MEMORANDUM

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SUBJECT: SIMULATION OF 1,3-DICHLOROPROPENE EMISSIONS FROM A BROADCAST APPLICATION WITH PARTIAL LOW PERMEABILITY FILM SURFACE COVER

Field fumigation methods (FFMs) are regulatory prescriptions of field management practices for the application of a fumigant, each of which is given a unique code ('FFM Codes', see CDPR 2017). For applications of 1,3-dichloropropene (1,3-D), the selection of an FFM by an applicator has implications for both buffer zone credits and the emissions weighting used under the township cap system (CDPR 2016). The FFMs available to an applicator may also vary with season (CDPR 2016), regional air quality concerns (3 CCR § 6448.1[d]), or a field's history of fumigation (3 CCR § 6448.1[c]). While an applicator may choose to go beyond the minimum requirements of an FFM, there is little incentive for this extra expense because no additional emission or buffer zone credits are given. Therefore, where the use of a new method is encouraged, it is ideally introduced as a new FFM and accompanied by its own emission estimates and buffer zone credits, if applicable.

This document describes HYDRUS simulation of a proposed application method (designated here as 'FFM 1250') that combines elements of 'totally impermeable film' (TIF) strip applications (FFM 1249) and untarped deep broadcast applications (FFM 1206). Such a method is being evaluated for potential use as an application method in orchard fumigations to determine if this method would satisfactorily mitigate emissions while reducing the high costs associated with broadcast TIF methods. Under the proposed application method, a field is fumigated as would be done in a broadcast application at a 45-cm (18") injection depth (all rows receiving fumigant), but with only alternate rows sealed with TIF. This differs from the existing TIF strip method in that both tarped and untarped rows are fumigated, rather than only tarped rows.

Methods

The simulation methods used here are essentially identical to those described by Brown (2019). In brief, HYDRUS 2D was used to simulate a modified TIF strip injection application across a series of 16 soil types collected by DPR staff from prepared fields within 24 h prior to fumigation (see Brown 2019 for a description of soil properties). Simulation results are output at 1-h intervals over 21 days, from which estimates of cumulative flux and period-averaged peak emissions can then be estimated.

In designing the simulation of the proposed method, I referenced Spurlock (2014), who describes the original simulation design of the strip configuration. He describes strip applications as commonly using 5 to 7 shanks at 51-61 cm spacing (20”-24”) with a typical row width of 335 cm (11’), each row being covered with a 396 cm (13’) wide tarp, and each end being tucked approximately 30 cm (12”) into the soil. Untreated rows of various widths (depending on orchard type) are then left between treated strips. Spurlock (2014) assumed a narrower untreated row width relative to treated row width, such that the area covered by TIF amounted to approximately 70% of the domain area (when considering the tarp ‘tuck’).

The present simulations relied on the original TIF strip domain design as a template; modifications were then implemented to meet the design requirements. These modifications consisted of (1) the insertion of additional solute injection points in the untarped row and (2) the widening of the untarped row to match the width of the tarped row. The widening of the untarped row width was considered necessary as—with the addition of fumigant—the width of the untarped row is now constrained by rig shank spacing. Like the original TIF strip application method, fumigation plugs were spaced evenly at 51 cm intervals (center-to-center) and centered at 45 cm depth across the entirety of the modeling domain (Figure 1). Separate simulations were performed with simulated tarp-cuts at 9 days (the current minimum) and 14 days.

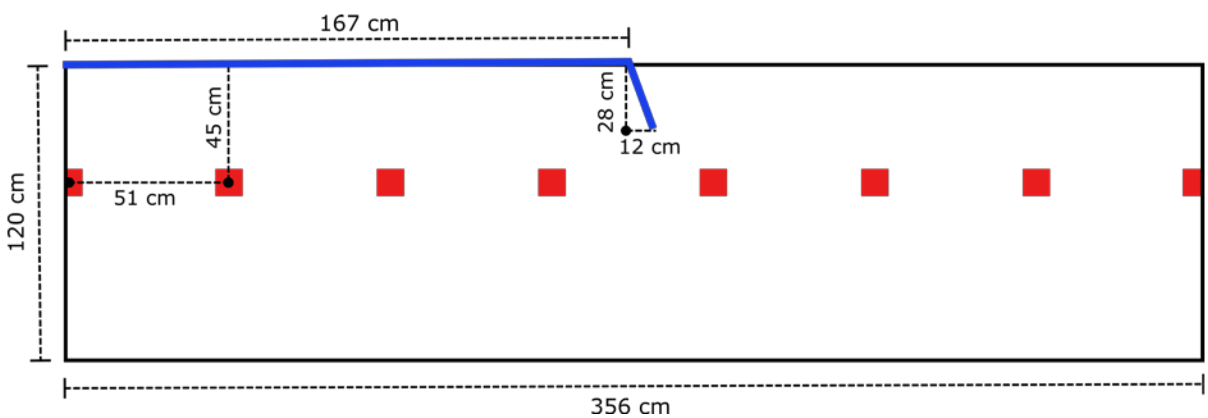

Figure 1. Schematic of the domain geometry used in simulations of the proposed ‘Broadcast TIF Strip’ application method. Fumigant plugs (red) are centered 45 cm below surface level and spaced at 51 cm intervals. A surface seal of TIF (blue) is tucked into the soil at the edges and covers approximately half of the domain width.

A separate series of simulations was performed to test the effect of row width on emissions while maintaining the ratio of tarped to untarped surface area (approximately 50:50). These simulations used a shortened domain length of 251 cm. The primary simulations (as shown in Figure 1) assume a tarp width of approximately 13 feet (392 cm), which is the standard roll width for broadcast tarp**.** The narrow domain assumes a tarp width of 9.8’ (118 cm), a non-standard width which is only evaluated for purposes of understanding the implications of row spacing. In practice, it is unlikely that anything other than a 13-foot width would be applied in a strip application due to this being the only standard (i.e., non-custom) size for broadcast and strip applications, and the increased material and labor costs associated with narrower bed-specific tarps (H. Ajwa, personal communication).

<u>Results</u>

Results from the simulations are summarized in Tables 1 and 2. Orchard applications are presently performed as either untarped, deep shank injections (FFM 1206) or as TIF strip applications (FFM 1249). The proposed TIF strip broadcast method yields emissions lower than those of FFM 1206 but higher than those of FFM 1249. Table 3 summarizes emission values for each of these three orchard methods, and a comparison of flux profiles with these methods is shown in Figure 2.

Unlike broadcast TIF methods, an extended holding period of 14 days had minimal effect on cumulative emissions, and no effect on peak emission values. Emission profiles (Figure 2) suggest that this is likely due to preferential transport through the untarped area of the soil surface prior to tarp-cut, resulting in peak flux values occurring in the first few days following application and resulting in a minimal ‘flush’ of fumigant emission at tarp-cut that would otherwise be mitigated with an extended holding time.

Negligible differences in peak and cumulative flux were observed on the basis of change in row spacing, under the condition of constant ratio between tarped and untarped area (Table A2). Should applicators vary the ratio of tarped-to-untarped row area, important differences in emissions will occur, with emission values approaching those of FFM 1206 (ER = 0.38) as the proportion of untarped area increases. It is an assumption of this analysis that such changes in proportion are unlikely to be common due to the need to adjust shank spacing with each pass, although it possible to envision edge cases where an applicator may fumigate two untarped rows for every tarped row. For this reason, it is recommended that the definition for FFM 1250 require (1) at least one tarped row for every one untarped row, (2) constant row width, and (3) a constant application rate between rows.

As observed in prior simulations, substantial variation in emissions is possible due to variation in soil conditions, specifically soil moisture. Use of a higher moisture minimum would be one method to reduce the potential for higher-than-expected emissions from the proposed method resulting from very dry soil. Using methods described by Kandelous and Brown (2019), a minimum moisture requirement of 50% of field capacity would be sufficient to mitigate average cumulative emissions to those similar to those in Tables 1 and 2, but with a substantially lower ceiling of emissions (Table A1).

Table 1. Summary of HYDRUS output for the simulated 'Broadcast TIF Strip' method with a 9 day holding period prior to tarpcut. Per CDPR convention, emission values have been normalized to a 100 lb/ac application rate.

Soil no.	ER	Peak 3h (ug m-2 s-1)	Peak 24h (ug m-2 s-1)	Peak 72h (ug m-2 s-1)
1	0.20	5.56	4.15	3.82
2	0.15	3.66	2.54	2.39
3	0.14	3.29	2.40	2.25
4	0.33	13.16	9.66	7.71
5	0.48	21.72	17.72	11.67
6	0.39	18.12	13.34	9.63
7	0.26	8.62	6.55	5.64
8	0.32	12.97	9.45	7.57
9	0.36	18.36	12.34	9.03
10	0.21	5.44	4.13	3.82
11	0.31	12.05	8.66	7.10
12	0.15	3.01	2.04	1.97
13	0.28	9.23	7.02	6.06
14	0.20	5.11	3.70	3.43
15	0.26	8.15	5.90	5.22
16	0.26	8.43	6.39	5.52
Mean (SD)	**0.27 (0.09)**	**9.80 (5.79)**	**7.25 (4.42)**	**5.80 (2.84)**

Table 2. Summary of HYDRUS output for the simulated 'Broadcast TIF Strip' method with a 14 day holding period prior to tarpcut. Emission values are virtually unchanged by the longer holding period, likely due to rapid loss of fumigant from the untarped area prior to tarpcut. Per CDPR convention, emission values have been normalized to a 100 lb/ac application rate.

Soil no.	ER	Peak 3h (ug m-2 s-1)	Peak 24h (ug m-2 s-1)	Peak 72h (ug m-2 s-1)
1	0.19	5.56	4.15	3.82
2	0.14	3.66	2.54	2.39
3	0.13	3.29	2.40	2.25
4	0.31	13.16	9.66	7.71
5	0.45	21.72	17.72	11.67
6	0.36	18.12	13.34	9.63
7	0.25	8.62	6.55	5.64
8	0.30	12.97	9.45	7.57
9	0.34	18.36	12.34	9.03
10	0.19	5.44	4.13	3.82
11	0.29	12.05	8.66	7.10
12	0.13	2.92	2.04	1.97
13	0.26	9.23	7.02	6.06
14	0.19	5.11	3.70	3.43
15	0.24	8.15	5.90	5.22
16	0.24	8.43	6.39	5.52
Mean (SD)	**0.25 (0.09)**	**9.80 (5.79)**	**7.25 (4.42)**	**5.80 (2.84)**

Table 3. Mean cumulative emission and peak flux values for three common orchard fumigation methods: FFM 1206 (untarped, 18” injection), FFM 1249 (TIF strip 18” injection), and the proposed method, tentatively FFM 1250 (TIF strip broadcast 18” injection). Emissions for FFM 1250 are predicted to be slightly higher than the mean of FFM 1206 and FFM 1249.

FFM	ER	Peak 3h (ug m-2 s-1)	Peak 24h (ug m-2 s-1)	Peak 72h (ug m-2 s-1)
1206	0.38 (0.13)	17.66 (10.46)	13.63 (8.46)	10.17 (4.99)
1249	0.13 (0.07)	8.08 (3.68)	3.11 (1.29)	2.06 (1.05)
1250	0.27 (0.09)	9.80 (5.79)	7.25 (4.42)	5.80 (2.84)

<u>References</u>

Brown, C. (2019). HYDRUS-simulated flux estimates of 1,3-dichloropropene maximum period-averaged flux and emission ratio for approved application methods. California Department of Pesticide Regulation, Sacramento, CA.

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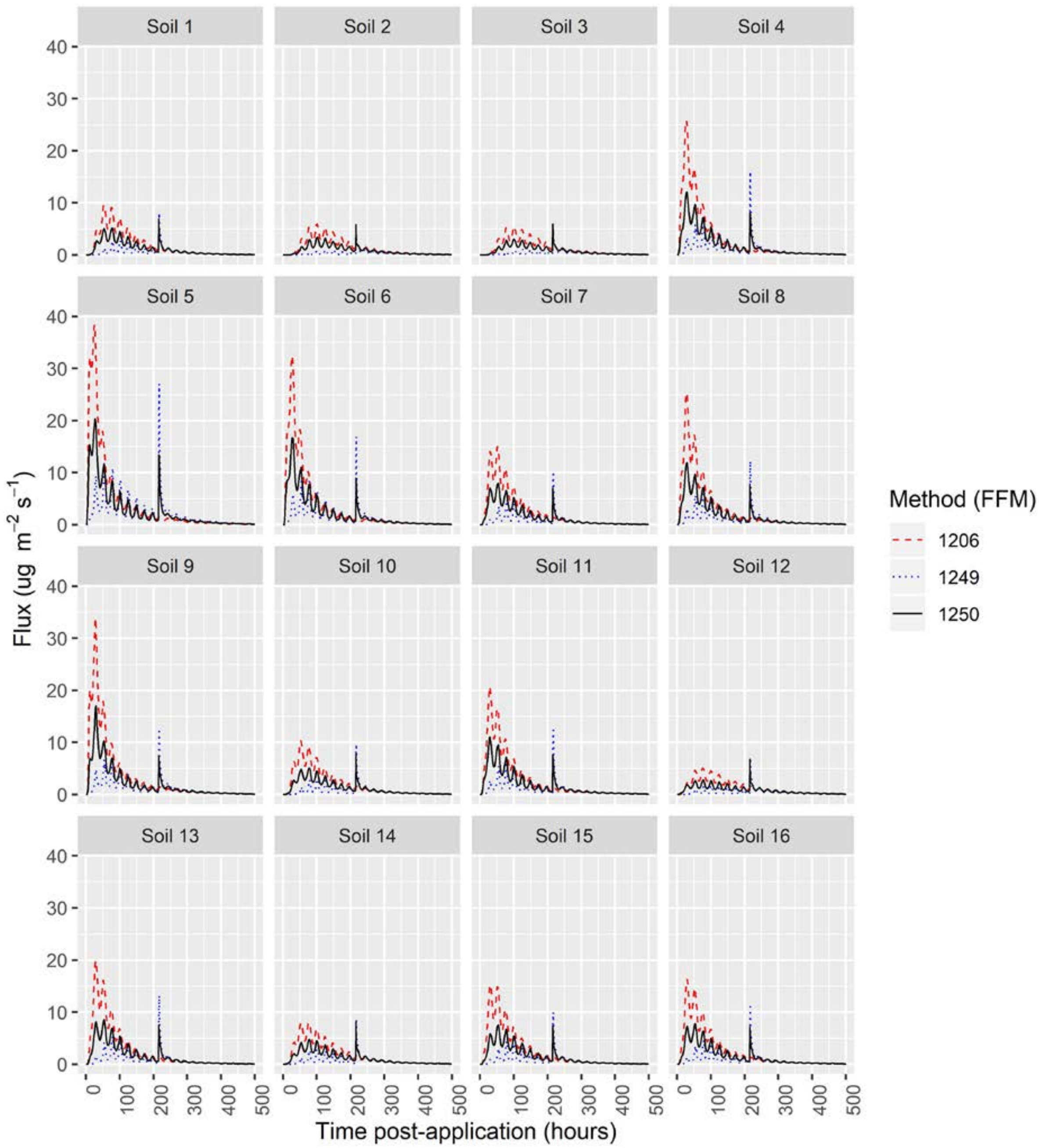

Figure 2. Time series of predicted 1,3-D flux for each set of soil conditions for FFM 1206 (red dashes), FFM 1249 (blue dots), and FFM 1250 (solid black). Flux profiles are based on a 9 day tarp holding period for FFM 1249 and 1250. See Brown (2019) for a description of each soil type.

Table A2. Summary of HYDRUS output for the simulated 'Broadcast TIF Strip' method with a 9 day holding period prior to tarpcut. The simulation uses simulated moisture conditions of 50% of field capacity, rather than moisture conditions based on measured field values as part of the CDPR soil variability study. Per CDPR convention, emission values have been normalized to a 100 lb/ac application rate.

Soil no.	ER	Peak 3h (ug m-2 s-1)	Peak 24h (ug m-2 s-1)	Peak 72h (ug m-2 s-1)
1	0.32	8.96	7.12	5.86
2	0.30	8.25	6.27	5.32
3	0.29	7.78	5.81	5.01
4	0.28	7.06	5.21	4.61
5	0.25	6.37	4.52	4.12
6	0.27	7.21	5.17	4.55
7	0.35	11.62	8.43	6.81
8	0.29	7.47	5.59	4.90
9	0.32	8.71	6.86	5.81
10	0.28	7.16	5.17	4.60
11	0.34	10.39	7.71	6.40
12	0.27	6.68	4.80	4.33
13	0.30	8.28	6.19	5.33
14	0.28	7.24	5.41	4.75
15	0.30	8.15	6.05	5.25
16	0.31	8.35	6.33	5.45
Mean (SD)	**0.25 (0.02)**	**8.11 (1.36)**	**6.04 (1.07)**	**5.19 (0.75)**

Table A2. Summary of HYDRUS output for the simulated 'Broadcast TIF Strip' method with a 9 day holding period and narrow row spacing. The ratio of tarped-to-untarped area matched that of other FFM 1250 simulations. The resulting values are nearly identical to those described in Table 1. The results suggest that row spacing is unimportant provided that the ratio of tarped-to-untarped area is held constant.

Soil no.	ER	Peak 3h (ug m-2 s-1)	Peak 24h (ug m-2 s-1)	Peak 72h (ug m-2 s-1)
1	0.20	5.52	4.13	3.76
2	0.15	3.58	2.49	2.33
3	0.14	3.33	2.30	2.19
4	0.33	13.05	9.59	7.69
5	0.49	21.76	17.70	11.72
6	0.39	18.07	13.29	9.64
7	0.26	8.56	6.50	5.60
8	0.32	12.89	9.41	7.57
9	0.37	18.38	12.29	9.04
10	0.21	5.41	4.11	3.77
11	0.31	11.93	8.61	7.08
12	0.15	2.94	2.00	1.93
13	0.28	9.19	6.96	6.02
14	0.20	5.04	3.65	3.39
15	0.26	8.06	5.83	5.18
16	0.26	8.40	6.36	5.49
Mean (SD)	**0.27 (0.10)**	**9.76 (5.80)**	**7.20 (4.43)**	**5.78 (2.87)**