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SUBJECT: COMPARING EMISSIONS FROM SIMULATED 18 INCH AND 24 INCH SHANK INJECTION TREATMENTS OF 1,3-DICHLOROPROPENE

Introduction

Reducing acute exposure to 1,3-dichloropropene (1,3-D) may be accomplished by three primary means: increased buffer zone distances, reduced use through lower application rates or acreage, or application method changes that lead to decreased emission fluxes. The last of these options—decreased emission fluxes—is most readily achieved through use of totally impermeable films, but the use of such films may not be not viable for certain use conditions, including orchard fumigations. Therefore, there is a need to determine whether sufficient reductions in emission flux can be achieved by other approaches, such as increased soil moisture or increased injection depth. This document evaluates the potential of increased injection depth to reduce emission fluxes.

Emissions have been long understood to decrease with application depth. A deeper injection point essentially permits a greater proportion of injected fumigant to be sorbed and degraded in the soil column, thereby reducing emissions. Johnson (2013) describes the prior assumption in the department of a linear relationship between injection depth and emissions, which was reasonably borne out by field studies. More recent developments in emissions modeling with HYDRUS (i.e., Kandelous 2019, Brown et al. 2019, Spurlock et al. 2013) show that the model can provide flux estimates similar to those provided by field studies, and can therefore be useful for prediction of flux from a variety of application scenarios. The HYDRUS model takes into account variation in soil conditions and can thereby provide a more nuanced estimation of the relationship between injection depth and emission flux as compared to a linear approach.

In this memo, I describe simulation results for an untarped 24” deep broadcast shank injection (tentatively coined Field Fumigation Method [FFM] 1212). The simulations are performed across 16 soil types based on measured soil properties obtained from prepared fields prior to fumigation. The results are then compared to prior simulation output for an untarped 18” deep broadcast shank injection—currently the standard fumigation approach in much of the Central

Valley—in order to quantify the relative emissions reduction of the 24” application. The results are additionally evaluated on a soil-by-soil basis to understand the interaction between soil conditions and application depth.

Methods

The methods used are essentially identical to those described in Brown (2019) and Brown et al. (2019). In brief, HYDRUS 2D was used to simulate a shank injection application across a series of 16 soil types collected by DPR staff from prepared fields within 24 h prior to fumigation. I based the layout of the untarped 24” deep broadcast scenario off the pre-existing layout for FFM 1206 (untarped 18” deep broadcast). An initial plug of fumigant was centered at 24” below the soil surface, rather than 18”. Other aspects of the simulation domain, including material distribution and initial temperature distribution, were unchanged. Fumigant physicochemical properties are the same as those described in Brown (2019).

Results

Results from the 24” simulation are summarized in Table 1. Results from the 18” simulation, performed as part of Brown (2019), are summarized in Table 2 for convenience. Table 3 summarizes the relative decline in emissions when opting for a 24” injection in place of an 18” injection. On average, the simulations predict a 39% decline in cumulative emissions, a 53% decline in peak 72-hour emissions, and a 59% decline in both 24-hour and 3-hour emissions. Figure 1 compares flux time series of 18” and 24” injection depths for each soil type and indicates a delay in the timing of peak flux under some soil conditions.

While both cumulative and peak emissions declined with increased injection depth, the extent of reduction varied with soil type, and soil moisture conditions especially. When increasing injection depth from 18” to 24” (45 cm to 61 cm), the additional 6” of depth occurs in the deepest—and generally wettest—of the 3 material layers used in our HYDRUS simulations (0-10 cm, 10-30 cm, and 30-120 cm depths). The deepest soil layer resultantly comprises a greater proportion of the distance between the injection point and the soil surface at the 24” injection depth as compared to the 18” injection depth (50% vs. 33%, respectively), effectively increasing the average soil moisture above the injection point. Therefore, the decline in emissions is due to both increased depth and higher effective soil moisture.

Figure 2 summarizes the relationship between decline in emissions and volumetric soil water content of each soil, averaged between 0-24” depth, indicating a strong correlation between average soil moisture and the relative percent reduction in emissions. At the extremes, the soil with greatest moisture (soil # 12) saw an 80% decline in cumulative emissions with the move to a 24” depth, whereas the driest soil (soil # 5) saw just a 15% decrease. Similarly, ER declined greatly for soils with relatively low ER under FFM 1206 (e.g., ER for soil 12 declined from 0.20

to 0.04—an extremely low value), whereas ER declined only modestly for soils with high ER under FFM 1206 (e.g., ER for soil 5 declined from 0.63 to 0.54—still very high).

Table 1. Results of simulated 24" shank injection including proportion of initial fumigant emitted (emission ratio, 'ER'), peak 3 hour flux, peak 24 h flux, and peak 72 h flux. Soil conditions are based on field-measured values. Fluxes are based on 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	0.15	3.55	2.67	2.54
2	0.08	1.60	1.18	1.15
3	0.08	1.55	1.16	1.12
4	0.35	11.42	9.26	7.87
5	0.54	24.29	18.76	13.83
6	0.43	16.92	13.37	10.68
7	0.24	6.60	5.01	4.59
8	0.34	11.55	8.89	7.61
9	0.44	18.91	13.93	10.87
10	0.16	3.65	2.83	2.68
11	0.31	10.26	7.79	6.77
12	0.04	0.59	0.45	0.44
13	0.26	7.77	6.04	5.42
14	0.13	2.60	1.98	1.90
15	0.22	6.09	4.59	4.23
16	0.26	7.45	5.76	5.19
Mean (SD)	**0.25 (0.14)**	**8.43 (6.84)**	**6.48 (5.27)**	**5.43 (3.94)**

Table 2. Results of simulated 18" shank injection. Soil conditions are based on field-measured values. See Brown (2019) for additional details.

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	0.29	9.50	7.09	6.30
2	0.22	5.85	4.16	3.91
3	0.20	5.41	3.93	3.68
4	0.48	25.21	19.56	14.01
5	0.63	37.71	32.59	19.86

Soil no.	ER	Peak 3h (ug m-2 s-1)	Peak 24h (ug m-2 s-1)	Peak 72h (ug m-2 s-1)
6	0.54	31.99	24.54	16.47
7	0.38	14.62	11.60	9.62
8	0.47	25.09	18.31	13.43
9	0.54	32.61	24.14	16.26
10	0.31	10.21	7.71	6.79
11	0.43	20.60	15.37	11.87
12	0.20	4.98	3.75	3.53
13	0.42	19.79	14.77	11.51
14	0.28	7.97	6.25	5.70
15	0.38	14.97	11.92	9.81
16	0.38	16.03	12.36	9.97
Mean (SD)	**0.38 (0.13)**	**17.66 (10.46)**	**13.63 (8.46)**	**10.17 (4.99)**

Table 3. Relative decline in emissions of 24” deep injection vs. 18” deep injection

Soil no.	ER	Peak 3h	Peak 24h	Peak 72h
1	-46%	-63%	-62%	-60%
2	-61%	-73%	-72%	-71%
3	-60%	-71%	-71%	-70%
4	-28%	-55%	-53%	-44%
5	-15%	-36%	-42%	-30%
6	-20%	-47%	-46%	-35%
7	-37%	-55%	-57%	-52%
8	-27%	-54%	-51%	-43%
9	-18%	-42%	-42%	-33%
10	-47%	-64%	-63%	-60%
11	-27%	-50%	-49%	-43%
12	-80%	-88%	-88%	-88%
13	-37%	-61%	-59%	-53%
14	-54%	-67%	-68%	-67%
15	-41%	-59%	-61%	-57%
16	-33%	-54%	-53%	-48%
Mean (SD)	**-39% (18%)**	**-59% (13%)**	**-59% (12%)**	**-53% (16%)**

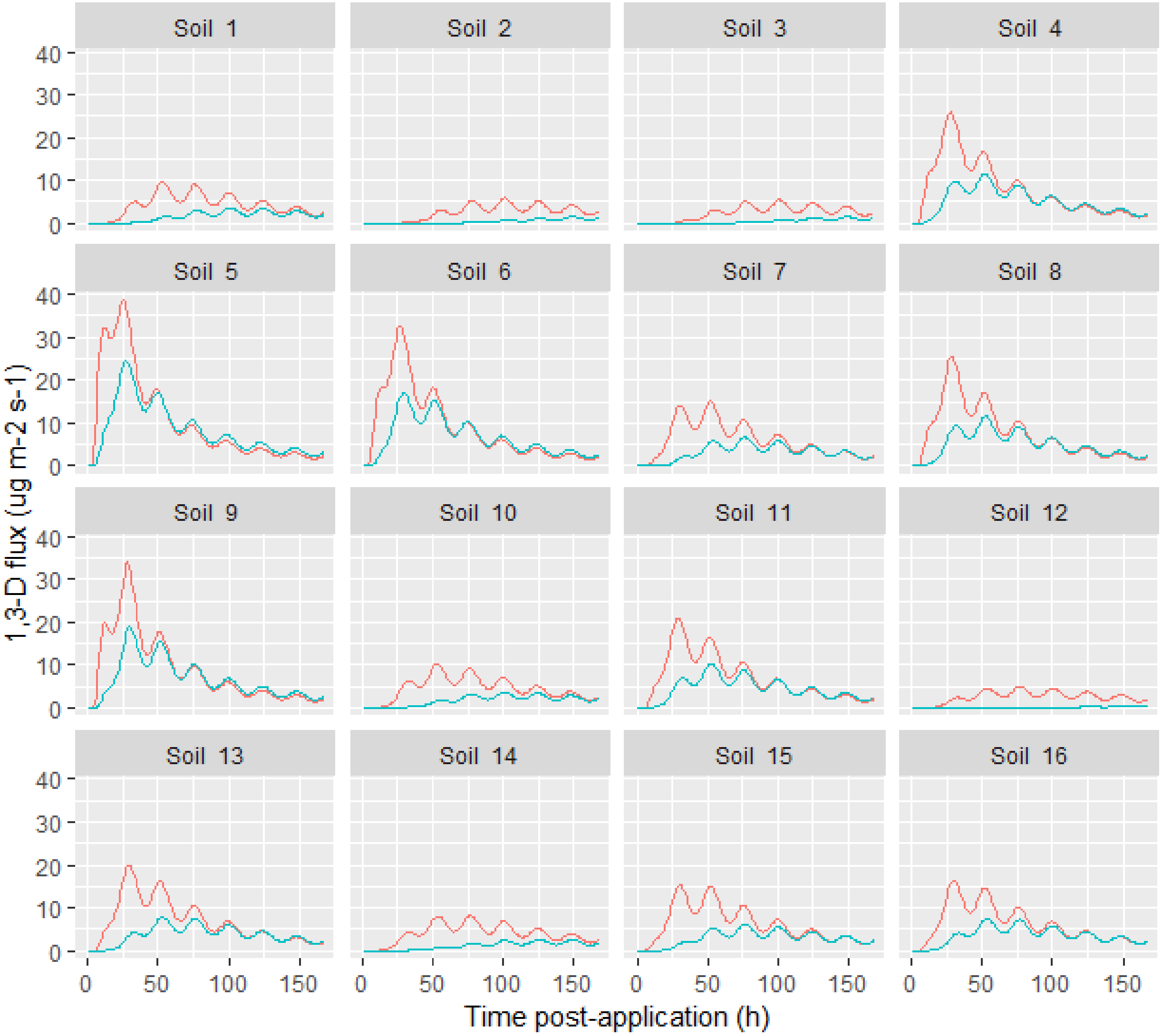

Figure 1. Comparison of simulated hourly flux from 24” deep (blue) and 18” deep (red) untarped broadcast shank injection presented over a 7 day period. A deeper injection reduces peak flux and sometimes delays the timing of peak flux relative to the 18” injection.

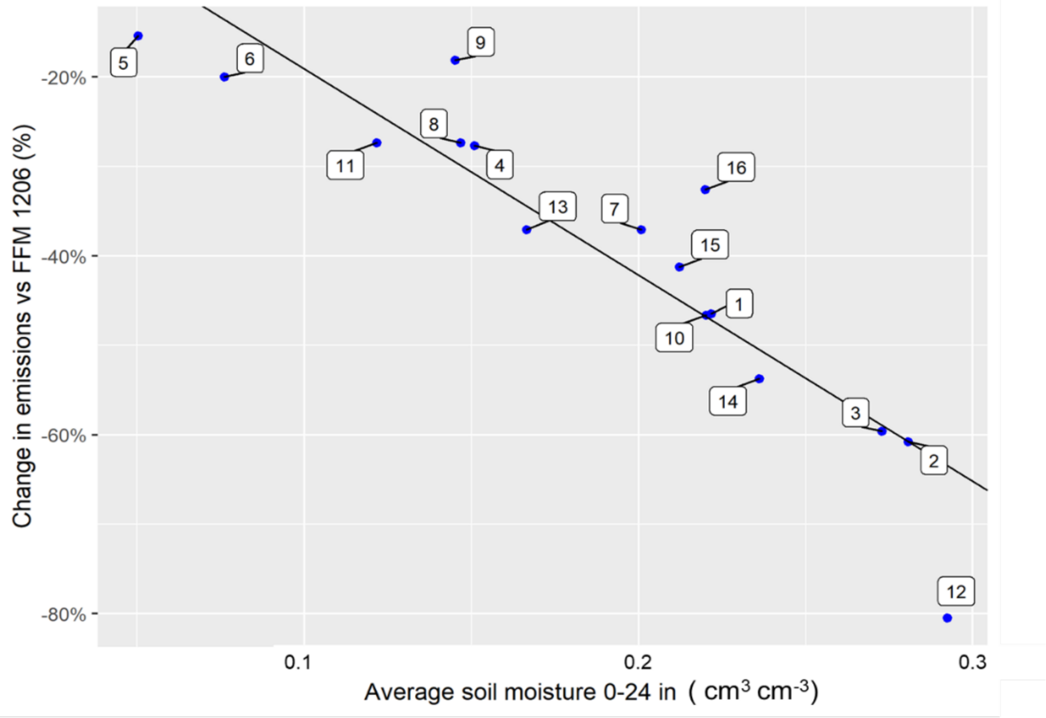

Figure 2. A strong correlation is observed between average volumetric soil water content in the top 24” of soil and the relative reduction in emissions when changing from 18” to 24” deep shank injection. Each point is labeled with its soil number (see tables 1-3). The observation suggests that an increase in injection depth is most effective at higher soil water contents.

Discussion

The work here describes HYDRUS predictions of emissions from a method for which little high-quality field data is available, and the few examples of sub-18” injection emissions data in the literature provide conflicting results regarding the effectiveness of deeper applications. One such case describes the design and performance of a specialized shank which simultaneously injects fumigant at 18” and 24” depths, while multiple ‘wings’ welded to the shank body are purposed to close the shank trace and slow the upward movement of fumigant (McKenry et al. 2003, Gao et al. 2009). Such a design would be expected to reduce emissions relative to a standard 18” depth injection due both to the shank trace closure and the lower point of injection, but emissions data repeatedly indicated a slight increase in emissions from the method (Gao et al. 2009). Qin et al. (2008) speculates that the lack of reduction may be attributed to systematic undersampling of low-emission regions of the treatment rows due to the flux chambers being too narrow to fully span the width of the treatment rows (which were ~20% wider than the control rows), or alternatively a design issue inherent to the shank itself. Another factor contributing to the lack of emissions reduction may have been the dry soil conditions of the study, reported to be between 5.1-6.6% by volume in the top meter of soil (Qin et al. 2008), which would fall near the low end of soil moisture observed as part of the DPR soil variability study (Figure 2).

Gao et al. (2018) reports 1,3-D emissions estimates from 18” and 25.5” shank injection treatments in an orchard replant scenario. Flux time series graphs show emission reductions in the range of 30-60% following use of a 25.5” injection as compared to a 18” injection—consistent with the estimates of the HYDRUS modeling here—but the reliance of the study on passive sampling chambers means that these are very rough approximations. Heavy rains and high reported soil moisture conditions may have also led to a greater reduction in cumulative emissions than would normally be expected (following from the observations in Figure 2).

HYDRUS simulations and field data together suggest that a move to a 24” injection depth be paired with an increase to the minimum allowable soil moisture. A 24” deep injection method will most likely be used in the pre-plant fumigation of orchards and other deep-rooted perennial crops. Experience among DPR staff suggests that fields with a history of deep-rooted crops, such as orchards, may be particularly dry down to depths of 3-4 ft. Growers have little incentive to raise field soil moisture above current label minimums due to the expense of irrigation and because it is understood to reduce fumigant efficacy. However, figure 2 suggests that a 24” injection method will provide relatively little benefit over an 18” injection (in terms of emissions reduction) unless the field is sufficiently irrigated prior to fumigation.

A report by Kandelous and Brown (2019) describes a HYDRUS method to estimate the ‘field capacity’ of soils sampled as part of CDPR’s soil variability study. Using these methods, exploratory simulations suggest that a minimum moisture requirement of 50% of field capacity would be sufficient to mitigate average cumulative emissions to those similar to those in Table 1, but with a substantially lower ceiling of emissions (Table A1). A decrease to 40% field capacity conditions (Table A2) yields emission estimates much higher than the averages in Table 1 and would not be appropriate. Therefore, a minimum soil moisture content of 50% in the region above a 24” shank injection would be appropriate in ensuring the effectiveness of the deeper injection while greatly reducing the ceiling of potential high emissions.

Conclusions

A move towards 24” injection depth could lead to substantial 1,3-D emission reductions. On average, the simulations predict a 39% decline in cumulative emissions and a greater than 50% decline in several measures of peak emissions. The effectiveness of the approach relies heavily on there being sufficient soil moisture in the region above the injection point to slow the upward movement of fumigant through the soil profile; without the presence of such moisture, reductions in cumulative emission are estimated to be as little as 15%. Importantly, the largest emission reductions are observed in moist soils that already emit relatively little at shallower injection points, while the drier and more problematic ‘high-emitting’ soils see only marginal reduction with the increased injection depth. Due to the potential for this method to be primarily used in soil conditions near the lower limit of existing soil moisture requirements, it is strongly recommended that this method be paired with increased minimum soil moisture requirements in the region above the injection point for effective mitigation. A minimum soil moisture of 50% of field capacity is suggested as one way to achieve similar mean cumulative emissions while greatly improving the predictability of emissions under the proposed method.

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Appendix

Table A1. Results of simulated 24” shank injection including proportion of initial fumigant emitted (emission ratio, ‘ER’), peak 3 hour flux, peak 24 h flux, and peak 72 h flux. Soil moisture conditions are fixed at 50% of field capacity. Fluxes are based on 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	0.26	7.65	5.90	5.29
2	0.24	6.74	5.08	4.63
3	0.22	6.31	4.72	4.33
4	0.22	6.01	4.57	4.20
5	0.19	4.72	3.52	3.29
6	0.20	5.54	4.08	3.76
7	0.31	10.88	7.99	6.93
8	0.23	6.14	4.68	4.30
9	0.27	7.83	6.10	5.48
10	0.21	5.57	4.27	3.95
11	0.29	9.08	6.78	6.00
12	0.21	5.66	4.22	3.89
13	0.25	7.09	5.54	5.00
14	0.22	5.85	4.44	4.10
15	0.25	7.12	5.40	4.90
16	0.26	7.44	5.73	5.16
Mean (SD)	**0.24 (0.03)**	**6.85 (1.53)**	**5.19 (1.14)**	**4.70 (0.93)**

Table A2. Results of simulated 24” shank injection including proportion of initial fumigant emitted (emission ratio, ‘ER’), peak 3 hour flux, peak 24 h flux, and peak 72 h flux. Soil moisture conditions are fixed at 40% of field capacity. Fluxes are based on 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	0.34	12.09	9.20	7.82
2	0.32	11.01	8.21	7.09
3	0.31	10.52	7.82	6.78
4	0.31	10.34	7.81	6.78
5	0.28	8.36	6.26	5.60
6	0.29	9.52	6.99	6.15
7	0.40	14.47	11.67	9.51
8	0.32	10.25	7.80	6.78
9	0.36	12.00	9.46	8.02
10	0.30	9.32	7.15	6.29
11	0.37	13.14	10.19	8.53
12	0.30	9.94	7.37	6.44
13	0.34	11.75	8.99	7.65
14	0.31	9.78	7.42	6.49
15	0.33	11.54	8.66	7.41
16	0.35	12.07	9.46	8.00
Mean (SD)	**0.33 (0.03)**	**11.00 (1.56)**	**8.40 (1.38)**	**7.21 (1.00)**