Distribution of a tracer gas in a naturally ventilated greenhouse. measurements and simulations for pesticides dispersion determination

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ABSTRACT

Numerical and experimental results concerning the emission of a tracer gas (N_2O) inside a naturally ventilated greenhouse are presented and analyzed. Air samples were continuously taken at six points in the greenhouse and in two positions outside the greenhouse using two infrared gas analysers with multiple inlets. The calculations by the numerical model were done for several wind directions and wind speeds. In each set values for the experiments were used for air speed and direction. The comparison between experimental data and simulation results has shown a quantitatively and qualitatively good agreement, since, for the tested cases, the correlation coefficients between measured and numerically obtained values were varied between 0.81 and 0.985. The simulation results provided useful information about the emission of N_2O around the experimental greenhouse and are a first step towards the determination of the behaviour of pesticides around greenhouses, since a similar behaviour should be expected when instead of N_2O, a pesticide is used.

1. INTRODUCTION

Every year between 2 and 3 million tons of various pesticides are put up for sale in the world. As a large fraction of these pesticides is aimed towards crop production, pesticide application for agricultural purposes, that may be large in places, is a major source of organic pollutants in the atmosphere. The European Commission in order to minimise the detrimental environmental impact of pesticides the EU seeks to ensure their correct use. As it was reported by the European Commission in a memorandum on sustainable use of pesticides (Commission of the European Communities 2002) "The potential exposure of bystanders and residents to pesticides via the air might constitute an exposure route, which needs further attention by research and possibly regulatory measures".

Agricultural buildings, especially those used for intensive production like greenhouses, received a large amount of pesticides. Greenhouses are therefore likely to be a strong source of environmental pollution.

Experimental data, collected over many crops with various application techniques, have demonstrated that pesticide spraying releases chemical contaminants into the atmosphere. During application the loss to the air usually stands from a few percent to 20–30%, although it can reach 50% of the total amount applied (Van-den Berg et al., 1999). This estimation is in good agreement with reported measurements of deposition on leaves and on the ground, that turn out to be of the order of 80% at least in normal conditions (Cross et al., 2001). The amount of atmospheric loss is influenced by several factors like the physico-chemical properties of the compounds, the environmental conditions and the agricultural techniques (Bedos et al., 2002).

In recent years several research projects have been carried out to quantify the levels of pesticides in a greenhouse environment and the impact of these levels both to human health and the environment. Nevertheless, the relation between climatic conditions and the behaviour of pesticides substances in greenhouse and ambient environments still remain an important issue which attracts scientific circumspection. In addition, understanding the process of dispersion of pesticides from greenhouses will be a useful tool for authorities to specify the frame of pesticide legislation, integrating all necessary precautions to protect workers, bystanders, surrounding communities and the environment (FAO, 2005).

Concerning specific pesticides, analysis of lindane and of some endosulfan isomers in the greenhouse air indicates that 24 h after their application, concentration levels of about 8.5% of the initial values still remain in the air (Vidal et al., 1997). It was also found that the dissipation rate and the concentration decline rate were influenced by parameters such as vapour pressure, temperature and relative humidity. An application of metamidophos in a greenhouse showed that the concentration decreased dramatically the first hour after application, but in the following hours the diminution was slower and even 52 h after application metamidophos was detected in the air (Egea Gonzalez et al., 1998). The levels of chlorpyrifos in air, leaves and soil from a greenhouse were determined by Guardino et al. (1998) in order to evaluated three analytical techniques. The results indicated that chlorpyrifos levels in the air depend on greenhouse ventilation.

During recent an increasingly use of numerical techniques has given researchers the ability to simulate transfer phenomena which occur in agricultural buildings, considering of building structural details and its ambient environment. CFD models have been used successfully in greenhouse ventilation studies (Bartzanas et al., 2004). Despite the limitations of simulation models (Abraheem et al., 2001), CFD could be a powerful tool to optimize the use of application of pesticides, understanding their dispersion in the greenhouse environment. In the frame of development of a sustainable agriculture, the necessity of combining ecology and technology is crucial in order for the future target of 'zero-application' of agrochemicals to be achieved (Jongebreur, 2000).

The phenomenon of ventilation, through which pesticide pollutants are emitted from the experimental greenhouse side openings, was analyzed by simulating the emission and dispersion of a tracer gas. The objective of the present study, after validating a commercial CFD code against experimental measurements, was to use the code in order to determine the potential behaviour of the tracer gas in relation to wind speed and direction and greenhouse and vent characteristics.

2. NUMERICAL MODEL

2.1 Experimental greenhouse and measurements

The experiments were performed in an arch type greenhouse, N-S oriented (36º declination from north 0º), located at the University of Thessaly near Volos, (Latitude 39º44´, Longitude 22º79´, Altitude 85 m) on the continental area of Eastern Greece, during the summer of 2005. The greenhouse was covered by a double inflated polyethylene film on the roof and by glass on the sidewalls and gables. The geometrical characteristics of the greenhouse were as follows (fig.1): eaves height =3 m; ridge height = 4.65 m; total width = 10 m; total length = 30 m; ground area A_g =300 m2 and volume V =1237 m^3. The greenhouse was equipped with two side flap vents located at a height of 1.5 m above the ground with a maximum opening area of 13.5 m^2 (30 m length × 0.45 m height) for each.

The greenhouse was occupied by a tomato crop which, during the period of measurements, had an average height of about 1.7 m. The air exchange rate measurements were performed by means of the impulse peak method using N_2O as tracer gas since the natural concentration of this gas in the atmosphere is almost null (≈ 0.3 ppm). The tracer gas was added to give a concentration of 250 ppm while the vents were closed. After injection, some time was left before the vents were opened in order to obtain uniform gas distribution inside the greenhouse; the vents were then opened to the desired aperture. Air samples were continuously taken at six positions inside the greenhouse, by means of six equally distributed plastic pipes of the same length, located at a height of approximately 1.6 m above the ground, using a multiple inlet infrared gas analyzer. Additionally, in order to continuously measure a reference position, a second infrared gas analyzer was used to measure tracer gas concentration in the middle of the greenhouse. The measurements were carried out and stored in the data logger system every second, whereas the duration of each experiment varied between 5 and 20 minutes, depending on the environmental conditions and the ventilation opening. In the ambient environment, measurements of wind speed and direction on a mast 4 m above the ground at a distance of 15 m from the greenhouse were also carried out every second.

2.2 Numerical model

The commercially available computational fluid dynamics code Fluent was used, in this study, to obtain airflow and temperature patterns. Fluent (Fluent, 1998) is a general purpose commercial CFD package that uses the finite volume numerical scheme to solve the equations of conservation for the different transported quantities in the flow (mass, momentum, energy, water vapour concentration). Further information concerning the set-up of the numerical model can be found in Kittas et al. 2005. The experimental greenhouse and the ambient environment were designed using the geometrical processor Gambit 1.1. The simulation domain extends 198 m in the x-direction, 193 m in the z-direction and 30 m in the y-direction (Fig. 1).

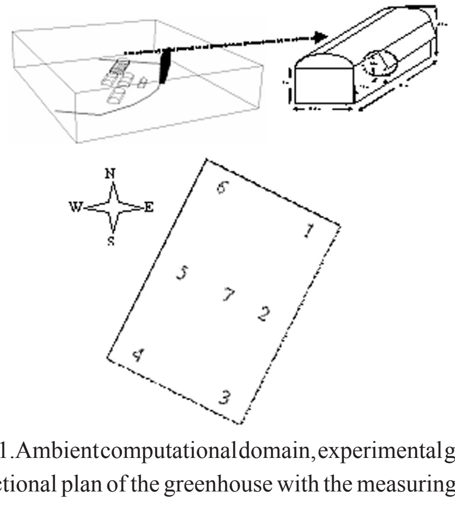

Figure 1. Ambient computational domain, experimental greenhouse and sectional plan of the greenhouse with the measuring positions.

The concentration of N_2O inside the greenhouse was set to 250 ppm, the range with the highest accuracy of the tracer gas measurement. The final solution was obtained firstly by a convergent solution under steady – state conditions and secondly by an unsteady one, where at the time which equals zero the volume of the experimental greenhouse was considered to contain a new mixture consisting of 'air' and 'N_2O' in a mass fraction of 1/0.0003799610, which corresponded to the initial concentration level of N_2O (250 ppm, Sapounas and Nikita-Martzopoulou, 2004). Average values obtained during the experiments were used for boundary conditions. In total, 25 different cases concerning different wind speeds and directions were investigated (Table 1).

3. RESULTS

Figure 2 presents numerically obtained values of N_2O concentration versus time, for the seven different locations inside the greenhouse. The simulations where carried out for a wind speed of 1.17 m s^{-1} and a wind direction of 122°deg.

It can be seen that the higher rate of N_2O reduction, that means the higher ventilation rate, was obtained for position 4, while the lower ones where those predicted for positions 1 and 6. The figure also shows the ventilation heterogeneity observed in the greenhouse even if the greenhouse under study has a covered area of only 300 m^2.

Table 1. Boundary conditions used in simulations for the tested cases

Case	Parameters: Wind velocity (m/s)	Parameters: Wind direction (º from North)
1	1.28	156
2	1.64	150
3	1.73	141
4	2.05	136
5	2.25	139
6	1.83	143
7	0.83	119
8	1.11	108
9	0.85	124
10	0.64	131
11	1.90	179
12	1.41	186
13	1.82	184
14	2.16	177
15	2.39	174
16	2.19	168
17	1.72	135
18	1.96	118
19	2.01	113
20	1.34	97
21	1.17	122
22	1.07	117
23	0.80	194
24	0.41	106
25	305	0.46

For the wind direction vertical to the greenhouse ridge, as is the case studied during the simulations presented in figure 2, it seems that the air enters the greenhouse through the windward vent (east side) and exits through the leeward.

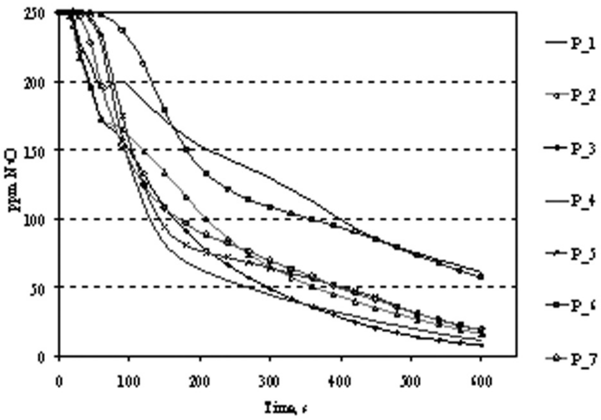

Fig. 2. Numerically obtained values of N_2O concentration for different positions inside the experimental greenhouse.

The measured and simulated values of air exchange rate for the 25 cases studied are presented in Table 2.

Table 2. Measured and simulated (in parenthesis) values of air exchange rate for the 25 tested cases.

Case\Position	1	2	3	4	5	6	7
1	6.8 (5.6)			8.2 (7.5)			5.4 (4.9)
2	7.6 (8.2)			7.2 (6.5)			5.1 (4.1)
3		6.9 (5.9)			7.3 (6.5)		4.8 (5.5)
4		9.0 (8.1)			9.3 (8.5)		4.6 (5.3)
5		8.6 (7.9)			8.5 (7.8)		4.7 (4.1)
6		10.3 (9.5)			9.6 (8.7)		5.1 (3.9)
7			5.5 (5.1)	5.7 (4.9)			4.3 (3.2)
8			7.5 (7.0)	7.6 (6.5)			5.5 (3.9)
9			3.9 (4.3)	5.3 (4.6)			5.7 (4.4)
10			6.5 (7.2)	5.7 (4.9)			4.2 (5.6)
11		7.6 (8.3)			6.5 (6.9)		5.3 (4.8)
12		6.5 (5.9)			5.5 (4.8)		5.0 (4.5)
13		6.5 (5.8)			6.3 (7.2)		5.7 (5.1)
14		5.9 (6.5)			7.1 (8.1)		5.1 (4.8)
15		9.5 (10.6)			8.2 (9.6)		5.8 (4.9)
16	8.3 (6.9)					7.6 (6.9)	5.3 (4.4)
17	4.4 (5.4)					4.8 (4.1)	4.1 (3.6
18	6.6 (5.9)					6.4 (5.8)	6.1 (5.2)
19	7.8 (6.9)					6.7 (7.5)	7.8 (7.1)
20	4.7 (5.6)					6.3 (7.2)	6.3 (5.5)
21					5.1 (6.1)	5.0 (5.8)	4.8 (4.1)
22					7.2 (6.5)	7.8 (8.5)	5.7 (5.1)
23					4.3 (3.6)	4.5 (3.9)	4.8 (4.2)
24							3.8 (3.1)
25					4.3 (3.9)	4.8 (4.1)	4.2 (2.9)

As shown in table 2, a good agreement was found between the measured and simulated values. It has to be noted that in order to obtain high accuracy in the measured values of air exchange rate, no more than 3 positions could be recorded simultaneously.

The N_2O dispersion from the greenhouse to the ambient environment mainly depends on wind speed and direction and vent opening. The concentration of the tracer gas inside the greenhouse was reduced by a rate proportional to air speed. The dissipation rate and the reduction in tracer gas was not homogeneous inside the greenhouse but depended on the inside air velocity profile. In Fig. 3, the N_2O concentration inside the experimental greenhouse and in the outside environment 1.5 m above the ground was calculated for a N-S wind direction a) 15 sec and b) 45 sec after vents opening. The concentration of the tracer gas was reduced first in the windward part of the greenhouse and afterwards in the rest of the greenhouse volume. This distribution is due to the air movement inside the greenhouse. When air flows parallel to greenhouse axis air enters the greenhouse through the windward opening and exits through the leeward. Similar airflow pattern was measured in a greenhouse with a continuous roof vent (Boulard et al., 1997), a phenomenon that is also comparable to the so-call "side wall effect" deduced from tracer gas measurements (Fernandez & Bailey, 1992).

A similar behaviour should be expected when instead of N_2O, a pesticide is used. A homogeneous dispersion of the pesticide over the crop canopy would be very difficult to achieve. Off target deposition of pesticide droplets can cause severe environmental contamination. In addition, off target deposition increases the crop production cost. Finally, N_2O, as simulated by the numerical model, was found to be dispersed more than 70 m away from the greenhouse (fig. 3). However, data analysis and simulations are continuing and further results will be obtained.

4. CONCLUSIONS

Numerical and experimental results concerning the emission of a tracer gas (N_2O) inside and outside an experimental greenhouse with a tomato crop were presented and analyzed. Good overall agreement was found between the numerically and experimentally obtained results. The dissipation rate of the tracer gas inside and outside the greenhouse depended mainly on the outside wind speed and direction. Simulation results provided useful information about the N_2O dispersion around the experimental greenhouse and are a first step towards the determination of the behaviour of pesticides around greenhouses.

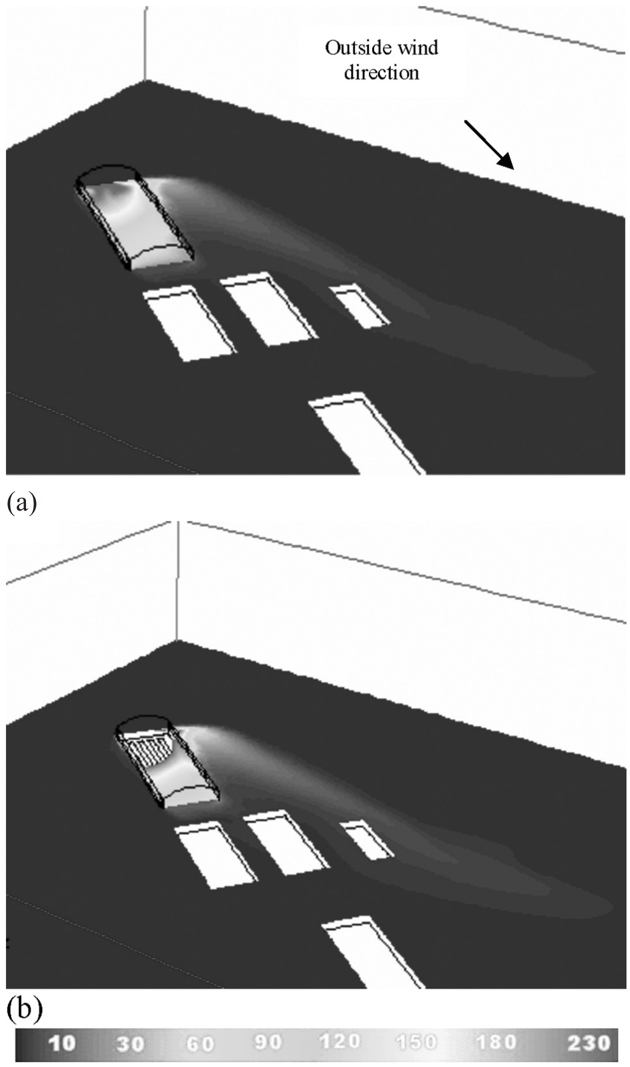

Fig. 3. Contours of calculated N_2O concentration (ppm) in the experimental domain 1.5 m above the ground, (a) 15 sec and (b) 40 sec after vent opening for a N-S wind of 2 m s^{-1}

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