Almond Fumigant Studies: Continued Research on Methyl Bromide Alternatives

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Problem and Significance: Methyl bromide, the fumigant that has been used historically for control of replant problems, has been banned in developed countries. Research over the past ten years has determined suitable fumigant alternatives to methyl bromide that provide similar, if not better, control of some of the biological replant problems. Since these trials have been established relatively recently, there is little long term data on the efficacy of methyl bromide alternatives for control of nematodes, Prunus replant disease, and soil borne diseases. Further research is needed in order to determine the rate of re-infestation of the soil by these pests and pathogens.

Fumigants are also facing increasing regulatory pressure. Limitations on use of fumigants can prevent use within replant situations. Identifications of alternative fumigants and fumigant alternatives are needed to maintain productivity within replanted orchards.

Objectives:

1. To continue the work of established fumigant plots for control of Prunus replant disease and plant pathogenic nematodes.
2. To continue the development of non-fumigant based control measures for almond replant disease and plant pathogenic nematodes within fumigant buffer zones.

Methods: This work will continue the efforts set forth by the USDA-ARS Pacific Area-wide Methyl Bromide Alternatives project which concluded in June of 2012. Multiple fumigant projects within Merced County were established over the past eight years. Projects initially focused on alternatives to methyl bromide and have shifted to identifying alternative fumigants and techniques to reduce emissions. Trials and treatments are described in Table 1.

Treatments within the trials will be monitored for tree growth, yield, and nematode control. Harvest data will be collected upon first harvest and continued through the fifth year, possibly longer. Trunk caliper measurements are made in the dormant period following the year of growth. Nematodes are sampled in mid-October by collecting soil 12 inch deep soil cores from within the tree's drip-line.

Table 1: Basic description of the fumigant trials established in Merced and Stanislaus counties (treated rate per acre).

Trial	Year Established	Objective	Fumigants and other treatments applied	Fumigant Methods
Ballico	2011	Methyl Bromide alternatives	Methyl Bromide, Telone® II, Chloropicrin	Broadcast and row-strip
Winton	2012	Determining alternative fumigants and application strategies	Telone® II, chloropicrin and combinations of these fumigants	Broadcast, row-strip and spot
Ballico Area	2015	Determining alternative fumigant application strategies to reduce emissions	C-35	Broadcast, row-strip and spot
Ballico Alternatives	2015	Determine the effectiveness of post-plant nematicides in managing replant problems	Telone® II, Movento® and Velum® One	Injection of post-plant products in irrigation or applied foliarly
Ballico Fumigant	2015	Identifying alternative fumigants to Telone® II	Telone® II, chloropicrin, Dominus, and varying mixtures	Row-strip
Stanislaus Rootstock	2015	Identify rootstocks that are more tolerant to replant conditions	C-35, five rootstocks	Row-strip
Winton Rootstock	2015	Identify rootstocks that are more tolerant to replant conditions	C-35, five rootstocks	Row-strip

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Methyl Bromide Alternative Study:

Ballico Trial (Est. 2011):

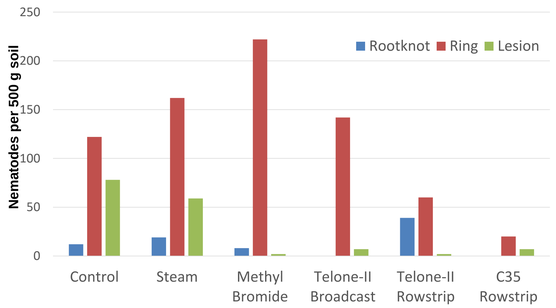

Figure 1: Nematode counts from various treatments taken after six years of growth at the Ballico trial. Sampling performed in Fall 2016.

Table 2: The effect of pre-plant treatments on the yield of replanted almonds at the Ballico trial for 2013-2016 and cumulatively. Treatments followed by * are significantly different from the control (p<0.05, Dunnett's). ⁺2017 experienced crop loss due to bacterial blast.

Ballico	Yield (Kernel lbs/acre)					
Treatment	2013	2014	2015	2016	2017⁺	Cumulative
Control	158.2	376.8	275.0	715.6	350	1875.7
Methyl Bromide	230.0	498.8	523.9*	863.6	605.7	2722*
Telone® II Row-strip	266.4*	652.1*	480.9*	1122.4*	527.4	3049.2*
Telone® II Broadcast	317.7*	764.6*	708.8*	1182.0*	758.4	3731.6*
C-35 Row-strip	258.1	525.6	460.0	830.0	403.7	2477.4*
Steam	138.1	357.4	206.3	618.8	172.6	1493.2

Fumigant Area Studies:

Ballico Trial (Est. 2015):

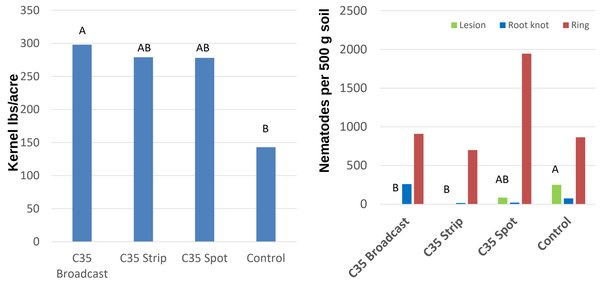

Figure 2: 2017 yield and 2016 nematode counts (sampling from fall of 2016) taken from various treatments at the Ballico trial. Treatments followed by different letters are statistically significant (p<0.05, Tukey's).

Winton Trial (Est. 2012):

Table 3: The effect of pre-plant treatments on the yield of replanted almonds at the Winton trial for 2014-2016 and cumulatively. Treatments followed by * are statistically significant (p<0.05, Dunnett's).

Winton	Yield (Kernel lbs/acre)			
Treatment	2014	2015	2016	Cumulative
Control	391.3	219.7	984.9	1595.9
Telone® II Broad	473.1	583.5*	1210.8	2267.3*
Telone® II Row-strip	441.4	537.3*	1304.3	2283.1*
C-35 Strip	531.3	560.3*	1231.4	2323.0*
C-35 Spot High	414.5	494.9*	1221.9	2131.3*
C-35 Spot Low	512.3	463.0*	1216.7	2192.1*
Chloropicrin Spot	493.2	378.3*	1171.9	2043.3*
Steam	349.2	237.8	959.1	1546.1

Rootstock and Fumigation Trials:

Table 5: The effect of C-35 row-strip pre-plant fumigation and unfumigated soil on the growth of five different rootstocks planted in soil previously planted to almonds and with the presence of plant parasitic nematodes. Treatments followed by different letters are statistically different, with treatments sharing letters not different (p<0.05, Tukey's).

Rootstock and Fumigation Treatment	Stanislaus County Trial (R. Duncan)		Merced County Trial (D. Doll)	
	2017 Yield (lbs/acre)	Relative % of Yield of the Fumigated Plot	2017 Yield (lbs/acre)	Relative % of Yield of the Fumigated Plot
Empyrean-1 Fumigated	672 A		347 A	
Empyrean-1 Control	629 AB	93	155 BC	45
Hansen 536 Fumigated	595 AB		216 ABC	
Hansen 536 Control	551 ABC	92	168 BC	78
Nemaguard Fumigated	454 CD		280 AB	
Nemaguard Control	345 DE	76	167 BC	60
Rootpac-R Fumigated	443 CD		234 ABC	
Rootpac-R Control	247 E	56	114 C	49
Viking Fumigated	511 BC		201 ABC	
Viking Control	438 CD	86	165 C	82

Telone® II and Fumigant Alternative Studies:

Ballico Trial (Est. 2015):

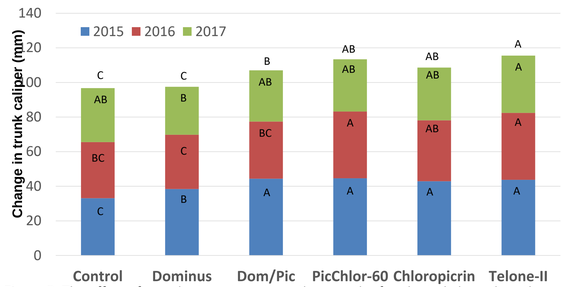

Figure 3: The effect of pre-plant treatments on the growth of replanted almonds at the Ballico trial for 2015-2017 and cumulatively. Annual growth is marked with different colors. Different letters indicate different statistical groupings (p<0.05, Tukey's). Shared letters indicate similar growth.

Table 4: The effect of pre-plant and post-plant treatments on the growth and yield of replanted almonds at the Ballico trial for 2015-2017 and cumulatively. Different letters indicate different statistical groupings (Tukey's, p<0.05). Shared letters indicate similar groupings.

Treatment	Change in Trunk Caliper (mm)				2017 Yield (lbs/acre)
	2015	2016	2017	Cumulative	
Telone® II & Movento® + Velum® One	41.4 A	36.4	59.0 A	136.8 A	241 A
Telone® II	41.7 A	34.9	58.8 A	135.4 A	224 AB
Movento® + Velum® One	31.2 B	36.8	55.1 A	123.1 B	203 AB
Control	33.6 B	36.0	46.8 B	116.4 B	169 B

Results and Discussion:

- Cumulative yields from all fumigant treatments were higher than the control at the Ballico trial (Table 2), with broadcast Telone® II treatment yielding the highest. Nematodes were present in all treatments at similar levels (Fig. 1).
- At the Winton trial, cumulative yields of all fumigation treatments were higher than the steam and control; spot fumigation yielded similarly to row-strip and broadcast methods (Table 3).
- Tree-spot treatments performed similarly to the row-strip and broadcast treatment at the 2015 Ballico trial (Fig. 2), but did not out-yield the control. Tree-spot treatments appear to be as effective as row-strip treatments and reduced fumigant usage by 25%.
- Fumigants containing Telone® II or chloropicrin outperformed the non-fumigated control or Dominus treatments (Fig. 3).
- Surprisingly, the Movento® and Velum® One combination outgrew the untreated control in 2017. This treatment, however, did not out-yield the untreated control (Table 4).
- All rootstocks exhibited growth suppression when planted in non-fumigated soils (Table 5). Results did vary between rootstocks.