Integrated strategies for management of charcoal rot caused by *Macrophomina phaseolina*

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Summary

Management of charcoal rot, caused by *Macrophomina phaseolina*, relies on the reduction of pathogen inoculum in the field. Besides the soil, *M. phaseolina* can survive in old strawberry crowns and serve as a source of inoculum for new healthy transplants. Our studies showed that charcoal rot can be managed when integrated approaches, such as a combination of cultural and chemical tools, are adopted. Among these approaches, application of fumigants at crop termination and at pre-planting under optimum conditions, the use of resistant cultivars, the adoption of white-striped plastic mulch, and removal or destruction of crop residue have been shown to reduce charcoal rot incidence in commercial farms under high disease pressure. Moreover, we determined that low rates of metam potassium (K-pam), commonly used by growers at crop termination, were not sufficient to significantly reduce *M. phaseolina* in strawberry crowns and that the full labeled rate should be used.

Methods

Impact of integrated management strategies on control of charcoal rot in commercial strawberry fields

During the 2018-19 season, we collaborated with three commercial strawberry growers in determining the efficacy of adopting integrated approaches to manage charcoal rot, such as the combination of optimum applications of fumigants at crop termination and pre-planting, the use of resistant cultivars, the adoption of white-striped plastics, and the removal or destruction of crop residue.

Farm 1: Five fumigant treatments were tested: 1 – K-pam Drip; 2 – K-pam MiniCoulter; 3- K-pam Drip + Kpam MiniCoulter; 4 – Pic60 + K-pam Drip; 5 – Pic80 + K-pam Drip; 6 – Pic100 + Kpam Drip. At the K-pam Drip area (1), plug plants from a California nursery of cultivars Sensation, Brilliance, and Radiance were planted. For all the other areas and also for the K-pam Drip area, Radiance (plug plants) from a North Carolina nursery was used. Soil was sampled at the end of the 2018-19 season, at the end of the pepper season before crop termination with Vapam, after crop termination with Vapam, before and after pre-plant fumigation, and at the end of the 2018-19 season. Disease incidence was evaluated monthly from November 2018 to February 2019.

Farm 2: Three areas were studied:
Area 1: crop termination with a burner; pre-plant fumigation with Kpam. Plants from a Canadian nursery from cultivars Winterstar, Radiance, Sensation, and Brilliance were used.
Area 2: crop termination with Vapam; pre-plant fumigation with Kpam. Some rows were left nontreated at pre-plant fumigation and other rows had silver striped plastic. Cultivars FL Beauty, Radiance, Sensation, and Winterstar from a California nursery were evaluated. Grower plants from a different Canadian nursery (Radiance) were also evaluated in all areas.
Area 3: no crop termination treatment; pre-plant fumigation with Paladin. Grower plants from the same Canadian nursery (Sensation).
Soil samples were collected at the end of the 2017-18 strawberry season, at the end of the cucurbit season (before crop termination), after crop termination with Vapam or use of the burner, before and after

pre-plant fumigation, monthly from November 2018 to February 2019, and at the end of the 2018-19 season.

Farm 3: Two areas were selected: Area 1 - crop termination with Vapam, flat-fumigation with Pic-80, and pre-plant fumigation with K-pam; and Area 2 - crop termination with Vapam and pre-plant fumigation with K-pam. At Area 2, crop residue (primarily strawberry crowns) was removed from 0.5 acre. Soil was sampled after crop termination with Vapam (end of the 2017-18 strawberry season), before flat-fumigation with Pic-80 (Area 1), before and after pre-plant fumigation with K-pam, and at the end of the 2018-19 season. Both areas were planted with cultivar Pilgrim and disease incidence was evaluated monthly from November 2018 to February 2019.

Rates of metam potassium (K-pam) to reduce *Macrophomina phaseolina* population

Different rates of metam potassium (K-pam) for the reduction of *M. phaseolina* inoculum in infected strawberry crowns were evaluated by using drip stakes to simulate drip injection of the fumigant (Figure 1). Strawberry crowns infected with *M. phaseolina* were buried in plastic-mulched, raised beds at 6 and 12 inches from the source of fumigant application and treated with 0, 10, 20, 40, 60 and 80 gpta of K-pam.

Figure 1. K-pam application using drip stakes to simulate drip application of the fumigant. Crowns infected with *Macrophomina phaseolina* were buried at 6 inches (yellow strings) or 12 inches (white strings) from the source of fumigant application (water bottle).

Results

Impact of integrated management strategies on control of charcoal rot in commercial strawberry fields

Most of the isolations from symptomatic plants in the three commercial fields confirmed *M. phaseolina* as the causal agent.

Farm 1: Application of K-Pam with the MiniCoulter and additional applications of different formulations of chloropicrin (Pic) on top of K-Pam drip had lower disease incidence than K-Pam alone through the drip. However, it is important to note that application of K-Pam on this farm was not ideal since K-Pam was injected for only one hour due to moist soil conditions (Table 1). Application of Vapam for crop termination reduced *Macrophomina* inoculum in the soil and in the crowns, however, it did not completely eliminate the pathogen and the population re-built over the summer to levels similar to prior crop termination (Table 2).

Farm 2: Results from these trials confirmed 'Florida Brilliance' as having good resistance to charcoal rot (Table 3). Although crop termination with a fumigant reduced the *M. phaseolina* population in the soil and crowns, it was not sufficient to reduce charcoal rot incidence since the population that survived fumigation built up over the summer (Tables 4 and 5). Even cultivars considered moderately resistant did not hold up well under the high disease pressure, when fumigants were not used (Figure 2).

Farm 3: Results from trials on this farm confirmed that fumigation for crop termination and pre-planting with Vapam and K-Pam, respectively, significantly reduced *M. phaseolina* in the crowns. However, under such high inoculum levels in the crop residue (crowns), even a significant reduction (1/2,000th of the initial inoculum, i.e. from 16,000 CFU/g to 8 CFU/g), was still not enough to provide complete control of charcoal rot (Tables 6 and 7). Nevertheless, charcoal rot incidence at the end of the season (20%) was significantly lower than incidence the previous season (~60%).

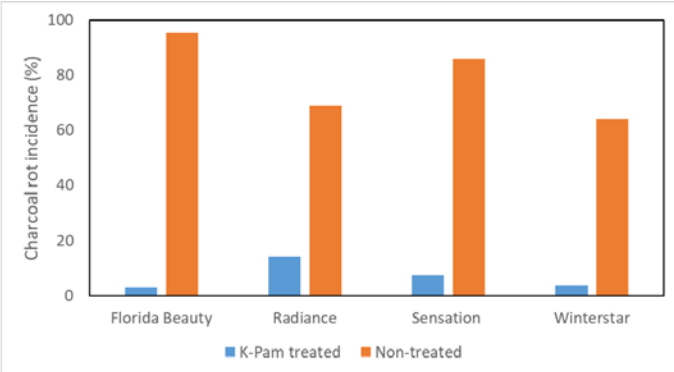

Figure 2. Charcoal rot incidence (%) on strawberry cultivars 'Florida Beauty', 'Radiance', 'Sensation', and 'Winterstar' planted in K-pam treated beds and non-fumigated beds.

Rates of metam potassium (K-pam) to reduce *Macrophomina phaseolina* population

In the crowns buried at 6 inches from the source of fumigant application (Figure 1 – yellow strings), higher doses of K-pam (60 and 80 gpta) reduced the population of *M. phaseolina* (Table 8). However, the pathogen was not controlled by any of the K-pam doses used when buried at 12 inches from the source of inoculum, i.e. edge of the beds (Figure 1 – white strings). These results demonstrate that the full labeled rate (62 gpta) of K-pam should be used in field fumigations, but the fumigant did not move to the edges of the beds.

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Table 1. Effect of products and cultivar selection in a commercial strawberry field (Farm 1) in Dover, FL on charcoal rot incidence.

Pre-plant fumigation treatment	Cultivar	Charcoal Rot Incidence (%)
K-pam Drip	Radiance (grower)	41.7
	Sensation	47.9
	Brilliance	36.9
	Radiance	41.7
Probability of a greater F value		0.8052
K-pam MiniCoulter	Radiance (grower)	18.9 bc[z]
K-pam MiniCoulter + Drip	Radiance (grower)	36.9 ab
K-pam Drip	Radiance (grower)	41.7 a
K-pam Drip + Pic60	Radiance (grower)	17.0 c
K-pam Drip + Pic80	Radiance (grower)	21.0 bc
K-pam Drip + Pic100	Radiance (grower)	13.5 c
Probability of a greater F value		0.0184

[z] Treatments followed by the same letter within a column are not significantly different according to Fisher's Protected LSD test (a = 0.05).

Table 2. Effect of products in a commercial strawberry field (Farm 1) in Dover, FL on natural populations of *Macrophomina phaseolina* in the soil.

Period	Soil	Crown
End of strawberry season	1.5	2488.9
End of pepper season/ Pre-crop termination	12.2	2170.6
Post crop termination with Vapam	0.2	535.3
Pre pre-planting fumigation with Kpam	9.6	2131.7
Post fumigation treatment		
K-pam Drip	2.0	-
K-pam MiniCoulter	0.2	-
K-pam MiniCoulter + Drip	0.5	-
K-pam Drip + Pic60	0.2	-
K-pam Drip + Pic80	0.0	-
K-pam Drip + Pic100	0.0	-
End of strawberry season		
K-pam Drip	1.2	-
K-pam MiniCoulter	1.3	-
K-pam MiniCoulter + Drip	0.8	-
K-pam Drip + Pic60	0.0	-
K-pam Drip + Pic80	0.1	-
K-pam Drip + Pic100	0.1	-

Table 3. Effect of cultivar selection in area 1 of a commercial strawberry field (Farm 2) in Plant City, FL on charcoal rot incidence.

Cultivar	Charcoal Rot Incidence (%)
Winterstar	26.1 a[z]
Radiance	19.7 ab
Sensation	11.9 bc
Brilliance	3.0 c

[z] Treatments followed by the same letter within a column are not significantly different according to Fisher's Protected LSD test (a = 0.05).

Table 4. Effect of integrated approaches in a commercial strawberry field (Farm 2) in Plant City, FL on charcoal rot incidence on 'Sensation' strawberry plants.

Area	Fumigant	Type of plastic	Charcoal Rot Incidence (%)
1	Burner/Kpam	black	11.9 b[z]
2	Vapam/--[y]	black	85.7 a
2	Vapam/Kapam	black	3.6 b
2	Vapam/Kapam	striped	2.5 b
3	--/Paladin	black	7.2 b

[z] Treatments followed by the same letter within a column are not significantly different according to Fisher's Protected LSD test (a = 0.05).
[y] -- = non-treated

Table 5. Effect of integrated approaches in a commercial strawberry field (Farm 2) in Plant City, FL on natural populations of *Macrophomina phaseolina* in the soil.

	M. phaseolina CFU/g					
Area/Period	**End of strawberry season**	**End of cucurbit season/ Pre-crop termination**	**Post crop termination with Vapam / Post burn**	**Pre pre-planting fumigation with Kpam**	**Post pre-planting fumigation**	**End of strawberry season**
		Soil				
Area 1	-	34.2	23.6	24.3	10.4	0.10
Area 2	-	26.8	1.8	14.1	-	-
Non-fumigated					17	22.18
K-pam					0.2	0.02
Area 3	8.1	-	-	-	-	0.02

Table 6. Effect of fumigant application in area 1 of a commercial strawberry field (Farm 3) in Plant City, FL on natural populations of *Macrophomina phaseolina* in the soil and strawberry crowns and on charcoal rot incidence.

	M. phaseolina CFU/g					
Sample	**Post-crop termination with Vapam**	**Pre-flat fumigation with Pic80**	**Post-flat fumigation with Pic80/ Pre pre-planting fumigation**	**Post pre-planting fumigation with Kpam**	**End of strawberry season**	**Charcoal Rot Incidence (%)**
Soil	0.8	2.2	0.0	0.1	0.7	19.2
Crown	16344.4	1158.3	-	8.3	-	

Table 7. Effect of fumigant application and crop residue removal in area 2 of a commercial strawberry field (Farm 3) in Plant City, FL on natural populations of *Macrophomina phaseolina* in the soil and strawberry crowns and on charcoal rot incidence.

Sample	*M. phaseolina* CFU/g				
	Post-crop termination with Vapam	**Pre pre-planting fumigation with Kpam**	**Post pre-planting fumigation with Kpam**	**End of strawberry season**	**Charcoal Rot Incidence (%)**
Crop residue removed					
Soil	0.1	1.3	0.1	6.8	15.2
Crop residue NOT removed					
Soil	0.8	0.7	0.2	0.9	14.0
Crown	28903.9	-	5.0	-	

Table 8. Efficacy of K-pam applied through drip stake to soil in a strawberry field at GCREC in Wimauma, FL in the 2018-19 strawberry season on crowns infected with *M. phaseolina* at different distances from the point of application

Treatments/Rate	*M. phaseolina* (CFU g^{-1} crown)		Pr > F[z]
	6 inches	12 inches	
NTC	1334.9 a	306.4 c[z]	0.0030
20 gpta	1380.3 a	612.3 abc	0.8614
40 gpta	168.1 b	865.0 ab	0.0013
60 gpta	**82.2 bc**	495.6 abc	0.0005
80 gpta	**16.2 c**	1010.4 a	<0.0001
Probability of a greater F value	<0.0001	0.0397	

[z] Treatments followed by the same letter within a column are not significantly different according to Fisher's Protected LSD test (α = 0.05).