Planting at the right time after fumigation saves money

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- Planting runners or plugs too early into soil that still contains fumigant residues can kill or reduce the vigour and yield of strawberry plants
- Growers need an accurate and instantaneous method for measuring fumigants in soil to predict when it is safe to plant their crop
- VSICA Research has trialled a colorimetric test to measure fumigant levels in soils on 30 farms in the Yarra Valley
- Without the fumigant detection tests, growers at 55% of the trial sites would have planted into soils containing concentrations of fumigants with the potential to cause phytotoxicity in their crops

Summary

The Victorian Strawberry Industry Development Committee (VSIDC) have funded research by VSICA Research to develop tests for measuring fumigants in soil so that growers know when it is safe to plant their crops. Researchers field-tested colorimetric tubes that instantaneously detect fumigants in soil. Results showed a strong relationship where the greater the concentration of fumigants still in the soil at planting, the lower the strawberry fruit yield and revenue over the season. Planting into soil that contained low concentrations of fumigant residues in autumn/winter affected strawberry yields and revenue more than when planting in summer. Results showed there were only slight differences in the susceptibility of different strawberry varieties or planting material to the presence of low concentrations of fumigant residues at planting. The use of the colorimetric method has already prevented growers from planting into soil containing fumigant residues at over 30 sites across Victoria. The VSIDC and VSICA Research will work together to commercialise the test for growers.

Soil Fumigation and Crop Phytotoxicity

Soil fumigation is an effective practice used by many strawberry growers to control weeds and pathogens that cause disease, like charcoal rot and crown rot. In addition, fumigation causes an 'increased growth response' in strawberry crops that stimulates fruit yields by up to 30%, even when there are few weeds or pathogens in the soil. This response is due to the short-lived changes in soil biology and chemistry caused by fumigation that favour plant growth.

One of the challenges for growers with soil fumigation is knowing when they can safely plant after treatment. Planting runners or plugs too early into soil that still contains fumigant residues can kill or reduce the vigour and yield of strawberry plants (this condition is called fumigant phytotoxicity). Common non-lethal symptoms of fumigant phytotoxicity in strawberry are red margins and yellowing on the emerging leaves of plants, plant stunting (Figure 1), and new roots emerging from the crown of the plant above the soil level.

Part of the difficulty for growers is that fumigant labels usually indicate variable plant-back periods (the time between fumigation and planting) for strawberry, ranging from 7 days to longer than 35 days. This is because there are so many factors that influence how long fumigant residues remain in soil after treatment, including fumigant type and formulation, application rate, soil temperature and moisture, organic matter, clay content and others.

Compounding this, nearly all strawberry growers in Victoria that fumigate soils recently transitioned from the use of mulch made from traditional plastic (low density polyethylene, LDPE) to totally impermeable films (TIFs). LDPE mulches do not retain fumigant gases in the soil very well, whereas TIFs are impermeable and seal them in the soil for long periods. The adoption of TIF dramatically increased the control of soil-borne diseases, like charcoal rot, and minimised the emissions of gaseous fumigants to the atmosphere. However, the longer residual times of fumigants under TIF may have contributed to incidences of phytotoxicity in strawberry in Victoria because growers are unsure of how long to increase their plant-back times (Figure 1).

Shortfalls with traditional tests for predicting when it is safe to plant after fumigation

Most fumigant labels recommend that growers conduct a seed germination test before planting their crop to determine if there are phytotoxic levels of fumigants in the soil.

There are several versions of the test, but a common one involves collecting a small sample of treated soil in a gas-tight jar and then germinating lettuce or cress seed on the soil in the jar.

These seed species are chosen because they are highly susceptible to fumigant residues. A jar containing a similar soil that is not fumigated should be included in the test as a control.

The concept is that if the seeds in the treated soil germinate at the same rate as those in the control, then fumigant residues in the soil should be below phytotoxic levels, and it is safe to plant your crop (Figure 2).

Figure 1. Stunting of strawberry plants in the field caused by fumigant phytotoxicity
Photo credit: VSICA Research

Figure 2. Set up of a seed germination test to predict when it is safe to plant after fumigation. Left jar contains fumigated soil and has suppressed the germination of lettuce, right jar contains untreated 'control' soil.
Photo credit VSICA Research

Although the method is simple, the test takes 2-7 days to complete to allow adequate time for seed germination and growth. Also, our research showed there are several variables that can influence the results of the test, including:

- How much soil is placed in the jar relative to its volume (too little soil and fumigant residues may be too low to affect germination; too much soil can cause anaerobic conditions in the jar and lower seed germination)
- The volume of water added to the jar to germinate seeds (too much water can cause anaerobic conditions in the jar and lower seed germination; too little can slow germination)
- When you measure germination (early germination is more sensitive to fumigant residues than later germination, Table 1)

We conducted a replicated field experiment in the Yarra Valley, Victoria in autumn where we fumigated strawberry beds with 1,3-dichloropropene / chloropicrin (1,3-D/Pic, 20:80) at 40 g/m^2 under TIF film. We planted strawberry plugs (var. *Albion*) into the soil at regular intervals, starting at two weeks after treatment.

We conducted lettuce germination tests and measured the concentration of fumigants in the soil each time we planted the strawberry crop. The results from the seed germination test varied according to the parameter we used to measure lettuce growth (Table 1). For example, measuring the height of the germinated seedlings after 7 days, was much more sensitive to presence of fumigant residues in soil than seed germination. We found that another important symptom in lettuce seedlings that predicted phytotoxicity was burnt root tips, which can be seen by using a hand lens.

Starting from October, we picked fruit from the experiment 2-3 times per week through the season and calculated revenue using weekly wholesale prices from the Melbourne market (FreshLogic, Hawthorne). Unexpectedly, using the seed germination test to predict when it was safe to plant the strawberry crop resulted in a reduction in fruit yield of up to 30%, and loss in revenue of up to $1.66 per plant, depending on the parameter of lettuce growth we measured (Table 1).

Overall, our experiment showed that conducting and interpreting seed germination tests can be difficult and unreliable, and that getting it wrong can cause significant economic losses. Instead, growers need an accurate and instantaneous method for measuring fumigants in soil to predict when it is safe to plant their crop.

Table 1. The impact of using seed germination tests to predict when it is safe to plant after fumigation with 1,3-dichloropropene/chloropicrin on strawberry yield and revenue (var. *Albion*). Different parameters of seedling growth measured in the germination test predicted different safe threshold concentrations of 1,3-dichloropropene for planting. These results highlight the difficulty in interpreting seed germination tests for predicting when it is safe to plant after fumigation.

Parameter of lettuce growth measured in the germination test	Concentration (µg/ml) of 1,3-D in soil when germination test and parameter predicted it was safe to plant	Yield loss (%) of strawberry fruit when planted at the 1,3-D concentration predicted by the germination test	Revenue loss ($/plant) from strawberry fruit when planted at the 1,3-D concentration predicted by the germination test
Germination (7 days)	10	29.8	1.66
Germination (2 days)	7	15.1	0.85
Incidence (%) of roots with burnt tips (2 days)	5	8.8	0.49
Average height of 10 seedlings (7 days)	1	1.2	0.07

Real-time method for predicting when it is safe to plant strawberries after fumigation

We tested colorimetric tubes as a method for detecting fumigant residues in soil in the field. The tubes contain reagents bound on a particulate matrix that react with target fumigant gases to produce a colour change, proportional to the concentration in the sample (Figure 3). In the method we attached the tubes to a brass probe inserted into the soil and drew set volumes of soil air through the tubes. The method gave a concentration reading within 30 seconds and was highly specific to the fumigant being measured. There are different types of colorimetric tubes for different fumigants, including 1,3-dichloropropene (1,3-D), chloropicrin (Pic), methyl iodide, methyl isothiocyanate, and others.

It is important to note that all fumigants have the potential to cause phytotoxicity in strawberry crops if residual concentrations are too high at planting.

In the laboratory, we found that the concentration of fumigants measured in soil with the colorimetric tubes was highly correlated ($r > 0.95$) with those determined by sensitive laboratory methods (gas chromatography/mass spectrometry).

We conducted two experiments in the Yarra Valley, Victoria to test the usefulness of the tubes for fumigant detection in the field. One experiment was set up in autumn with different varieties of freshly dug runners or plug plants (var. *Albion*, *Cabrillo*, *Monterey*), and the other was conducted in summer with different varieties of cold-stored (frigo) runners or plugs (var. *Tamara*, *Albion*, *Cabrillo*, *Monterey*).

Starting from 2 weeks after treatment with 1,3-D/Pic under TIF, we planted strawberries into plots at regular intervals and measured the concentration of fumigants in the soil using the colorimetric tubes at each planting. We had three replicates of each treatment and measured fruit yield and revenue through the season.

Results showed that strawberry yield declined as the concentration of fumigant in soil at planting increased (e.g., Figure 4). We modelled the data using logistic functions for each variety and planting material, which fitted the raw data well ($r^2 = 0.84$ to 0.91). Using this data, we developed risk profiles for yield and revenue loss for planting into soil containing different concentrations of fumigants (e.g., Figure 5). Soils where no fumigant residues were detected represented the lowest risk for developing symptoms of phytotoxicity. However, results also showed that some varieties were slightly more tolerant of low concentrations of fumigant residues than others (e.g., *Cabrillo* was more tolerant of small concentrations of 1,3-D in the soil than *Monterey*). Also, transplants were more susceptible to phytotoxicity from low concentrations of fumigants in the soil when planted in autumn under cooler temperatures and higher soil moistures, than when planted in summer.

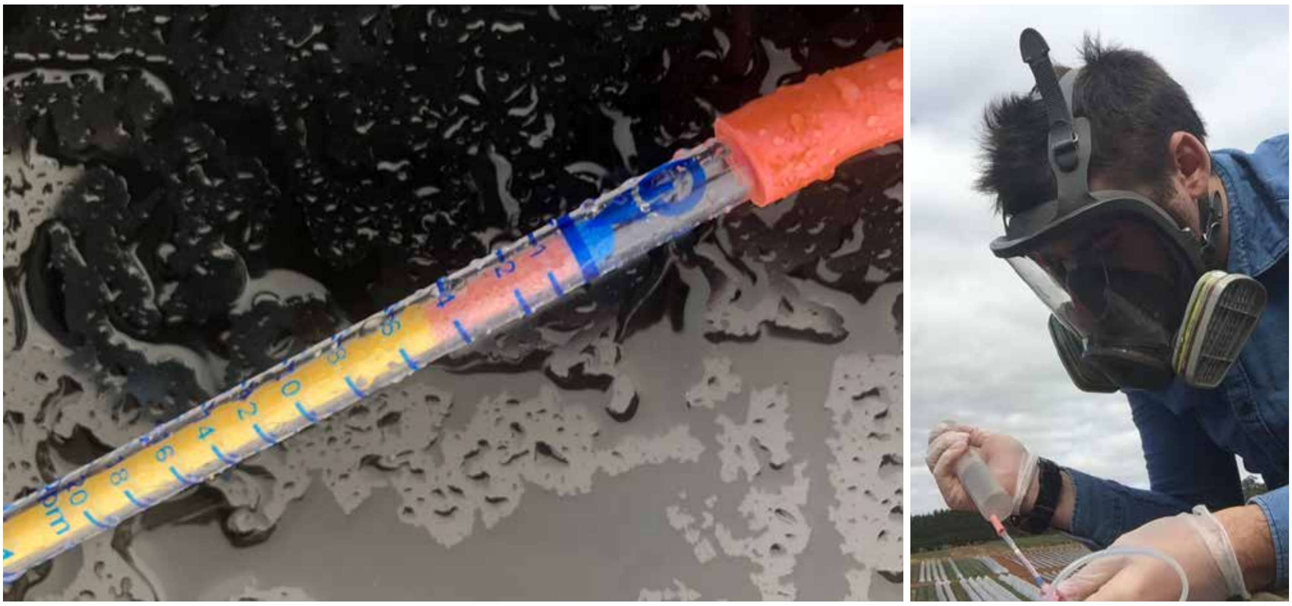

Figure 3. Colorimetric tubes contain reagents that change colour proportional to the amount of fumigant in the soil. (L) tubes for the fumigant 1,3-dichloropropene change from yellow to pink and (R) measuring fumigant residues in soil before planting using colorimetric tubes. Photo credit VSICA Research

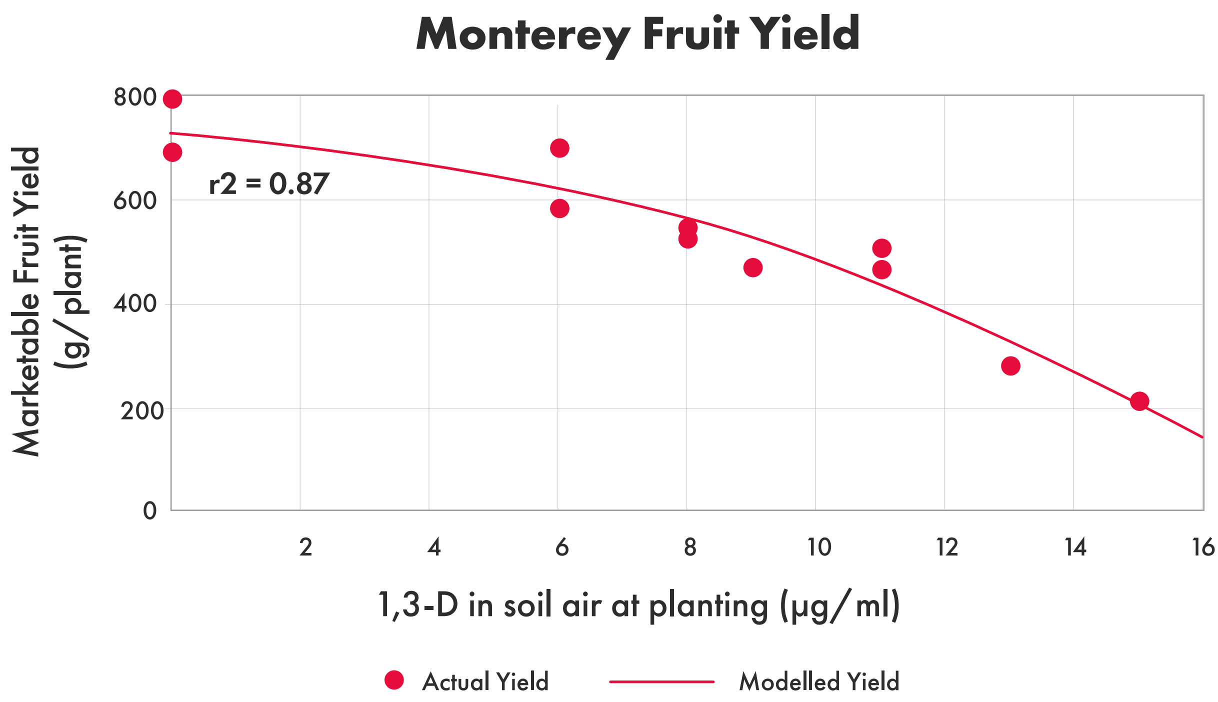

Figure 4. Yield response of strawberry (var. *Monterey*) to the presence of different concentrations of the fumigant 1,3-dichloropropene in soil at planting, in a field experiment conducted in the Yarra Valley, Victoria. Concentrations of 1,3-dichloropropene were measured using an in-field colorimetric method.

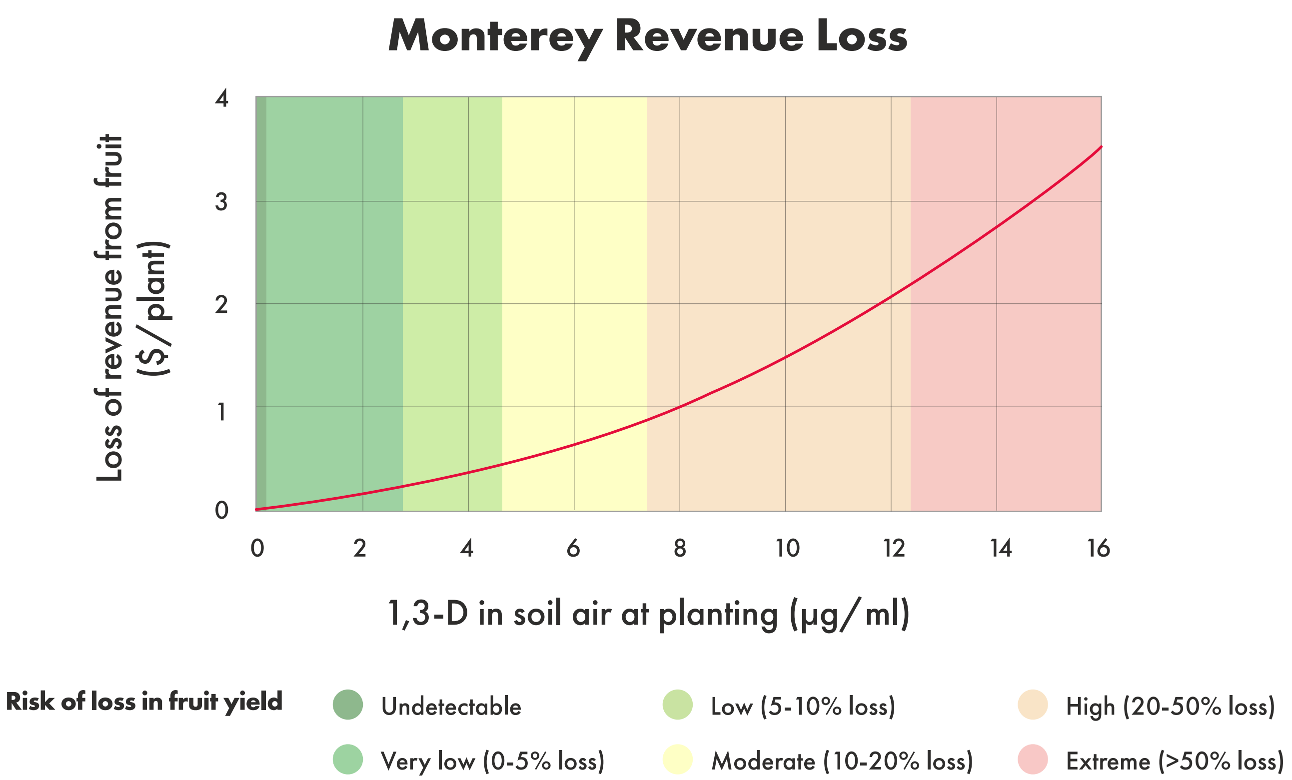

Figure 5. Modelled loss in revenue from strawberry fruit (var. *Monterey*) and associated yield loss when planting into soil containing different concentrations of the fumigant 1,3-dichloropropene. The model is based on data from a field experiment conducted in the Yarra Valley, Victoria and using an in-field colorimetric method for measuring fumigant residues in soil.

Figure 6. The adoption of TIF mulch used in conjunction with fumigants (L) has already drastically increased control of some soil-borne diseases compared with standard LDPE mulch (R) in the strawberry industry in Victoria.
Photo credit VSICA Research

How will this project help strawberry growers?

We have already used the colorimetric tubes to measure the concentration of fumigant residues of 1,3-D and Pic in soil prior to planting at 30 strawberry farms across Victoria. We commenced the tests after the minimum plant-back period listed on the product labels. The sites were chosen to cover different growing regions, soil types, moisture and organic matter contents, and temperatures for strawberry production across Victoria.

Without the fumigant detection tests, growers at 55% of the sites we tested would have planted into soils containing concentrations of fumigants with the potential to cause phytotoxicity in their crops. Most of the growers at these sites decided to delay planting a further week based on the test and this resulted in no plant deaths.

At one of the sites, however, the grower decided to plant into soils where fumigant residues were detected and determined to be a moderate risk of phytotoxicity. A few months after planting the grower noticed signs of phytotoxicity (wilting and black roots followed by plant death) on 20% of their plants at the site. These results demonstrate the potential benefit of the test to growers.

Currently we are conducting further experiments with the use of the colorimetric tubes to understand the influence of soil type, and moisture on fumigant phytotoxicity with a greater range of fumigants. Ultimately, the VSIDC and VSICA Research plan to work together to commercialise the test for growers.

Acknowledgements

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Note: A list of registered products and permits for strawberry runner and fruit production are available on the Australian Pesticides and Veterinary Medicines Authority website (www.apvma.com.au). The product label is the official authority and should always be followed in relation to the use of a chemical.

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