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COMMERCIAL QUARANTINE FUMIGATION OF NARCISSUS BULBS TO CONTROL NARCISSUS FLIES

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ABSTRACT

Fumigation trials were carried using methyl bromide (MB) to control narcissus flies in bulbs destined for export. The objective was to increase fumigation efficiency by utilizing two gastight fumigation chambers (fumigation bubbles) in order to reduce the danger of phytotoxic damage by applying the minimum effective dose required to kill the insects.

It was found that for the 4 h exposure regime required for quarantine purposes, recirculation was necessary to produce initial uniform concentrations. Dosage in the 48 m^3 and 102 m^3 capacity bubbles (without inflation) had to be adjusted to take into account both the volume of free space within the bubbles and sorption by the bulbs. MB concentrations recorded by thermal conductivity (TC) monitors were influenced by the CO_2 concentrations generated from bulb metabolism during fumigation. With recirculation in the 48 m^3 bubble, an initial dosage of 25 g m^{-3} resulted in stabilization of MB concentrations after 90 min at close to 20 g m^{-3}. This concentration is close to the LD_{99} of *Merodon eques* as evaluated in laboratory studies.

INTRODUCTION

Israeli growers have been requested to fumigate narcissus bulbs in order to comply with the quarantine requirements set by importing countries, in particular the USA. This is due to the presence of at least two species of narcissus fly, belonging to the genera *Merodon* and *Eumerus*, that attack the bulbs of *Narcissus* and *Amaryllis* and are not present in some of the importing countries.

In the past the commercial fumigations were carried out in rigid fumigation chambers based on fumigation schedule N (fumigation of flower bulbs and corms) in the *Manual of Fumigation for Insect Control* (Bond, 1984) that requires a methyl bromide (MB) fumigation at a dosage of 45 g m^{-3} for 4 h at temperatures above 21°C. However, in recent years several fumigations with this schedule were found to have caused phytotoxic damage. Quality control operators discarded the damaged lots in which scorching was observed.

Although there was no clear explanation for these phenomena, certain possibilities were suggested. The cause may have been lack of uniform gas distribution within the fumigation chamber (in routine fumigations carried out under standard practice, MB concentrations were not monitored at different points within the chamber). It may have been insufficient aeration after fumigation because as the gas desorbs from the bulbs at the end of the exposure period, high concentrations are liable to accumulate and damage the bulbs unless they are removed rapidly and effectively by forced aeration. It may have been excessive dosage levels; since the amount of MB sorption by the bulbs was not known, it was not possible to calculate the concentration of free gas available to control the insects.

In order to provide better distribution, it was decided by the pest control operator to use an especially designed flexible plastic chamber (fumigation bubble) equipped with a fan driven dispenser system to facilitate distribution of MB. Because of the increased gas-tightness obtainable in these chambers, it was also planned to reduce the dosage on the assumption that the schedule N listed by Bond (1984) was based on some allowance for leakage in previously employed, less gastight, rigid structures.

To examine these possibilities and establish a fumigation schedule acceptable to both the growers and quarantine authorities, four commercial fumigations, from among a series of commercial fumigations of narcissus bulbs carried out for quarantine purposes prior to export, were monitored. The treatments were carried out at Ashdod harbor in Israel. In order to enable the results of these fumigations to be evaluated, the level of sorption of MB into bulbs was examined, and the sensitivities to MB of both the large and small narcissus flies occurring in Israel were also examined in the laboratory (Donahaye *et al.*, 1997).

The objectives of this study were to examine concentrations and application techniques at the recommended dosage levels, adjust them in order to obtain lethal concentrations over the required exposure period and, at the same time, minimise phytotoxic damage to the narcissus bulbs.

MATERIALS AND METHODS

The flexible fumigation chambers

The chambers were "Rentokill fumigation bubbles" of two sizes, consisting of flexible plastic over- and under-liners zipped together to form a sealed enclosure. The bubbles were linked to an application unit consisting of a MB dispenser and a fan employed to inflate the chamber initially, to introduce the gas into the bubble and to aerate it after fumigation.

The bulbs were packed in crates that were arranged nine layers high on wooden pallets; each layer consisted of five crates containing 20 kg of bulbs each. The pallets were then trucked to holding sheds at the port, where the fumigations were carried out. Forty-two crates were placed in the large fumigation bubble and 15 to 18 in the small one.

Dimensions and treatment capacity of the bubbles were as shown in Table 1.

TABLE 1
Dimensions and treatment capacity of the bubbles

Parameter	Large bubble	Small bubble
Length	8.5	6.0
Width	6.0	4.0
Height	2.0	2.0
Volume (not inflated, m^3)	102	48
Volume (inflated, m^3)	180	80
Number of pallets	42	15–18
Volume of each pallet with crates (m^3)	2.22	2.22
Gross volume of pallets (m^3)	93.2	33.3–40.0

Pre-fumigation procedure. The lower section of the bubble was laid on the ground, and the pallets were placed on it with a fork lift. Gas sampling points were then laid out and threaded through a gasket in the liner membrane, and the overliner was drawn over the stack and attached to the underliner by means of a tongue-and-groove zipper.

Gasing and degasing. Four fumigation trials were carried out. In the first three trials, the fumigant dosage was calculated per canister of MB and the dispenser fan was operated to blow air into the bubble. Then the canister was punctured and gas liberated into an expansion chamber in the ventilation duct from which it passed into the bubble. The fan was turned off after the bubble had been partially inflated. In the fourth trial, the MB was dispensed from a weighed cylinder and the fan was used to recirculate the gas for about 1 h after the introduction of MB after which it was turned off.

After 4 h the zipper of the bubble was opened by fumigation operators wearing gas masks. Aeration was carried out using large axial fans designed for greenhouse ventilation. Two fans were used for the large bubble and one for the small. They were located facing the pallets at a distance of about 2 m and were activated all night to remove the desorbing gas and prevent possible build-up of gas concentrations in the air spaces between the bulbs within the crates.

Monitoring and sampling procedures

Concentrations of MB. Concentrations within the bubble were measured by attaching the gas sampling tubes to a Bedfont MB gas monitor Model 415, equipped with a thermal conductivity detector which is also susceptible to carbon dioxide (CO_2) concentrations in the air. Additional laboratory tests were made to determine the rate of CO_2 release by the metabolism of the bulbs. The concentrations of CO_2 were measured separately during the trials using an infra red CO_2 analyser (Riken Model RI 550A).

In order to adjust the MB concentration readings, a set of laboratory fumigations was carried out using different combinations of MB and CO_2. A CO_2 calibration curve was

then prepared for the MB monitor, and the MB readings in these trials were corrected accordingly.

Temperature measurement. Temperatures inside and outside the fumigation bubbles were measured several times during each fumigation using t-type thermocouple cables and an electronic thermometer. Temperatures were measured at the top and bottom of the bubble.

Gas sampling. MB measurements were taken by placing sampling tubing at five positions within the bubble, points 1, 2, 3 and 5 situated at the centre of the bubble from floor level to below the upper plastic liner, point 4 next to the gas inlet site and point 6 adjacent to the wall opposite the gas inlet site, the latter two half-way up the pallets (Fig. 1).

Bulb sampling. Before fumigation, 30 bulbs previously sorted for suspected infestation were placed in the bubble at the bottom, top and center of each fumigated stack. These were removed at the end of fumigation and examined for fly mortality and visible phytotoxicity in the laboratory. Additional bulbs were taken from the gas sampling points for subsequent planting in order to examine possible phytotoxic effects.

Description of fumigations

Trial 1. The first fumigation trial was carried out using a large fumigation bubble according to the fumigation operator's normal schedule. This fumigation lasted 3 h 50 min.

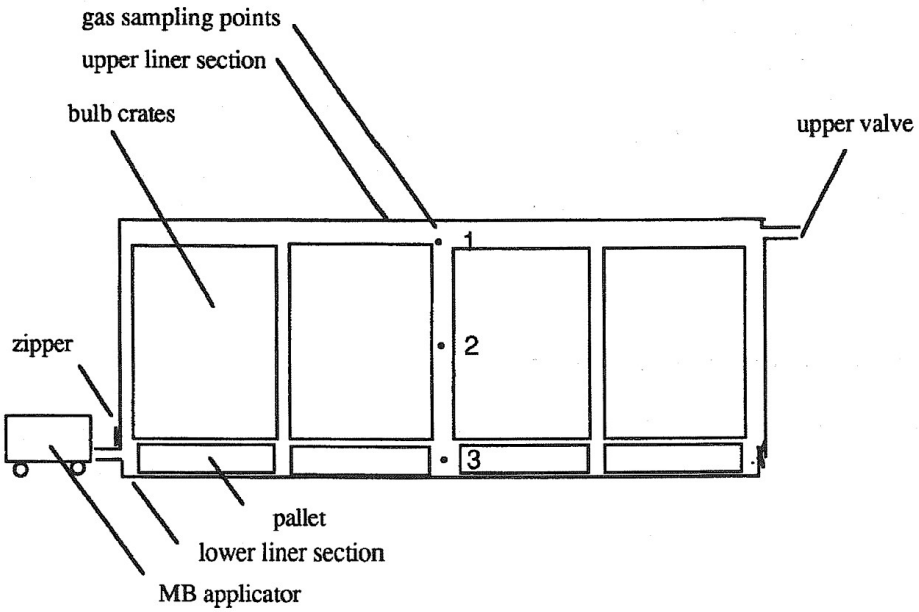

Fig. 1. Schematic view of the fumigation bubble indicating position of gas sampling points.

Dosage was with seven canisters containing 681-g MB each, calculated as equivalent to 27 g m^{-3} total space (based on a volume of 180 m^3 for the inflated bubble). Gas was introduced from the dispenser fan to the bottom of the bubble, thereby inflating it. After the gas had been dispensed and the bubble inflated, the fan was turned off.

At the end of the exposure period, the upper section of the bubble was removed and the crates were aerated with the external axial fans. Gas concentrations were measured 30 min and again 1 h after aeration was started.

Trial 2. Because of the difficulty in controlling the level of bubble inflation, and consequently in obtaining a predetermined gas concentration, the objective of this fumigation was to reduce the initial inflation and lower the dosage in order to avoid the high initial concentrations, particularly in the floor area, that were suspected of causing scorching of the bulbs. The fumigant was introduced from the bottom, as in the previous trial.

Fumigation in the large bubble was with a dosage of three canisters and minimal inflation, and in the small bubble with two canisters, to release 2,043 g and 1,362 g (equivalent to calculated dosages of 27 g m^{-3} and 30 g m^{-3}), respectively.

Trial 3. In this trial, carried out in both large and small bubbles, the fumigant was applied at the top in an attempt to decrease the problem, encountered in the previous trial, of layering at ground level. Dosage rates, monitoring and bulb sampling were all the same as in trial 2.

Trial 4. In this trial only the small bubble was used and 15 pallets were loaded instead of the 18 in previous trials. The bubble was not inflated, and the volume of the bubble was confined to the rigid volume of the pallets (including the space comprising the pathways between the pallets). The volume of this enclosure was 44 m^3. Dosage was administered from a MB canister placed on scales to enable the MB to be released by predetermined weight. The objective of this trial was to use closed-circulation fumigation so as to equalise concentrations as soon as possible after application of the dose. Recirculation using the applicator fan was carried out for 90 min. During this time the possibility of gas leakage via the aeration ducting was examined using a halogen detector, and leakages were detected at the joint flanges. An initial dose of 1,104 g of MB, equivalent to 30 g m^{-3} (non-inflated bubble), was applied by recirculation.

RESULTS

Trials

Trial 1. The results of this trial are given in Fig. 2. MB concentration readings show that although a calculated dose of 27 g m^{-3} was given, initial concentrations ranged from 36 to 81 g m^{-3} and averaged 67 g m^{-3}. At the end of the fumigation they were uniform and had stabilized at 59 g m^{-3}. Concentrations throughout the exposure period were highest at the bottom of the stack.

After 30 min of post fumigation aeration, MB concentration had fallen to between 0 and 3 g m^{-3}, and after 1 h no MB was detected. Temperatures during fumigation ranged

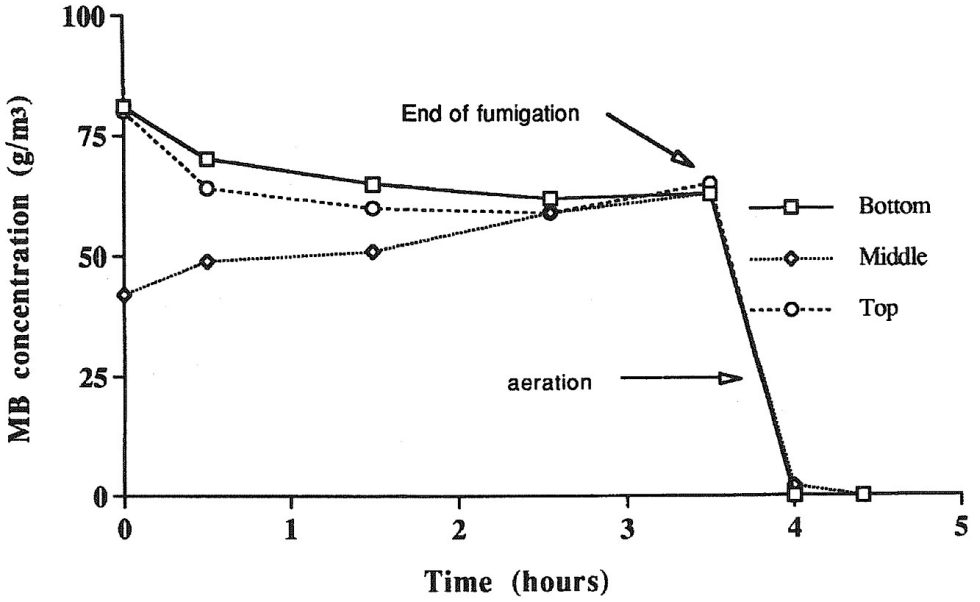

Fig. 2. Fumigation in large bubble by inflation with gas introduced from below — trial 1 (intended dose 27 g m^{-3}, actual average initial concentration 67 g m^{-3}).

between 25.6 and 30.8°C. The infested bulbs exposed to the fumigation revealed 12 dead larvae and 7 dead pupae of *Eumerus* sp.

Trial 2. In this trial, an attempt was made to reduce the number of 681-g MB cans, and the bubbles were inflated only slightly to adjust the volume approximately to the calculated concentrations. Results of the two fumigations carried out in this trial are given in Fig. 3. At the beginning of dose release, high concentrations were still recorded at the base of the fumigation bubbles, reaching a maximum of 54 g m^{-3} in the large bubble and 36 g m^{-3} in the small bubble. Only towards the end of the fumigation period were the concentrations fairly uniform at about 27 g m^{-3} in the large bubble and 30 g m^{-3} in the small one. One half hour after the bubbles had been opened and aerated, no fumigant concentrations were recorded at any of the sampling points. Fumigation temperatures were between 27.6 and 29.6°C in the large bubble and between 29.2 and 30°C in the small bubble.

Trial 3. The design of this trial was similar to trial 2, but the gas was introduced from the top of the bubbles. The results of the fumigations are given in Fig. 4. From the figure it can be seen that differences in MB concentrations in both bubbles were smaller than in the previous trials; however, there was still a tendency for the gas to sink to the bottom of the bubble, producing higher initial concentrations (35 g m^{-3}) in this region, and only towards the end of the exposure period were more uniform concentrations, averaging about 20 g m^{-3} for the large bubble and 19 g m^{-3} for the small bubble, obtained.

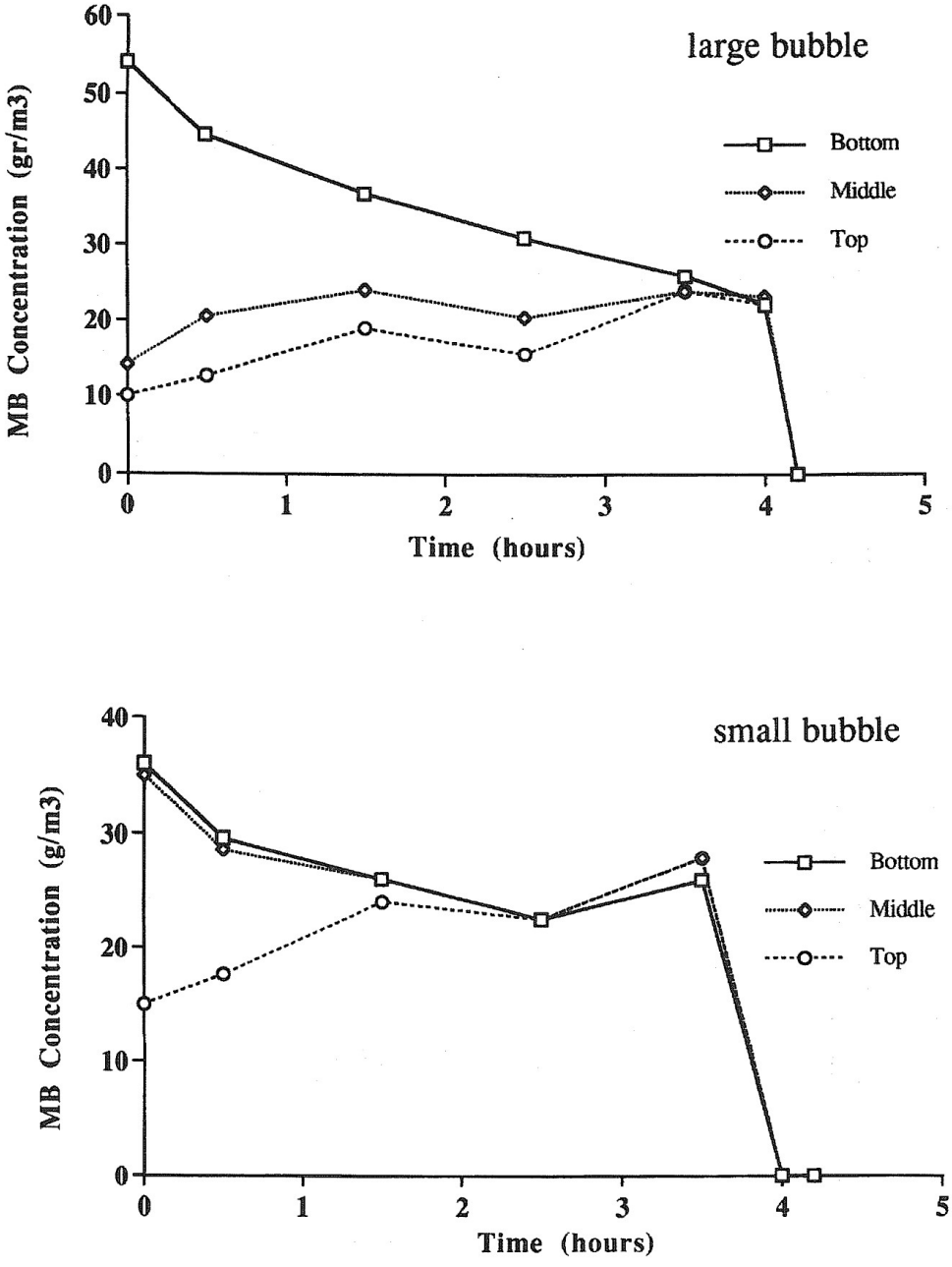

Fig. 3. Fumigation with minimum inflation and gas introduced from below — trial 2 (large bubble: intended dose 27 g m^{-3}, actual average initial concentration 26 g m^{-3}; small bubble: intended dose 30 g m^{-3}, actual average initial concentration 28 g m^{-3}).

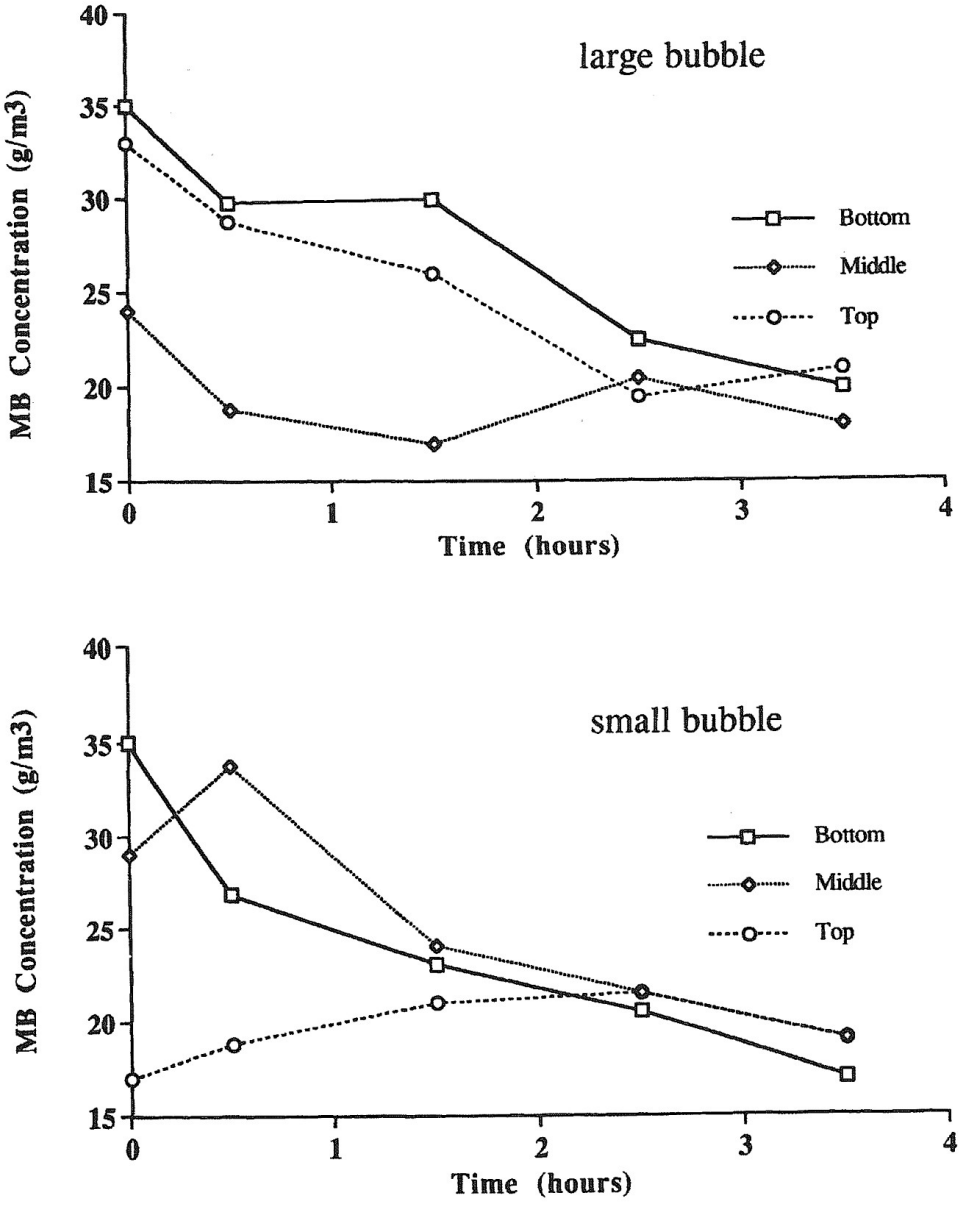

Fig. 4. Fumigation with minimum inflation and gas introduced from top — trial 3 (large bubble: intended dose 27 g m^{-3}, actual average initial concentration 31 g m^{-3}; small bubble: intended dose 30 g m^{-3}, actual average initial concentration 27 g m^{-3}).

Trial 4. This trial was designed to introduce MB without inflating the bubbles (in contrast to previous trials). Since it was very difficult to accurately calibrate the dosage using entire cans of 681 g MB each, in this trial the MB was introduced by weight. In addition, to obtain a better distribution, in this trial the fumigant was circulated. Figure 5 shows that the MB concentrations became uniformly distributed after about 1.5 h, at which time the circulation fan was turned off. Concentrations from then on remained at about 20 g m^{-3} throughout the fumigation.

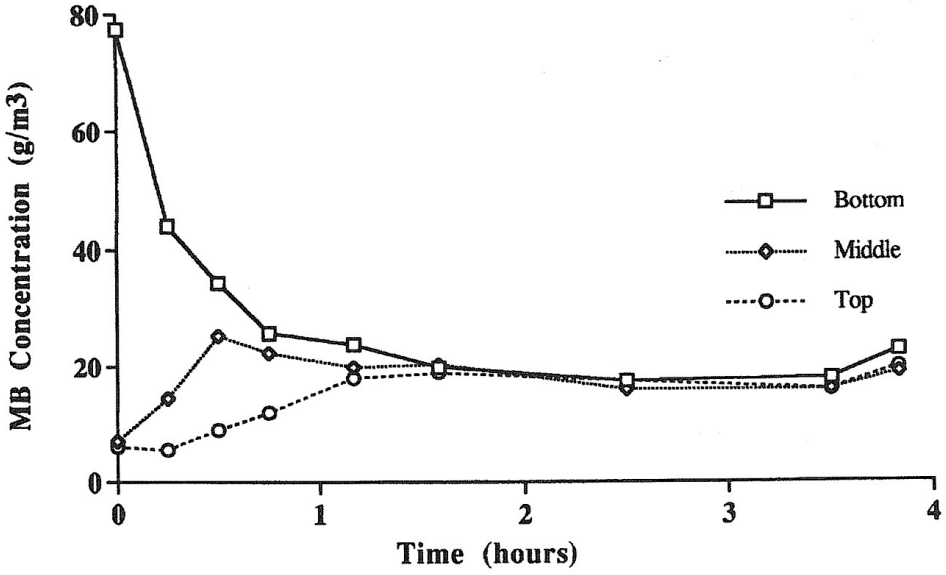

Fig. 5. Fumigation of small bubble with aisles between crates, gas introduction from top and closed recirculation — trial 4 (small bubble: intended dose 30 g m^{-3}, actual average initial concentration 30 g m^{-3}).

Plant growth

Bulbs taken from trials 1, 2 and 3 were planted, together with unfumigated bulbs as controls, in a plot at Moshav Bitzaron. Although high initial concentrations were observed in these trials, no significant differences between treated and control bulbs were observed as regards vegetative deformation, reduction in flowering heads or retardation of growth.

Typical CO_2 concentrations measured in trial 4 are shown in Fig. 6. This accumulation of CO_2, as measured within the 4 h fumigation period, shows that a considerable concentration (up to 3.8%) can evolve from the bulbs. This CO_2 concentration renders the use of instruments equipped with TC detectors unfit for monitoring changes in MB concentration. Therefore, it was decided in these trials to use an infrared detector for measuring the CO_2 accumulation within the fumigation bubbles separately in order to correct the MB readings.

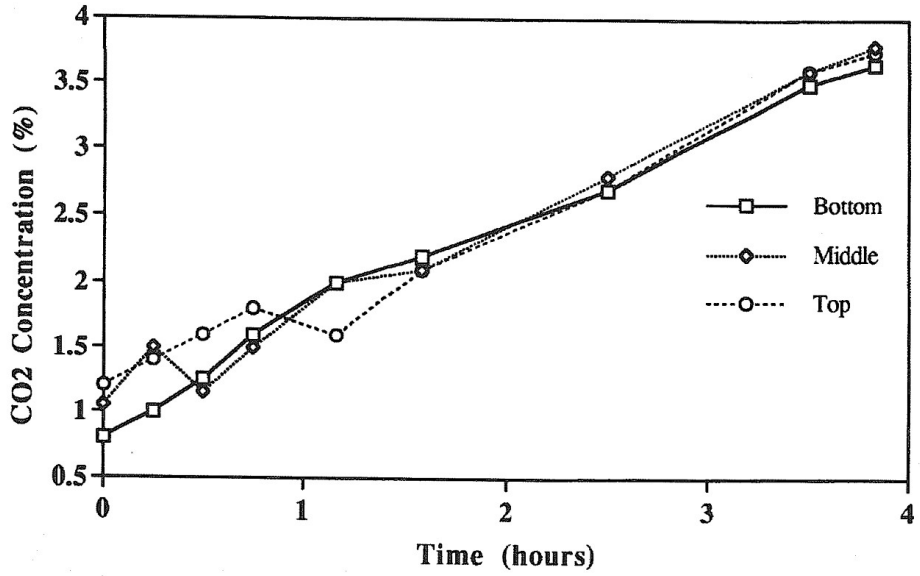

Fig. 6. Fumigation of small bubble with aisles between crates, gas introduction from top and closed recirculation — trial 4: CO_2 emission during fumigation.

DISCUSSION

Sensitivity of narcissus flies to MB has also been studied by Zumreoglu and Erakay (1978) in Turkey, though they used a 2-h exposure period and higher Ct ratios than the 180 g h m^{-3} advocated by Bond. In the present trials the Ct product was designed to be within the range of 80 to 100 g h m^{-3}. This dosage schedule was adopted following the work carried out by Donahaye *et al.* (1997).

The above series of fumigations form an initial stage in the establishment of a fumigation schedule suitable for the treatment of narcissus bulbs inside fumigation bubbles with MB. The results show that when an exposure limit of 4 h is set, the method advocated by the manufacturer, in which the gas is dispensed into the fan duct used to inflate the bubble, does not provide rapid uniform concentrations. For this to happen, the applied dosage must be recirculated and passage ways provided between the palleted crates. For bulbs, in contrast to the fumigation of less sensitive commodities, there is also a relatively narrow range of permissible fumigant concentrations that will assure complete kill of the insects yet ensure no phytotoxic effects. Therefore dosage application using canisters does not enable sufficiently fine adjustment of the required dose, and the method of weighing the dose, although less convenient, should be preferred. Further trials will be undertaken in order to optimize the fumigation method.

CONCLUSIONS

The trials revealed that the bubbles were sufficiently gastight to enable fumigation with MB for an exposure period of 4 h. For accurate calculation of the dosage, it was shown that the bubbles should not be inflated and that the considerable sorption of MB by the bulbs should be taken into account. Recirculation was needed to achieve a rapid equalization of gas concentrations. No phytotoxic effects were observed in treated bulbs grown in experimental plots, and samples of fly-infested bulbs examined after fumigation indicated complete mortality.

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