2014 National FFA Clinic Problem

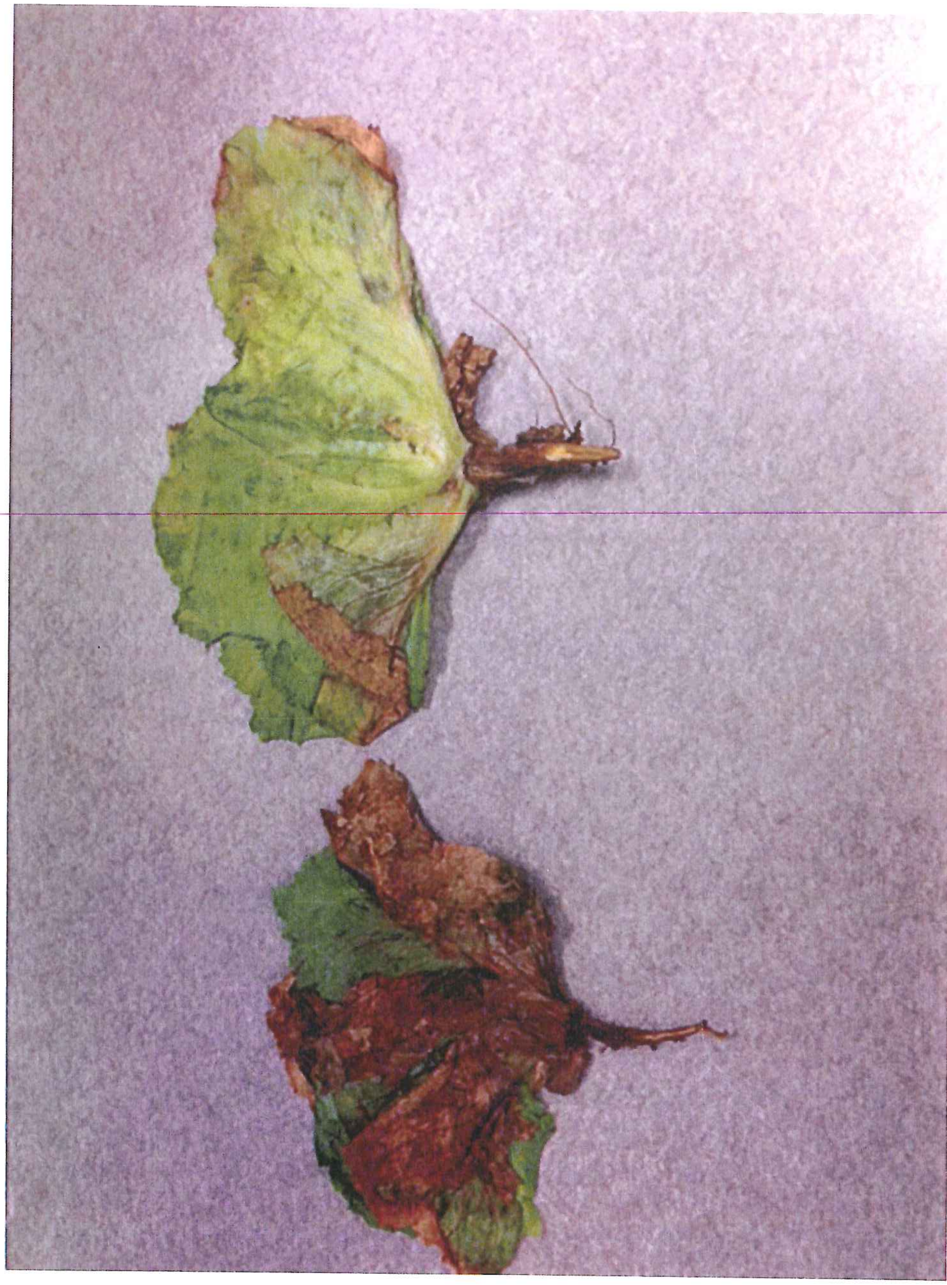
For Event Use Only:

Use the provided resources to solve these problems:

Farmer: Tanner Nelson, 121 Alpha Street, Yuma, Arizona 85364

October 28, 2014

Problem 1. You go to scout a lettuce field after it has dried down a little from the irrigation and you see (see picture/ sample plants) random spots in the field where there are groups of small plants next to normal sized plants. You also observe that the smaller plants and some of the normal sized plants have leaves that are yellowing. What happened to these plants since you scouted last, before the irrigation? What are the weather conditions needed for this disease? And how would you treat this disease?



Agronomy
Plant and Pest Diagnostic Clinic Scorecard

Name: ______________________ Sample Type: ______________________

Team #: ______________________ Inquirer Wants: ______________________

Participant #: ______________________

Describe Problem and Symptoms:

____

____

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Insect and Pest Identification

Plant Identification	
Crop	
Weed ID	

Recommendations:

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Farmer: Tanner Nelson- Yuma Arizona

October 28, 2014

Problem 1. You go to scout a lettuce field after it has dried down a little from the irrigation and you see (see picture/ sample plants) random spots in the field where there are groups of small plants next to normal sized plants. You also observe that the smaller plants and some of the normal sized plants have leaves that are yellowing. What happened to these plants since you scouted last, before the irrigation? What are the weather conditions needed for this disease? And how would you treat this disease?

Answer: The smaller plants are being stunted and dying off because they have been infected with Fusarium, which is a pathogen that resides in the soil and is encouraged to activate and move into plants after watering. Key indicators of Fusarium are: yellowing leaves, stunted growth, random infected field locations and the core of the tap root is a brownish red color. The normal sized plants with yellowing leaves are not infected because they do not have the brownish red core in their tap root. Instead these plants just got to wet from the irrigation and the leaves sat in the water. This disease needs warm moist temperatures . Treatment of this disease is water management, solarization and crop rotation.

Instructions:

Please use the Soil Test Report information provided to the left and also below to solve the 2 questions below.

Please use the products and prices in the list below to give the farm the fertilizer they need for the corn crop.

Fertilizer Products and Prices

11-52-0	$ 600	per ton
46-0-0	$ 500	per ton
21-0-0-24S	$ 400	per ton
0-0-60	$ 500	per ton

Questions 1 and 2 (25 points each):

Solve for: 1). The number of Pounds(lbs.) blended fertilizer they need per acre to grow 120 Bushels(Bu.)

Corn = ________ lbs./acre total

2). The number of Dollars($) of blended fertilizer they need per acre to grow 120 Bushels(Bu.)

Corn = $__________/acre total

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KEY: 2014 FFA Agronomy CDE- Fertilizer Problem for Individuals

120-50-10 20(S)

P2O5: 50# needed. 50/52 in 11-52-0 > 96.2#
96.2# 11-52-0 yields 10.58# N

S: 20# needed. 20/24(S) in 21-0-0-24 > 83.3#
83.3# 21-0-0-24(S) yields 17.49# N

N: 120# needed. 120# N needed
-10.58# N in 11-52-0
-17.49# N in 21-0-0-24(S)
=======
91.93# N/46 in 46-0-0 > 199.8#

K2O: 10# needed. 10/60 in 0-0-60 > 16.7#

11-52-0	96.2#/A @ $600/ton	= $28.26/A
21-0-0-24(S)	83.3#/A @ $400/ton	= $16.66/A
46-0-0	199.8#/A @ $500/ton	= $49.95/A
0-0-60	16.7#/A @ $500/ton	= $ 4.18/A
	========	=========
Totals	**396 lbs./Acre**	**$99.65/Acre**

Effect of Planting Date, Cultivar, and Stage of Plant Development on Incidence of Fusarium Wilt of Lettuce in Desert Production Fields

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ABSTRACT

Matheron, M. E., McCreight, J. D., Tickes, B. R., and Porchas, M. 2005. Effect of planting date, cultivar, and stage of plant development on incidence of Fusarium wilt of lettuce in desert production fields. Plant Dis. 89:565-570.

Fusarium wilt of lettuce, first recognized in Japan in 1955, has since been discovered in the United States (California in 1990, Arizona in 2001), Iran (1995), Taiwan (1998), and Italy (2001). In Arizona, the causal agent, *Fusarium oxysporum* f. sp. *lactucae*, has been recovered from lettuce plants in 27 different lettuce fields during the 2001 to 2003 production seasons. Studies were initiated to examine the impact of planting date, cultivar, and stage of plant development on the incidence of disease in the field. In 2002 and 2003, tested lettuce cultivars were sown in at least one of the following planting windows; early-season (September), mid-season (October), and late-season (December). Within each planting window, significant differences in disease incidence among lettuce cultivars were noted at plant maturity. The mean incidence of Fusarium wilt on cultivars sown in September, October, and December was 92.3, 15.1, and 2.0%, respectively, in 2002 and 74.2, 5.1, and 0.7%, respectively, in 2003. The mean soil temperatures at the10-cm depth during the September, October, and December plantings for both years were 26, 14, and 14°C, respectively. Initial symptoms of Fusarium wilt were apparent as early as 14 days after seeding, with increasing incidence of disease noted as the crop developed and reached maturity. Among all lettuce cultivars planted in September, only one and two cultivars of romaine in 2002 and 2003, respectively, reached maturity with ≤5% incidence of Fusarium wilt, whereas the lowest incidence of disease among crisphead, green leaf, red leaf, or butterhead cultivars was 73.7, 27.0, 20.2, and 65.7%, respectively, in 2002 and 62.1, 29.0, 100, and 100%, respectively, in 2003. For October plantings, all romaine cultivars had ≤5% incidence of Fusarium wilt at maturity, whereas disease incidence among tested cultivars of crisphead lettuce in 2002 and 2003 ranged from 0.8 to 66.8% and 0.3 to 43.3%, respectively. When planted in December, 82 and 88% of tested cultivars, including all romaine entries, reached maturity with ≤1% incidence of Fusarium wilt. Selection of appropriate lettuce cultivars and planting times should allow successful production of lettuce in the southwestern Arizona production region with minimal or no incidence of disease in fields infested with *F. oxysporum* f. sp. *lactucae*. On the other hand, successful production of lettuce in infested fields when temperatures favor disease development will not be possible until lettuce cultivars are developed that possess high tolerance or resistance to the pathogen.

Fusarium oxysporum f. sp. *lactucae* was first identified as the cause of a root rot on lettuce (*Lactuca sativa* L.) in 1955 in Japan (13). Since that initial discovery, three races of the pathogen have been identified on lettuce in that country (4,5). A Fusarium wilt on lettuce was reported in California in 1990, and the causal pathogen was named *Fusarium oxysporum* f. sp. *lactucum* (10). Recently, Japanese race 1 and the California pathogen were determined to belong to the same vegetative compatibility group and were considered to be the same forma specialis (4). Lettuce showing symptoms of wilt, yellowing of leaves, and a red-brown to black necrosis of internal taproot and crown tissue was first recognized in 2001 in six different lettuce fields in Arizona. Infected plants were stunted and often died, resulting in significant losses to the grower. *F. oxysporum* was consistently isolated from necrotic taproot tissue from affected field plants, caused symptoms of wilt, yellowing, and root necrosis when lettuce seedlings were inoculated with the fungus, and was of the same vegetative compatibility group and race as an isolate of *F. oxysporum* f. sp. *lactucae* from lettuce in California reported in 1993 (12,14). Since the initial discovery in six Arizona lettuce fields in 2001, the pathogen has been recovered from 21 additional fields during the 2002 and 2003 production seasons. The infested fields ranged in size from 4 to 16 ha. In addition to Japan and the United States, the pathogen has been reported on lettuce in Iran in 1995 (15), Taiwan in 1998 (9), and Italy in 2001 (8).

Lettuce has become the dominant vegetable crop in southwestern Arizona (Yuma County), with over 28,000 ha devoted to its production. Crisphead (iceberg) lettuce accounts for 20,000 ha, followed by 5,000 ha of romaine and 3,000 ha of green leaf, red leaf, and butterhead. Lettuce seed is sown from early September though December to provide a daily supply of lettuce from November through late March. There are significant differences in soil and air temperatures as well as time required to achieve maturity within this September through December planting season. Lettuce cultivars have been developed for optimum performance within a specific window or time period during the planting season. Some cultivars are bred to endure the high to moderate temperatures (daily maximum ranges from ca. 30 to 45°C) encountered in September and October, others grow best in the moderate to mild temperatures (daily maximum ranges from ca. 25 to 30°C) common from late October through early December, while some cultivars are best suited for the cool to mild temperatures (daily maximum ranges from ca. 10 to 30°C) from December through March.

Lettuce plants displaying symptoms of Fusarium wilt to date have all been found in commercial fields from mid-October through early January. Planting dates for these fields ranged from September to mid-October. Furthermore, 25 of 27 fields in which Fusarium wilt was found were planted to a crisphead cultivar. These observations suggest that lettuce plantings established in September to mid-October, especially plantings of crisphead lettuce, may be more at risk to Fusarium wilt than lettuce plantings made later in the season.

The objective of our research was to examine the impact of planting date, cultivar, and stage of plant development on the resultant incidence of Fusarium wilt of lettuce in the field, with the goal of acquiring data that may facilitate development of disease management guidelines that would enable growers to minimize losses due to Fusarium wilt of lettuce.

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MATERIALS AND METHODS

Trials were established in a 16-ha commercial field in southwestern Arizona. When planted to crisphead lettuce in the fall of 2001, this field sustained severe crop loss due to Fusarium wilt. Laser-leveling and other cultivation practices helped spread the infested soil to produce a uniformly infested field for these studies. In 2002 and again in 2003, each lettuce cultivar was sown in at least one of the following planting windows: early-season (September), mid-season (October), and late-season (December). In 2002, the September, October, and December plantings were located in the western, middle, and eastern one-third of the 16-ha field, respectively. In 2003, all three plantings were made in the portion of the field used for the September planting in 2002, with the September, October, and December plantings located in the western, middle, and eastern one-third of this 5.3-ha area of land. The majority of the lettuce cultivars within each planting date were those that would be planted in the desert southwest production region at that time. The remaining cultivars were included for comparison of disease incidence on the same cultivar among different planting dates or for evaluation of plant material not grown commercially in the desert. Plots were planted and managed using current commercial practices, utilizing raised beds with 92 cm between bed centers, with each bed containing two rows of lettuce spaced 30 cm apart. In each planting, the four replicate plots for each tested cultivar were arranged in a randomized complete block design. Each plot contained 600 plants in each of the three plantings in 2002, 180 plants in September 2003, and 550 plants in October and December 2003.

Disease incidence was assessed three times for each planting. Each plant within a plot was counted as diseased if the plant was dead or stunted and displayed the typical wilting and yellowing associated with Fusarium wilt of lettuce. All living plants with these symptoms of Fusarium wilt were not marketable at plant maturity. During the third and final rating, root cortex tissue was examined for the presence of discoloration and necrosis as well. Samples of necrotic root cortex tissue from each lettuce planting were placed on acidified potato dextrose agar to verify the presence of *F. oxysporum* f. sp. *lactucae*. Soil temperature in the bed was recorded hourly at a depth of 10 cm. Planting dates were 7 September, 17 October, and 6 December in 2002 and 3 September, 21 October, and 18 December in 2003. For 2002 plantings, disease incidence was recorded 2 and 14 October and 8 November 2002 for the 7 September planting; 24 November, 15 December 2002, and 11 January 2003 for the 17 October planting; and 25 January, 15 February, and 22 March 2003 for the 6 December planting. For 2003

Table 1. Incidence of Fusarium wilt on lettuce cultivars at crop maturity after sowing seed at three different time periods for 2 years in a field naturally infested with *Fusarium oxysporum* f. sp. *lactucae*

	Percentage of plants dead or diseased[z]					
	Planting date: 2002			Planting date: 2003		
Lettuce cultivar	7 Sep	17 Oct	6 Dec	3 Sep	21 Oct	18 Dec
Crisphead						
Acacia	100.0 a	…	…	…	…	…
Annie	99.5 ab	…	…	98.6 ab	…	…
AZ 90	…	66.8 cd	…	…	1.4 jk	0.8 cd
AZ 2000	…	…	10.1 b	…	…	…
Beacon	100.0 a	72.0 bc	…	100.0 a	23.3 d	1.6 bc
Big Sur	…	…	0 f	…	…	0.2 h
Bubba	…	45.2 i-k	…	…	24.7 d	2.2 b
Buccaneer	87 f-h	1.2 v	0 f	51.0 i-k	0.6 k	0 d
Cavalier	100.0 a	…	…	96.7 ab	…	…
Cibola	…	62.2 c-f	…	…	16.2 e	…
Climax	…	…	0.1 f	…	…	…
Cochise 47	…	59.5 d-g	…	…	0.3 k	…
Colossus	…	16.2 q-s	…	…	…	…
Coolgreen	…	…	4.6 c-e	…	…	…
Coolguard	…	41.0 k-n	…	…	3.3 g-k	…
Coyote	…	14.0 q-u	…	99.3 a	3.3 g-k	0.7 cd
Crusader	95.2 a-e	…	0.2 f	98.6 ab	…	0.2 d
Daneberg 66	…	…	0.2 f	…	…	0.6 d
Del Oro	…	44.0 i-l	…	…	8.5 f	0 d
Del Rio	…	6.0 r-v	0 f	100.0 a	…	…
Desert Heat	100.0 a	46.5 i-k	10.9 b	100.0 a	0.7 k	0.4 d
Desert Queen	100.0 a	…	…	92.5 ab	…	…
Desert Spring	…	…	3.3 d-f	…	…	0.6 d
Desert Storm	100.0 a	…	…	91.2 ab	…	…
Diamond	…	…	0 f	…	…	…
Diamond Back	95.2 a-e	…	0 f	73.5 de	…	0 d
Domingos 67	…	…	0.1 f	…	…	0.2 d
Durango	…	…	0 f	…	…	…
Emperor	100.0 a	…	…	…	…	…
Fallgreen	100.0 a	…	…	95.1 ab	…	…
Fiorette	…	…	0 f	…	…	…
Fortuna	100.0 a	…	…	99.0 ab	…	…
Gabilan 1315	…	…	17.8 a	…	…	0.9 cd
Grand Max	98.5 a-c	…	…	95.9 ab	…	…
Green Lightning	…	…	0.2 f	…	…	0.2 d
Green Pack	87.2 f-h	3.0 uv	…	68.4 ef	…	…
Grizzly	…	30.0 n-p	…	…	2.2 i-k	…
Headmaster	…	…	0 f	…	…	0.2 d
Heatmaster	100.0 a	…	…	…	…	…
Heavy Weight	…	…	…	98.7 ab	13.7 e	…
Honcho II	…	46.8 h-k	…	…	25.4 d	…
Husky	100.0 a	16.8 q-r	0.5 f	…	…	…
Icon	…	…	0.4 f	…	…	0.3 d
Jackel	…	…	0.2 f	…	…	0.3 d
Javelina	97.7 a-c	…	…	58.0 g-i	…	…
Kahuna	99.5 ab	…	…	100.0 a	…	…
Kofa	…	40.0 k-o	…	…	15.5 e	…
Laguna Fresca	100.0 a-d	…	…	99.4 a	…	0.9 cd
La Quinta	81.7 h	…	…	…	…	…
Lighthouse	100.0 a	66.0 c-e	…	100.0 a	43.3 a	0.9 a
Mighty Joe	…	…	…	100.0 a	3.9 f-k	…
Milestone	100.0 a	…	…	…	…	…
Mohawk	100.0 a	…	…	79.6 d	…	…
Monarch	100.0 a	…	…	…	…	…
Monolith	…	28.2 op	…-	95.3 ab	2.5 i-k	0.8 cd
Palma	100.0 a	…	…	…	…	…
Patriot	…	…	0.5 f	…	…	…
Raider	92.5 a-f	…	…	94.1 ab	…	…
RC 74	…	66.8 cd	…	…	17.5 e	…
Rivergreen	…	…	0 f	…	…	…

(*continued on next page*)

[z] Each of the four replicate plots for each tested lettuce cultivar, arranged in a randomized complete block experimental design within each planting date, contained 600 plants in all three plantings in 2002, 180 plants in September 2003, and 550 plants in October and December 2003 plantings. Final disease incidence at crop maturity for lettuce planted 7 Sep, 17 Oct, and 6 Dec 2002 was determined 8 Nov 2002, 11 Jan and 22 Mar 2003, respectively; and for plantings sown 3 Sep, 21 Oct, and 18 Dec 2003 was determined on 6 Nov 2003, 26 Jan and 22 Mar 2004, respectively. Entries denoted by "…" were not planted on a given date. Values in each column followed by a different letter are significantly different according to the Duncan multiple range test ($P = 0.05$).

Table 1. (*continued from previous page*)

Lettuce cultivar	Percentage of plants dead or diseased[z]					
	Planting date: 2002			Planting date: 2003		
	7 Sep	17 Oct	6 Dec	3 Sep	21 Oct	18 Dec
Sahara	100.0 a	…	…	100.0 a	…	…
Salinas 88	…	0.8 v	…	…	…	…
Sharpshooter	73.7 i	2.1 uv	0 f	62.1 f-h	1.0 k	0 d
Silverado	…	…	0 f	…	…	…
Sniper	85.2 gh	3.7 t-v	0 f	65.1 e-g	0.8 k	0 d
Snowbird	100.0 a	15.5 q-t	0.8 f	…	…	…
Spector	98.7 a-c	…	…	95.0 ab	…	…
Spring Pac	…	…	0 f	…	…	0.2 d
Sun Blaster	…	…	…	78.0 d	…	…
Sun Devil	93.0 a-f	…	…	93.0 ab	…	…
Supercoach	…	40.5 k-o	…	…	37.2 b	…
Synergene 352	…	40.0 k-o	…	…	3.0 h-k	…
Target	…	…	0.1 f	…	…	…
Telluride	…	…	0 f	…	…	0 d
Toronto	…	…	0 f	…	…	…
Tradition	100.0 a	20.1 pq	1.8 ef	100.0 a	…	…
Tres Equis	97.5 a-c	…	…	100.0 a	…	…
Valley Green	100.0 a	…	…	99.3 a	…	…
Valley Queen	100.0 a	42.8 j-m	…	100.0 a	7.8 f-h	…
Vanguard 75	…	49.2 g-k	…	…	…	…
Van Max	…	47.8 g-k	10.2 b	…	7.4 f-i	2.1 b
Van Mor	…	54.2 e-j	…	…	…	…
Wellton	100.0 a	…	…	100.0 a	…	…
Westland	…	51.8 f-k	…	…	8.3 fg	…
Wintergold	…	29.8 n-p	…	…	2.2 i-k	…
Winterhaven	…	59.8 d-g	…	…	40.4 ab	…
Winterking	…	45.8 i-k	…	…	2.3 i-k	…
Wolverine	…	4.4 s-v	…	99.0 ab	2.8 h-k	0 d
Yuma	…	46.2 i-k	…	100.0 a	6.5 f-j	…
Romaine						
Apollo	…	…	…	93.6 ab	0 k	0.2 d
Big Green	…	…	0 f	…	0 k	0.2 d
BOS 9021	9.6 t-w	…	…	8.8 n	…	…
Braveheart	…	…	…	82.3 cd	…	…
Clemente	14.0 s-u	0.8 v	…	48.2 jk	0 k	0.1 d
Coastal Star	32.0 m	2.3 uv	…	89.2 bc	…	0.2 d
Conquistador	12.7 t-v	0 v	…	100.0 a	0 k	0.1 d
Costa Rica # 4	…	…	0 f	…	…	…
Darkland	20.0 p-s	0.7 v	…	50.7 i-k	…	…
DF 7	12.9 t-v	0.2 v	…	56.4 h-j	…	0.3 d
Fresheart	18.8 q-t	…	…	7.6 n	4.6 f-k	…
Green Forest	26.3 m-p	…	…	77.9 d	…	…
Green Towers	19.2 q-t	…	…	39.3 l	0 k	0 d
King Louie	6.9 vw	0.9 v	…	3.0 n	…	0.3 d
Paragon PIC	24.2 n-q	1.2 v	…	66.6 eg	0 k	…
PIC	29.2 mn	…	…	…	…	…
Robusto	21.5 o-q	0.9 v	…	45.4 kl	…	…
Slugger	5.2 w	0.4 v	0 f	0.8 n	0 k	2.0 b
Sunbelt	…	0.4 v	0 f	…	0.8 k	2.2 b
Triton	16.7 r-t	…	…	33.6 kl	…	0.2 d
Green leaf						
Big Star	…	0.8 v	…	…	0.1 k	…
Marin	89.7 d-g	0.8 v	…	99.1 ab	0 k	…
North Star	27.0 m-o	1.9 uv	…	29.0 m	0.7 k	0.2 d
Shining Star	…	…	…	99.0 ab	…	…
Superstar	…	…	…	…	2.5 i-k	…
Two Star	88.7 e-g	2.9 uv	0 f	99.4 a	0 k	0.2 d
Red leaf						
Red Baron	…	…	…	…	2.1 i-k	…
Red Fox	50.0 k	1.6 uv	…	…	0 k	…
Red Tide	100.0 a	88.2 a	10.2 b	100.0 a	2.2 i-k	0.1 d
Vulcan	20.2 p-s	2.8 uv	…	…	…	…
Western Red	39.2 k	…	…	…	…	…
Butterhead						
Connick	…	66.5 cd	0.3 f	…	…	…
Encanto	65.7 j	…	…	…	…	…
Odyssey	…	…	…	100.0 a	2.6 h-k	…
Optima	86.2 f-h	…	…	100.0 a	…	…

plantings, disease incidence was recorded 1 and 21 October and 6 November 2003 for the 3 September planting; 22 November 2003 and 5 and 26 January 2004 for the 21 October planting; and 2 and 20 February and 22 March 2004 for the 18 December planting.

Analysis of data. CoStat statistical software (CoHort Software, Monterey, CA) was used to perform analysis of variance with the GLM procedure, to determine significant differences among main effects and any interactions, and to conduct linear regression analysis. Means were separated by LSD or Duncan's multiple range test.

RESULTS

The final incidence of Fusarium wilt recorded for each tested lettuce cultivar at crop maturity within each of the three planting dates in 2002 and 2003 is presented in Table 1. Within each planting date, significant differences in disease incidence were noted among lettuce cultivars. Seven and 16 lettuce cultivars in 2002 and 2003, respectively, were planted at each of the three planting dates for that year. In both years, the incidence of Fusarium wilt was significantly higher in the September planting compared with the October and December plantings (Table 2). In 2002, disease incidence also was significantly higher in the October planting compared with that in December. The mean soil temperatures at a depth of 10 cm during the September, October, and December plantings for 2002 and 2003 were 24 and 28°C, 15 and 14°C, and 14°C, respectively (Table 2).

Initial symptoms of Fusarium wilt in September plantings began to appear on some plants approximately 14 days after seeding, when plants were thinned to a stand with 30 cm between seedlings in a row. Within each September planting, the mean incidence of Fusarium wilt increased significantly from the first to the second rating, and from the second to the third and final rating (Table 3). In all plantings, the level of Fusarium wilt increased as plant development progressed from juvenility to maturity and was significantly higher at the third rating at crop maturity compared with earlier ratings of younger immature plants. The stage of plant development at the time of each disease assessment in 2002 and 2003, expressed as the percentage of time elapsed from seeding to plant maturity, ranged from 33 to 48%, 60 to 77%, and 100% at the first, second, and third rating dates, respectively. For both years, the mean time from seeding to crop maturity during the September, October, and December plantings was 63, 91, and 101 days, respectively (Table 4). The mean soil temperature from seeding to first disease rating, from first to second rating, and from second to third and final rating, for the September, October, and December plantings, ranged from 28 to 21°C, 20 to 10°C, and 12 to 18°C, respectively, in the 2002–2003 season and from 32 to 22°C, 19 to 12°C, and 12 to 18°C, respectively, in the 2003–2004 season (Table 4).

Four crisphead lettuce cultivars, Buccaneer, Desert Heat, Sharpshooter, and Sniper, were present in all three plantings in 2002 and in 2003. Among these cultivars, the main effects of time of planting and stage of plant development, as well as the interaction of time of planting × stage of plant development, stage of plant development × year, and time of planting × stage of plant development × year on the incidence of Fusarium wilt were significant (Table 5). On the other hand, the main effect of year and the interaction of time of planting × year were not significant. There also was a significant linear correlation ($r = 0.886$, $P < 0.001$), described by the equation $y = 5.8x - 77$, between the final incidence of Fusarium wilt at plant maturity and the mean soil temperature at a depth of 10 cm (from seeding to plant maturity) for the lettuce cultivars Buccaneer, Desert Heat, Sharpshooter, and Sniper.

Among all types of lettuce in September plantings, only one and two cultivars of romaine in 2002 and 2003, respectively, reached maturity with ≤5% incidence of Fusarium wilt (Table 1), whereas the lowest incidence on crisphead, green leaf, red leaf, or butterhead cultivars was 73.7, 27.0, 20.2, and 65.7%, respectively, in 2002 and 62.1, 29.0, 100, and 100%, respectively, in 2003 (Tables 1 and 6). In October plantings, all romaine cultivars had ≤5% incidence of Fusarium wilt at maturity, whereas disease incidence among the 37 and 30 tested cultivars of crisphead lettuce in 2002 and 2003 ranged from 0.8 to 66.8% and 0.3 to 43.3%, respectively. For December plantings, 82 and 88% of tested cultivars, including all romaine entries, reached maturity with ≤1% incidence of Fusarium wilt (Tables 1 and 6).

DISCUSSION

Planting date had a profound effect on the final incidence of Fusarium wilt in these studies. One prominent difference among planting dates was soil temperature. In the September plantings of 2002 and 2003, the mean incidence of Fusarium wilt was 88% and the mean soil temperature was 26°C. Disease incidence for both October plantings was 22%, and the mean soil temperature was 14°C, and for both December plantings, mean disease incidence was 1% and the mean soil temperature also was 14°C. Lower disease incidence in December compared with October plantings, when mean soil temperatures were the same, may be explained by the change in soil temperatures as the October and December lettuce plantings grew and reached maturity. In the October plantings, the recorded mean soil temperature for 2002 and 2003 from seeding to first disease rating, first rating to second rating, and second rating to third (final) rating was 20, 12, and 11°C, respectively; whereas during December plantings, mean recorded soil temperatures at these respective periods of time were 12, 14, and 18°C. Higher soil temperatures early in the development of the lettuce plant, as recorded in October plantings, apparently were more favorable for disease development than higher soil temperature near the end of the crop development cycle, as recorded in December plantings. Hubbard and Gerik (10) reported that an isolate of the lettuce Fusarium wilt pathogen grew in culture from 8 to 32°C, with maximum growth at 28°C. In our studies, a greater incidence of Fusarium wilt was recorded among lettuce plantings when mean soil temperatures were 24 and 28°C compared with disease levels at 14 and 15°C. Temperatures ranging from 25 to 35°C, compared with 10 to

Table 2. Incidence of Fusarium wilt at crop maturity for lettuce cultivars grown in all three plantings in 2002 or 2003 in a field naturally infested with *Fusarium oxysporum* f. sp. *lactucae*

	Plants dead or diseased (%)[x]		Mean soil temp (°C)[y]	
Planting time[z]	2002	2003	2002	2003
September	92.3 a	74.2 a	24	28
October	15.1 b	5.1 b	15	14
December	2.0 c	0.7 b	14	14

[x] Each plant within a plot was determined to be diseased if the plant was dead or stunted and displayed the typical wilting and yellowing associated with Fusarium wilt of lettuce. Each value for 2002 and 2003 was derived from seven and 16 lettuce cultivars, respectively. Values in each column followed by a different letter are significantly different according to the LSD test.

[y] Mean soil temperature at a depth of 10 cm from seeding to plant maturity.

[z] Planting dates were 7 Sep, 17 Oct, and 6 Dec in 2002 and 3 Sep, 21 Oct, and 18 Dec in 2003. Final disease incidence at crop maturity was determined for each respective planting in 2002 on 8 Nov 2002, 11 Jan and 22 Mar 2003, and for 2003 plantings on 6 Nov 2003, 26 Jan and 22 Mar 2004.

Table 3. Incidence of Fusarium wilt at the first, second, and final disease rating date within each lettuce planting grown in a field naturally infested with *Fusarium oxysporum* f. sp. *lactucae*

	Plants dead or diseased (%)[y]					
	Planting date: 2002-2003			Planting date: 2003-2004		
Disease rating[z]	7 Sep	17 Oct	6 Dec	3 Sep	21 Oct	18 Dec
First	15.3 c	1.3 c	0 b	44.2 c	0.7 b	0 b
Second	75.0 b	12.8 b	0.2 b	64.0 b	2.4 b	0.1 b
Last	96.8 a	37.4 a	1.8 a	80.1 a	7.1 a	0.6 a

[y] Each plant within a plot was determined to be diseased if the plant was dead or stunted and displayed the typical wilting and yellowing associated with Fusarium wilt of lettuce. Each value for the September, October, and December plantings in 2002 was derived from 38, 34, and 40 cultivars, respectively, and in 2003 from 60, 48, and 41 cultivars, respectively. Values in each column followed by a different letter are significantly different according to the LSD test.

[z] The first, second, and last determinations of Fusarium wilt incidence for 2002 plantings in September, October, and December were conducted 25, 37, and 62 days; 37, 58, and 86 days; and 50, 71, and 107 days after seeding, respectively. For 2003 plantings in the same months, disease was evaluated 28, 48, and 64 days; 32, 76, and 97 days; and 46, 64, and 95 days after seeding, respectively.

Table 4. Mean soil temperature during intervals of time before Fusarium wilt incidence ratings

	Seeding to first rating		First rating to second rating		Second rating to final rating		Seeding to final rating	
Planting date	Time[y] (days)	Temp.[z] (°C)	Time (days)	Temp. (°C)	Time (days)	Temp. (°C)	Time (days)	Temp. (°C)
2002-03								
7 Sep	25	28	12	24	25	21	62	24
17 Oct	37	20	21	14	28	10	86	15
6 Dec	50	12	21	15	36	18	107	14
2003-04								
3 Sep	28	32	20	28	16	32	64	28
21 Oct	32	19	44	11	21	12	97	14
18 Dec	46	12	18	12	31	18	95	14

[y] Elapsed time in days.

[z] Mean soil temperature at a depth of 10 cm.

20°C, are associated with higher levels of Fusarium wilt on several other crops as well. Punja et al. (17) noted that symptoms of Fusarium wilt on muskmelon, caused by *F. oxysporum* f. sp. *melonis*, occurred when temperatures exceeded the 25 to 30°C range. For Fusarium wilt on banana, caused by *F. oxysporum* f. sp. *cubense*, Peng et al. (16) reported an increase in disease severity as temperature increased from 24 to 34°C, whereas at 14°C, no wilt symptoms were evident even though the pathogen could be recovered from within banana plant tissue. Fusarium wilt of carnation, caused by *F. oxysporum* f. sp. *dianthi*, was most severe at 25 to 26°C, whereas plants below 18°C remained symptomless (1). Symptoms of Fusarium wilt of chickpea were less severe from 10 to 20°C than from 25 to 30°C (2), and a constant temperature of 35°C was most favorable for disease development on chrysanthemum (6).

Initial symptoms of Fusarium wilt appeared as early as 14 days after seeding on some lettuce cultivars planted in September. The number of plants with symptoms continued to increase from this time to maturity, and disease incidence for all plantings was significantly higher at maturity compared with the first rating early in crop development. Evaluation of plant material for resistance to Fusarium wilt should be conducted at temperatures expected in the field and continued for the duration of time required for plants to mature to generate resistance evaluation data from greenhouse or growth chamber studies that will accurately predict performance in fields infested with *F. oxysporum* f. sp. *lactucae*.

Fusarium wilt of lettuce is an emerging disease in the southwestern Arizona production region. The 27 fields currently known to contain *F. oxysporum* f. sp. *lactucae*, ranging in size from 4 to 16 ha, currently represent <1% of the total land area devoted to lettuce production in this area. Disease incidence at the time of initial detection of Fusarium wilt ranged from fields with less than 10 symptomatic plants to the occasional field with virtually 100% infected plants. The number of fields infested with *F. oxysporum* f. sp. *lactucae* will likely increase as contaminated soil is inadvertently introduced into fields currently free of the pathogen through farming activities such as laser-leveling, disking, and other seed-bed preparation activities, movement of mud-encrusted irrigation pipe used to germinate seed, cultivation, and harvesting crew operations. Growers and harvesters are strongly encouraged to minimize dissemination of the Fusarium wilt pathogen. All agricultural land in southwestern Arizona is double-cropped, i.e., two crops per year, which increases the potential for dispersion of the pathogen. After lettuce or another winter vegetable has been harvested, spring and summer crops, such as melons, cotton, wheat, corn, safflower, or Sudan grass, are planted and grown. Sanitation practices directed at a lettuce pathogen may easily be neglected during the production of these crops.

Seed transmission of *F. oxysporum* f. sp. *lactucae* is another means of pathogen dissemination that may account for the appearance of Fusarium wilt on lettuce in geographically distant areas, such as California, Taiwan, Iran, and Italy, at least 35 years after initial discovery in Japan. Garibaldi et al. (7) found that nine of 27 samples of lettuce seed obtained from commercial seed lots planted in fields that were subsequently affected by Fusarium wilt in Italy were contaminated by *F. oxysporum*. Three of the isolates were pathogenic to lettuce and exhibited a level of pathogenicity similar to that of isolates of *F. oxysporum* f. sp. *lactucae* originally isolated from infected plants in Italy, the United States, and Taiwan.

The primary management tool for Fusarium wilt on other crops is the use of resistant cultivars. Our evaluation of crisphead lettuce cultivars, the primary type of lettuce grown in southwestern Arizona, revealed no resistant or tolerant cultivar available for early-season planting in September. Long-term management of Fusarium wilt, using current planting schedules and farming practices, will require development of resistant crisphead and other

Table 5. Analysis of variance table evaluating the effects of time of planting, stage of plant development, year, and their interactions on the incidence of Fusarium wilt with four lettuce cultivars (Buccaneer, Desert Heat, Sharpshooter, and Sniper) grown in all three plantings in 2002 and 2003 in a field naturally infested with *Fusarium oxysporum* f. sp. *lactucae*

Source[x]	df[y]	Incidence of Fusarium wilt: F	Incidence of Fusarium wilt: $P > F$[z]
Time of planting (TP)	2	358.1	<0.0001***
Stage of plant development (PD)	2	54.0	<0.0001***
Year (Y)	1	0.9	0.3376 ns
TP × PD	4	35.2	<0.0001***
TP × Y	2	1.7	0.1821 ns
PD × Y	2	10.8	<0.0001***
TP × PM × Y	4	4.8	0.0011**

[x] Sources of variation. Time of planting: September, October, and December. Stage of plant development, expressed as the percentage of time elapsed from seeding to plant maturity at each of the three disease rating dates for each planting in 2002 and 2003, ranged from 33 to 48% at the first disease rating date, 60 to 77% at the second rating date, and 100% for the third rating date. Years: 2002 and 2003.

[y] Degrees of freedom.

[z] **, *** = significant at $P < 0.01$ and $P < 0.001$, respectively.

Table 6. Incidence of Fusarium wilt at crop maturity among types of lettuce planted in September, October, and December in 2002 or 2003 in a field naturally infested with *Fusarium oxysporum* f. sp. *lactucae*[z]

	September planting			October planting			December planting		
	Cultivars	Disease incidence (%)		Cultivars	Disease incidence (%)		Cultivars	Disease incidence (%)	
Lettuce type	tested	Range	Mean	tested	Range	Mean	tested	Range	Mean
2002-2003									
Crisphead	38	73.7-100	96.9	37	0.8-66.8	35.1	33	0-17.8	1.9
Romaine	15	5.2-32.0	17.9	10	0-2.3	0.8	4	0	0
Green leaf	3	27.0-89.7	68.5	4	0.8-2.9	1.6	1	0	0
Red leaf	4	20.2-100	52.4	3	1.6-88.2	30.9	1	10.2	10.2
Butterhead	2	65.7-86.2	76.0	1	66.5	66.5	1	0.3	0.3
2003-2004									
Crisphead	37	62.1-100	91.2	30	0.3-43.3	10.9	27	0-5.6	0.7
Romaine	16	0.8-100	50.2	9	0-4.6	0.6	11	0-2.2	0.5
Green leaf	4	29.0-99.4	81.6	5	0-2.5	0.7	2	0.2	0.2
Red leaf	1	100	100	3	0-2.2	1.4	1	0.1	0.1
Butterhead	2	100	100	1	2.6	2.6	0	...	...

[z] Each plant within a plot was determined to be diseased if the plant was dead or stunted and displayed the typical wilting and yellowing associated with Fusarium wilt of lettuce.

lettuce types that can be grown successfully in infested fields when temperatures favor disease development. On the other hand, for the short-term, some important disease management strategies can be implemented. The long planting and growing season, starting with first sowing of seed in early September and ending with final harvest in late March, coupled with the effect of temperature on disease development, allows growers to plant some crisphead cultivars in the cool soil during December in the presence of *F. oxysporum* f. sp. *lactucae* and expect minimal to no crop loss. Furthermore, several romaine lettuce cultivars could be successfully planted from October through December in fields infested with the pathogen. Other vegetable crops produced in the area, primarily broccoli, cauliflower, and cabbage, can also be grown on land known to be infested with *F. oxysporum* f. sp. *lactucae*. These short-term management practices should remain effective until the pathogen has spread to such a large proportion of available land that timing and rotation strategies will no longer be usable. Hopefully, by that time some lettuce cultivars with a high level of tolerance or resistance to the Fusarium wilt pathogen will be available.

Management strategies directed at lowering inoculum levels of *F. oxysporum* f. sp. *lactucae* in infested fields could be beneficial in reducing spread of the pathogen both within and between fields. Soil solarization, in particular, may be a useful technique to reduce population levels of the pathogen and disease incidence in infested fields. Chellemi et al. (3) found no difference in the incidence of Fusarium wilt of tomato in plots solarized 40 to 55 days compared with plots fumigated with a mixture of methyl bromide + chloropicrin. Lodha (11) noted that soil solarization for 15 days led to significant reduction in the incidence of Fusarium wilt of cumin. Experiments are in progress to assess the potential of soil solarization as a management tool for Fusarium wilt of lettuce in southwestern Arizona production fields.

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Evaluation of Soil Solarization and Flooding As Management Tools for Fusarium Wilt of Lettuce

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ABSTRACT

Matheron, M. E., and Porchas, M. 2010. Evaluation of soil solarization and flooding as management tools for Fusarium wilt of lettuce. Plant Dis. 94:1323-1328.

Fusarium wilt of lettuce caused by *Fusarium oxysporum* f. sp. *lactucae* continues to spread and cause economic losses in Arizona lettuce fields since the initial discovery of the disease in the state in 2001. Studies were initiated to assess the potential of summer soil solarization and flooding as management tools for Fusarium wilt of lettuce in southwestern Arizona production fields. In microplot studies, lettuce plant growth in soil naturally infested with *F. oxysporum* f. sp. *lactucae* that was solarized from 2 to 8 weeks was consistently greater than growth in nonsolarized soil. Growth of lettuce in flooded soil containing the pathogen occasionally was significantly higher than in nonflooded soil; however, the effect on plant growth and health was not as consistent as that recorded for solarized soil. In four trials within a field containing *F. oxysporum* f. sp. *lactucae*, the incidence of Fusarium wilt on lettuce sown in soil after solarization was reduced from 42 to 91% compared with disease in nonsolarized plots. There was no significant benefit of a 2- over a 1-month solarization period under the conditions of these trials, where the mean soil temperature at a depth of 5 cm during a 1-month solarization period in 2005 and 2006 was 47 and 49°C, respectively. These findings suggest that soil solarization can be an effective tool for management of Fusarium wilt on lettuce, especially when used within an integrated program in conjunction with existing disease management tactics.

Fusarium wilt of lettuce (*Lactuca sativa* L.), caused by *Fusarium oxysporum* Schltdl.:Fr. f. sp. *lactucae* Matuo & Motohashi, was first reported in Japan in 1955 (20). Since then, the disease has been reported in the United States (California and Arizona in 1990 and 2001, respectively) (9,17), Brazil (32), Iran (21), Italy (5), and Taiwan (8). Since 2001, when Fusarium wilt was first discovered in Arizona, the causal pathogen had been found in a total of 26 fields planted to lettuce by 2003 (18) and is continuing to spread and cause economic losses in infested fields.

The primary management tool for Fusarium wilt on most host plants is the use of resistant cultivars. Studies conducted in Italy identified a number of cultivars, mostly of the leaf lettuce type, that were completely resistant to *F. oxysporum* f. sp. *lactucae* after inoculation with the pathogen (6). Evaluation trials in a field naturally infested with a high population of *F. oxysporum* f. sp. *lactucae* in Arizona identified 2 of 16 tested romaine cultivars, Slugger and King Louie, which sustained very low levels of disease and would be considered resistant or tolerant to Fusarium wilt (18). However, in the same trials, none of the 89 tested commercial crisphead cultivars were resistant to the disease. Lettuce has become the dominant vegetable crop in southwestern Arizona (Yuma County), with 24,000 ha devoted to its production in the 2007–08 growing season that runs from September through March. Crisphead (iceberg) lettuce accounts for 13,200 ha, followed by 6,700 ha of romaine and 4,000 ha of green leaf, red leaf, and butterhead types. Additional efforts are needed to identify and incorporate resistance to *F. oxysporum* f. sp. *lactucae* into commercially acceptable crisphead lettuce cultivars that will meet the needs of growers in the various regions where Fusarium wilt is a concern.

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There are some cultural disease management strategies that can limit losses in lettuce-growing areas where *F. oxysporum* f. sp. *lactucae* is present. Where possible, growing lettuce at times when soil temperatures are cooler and less favorable for development of Fusarium wilt can be a very effective tactic. For example, several crisphead lettuce cultivars could be grown with losses ranging from 0 to 1.8% due to Fusarium wilt when soil temperatures were in the range of 11 to 14°C, whereas the same set of cultivars sustained disease losses ranging from 51 to 100% in the same field when soil temperatures ranged from 21 to 32°C (18). Furthermore, several tested romaine cultivars which, in general, displayed more disease tolerance than crisphead cultivars, sustained losses due to Fusarium wilt ranging from 0 to 2.3% when soil temperatures ranged from 10 to 20°C compared with disease losses ranging from 5.2 to 100% when soil temperatures ranged from 21 to 32°C (18).

Good field sanitation practices should be followed to the extent possible to minimize the spread of *F. oxysporum* f. sp. *lactucae* within and between fields in a lettuce production area by focusing on any farming operation that could move infested soil or plant material, such as seed-bed preparation activities, cultivation, harvesting crew operations, and movement of infested soil and plant debris on sprinkler-irrigation pipe, tractors, and other farm equipment. These lettuce pathogen-dispersal considerations should also be kept in mind when crops other than lettuce are planted in fields infested with *F. oxysporum* f. sp. *lactucae.* Finally, care should be taken to sow seed not contaminated with the pathogen.

Management tools focused on lowering inoculum levels of *F. oxysporum* f. sp. *lactucae* in infested fields could be beneficial in reducing disease incidence as well as spread of the pathogen within and between fields. Crop rotation, which can be a useful disease management tool in this regard, is not an effective means of reducing inoculum levels of *F. oxysporum* in soil, because the pathogen may survive in the field for 10 years or more (16), even in the absence of a host (27). Soil solarization has demonstrated efficacy in reducing Fusarium wilt on several crops. Garibaldi et al. (7) reported that a simulated soil solarization at 45 ± 2°C for a 1- to 2-week period combined with soil application of dried pellets of *Brassica carinata* A. Braun significantly reduced Fusarium wilt on lettuce caused by *F. oxysporum* f. sp. *lactucae*. Chellemi et al. (3) found that the incidence of Fusarium wilt of tomato was similar in plots solarized for 40 to 55 days compared with plots fumigated with a mixture of methyl bromide + chloropicrin. Lodha (14) noted that soil solarization for 15 days led to significant reduction in the incidence of Fusarium wilt of cumin. The mechanisms of disease control brought about by solarization include physical, biological, and chemical changes in soil. The most prominent effect is the physical increase in temperature for several hours each day. Other associated processes that may also affect the survival of soilborne plant pathogens include shifts in microbial populations, changes in chemical and gas composition as well as the physical structure of soil, and high sustained moisture levels (10).

Flooding of soil can effectively reduce inoculum levels of some plant pathogens and reduce the incidence of the associated diseases that they cause. Moore (22) reported complete decay of sclerotia of *Sclerotinia sclerotiorum* (Lib.) de Bary after 24 to 45 days in three different types of flooded soils at temperatures of 22 to 26°C. Likewise, sclerotia of *S. minor* Jagger and *S. sclerotiorum* were no longer viable after 3 weeks in flooded soil at mean temperatures ranging from 30 to 33°C (19). Furthermore, a summer flooding treatment for 60 days of soil infested with *F. oxysporum* f. sp. *vasinfectum* significantly reduced the occurrence of Fusarium wilt on subsequent cotton plantings (1). Soil flooding can cause physical, biological, and chemical changes, such as alterations in soil structure, anaerobic conditions (31) that modify soil microbial communities (30), decrease in nitrate nitrogen levels (26,31), and an increase in ammonia concentration (26). One or more of these factors may play a role in reducing the survival of soilborne pathogen propagules. The objective of our research was to assess the potential of summer soil solarization and flooding as management tools for Fusarium wilt of lettuce in southwestern Arizona production fields.

MATERIALS AND METHODS

Microplot and bioassay trials. Soil naturally infested with *F. oxysporum* f. sp. *lactucae* was collected on 22 and 12 July in 2003 and 2004, respectively, from a commercial field in southwestern Arizona and placed into a series of 17-liter-capacity white plastic containers (28.5 cm in diameter by 30.5 cm deep). Each container was buried in a field at The University of Arizona Yuma Mesa Agricultural Center so that the upper lip of each container was level with the surface of the field soil. Each container was considered a replicate microplot. Soil for the control treatment was maintained in microplots without irrigation. The flooding treatment was achieved by completely saturating the soil with water and maintaining a 2-cm layer of water on the soil surface by daily addition of water to replace that lost due to evaporation (19). The solarization treatment was accomplished by thoroughly saturating soil with water, then covering the soil with 1.0-mil-thick solid clear polyethylene plastic containing a 180-day UV stabilizer (Water Tech, Charlotte, NC). The microplot containers used for the soil solarization treatment contained holes in the bottom to allow drainage of excess water, whereas no drain holes were present in microplot containers used for the soil flooding treatment. At the end of treatment intervals of 2, 4, 6, and 8 weeks, no additional water was added to flooded microplots and plastic was removed from solarized microplots. Soil remained in microplots without further irrigation until samples were collected to initiate bioassay trials. The time interval from cessation of soil treatments to initiation of bioassay trials ranged from 2 to 3.5 and 3.5 to 5 months for the soil treatment trials in 2003 and 2004, respectively. Five replicate microplots were established as controls and for each treatment interval–soil treatment combination. Temperature in one control, flooded, and solarized microplot was recorded hourly at a soil depth of 10 and 23 cm for the duration of each trial from 23 July to 24 September 2003 and 13 July to 10 September 2004.

Crisphead lettuce (cv. Lighthouse) was seeded in transplant trays containing cells 2.5 cm square at the top and 5.0 cm deep filled with potting mix (Aqua Guard, St. Louis). Trays containing lettuce seed were maintained in the greenhouse until seedling emergence, then moved outdoors for further seedling growth. White plastic pots with a capacity of 473 cm^3 (9.0 cm in diameter by 13.5 cm deep) were filled with soil from microplots: two pots with soil from a depth of 2 to 8 cm and two pots with soil from a depth of 20 to 26 cm from each microplot. When lettuce seedlings had developed four true leaves, a plant was transplanted into each pot containing soil on 25 November 2003 and 22 December 2004, then maintained in the greenhouse. Plants were watered daily and fertilized weekly with Miracle Gro fertilizer (Scotts Co., Marysville, OH). Hourly temperature of the soil within a pot was recorded at a depth of 10 cm. The 2003 and 2004 bioassay trials were concluded after 2 months, at which time plant fresh weight as well as foliar and root symptom disease ratings were determined. Plant weight values recorded in 2003 are for the entire plant, whereas values in 2004 are for the aboveground portion of plants. Foliar disease symptoms were rated according to a scale where 1 = no apparent disease, 2 = slight to moderate stunting, 3 = severe stunting and yellowing, and 4 = dead plant, whereas root disease symptoms in the tap root cortex were rated as 1 = no discoloration, 2 = slight to moderate yellowing, 3 = slight to moderate red streaking, and 4 = necrotic tissue present. Although the bioassay trials were conducted in the winter, the temperatures in the greenhouse were conducive for development of Fusarium wilt.

Field solarization trials. Field trials were conducted from 2004 to 2007 to evaluate the efficacy of soil solarization as a potential management tool for Fusarium wilt of lettuce (Table 1). Raised beds, either listed but unshaped or shaped and ready for planting, were solarized for 1 or 2 months during the summer in a 2-ha commercial field in southwestern Arizona. The listed but unshaped beds were 107 cm wide at the base and tapered to a rounded ridge at their apex, whereas shaped beds were 107 cm wide at their base with a flat top surface 51 cm wide. Soil aggregates in unshaped beds were larger and less densely packed compared with those in shaped beds. The distance between both unshaped and shaped bed centers was 107 cm. This was the same field from which soil was collected for the microplot studies described earlier. Crisphead lettuce was planted in this field in September 2003 and was severely affected by Fusarium wilt when the crop was terminated in November. Wheat was grown after lettuce and, following harvest in June 2004, the residue was incorporated into the soil and primary beds were listed but not shaped. Twelve days after a furrow irrigation, five 15.2-m lengths of bed were covered on 3 August with the 1.0-ml-thick clear plastic described earlier and solarized until 13 September. Five beds of the same length, alternated with solarized beds in the field, were not covered with clear plastic and served as a control. Soil temperature was recorded at a depth of 5 and 23 cm in a bed covered with plastic as well as in an uncovered bed. One additional furrow irrigation of all beds was performed on 1 September. At the conclusion of the solarization treatment on 13 September, all beds were shaped and planted to crisphead let-

Table 1. Experimental parameters for field solarization trials and subsequent assessment of Fusarium wilt on lettuce plantings

Year	Bed type	Days from final irrigation to laying of 1.0-mil plastic	Solarization dates and duration (days)	Crisphead lettuce cultivar	Seeding date	Trial end date
2004	Unshaped	12	3 August–13 September (41)	Lighthouse	10 October	14 January
2005	Shaped	12	7 July–4 August (28)	Lighthouse	13 September	18 November
	...	12	7 July–1 September (56)	Lighthouse	13 September	18 November
2006	Unshaped	12	3 July–2 August (30)	EXP-9145	16 September	17 November
	...	12	3 July–10 September (69)	EXP-9145	16 September	17 November
	Shaped	15	6 July–2 August (27)	EXP-9145	16 September	17 November
	...	15	6 July–10 September (66)	EXP-9145	16 September	17 November
2007	Shaped	4	14 August–16 September (33)	Raider	19 September	13 December

tuce (cv. Lighthouse) on 10 October 2004. The bed-shaping procedure removed the upper portion from each unshaped bed and redistributed the soil, primarily to the sides of the resultant shaped bed. Plots were planted and managed using standard commercial practices, using raised beds with 107 cm between bed centers, with each bed containing two rows of lettuce spaced approximately 30 cm apart. Each plot in this trial contained 100 plants. The incidence of Fusarium wilt was recorded on 9 December and again at plant maturity on 14 January 2005. Each plant within a plot was counted as diseased if the plant was dead or stunted and displayed the usual symptoms of wilting and yellowing associated with Fusarium wilt of lettuce. All living plants with these symptoms were not marketable at plant maturity. At the end of the trial, the taproots of some symptomatic plants were harvested and necrotic cortex tissue was placed on potato dextrose agar to verify the presence of *F. oxysporum* f. sp. *lactucae*.

Additional solarization trials were conducted from 2005 to 2007, each in an area of the 2-ha commercial field not part of a previous solarization trial. In 2005, beds were prepared and shaped 12 days after a flood irrigation of an area of the field that previously contained crisphead lettuce infected with Fusarium wilt followed by a planting of wheat. Five beds, 51 cm wide at the top and 30.5 m in length, either were covered with clear plastic and solarized from 7 July to 4 August or 1 September or not covered with plastic to serve as the control (Table 1). Following the end of the longest solarization period, beds were planted to crisphead lettuce (cv. Lighthouse) on 13 September. Each of the five replicate plots per treatment in this trial contained 220 plants. The incidence of Fusarium wilt was recorded on 12 and 24 October and, finally, on 18 November 2005. For 2006, following a crop of crisphead lettuce infected with Fusarium wilt, the field was flood irrigated; then, unshaped and shaped beds 30.5 m long were prepared 12 and 15 days later, respectively. Unshaped beds were solarized from 3 July to 2 August or 10 September, shaped beds from 6 July to 2 August or 10 September, and both unshaped and shaped beds not covered with plastic served as controls. At the end of the longest solarization period, unshaped beds were shaped and all beds planted to crisphead lettuce (cv. EXP-9145) on 16 September. Each of the four replicate plots per treatment in this trial contained 230 plants. The incidence of Fusarium wilt was recorded 11 and 30 October and at plant maturity on 17 November 2006. For the final trial conducted in 2007, beds were prepared and shaped 12 days after a flood irrigation of the field following a crop of crisphead lettuce infected with Fusarium wilt. Additional moisture was added by sprinkler irrigation after beds were shaped, followed 4 days later by covering four beds (30.5 m in length) with clear plastic and solarizing these beds from 14 August to 16 September or not covering an equal number of beds to serve as the control (Table 1). Following solarization, beds were planted to crisphead lettuce (cv. Raider) on 19 September. Each of the four replicate plots per treatment in this trial contained 230 plants. The incidence of Fusarium wilt was recorded on 5 November and at plant maturity on 13 December 2007.

Soil temperature during each solarization trial was recorded hourly at depths of 5 and 23 cm. Soil moisture content in solarized and nonsolarized beds was determined gravimetrically during the course of field solarization trials in 2006 and 2007. Soil moisture values presented are the means from three and two soil samples per treatment for soil depth and bed shape in 2006 and 2007, respectively.

Analysis of data. The SigmaPlot 11 software package (Systat Software, Inc, San Jose, CA) was used for statistical analysis of data. Data determined to be from normally distributed populations with the same variances were analyzed by the parametric unpaired t test (for comparing two means) or one-way analysis of variance test (for more than two means). Means were compared and separated at $P = 0.05$ according to the Holm-Sidak test. When data failed tests for normality or equal variance, the nonparametric Mann-Whitney rank sum test (for two values) or the Kruskal-Wallis one-way analysis of variance on ranks test (for more than two values) were used to analyze data. These values were compared and separated at $P < 0.05$ by the Tukey Test.

RESULTS

Microplot and bioassay trials. At the conclusion of both the 2003 and 2004 bioassay trials, fresh weight of lettuce plants grown in soil containing *F. oxysporum* f. sp. *lactucae* that was subjected to solarization for a period of 2, 4, 6, and 8 weeks was significantly higher than that recorded for plants grown in nontreated soil (Table 2). This significant difference was noted for soil collected from a depth of 2 to 8 cm as well as from a depth of 20 to 26 cm within microplots. Growth of lettuce plants in soil subjected to flooding occasionally was significantly higher compared with plants grown in nontreated soil; however, the effect was not consistent over time, year, and depth from which soil was collected within microplots (Table 2). Fresh weight of lettuce plants grown in soil collected from untreated soil microplots at a depth of 2 to 8 cm was significantly greater than growth of plants in soil from a depth of 20 to 26 cm in the same microplots in 2003 but not in 2004 (Table 2).

Compared with plants grown in nontreated soil, the Fusarium wilt foliar symptom rating of lettuce plants at the conclusion of the bioassay phase of the 2003 trial was significantly lower for plants grown in soil from a depth of 2 to 8 cm in microplots solarized for 4, 6, and 8 weeks and in soil collected from a depth of 20 to 26 cm within microplots solarized for 2, 4, 6, and 8 weeks (Table 2). The lettuce taproot cortex disease rating was significantly lower in plants grown in soil collected from a depth of 2 to 8 cm in microplots solarized for 6 and 8 weeks and in soil collected from a depth of 20 to 26 cm within microplots solarized from 2 to 8 weeks. In microplots flooded from 2 to 8 weeks, the Fusarium wilt foliar and root ratings were reduced significantly for plants grown in soil collected at a depth of 20 to 26 cm; however, there was no effect of flooding on the same disease ratings for soil collected at a depth of 2 to 8 cm from microplots flooded for any tested interval of time (Table 2). In the 2004 trial, there were no significant differences in Fusarium wilt foliar or root ratings among soil treatments within untreated, flooded, and solarized microplots for any time interval at either soil depth sampled. The mean temperature of soil at a depth of 10 cm within pots during the bioassay trials was 18 and 20°C in 2003 and 2004, respectively.

For both the 2003 and 2004 soil treatment experiments, the mean temperature of soil in microplots at a depth of 5 cm during both the 1- and 2-month treatment periods for nonsolarized, solarized, and flooded soil was 39, 45, and 32°C, respectively. At a soil depth of 23 cm, the mean temperature for the same respective soil treatments was 36, 40, and 34°C. Considering both trials together, the mean number of hours during the 2-month treatment period that soil at a depth of 5 cm was at or above 40, 45, and 50°C in nonsolarized soil was 512, 256, and 84 h, respectively, compared with values in solarized soil of 563, 414, and 262 h and in flooded soil of 10, 0, and 0 h, respectively. The number of hours that mean temperatures at a soil depth of 23 cm were at or above 40, 45, and 50°C was 127, 4, and 0 h for nonsolarized; 380, 84, and 0 h for solarized; and 0, 0, and 0 h for flooded soil.

Field solarization trials. In the initial trial conducted in 2004, unshaped beds were subjected to solarization under plastic for 41 days. In a subsequent planting of crisphead lettuce (cv. Lighthouse), the incidence of diseased plants due to *F. oxysporum* f. sp. *lactucae* in these solarized plots was 6 and 29% on 9 December and at crop maturity on 14 January, respectively, whereas, in nonsolarized plots, significantly higher values of 16 and 50% diseased plants were recorded for the same respective dates (Table 3).

In the 2005 study, where shaped beds were solarized for 28 or 56 days, the incidence of diseased crisphead lettuce plants (cv. Lighthouse) due to the *Fusarium* pathogen in solarized plots was 0 and 1% on 12 and 24 October, respectively, whereas significantly higher values of 11 and 71% diseased plants were recorded in nonsolarized plots on the same respective dates. The final disease incidence at crop maturity on 18 November in nonsolarized plots was 92%, whereas disease values in plots solarized for 28 and 56 days were significantly lower, at 9 and 8%, respectively (Table 3). There was no significant difference in disease incidence among plots solarized for 28 or 56 days at any of the disease evaluation dates.

The incidence of Fusarium wilt in 2006 for crisphead lettuce (cv. EXP-9145) grown on unshaped beds solarized for 30 days was 7 and 37% on 11 and 30 October, respectively, and, after solarization for 69 days, was 3 and 32% for the same respective dates. In comparison, disease frequency on unshaped nonsolarized beds on 11 and 30 October was 15 and 79%, respectively. For each evaluation date, the only significant difference in the extent of Fusarium wilt was that recorded on 30 October between unshaped beds solarized for 30 days and nonsolarized beds. At crop maturity on 17 November, there was no significant difference in Fusarium wilt incidence between unsolarized plots and those solarized for 30 or 69 days (Table 3).

In 2006, the incidence of Fusarium wilt for lettuce grown on shaped beds solarized for 27 days was 3 and 22% on 11 and 30 October, respectively, and, after solarization for 66 days, was 3 and 20% for the same respective dates. On the other hand, disease frequency on shaped nonsolarized beds on 11 and 30 October was 15 and 56%, respectively. The difference in the extent of Fusarium wilt on nonsolarized beds compared with those solarized for 27 days was significant on 30 October, whereas the difference in disease incidence on nonsolarized beds compared with beds solarized for 66 days was significant on both evaluation dates. At crop maturity on 17 November, disease levels were significantly lower on shaped beds solarized for 27 and 66 days compared with nonsolarized beds (Table 3).

In the trial conducted in 2007, shaped beds were subjected to solarization under plastic for 33 days. Disease incidence due to *F. oxysporum* f. sp. *lactucae* in solarized plots containing crisphead lettuce (cv.

Table 3. Effect of soil solarization on subsequent development of Fusarium wilt on lettuce in 2004 to 2007 field trials

Year, solarization period (days)	Soil temperature (°C)[y]	Beds shaped	Disease incidence (%)[z]
2004			
0	37	No	50 a
41	41	No	29 b
2005			
0	41	Yes	92 a
28	47	Yes	9 b
56	46	Yes	8 b
2006			
0	38	No	100 a
0	38	Yes	100 a
30	45	No	84 ab
27	49	Yes	52 b
69	44	No	79 ab
66	48	Yes	44 b
2007			
0	41	Yes	67 a
33	44	Yes	25 b

[y] Mean soil temperature at a depth of 5 cm during solarization period.
[z] Percentage of plants that were dead or diseased and displayed typical symptoms of Fusarium wilt at crop maturity. Values for each year followed by a different letter are significantly different according to the *t* test ($P = 0.13$ in 2004 and $P < 0.001$ in 2007) or the Tukey Test ($P < 0.05$ in 2005 and 2006).

Table 2. Effect of flooding or solarization of soil in microplots on subsequent development of Fusarium wilt on lettuce plants in 2003 and 2004

		Disease severity and plant growth[y]							
		Depth of 2 to 8 cm				Depth of 20 to 26 cm			
Rating[z]	Soil treatment	2 weeks	4 weeks	6 weeks	8 weeks	2 weeks	4 weeks	6 weeks	8 weeks
2003									
Weight	Control	29.9 b	29.9 b	29.9 b	29.9 b	8.8 b	8.8 b	8.8 b	8.8 b
	Flood	47.8 a	45.4 a	42.3 b	43.9 b	47.5 a	47.8 a	45.7 a	43.7 a
	Solarize	51.0 a	50.7 a	51.8 a	48.9 a	47.9 a	48.2 a	48.3 a	51.9 a
Foliar	Control	2.4 a	2.4 a	2.4 a	2.4 a	3.7 a	3.7 a	3.7 a	3.7 a
	Flood	2.6 a	2.0 a	1.8 a	1.9 ab	2.2 b	2.0 b	1.4 b	1.7 b
	Solarize	2.0 a	1.3 b	1.1 b	1.3 b	2.0 b	1.5 b	1.2 b	1.1 b
Root	Control	2.9 a	2.9 a	2.9 a	2.9 a	3.9 a	3.9 a	3.9 a	3.9 a
	Flood	2.8 a	2.4 a	2.4 a	2.6 a	2.4 b	2.3 b	2.4 b	2.5 b
	Solarize	2.0 a	2.0 a	2.0 b	2.0 b	2.0 b	2.0 b	2.0 b	2.0 b
2004									
Weight	Control	80 b	80 b	80 c	80 c	90 b	90 b	90 b	90 b
	Flood	121 ab	105 ab	112 b	114 b	126 b	107 b	103 b	128 ab
	Solarize	143 a	134 a	141 a	156 a	164 a	164 a	145 a	154 a
Foliar	Control	1.9 a	1.9 a	1.9 a	1.9 a	2.1 a	2.1 a	2.1 a	2.1 a
	Flood	1.3 a	1.1 a	1.0 a	1.0 a	1.1 a	1.0 a	1.0 a	1.0 a
	Solarize	1.0 a	1.1 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a
Root	Control	1.8 a	1.8 a	1.8 a	1.8 a	1.9 a	1.9 a	1.9 a	1.9 a
	Flood	1.3 a	1.2 a	1.0 a	1.1 a	1.3 a	1.4 a	1.0 a	1.0 a
	Solarize	1.0 a	1.2 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a	1.0 a

[y] Soil from depths indicated in microplots after treatment for each time period. From each replicate microplot, two samples of soil were collected at a depth of 2 to 8 and 20 to 26 cm and placed in 473-cm^3 capacity white plastic pots. Lettuce seedlings (cv. Lighthouse) were planted into the soil in each pot on 25 November 2003 and 22 December 2004 and maintained in a greenhouse until termination of trials 2 months later, at which time disease ratings and fresh weight of plants was determined. Each value was derived from 10 lettuce plants grown in soil from each of the treatment interval–soil treatment combinations or from control microplots. Values in each column for each year and type of disease rating parameter followed by a different letter are significantly different according to the Tukey Test ($P < 0.05$).
[z] Disease rating. Plant weight in grams; values for 2003 are the weight of the entire plant (above- and belowground parts) whereas 2004 values are the weight of the aboveground parts of plants only. Foliar symptom rating scale: 1 = no apparent disease; 2 = slight to moderate stunting; 3 = severe stunting and yellowing; 4 = dead plant. Tap root cortex rating scale: 1 = no discoloration; 2 = slight to moderate yellowing; 3 = slight to moderate red streaking; 4 = necrotic tissue present.

Raider) was 6 and 25% on 5 November and at crop maturity on 13 December, respectively, whereas, in nonsolarized plots, significantly higher values of 19 and 67% were recorded for the same respective dates (Table 3).

Compared with nonsolarized plots, the mean temperature for solarized soil at a depth of 5 cm was higher by 4°C in unshaped beds in 2004; 5 to 6°C in shaped beds in 2005; 6 to 7 and 10 to 11°C in unshaped and shaped beds, respectively, in 2006; and 3°C in shaped beds in 2007 (Table 3). Considering all four field solarization trials together, including unshaped and shaped beds, at a soil depth of 5 cm the mean number of hours during the single or longest solarization periods for that year that were at or above 40, 45, and 50°C in nonsolarized soil was 330, 103, and 3 h, respectively, compared with values in solarized soil of 635, 375, and 211 h, respectively. On the other hand, at a soil depth of 23 cm, mean temperature values were at or above 40, 45, and 50°C in nonsolarized soil for 66, 0, and 0 h, respectively, compared with periods in solarized soil of 100, 1, and 0 h, respectively.

In the 2006 field trial, on 6 July at the start of solarization for shaped beds and 3 days after beginning solarization for unshaped beds, the percent soil water content in solarized shaped and unshaped beds at a depth of 5 cm was 11.4 and 13.7%, respectively, compared with 8.8 and 13.0% for respective nonsolarized plots. At a depth of 23 cm on the same date, the mean percent water content for shaped and unshaped solarized beds was 16.3 and 17.7%, respectively, and 16.4 and 19.5% for respective nonsolarized plots. By 22 July, the percent soil water content in solarized shaped and unshaped beds at a depth of 5 cm was 12.0 and 5.5%, respectively, compared with 3.8 and 3.0% for respective nonsolarized plots. At a depth of 23 cm on the same date, the mean percent water content for shaped and unshaped solarized beds was 15.5 and 15.9%, respectively, and 14.7 and 15.7% for respective nonsolarized plots. In 2007, the mean soil water content at the end of the solarization period on 16 September at a depth of 5 and 23 cm in solarized shaped beds was 15.6 and 16.2%, respectively, compared with respective values of 5.7 and 10.8% in nonsolarized beds.

DISCUSSION

In microplot studies, lettuce plant growth in soil containing *F. oxysporum* f. sp. *lactucae* that was solarized from 2 to 8 weeks was consistently greater than growth in nontreated soil. This effect was noted for soil collected from depths of 2 to 8 as well as 20 to 26 cm. This growth response may be due to more than the direct effect of solarization on reduction of pathogen populations in soil, because solarization also is known to induce a plant growth response in soil free of known pathogens (2). Possible mechanisms for this growth response not related to pathogen control include increased nutrient availability in soil, elimination of minor pathogens or parasites, stimulation of beneficial microorganisms, destruction of phytotoxic substances in soil, and release of growth regulator-like substances (10).

Growth of lettuce in summer-flooded soil occasionally was significantly higher than in nontreated soil; however, the effect was not as consistent as that recorded for solarized soil in relation to treatment duration, trial year, and depth from which soil was collected. Also, significant reduction of foliar and taproot cortex disease ratings was more evident for lettuce plants grown in solarized compared with flooded soil. Due to the less-consistent effect of summer soil flooding compared with solarization on lettuce growth and development of Fusarium wilt, field evaluation of summer flooding was not addressed in these investigations. However, this potential disease management tool merits further examination. Soil flooding results in an accumulation of ammonia (31), which has been shown to reduce the population density of *Fusarium* spp. in soil (33). Flooding of soil also creates anaerobic conditions (31) that alter soil microbial communities (30) and may play a role in reducing the survival of some soilborne pathogens. In Australia, a summer flooding treatment for 60 days in fields infested with *F. oxysporum* f. sp. *vasinfectum* significantly reduced the occurrence of Fusarium wilt on subsequent cotton plantings (1). However, as noted by the researchers, one potential limitation of this procedure may be the availability of water for extended field flooding in arid locations.

In the four field trials conducted, the incidence of Fusarium wilt on lettuce sown in soil after solarization was reduced from 42 to 91% compared with disease in nonsolarized plots. In the single field trial that contained both unshaped and shaped beds, the reduction in Fusarium wilt for lettuce grown on solarized compared with nonsolarized beds was significantly different on shaped but not unshaped beds. One possible explanation for the higher reduction of Fusarium wilt on shaped compared with unshaped beds is that, in the process of shaping beds after solarization, the upper layer of soil from the unshaped bed is removed and redistributed, primarily to the sides of the resultant shaped bed. This upper layer of soil, which was subjected to higher temperatures and, presumably, was where solarization was more effective, was removed during the subsequent bed-shaping operation to expose soil that was less effectively solarized due to its original depth in the soil profile. Also, some nonsolarized soil adjacent to the edges of solarized beds could have been incorporated into the final shaped bed by the bed-shaping implement.

The two trials that compared 1- and 2-month solarization periods on shaped beds did not reveal a significant advantage for the longer solarization period. In 2005, Fusarium wilt reduction after a 28- and 56-day solarization period was 91% for both time periods and, in 2006, solarization durations of 27 and 66 days reduced the subsequent incidence of disease by 48 and 56%, respectively. In general, populations of soilborne pathogens are greatly reduced at temperatures in the range of 40 to 50°C (10). In these studies, the mean soil temperature at a depth of 5 cm for the 1-month solarization period in 2005 and 2006 was 47 and 49°C, respectively. Solarization periods exceeding 1 month may be beneficial in areas where soil temperatures are below levels achieved in these trials.

The elevated temperatures achieved by the soil solarization process are one important factor affecting the reduction of pathogen populations; however, the retention of soil moisture by the plastic film during the solarization process is also an important consideration. Soil moisture content at a depth of 5 cm, when measured during and at the conclusion of soil solarization trials in 2006 and 2007, was always higher in solarized compared with nonsolarized soil. Soil moisture content is a critical factor, because microorganisms are much more resistant to heat under dry conditions. Water affects the heat stability of proteins; thus, when water is present, less energy is necessary for unfolding of peptide chains in proteins, which results in decreased heat resistance (24). Consequently, heating dry soil does not effectively control most plant pathogens (12). In addition to increasing the thermal sensitivity of soilborne microorganisms, moisture increases heat transfer or conduction in soil (28). Mahrer (15) found that saturated soils were optimal. In our field trials, various methods were used to add water to soil beds, including furrow irrigation after bed preparation, bed preparation after flood irrigation of a flat field, and bed construction following flood irrigation followed by sprinkler irrigation. An alternative and effective method of supplying moisture to soil before or during the solarization process would be through drip irrigation.

Time of exposure to potentially lethal temperatures in solarized soil can affect the death rate within a pathogen population, resulting in various degrees of reduction in viability (10,25). Additionally, sublethal temperatures, which eliminate only a fraction of the pathogen population, may affect the survival of the remaining, potentially weakened propagules. Freeman and Katan (4) demonstrated that the viability of conidia of *F. oxysporum* f. sp. *niveum* that were heat treated or exposed to solarized soil declined faster than unheated conidia. Disease incidence in watermelon seedlings inoculated with heat-treated conidia of the pathogen was reduced from 35 to 82%, with a similar trend noted with *F. oxysporum* f. sp. *melonis* in muskmelon seedlings. In studies with other pathogens, sublethal doses of heat caused damage to sclerotia of *Sclerotium rolfsii*, which were then colonized by bacteria and actinomycetes (13), or made other pathogens more susceptible to antagonism by *Trichoderma* spp. (23,29).

Soil solarization has been shown to significantly reduce the number of plants affected by Fusarium wilt in a subsequent planting of a susceptible lettuce cultivar. The long-term effect of the solarization treatment on disease development in additional lettuce plantings was not addressed in our studies. However, depressed levels of Fusarium wilt and increased cotton yields were recorded for as long as 3 years following soil solarization of several fields heavily infested with *F. oxysporum* f. sp. *vasinfectum* (11). Furthermore, disease incidence was lower in the second year when a resistant cotton cultivar was planted the first year followed by a susceptible cultivar in the second year, compared with two successive plantings of the susceptible cultivar, thus extending the beneficial effect of solarization. Other factors may affect the longevity of a solarization treatment as well. Care should be exercised to minimize reintroduction of *F. oxysporum* f. sp. *lactucae* from contaminated soil within furrows during farming operations. The potential ability of the lettuce pathogen to grow and multiply on crops other than lettuce also is a concern. Hubbard and Gerik (9) found that *F. oxysporum* f. sp. *lactucae* could be recovered from tomato, muskmelon, watermelon, and cotton seedlings inoculated with the lettuce pathogen 4 weeks earlier. Furthermore, the mean weight of muskmelon and watermelon plants was reduced 51 and 39%, respectively, compared with plants not inoculated with *F. oxysporum* f. sp. *lactucae*.

The degree and duration of effective control of Fusarium wilt on lettuce can be maximized if soil solarization is used within an integrated program in conjunction with existing disease management tools, such as planting available tolerant or resistant lettuce cultivars and growing lettuce when lower soil temperatures are not conducive to disease development. An additional benefit of soil solarization is effective control of many types of weeds and some other soilborne pathogens of concern to lettuce growers (28).

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ARIZONA COOPERATIVE EXTENSION

THE UNIVERSITY OF ARIZONA.
College of Agriculture and Life Sciences

AZ1029

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PLANT DISEASE MANAGEMENT
Horticultural Crops

Damping-off

Mary W. Olsen

Pathogens

Soilborne fungi and fungal-like organisms: *Rhizoctonia solani, Thielaviopsis basicola, Pythium* spp.

Host

Seedlings of many plants, including most vegetables and flowers.

Symptoms/signs

Because damping-off is caused by several different organisms on many different plants, symptoms of disease vary. Emerging or established seedlings fall over and die rapidly, collapsing even when soil moisture is adequate. When dug up and inspected, the plants are soft, dark colored and usually disintegrating. Seeds may fail to emerge at all.

When infected with *Pythium* spp., the stems and roots of seedlings are black and rotted. Often the entire root system is soft and the outer root sloughs off.

Seedlings infected with *Rhizoctonia solani* have reddish brown to black lesions on the stem and roots. Stems are often girdled or become water-soaked and soft, causing the plant to fall over. Infections of small seedlings are often difficult to distinguish from Pythium rot without laboratory confirmation.

Thielaviopsis basicola causes a black root rot that may affect all or part of the root system. The fungus produces large dark spores on the root that form as a short column that breaks into several individual spores. These spores are diagnostic and can be easily seen under low power of a microscope.

Environmental conditions

Damping-off occurs in both cool and warm soils since the organisms that cause disease are active at different soil temperatures. Disease occurs in moist to wet soils. The optimum temperatures for disease vary: *Pythium aphanidermatum*, the most common species of *Pythium* in the low desert, is most active in wet, warm soils, and is most problematic in summer months, while other *Pythium* species may be active in cooler soils in the winter. *Rhizoctonia solani* causes damping-off most frequently in cool, moist soils. *Thielaviopsis basicola* is most active at cooler temperatures in wet to moist soils.

Disease

Damping-off is caused by several soilborne fungi or fungal-like organisms commonly found in soils that may or may not have been previously cultivated. None of these organisms needs a wound or natural opening to enter the plant, but wounding can increase the incidence of disease.

At a Glance

Damping off is caused by several different pathogens under different environmental conditions:

- Pythium damping-off—collapse of the seedling stem or a pre-emergence rot; blackened rotted roots on older seedlings; usually in warm, wet soils.
- Rhizoctonia damping-off—reddish brown to dark brown lesions on the stem or roots; in warm to cool soils.
- Thielaviopsis damping-off—black root rot of seedlings; plants may grow out of disease but remain stunted compared to healthy plants; usually in cool soils.

Prevent disease using good cultural practices: plant when temperatures are optimum for seedling growth; plant into soils that are moist but not wet and maintain uniform soil moisture; use vigorous seed and seedlings; plant at appropriate depth.

When environmental conditions are right and a susceptible host is present, *Pythium* produces motile spores that can infect a plant root within a few minutes. These spores germinate to produce hyphae, microscopic tubular filaments that are the "body" of the organism. The hyphae grow into the roots, killing plant tissue as they grow. *Pythium* also produces sexual spores in the roots or in the soil that are resistant to adverse environmental conditions such as drying or cold temperatures. They can survive in a dormant state for months or years. These spores germinate and produce hyphae in the presence of a susceptible host when there is plenty of moisture. The hyphae penetrate the host root and begin the infection process.

Rhizoctonia does not produce spores but grows on dead organic matter in the soil from which it can invade the roots and hypocotyls of susceptible hosts. Once the host tissue has died, *Rhizoctonia* can continue to live on the dead organic matter or may form survival structures from its hyphae called sclerotia that can remain in soils for a long time without a food source or moisture. Hyphae from germinating sclerotia infect host plants.

Thielaviopsis produces asexual spores that can survive in the soil for many years. When there is adequate soil moisture and cool soil temperatures, the spores germinate, probably in response to exudates from susceptible host roots, and produce hyphae that invade host plant roots.

Prevention/control

Cultural Practices

Host plant resistance to the pathogens that cause damping-off is not available. Therefore, cultural practices are extremely important for prevention and control. Seed beds should be irrigated carefully to avoid excessive soil moisture. Plants and seeds should be planted when environmental conditions are best for the most rapid growth of seedlings. Use only healthy transplants. When buying young transplants, look for healthy white roots, sturdy stems and good color. Put seeds and transplants at the appropriate depth since deep planting slows emergence or growth and encourages disease.

In low desert areas, wait until temperatures cool down in October and November to transplant winter flowers to avoid *Pythium* and *Rhizoctonia* damping-off. In high desert areas, where annual flowers and vegetables are planted in the spring, wait until days are warm enough for good plant growth to avoid infections of *Rhizoctonia* and *Thielaviopsis*. Healthy, fast-growing seedlings and soils that dry slightly between irrigations are the best prevention methods for damping-off.

Chemical Control

In infested soils, seed treatments may give some control. Look for treated seed from the distributor. Many seed companies offer the option of treated or non-treated seed. Seed is usually treated with metalaxyl for control of *Pythium* and with PCNB (pentachloronitrobenzene) or Chloroneb for control of *Rhizoctonia*. Seed treatments with myclobutanil are effective for control of *Thielaviopsis basicola*.

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AGVISE LABORATORIES

Soil Analysis by Agvise Laboratories
(http://www.agvise.com)
Northwood: (701) 587-6010
Benson: (320) 843-4109

SOIL TEST REPORT

FIELD ID N26
SAMPLE ID ___
FIELD NAME N26-111-73
COUNTY Hyde
TWP 111 RANGE 73
SECTION 26 QTR N ACRES 320
PREV. CROP Corn-Grain

N

W E

Date Sampled 03/07/2014 Date Received 03/13/2014 Date Reported 10/6/2014

Nutrient In The Soil			Interpretation
			VLow / Low / Med / High
Nitrate	0-6"	10 lb/ac	
	6-24"	12 lb/ac	****
	0-24"	22 lb/ac	
Phosphorus	Olsen	6 ppm	**********
Potassium		320 ppm	********************************
Chloride	0-24"	12 lb/ac	*****
Sulfur	0-6"	8 lb/ac	*******
	6-24"	18 lb/ac	***************
Boron		0.6 ppm	*********
Zinc		0.95 ppm	*******************
Iron		45.9 ppm	******************************
Manganese		22.4 ppm	******************************
Copper		0.98 ppm	**********************
Magnesium		572 ppm	******************************
Calcium		2688 ppm	******************************
Sodium		21 ppm	***
Org.Matter		4.7 %	*********************
Carbonate(CCE)		0.4 %	**
Sol. Salts	0-6"	0.24 mmho/cm	******
	6-24"	0.43 mmho/cm	**********

1st Crop Choice	
Corn-Grain	
YIELD GOAL	
120 BU	
SUGGESTED GUIDELINES	
University	
LB/ACRE	APPLICATION
N 120	
P_2O_5 50	Broadcast
	Band (2x2) *
K_2O 10	
Cl 0	
S 20	Broadcast
B 0	
Zn 0	
Fe 0	
Mn 0	
Cu 0	
Mg 0	
Lime 0	

Soil pH	Buffer pH	Cation Exchange Capacity	% Ca	% Mg	% K	% Na	% H
0-6" 6.1		15.1 meq	(65-75) 70.3	(15-20) 24.9	(1-7) 4.3	(0-5) 0.5	(0-5)
6-24" 7.4							

General Comments: Coarse Loams (CEC range = 11 to 20) (Medium)

Crop 1: * Caution: Seed Placed Fertilizer Can Cause Injury * Many crops may respond to a starter application of P & K even on high soil tests. Crop Removal: P2O5 = 48 K2O = 32 University guidelines will build P & K soil test levels to the medium range over many years.

Instructions:

Please use the Soil Test Report information provided to the left and also below to solve the 2 questions below.

Please use the products and prices in the list below to give the farm the fertilizer they need for the corn crop.

Fertilizer Products and Prices

11-52-0	$ 600	per ton
46-0-0	$ 500	per ton
21-0-0-24S	$ 400	per ton
0-0-60	$ 500	per ton

Questions 1 and 2 (25 points each):

Solve for: 1). The number of Pounds(lbs.) blended fertilizer they need per acre to grow 120 Bushels(Bu.)

Corn = ________ lbs./acre total

2). The number of Dollars($) of blended fertilizer they need per acre to grow 120 Bushels(Bu.)

Corn = $__________/acre total