UPDATE ON THE PHASE-OUT OF METHYL BROMIDE IN THE AUSTRALIAN STRAWBERRY INDUSTRY

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The strawberry industry in Australia currently relies on soil fumigation to manage soil-borne pathogens, weeds, and pests. The strawberry fruit sector phased-out methyl bromide (MB) in 2006 by adopting substitute fumigants such as chloropicrin (Pic), mixtures of 1,3-dichloropropene (1,3-D) and Pic, and metam sodium (MS). Since 2005, however, most of the strawberry nursery sector in Australia has applied annually to the UN for critical-use exemptions (CUEs) to continue use of MB/Pic. This is because research has shown that registered substitute fumigants are not as efficacious as MB/Pic in controlling soil-borne pathogens. In addition, substitute fumigants have regularly caused phytotoxicity in strawberry nursery crops and yield losses of up to 40%. This is related to the high organic matter (5-10%) and clay content (>50%) of soils where most of the nurseries are located. These factors combined with low soil temperatures at fumigation have contributed to long retention times of substitute fumigants in soil (>12 weeks), and phytotoxicity in strawberry nursery crops (Mattner et al., 2014).

This paper reviews changes that have occurred in diseases caused by soil-borne pathogens since the phase-out of MB in the fruit sector, and current research on substitute fumigants and soil disinfestation techniques in the nursery sector in Australia.

Increase in Soil-borne Diseases in the Fruit Sector

Since the phase-out of MB, soil-borne diseases caused by *Macrophomina phaseolina* (charcoal rot) and *Fusarium* spp. (Fusarium wilt) have increased in importance in the strawberry fruit sector in Australia (Fang et al., 2011; Hutton et al., 2013). For example, *M. phaseolina* was first isolated in strawberry plants grown in soils treated with 1,3-D/Pic in the State of Victoria in 2006 (Hutton et al., 2013). In 2017, an extensive survey was conducted in the strawberry fruit and nursery sectors in Victoria. Soil and strawberry plant samples were taken from 211 sites across 106 farms (94% of farms in Victoria). DNA concentrations of *M. phaseolina* were measured in soil samples using qPCR, and fungal pathogens isolated from plant samples using cultural techniques. Soils at 75% of the sites sampled were fumigated with Pic, 1,3-D/Pic or MS, while soils at 15% of sites were not fumigated. Soils sampled in the nursery sector (10% of all sites sampled) were treated with MB/Pic under a CUE. Results showed that *M. phaseolina* was present in soil or plants at 80% of farms growing strawberry fruit, in all districts in Victoria. This represents an exponential increase in the incidence of charcoal rot in strawberry plants at farms in Victoria, since previous surveys (Figure 1). The average incidence of charcoal rot in plants in the fruit sector in Victoria was 18%. *M. phaseolina* was not detected, however, in soil or in plants in the nursery sector, where MB/Pic is still used.

To address the charcoal rot issue, our research is evaluating different application techniques (e.g. barrier films, co-application of fumigants) for registered substitute fumigants (e.g. Pic, 1,3-D/Pic) and the effectiveness of non-registered fumigants (e.g. ethanedinitrile (EDN) and dimethyl disulfide (DMDS)/Pic) for controlling *M. phaseolina*.

Research on Phase-out of MB in the Nursery Sector

The most critical issue for the phase-out of MB in the nursery sector is control of soil-borne pathogens. Our research showed that registered substitute fumigants do not control pathogens to equivalent levels as MB/Pic at soil depths of 30-40 cm (Figure 2a). Pathogens surviving at greater depths recolonized soil at shallower depths (i.e. 0-10 cm). By harvest (9 months after fumigation), concentrations of pathogens in soils treated with substitute fumigants were equivalent to those in untreated soil (Figure 2b). Inadequate control of soil-borne pathogens with the substitute fumigants represents a significant risk of litigation for nursery growers. Current research is therefore evaluating different application techniques for substitute fumigants to improve pathogen control at greater soil depths (e.g. deeper injection, co-application of different fumigants, and co-application with biofumigation). In addition, research is analyzing the economics and efficacy of thermal disinfestation methods of soil, such as microwave and steam.

Recent research in the nursery sector has also considered ways to minimize the risk of crop phytotoxicity when using substitute fumigants. Results showed that decreasing the concentration of 1,3-D in mixtures of 1,3-D/Pic (i.e. 20:80 formulations) reduced the persistence of 1,3-D in soil, and the risk of crop phytotoxicity (Figure 3). EDN and DMDS/Pic have showed no evidence of causing crop phytotoxicity in trials in strawberry nurseries, but these products are not yet registered in Australia. In the future, it is likely that 1,3-D/Pic (20:80), EDN, and/or DMDS/Pic will form important substitute fumigants for nursery growers to manage the risk of crop phytotoxicity.

Most substitute fumigants do not provide adequate levels of weed control in the nursery sector when applied on their own. Recent research has evaluated co-application of pre- and post-emergent herbicides with different substitute fumigants. Results showed that fumigation with key substitutes, such as 1,3-D/Pic (20:80), followed by application of the herbicide isoxaben at planting, and then fortnightly application of the post-emergent herbicides phenmedipham and fluazifop-p, controlled weeds to equivalent levels as MB/Pic, without reducing crop yield (Figure 4). In the future, it is likely that herbicides will form an important component of weed management in strawberry nurseries.

Conclusions

Charcoal rot has become a significant disease in the strawberry fruit sector since the use of MB was phased-out in Australia. Most of the strawberry nursery sector in Australia has continued to use MB under CUEs, but it is acknowledged that such exemptions are unlikely to be granted for extended periods in the future. Current research in the nursery sector is focused on improving pathogen control with substitute fumigants to expedite phase-out of MB.

References

Fang et al. (2011) Severity of crown and root disease of strawberry and associated fungal and oomycete pathogens in Western Australia. Aust. Pl. Path. 40:109-119.

Hutton et al. (2013) Macrophomina phaseolina and its association with strawberry crown rot in Australia. Int. J Fruit Sci. 13:149-155.

Mattner et al. (2014) Critical challenges for the phase out of methyl bromide in the Australian strawberry industry. Acta Hortic. 1044: 367-374.

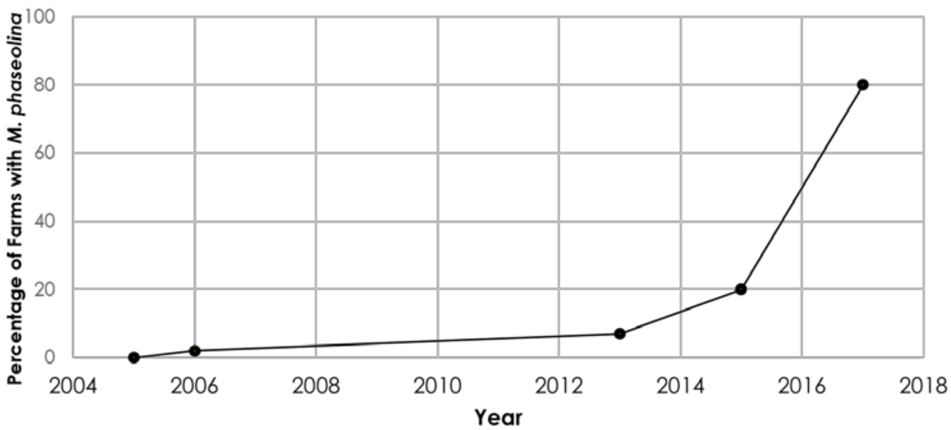

Figure 1. Percentage of strawberry fruit farms in Victoria, Australia with plants affected by charcoal rot caused by *Macrophomina phaseolina*. MB was phased-out in the strawberry fruit sector in Victoria in 2006.

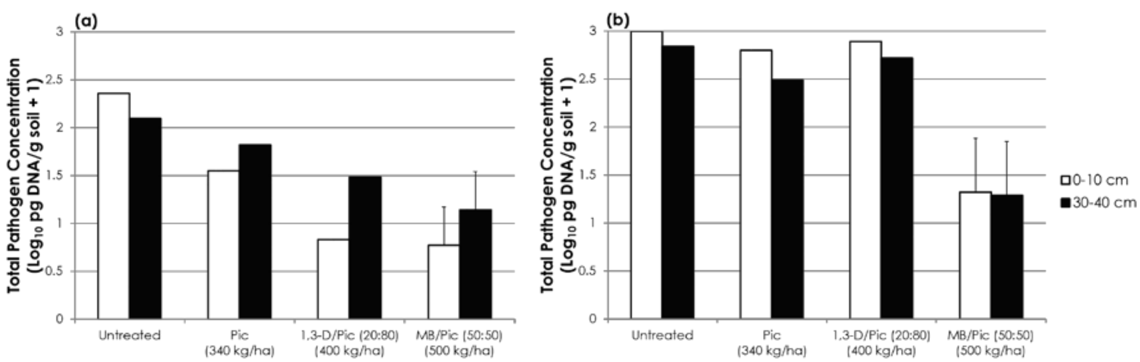

Figure 2. Total pathogen concentration in soil at two depths following treatment with various fumigants in a trial in the strawberry nursery sector in Victoria, Australia. Soil samples were taken at (a) planting (6 weeks after fumigation) and (b) harvest (9 months after fumigation). Pathogens measured included *Pythium* spp. Clades I & F, *Verticillium dahliae*, *Meliodogyne hapla*, and *Pratylenchus penetrans*. Error bars represent the LSDs where p = 0.05.

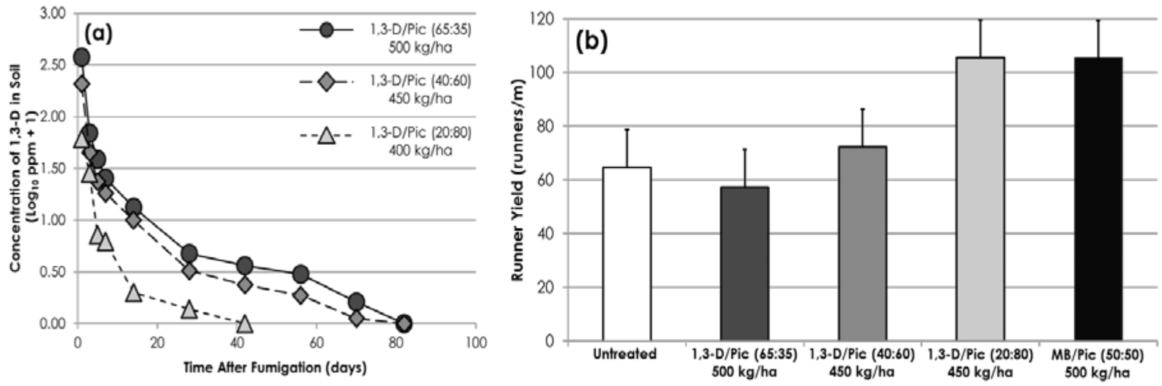

Figure 3. (a) Concentration of 1,3-D in soil over time following fumigation with different formulations of 1,3-D/Pic, and (b) strawberry runner yields (cv. Gaviota) in a trial in the strawberry nursery sector in Victoria, Australia. Strawberry mother plants were planted in the trial 42 days after fumigation. Error bars represent the LSD, where p = 0.05.

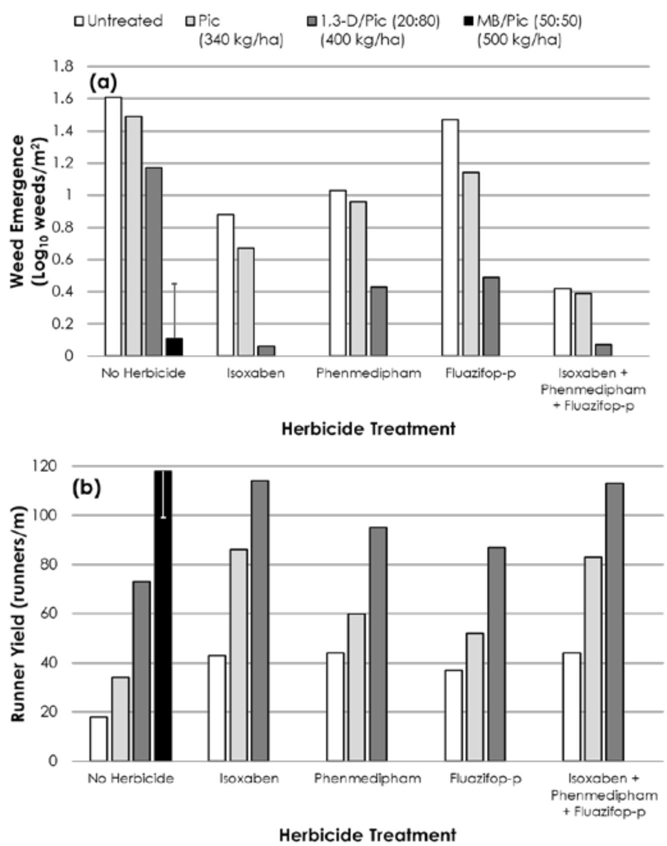

Figure 4. (a) Weed emergence and (b) runner yields (cv. San Andreas) in soils treated with different combinations of fumigants and pre- and post-emergent herbicides in a trial in the strawberry nursery sector in Victoria, Australia. Isoxaben was applied at a rate of 333 g/ha immediately following planting. Phenmedipham and fluazifop-p were applied fortnightly through the growing season at rates of 5.5 and 1.65 L/ha, respectively. Error bars represent the LSDs where p = 0.05.