

TABLE 4. Reaction of sprouts and roots of emerging potato plants to *Rhizoctonia solani* AG-3, AG-4, AG-5, AG-8, and *R. oryzae* at three temperatures[x]

Group and temperature (C)	No. of sprouts/seed piece		Damage assessment[y]	
	Killed	Injured	Sprouts	Roots
AG-3 (13 isolates)				
21.1	0.3 b[z]	1.1 b	2.3 b	1.8 b
15.5	0.8 a	1.4 a	2.4 b	2.5 a
10.0	0.9 a	1.1 b	2.8 a	1.5 b
AG-4 (7 isolates)				
21.1	0.0 a[z]	1.0 a	1.4 a	0.0 a
15.5	0.0 a	1.0 a	1.0 b	0.0 a
10.0	0.0 a	0.0 b	0.0 c	0.0 a
AG-5 (6 isolates)				
21.1	0.1 a[z]	1.3 a	2.2 a	0.0 a
15.5	0.0 a	1.6 a	1.8 b	0.1 a
10.0	0.0 a	0.2 b	0.2 c	0.2 a
AG-8 (3 isolates)				
21.1	0.0 a[z]	0.8 a	1.0 a	2.0 b
15.5	0.0 a	1.0 a	1.0 a	2.4 a
10.0	0.0 a	1.1 a	1.1 a	2.1 b
R. oryzae (3 isolates)				
21.1	0.0 a[z]	0.7 a	1.2 a	0.6 a
15.5	0.0 a	0.6 a	0.6 b	0.0 b
10.0	0.0 a	0.0 b	0.0 c	0.0 b

[x] All isolates evaluated on potato cultivar Russet Burbank.
[y] Damage assessment for sprouts and roots made on a five-position scale where 0 = no damage, no lesions and 4 = all sprouts (or roots) dead.
[z] For each group, numbers in columns followed by same letter are not significantly different according to Duncan's multiple range test at $P = 0.05$.

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