MODELING METHYL BROMIDE PERFORMANCE IN PLASTIC-MULCHED, BEDDED VEGETABLE PRODUCTION

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Methyl Bromide (MBr), a broad-spectrum pesticide, is utilized heavily as a very effective agricultural fumigant during vegetable and fruit production in Florida, California, and Hawaii. Newly revised MBr budget presented by Yvon-Lewis and Butler (1997) estimates that sinks (206 Gg y^{-1}) greatly exceed the sources (137 Gg y^{-1}). Plastic-covered soil bed systems are widely used in the southeastern United States for vegetable and fruit production. The physical dynamics of water and heat transport beneath plastic-mulched soil surfaces are quite complex. Temperature increases at the plastic mulch during the daytime by as much as 15 to 20 ^{o}C due to solar radiation are not uncommon (Ham and Kluitenberg, 1994). Modeling MBr fate and transport is needed to provide improved insight of system dynamics with regard to atmospheric emissions resulting from MBr fumigation. The model can be used to provide guidelines for the best management practices. The objective of this research was to investigate important major processes influencing MBr fate and transport including volatilization and degradation in fumigated soil beds, investigate the effect of non-isothermal and variably saturated soil conditions, evaluate the effectiveness of the current management technique-i.e., plastic-mulching of soil beds-in minimizing MBr emission from fumigated soil beds to the atmosphere, and using the computer model, examine alternative management methods for decreasing MBr emission during commercial use of soil fumigation.

The model used in this investigation represents many improvements over earlier efforts (Hemwall, 1959; Mignard and Benet, 1989; Rolston and Glauz, 1982; and Siebering and Leistra, 1979). The model includes coupled transient flows of both heat and water based upon Philip-deVries theory. Realistic plastic-mulch boundary conditions are described thoroughly by inclusion of optical properties of the plastic mulch in the energy balance at the soil/atmospheric interface. This model provides opportunity to consider the effect of improved temperature estimates upon estimates of MBr fate and transport (both in the liquid and gaseous phases).

Modeling investigations (synthetic simulations) of the fate and transport of MBr fumigant were conducted to obtain insight into the system dynamics for MBr fumigation of soils. Commonly used computer models that simulate the fate and transport of MBr utilize overly simplified assumption that: gaseous diffusive transport in air-filled soil pores under isothermal conditions with the effects of transient liquid-water flow neglected. The new computer model simulations here utilize an assumption that was more realistic of actual field conditions; i.e., non-isothermal soil conditions that fluctuate diurnally due to net solar radiation, thus altering vapor and liquid water flow as well as MBr diffusion.

Arredondo Fine Sand (loamy, siliceous, hyperthermic Grossarenic Paleudults), a coarse-textured soil commonly found in north central Florida, was used for the modeling investigation. The data for properties of the soil profile used are presented in Table 1 and Table 2. A spatial profile discretization of the cross-sectional soil bed resulted in 2782 elements with 1474 nodes (Fig. 1). Bed symmetry was assumed, so that only a half-section of the soil bed was considered for simulations. No flow boundary conditions on the left- and right-hand sides (AF and DE) were defined for heat, water, and solutes transport. The A through F boundary represents a vertical symmetry line through the middle of a soil bed. The lower boundary (F-E) was designated as a zero thermal gradient with gravitational water flow. The factors considered in the design of simulations included: effect of variable water saturation in the soil bed, effect of variable temperature regime in the soil bed, depth of fumigant injection (33 and 66 cm), and effect of irrigation. For solute transport, both convective (in the liquid phase) and diffusive (both in the aqueous liquid and gaseous phases) transport were allowed at the bottom (FE), with the assumption that solute leaving the lower boundary is lost from the flow domain (i.e., there is no return flow). The emission loss of MBr to the atmosphere (A-B-B-C) was described through diffusive flux, assuming a 1-cm boundary layer and zero concentration on the atmospheric side of the boundary layer.

Specific observations made from the model simulations include:

- An improved method to determine diffusion coefficients for MBr diffusion through plastic mulch under field conditions is needed. Use of lab-measured data for field simulations under predicted MBr emission losses through the plastic mulch which is in direct contradiction to reported field studies from the scientific literature.
- Non-isothermal soil conditions were found to be especially important to chemical transport in plastic-mulched soil beds, particularly in cases where highly volatile chemicals like MBr are used for soil fumigation.
- A wetter soil profile retained more MBr than a drier one, due to partitioning into water. Substantial reductions (approximately 23-36 % depending on injection depth over 3 day period) in MBr emission losses to the atmosphere were observed due to higher soil moisture content.
- Deeper injection (66 cm) of MBr fumigant provided less (approximately 10 and 23 % in dry and wet soil, respectively) emission losses to the atmosphere, irrespective of soil wetness, than a shallow injection zone (33 cm).
- For a sandy soil, dousing of water on the soil bed immediately after injection and before placing the plastic mulch was shown to slightly decrease MBr emission losses to the atmosphere. Dousing of finer- textured soil would be expected to provide more effective control of MBr emissions.

The analysis of soil-bed fumigation with MBr revealed modeling tool in providing insight of system dynamics of fumigation process. Application of validated numerical models in such analysis not only supplements field and laboratory investigations, but also provides a useful alternative practices to many field managers.

Table 1. Physical properties for 5 distinct horizons of a profile of Arredondo fine sandy soil .

Soil Layer	Sand (%)	Silt (%)	Clay (%)	OC† (%)	BD‡ ($g\ cm^{-3}$)	K_{sat} § ($cm\ hr^{-1}$)
Ap	91.9	3.3	4.8	0.83	1.52	6.2
E1	92.0	3.3	4.7	0.28	1.54	16.7
E2	91.4	3.0	5.6	0.14	1.52	15.1
Bt1	86.0	3.7	10.3	0.11	1.56	6.4
Bt2	75.2	3.0	21.8	0.20	1.57	2.4

† OC- Organic Carbon,
‡ BD- Bulk Density,
§ K_{sat}- Saturated Conductivity

Table 2. Parameter values for 5 distinct horizons of a profile of Arredondo fine sand soil.

Soil Layer	$\mu_{L,1}$ † (hr^{-1})	$K_{d,1}$ ‡ ($cm^{-3}\ g^{-1}$)	$K_{d,2}$ †† ($cm^{-3}\ g^{-1}$)	van Genuchten Parameters			
				α (cm^{-1})	m	θ_s	θ_r
Ap	0.014	0.1826	0	0.0225	2.124	0.43	0.03
E1	0.014	0.0616	0	0.0216	2.762	0.42	0.04
E2	0.014	0.0308	0	0.0271	2.626	0.43	0.04
Bt1	0.014	0.0242	0	0.0211	2.091	0.41	0.06
Bt2	0.014	0.0440	0	0.0307	1.557	0.41	0.13

†- hydrolysis rate coefficient for MBr,
‡- soil sorption coefficient for MBr, and
††- soil sorption coefficient for bromide ion.

Figure 1. Schematic of the discretized simulation domain of the soil bed. A-F are soil layers