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Ethylene: Sources, Effects, and Prevention for Greenhouse-Grown Crops

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Introduction

Ethylene (C_2H_4) is an odorless, colorless gas which acts as a plant hormone. Thus it can be a growth regulator or a harmful pollutant of horticultural crops. Major losses caused by the "death hormone" can occur with high value crops such as greenhouse-grown potted plants and cut flowers, and fresh fruit and vegetables. Ethylene is a simple organic substance which is highly active at low concentrations. Normally, as the concentration of the gas increases, so does the degree of damage. Ethylene can originate from several sources. Living sources include plant materials (vegetative and reproductive tissue and fruit) that are ripening or rotting. The major nonliving sources of ethylene include: improperly adjusted or cleaned greenhouse heating units, leaky gas lines, and exhausts from combustion engines. Economic losses to greenhouse growers from ethylene pollution are reported each year and many more probably occur, but are not correctly diagnosed. This leaflet discusses ethylene sources and symptoms of damage, and how to prevent it.

Ethylene Damage Symptoms

The effects of ethylene on greenhouse-grown crops can range from none to severe. No other air pollutant causes a greater range of damage symptoms than ethylene gas (Rodgers, 1980). Symptoms include malformed leaves and flowers, thickened stems and leaves, lack of growth (stunting), abortion of flowers and leaves, bud and leaf abscission, epinasty (drooping and curling of leaves), and hastening senescence of cut flowers. Plant species, temperature, duration of exposure, stage and state of plant development, and ethylene concentration influence symptom expression. Symptoms are also more likely to be observed in poly covered greenhouses because they are more airtight than glass greenhouses.

Harmful levels and effects of ethylene have been determined for many greenhouse crops (Table 1). Most ethylene effects have a similar dose-response curve: no effect between 0.001 to 0.01 ppm, discernible effects between 0.01 and 0.1 ppm, half-maximal responses between 0.1 to 1 ppm, and saturation from 1 to 10 ppm (Abeles, 1973).

Tomato plants are highly sensitive to ethylene and exhibit a characteristic wilting (epinasty) which can be used as an indicator plant for ethylene. The leaf petiole of an epinastic tomato leaf is bent downward, like it is wilted, however it is completely turgid to the touch and the root system is healthy. Once exposure to ethylene ends, most plants which flower continuously resume normal leaf growth and flowering within 1 to 2 weeks. Damage to the flower buds of plants which only flower once (e.g.: Easter lilies and tulips) cannot be reversed.

Preventing and Detecting Ethylene in the Greenhouse

When designing the greenhouse, economic loss due to ethylene can be minimized by physically separating the plants from engine exhaust from shipping trucks and combustion engine vehicles used for soil mixing. Ethylene contamination from ripening fruit, senescing plant materials, smoke, welding fumes, and poorly maintained greenhouse furnaces can also be controlled.

Concerns About Heating Units. A common source of ethylene and one of the major problems involving total crop loss in greenhouses is ethylene pollution from malfunctioning heating units. There are two major concerns that growers must address. First is the maintenance of the heater, distribution tube, vent stack, ventilation louvers, and fuel lines. The second is the importance of ventilation and intake of fresh air from outside the greenhouse.

Heater System Maintenance. Growers must become aware of the deterioration that occurs over time to heaters as well as the structural damage to the working components of the ventilation system. Exposing the heater to the elements, particularly in hot summers, can lead to rusting, cracking, and clogging of air intakes. Gas leaks resulting from cracked heat exchangers may allow harmful concentrations of ethylene to be released. Continual expansion and contraction of the metal in the heat exchanger of a furnace can stress the welds, producing cracks. Leaks at joints and seams can be detected by painting soapy water on them and looking for bubbles. Another method for detecting leaks is the placement of smoke bombs or furnace candles within the firebox. If light or smoke is observed, call a professional to inspect your equipment.

Rosenberg et al. (1969) have demonstrated that there were large differences in the ethylene content of the air surrounding a heater. Ethylene levels were 300 ppm when measured 0.25 inches [0.7 cm] away from the heater centerline, 50 ppm ethylene at 1 inch [2.5 cm] away from the burner, and 3 ppm in the flue gases. Thus, a distribution tube is essential to dilute the flue gas so plants closest the heater are not exposed to high levels of ethylene.

Heater Type. Growers must carefully consider the type of heater purchased. Greenhouse heaters can be vented or unvented. Unvented gas burners should have thermostats and shut off devices when no flame is detected. These burners are small, easy to use, highly efficient, have low maintenance costs, and control temperatures with reasonable accuracy. However, a unvented heating system creates ethylene pollution and excess water vapor and condensation. This can

Table 1. Effect of ethylene on selected greenhouse-grown plants.

Crop	Ethylene		Visual Symptoms and Reference[y]
	Sensitivity Range[z]	Concentration and Exposure Time[y]	
Achimene	+++	1 to 3 ppm for 24 hrs	Flower and flower bud abscission [7]
Aconitum	++		Premature flower aging [7]
African violet	+++		[7]
Ageratum	++		
Alstroemeria	++		Induces bud unfolding and premature flower aging [13]
Aluminum plant (*Pilea cadierei*)	++		Epinasty [6]
Alyssum	-		[2]
Anemone	++		Premature flower aging
Astilbe	++		Flowers are sensitive
Azalea	++		Leaf drop [7]
Bedding Plants			Sensitive species exhibit stunted, downward curled leaves, and deformed top growth. In some cases the flowers turn brown and die.
Begonia: Hiemalis, Elatior, Rieger	+++	0.1 ppm for 24 hrs	Flower buds will drop, ethylene does not affect the foliage [10]
Begonia, wax	+++	1 ppm for 12 hrs	Little effect [2]
		5 to 10 ppm for 12 hrs	Total abscission of open flowers, but only 25 to 30% of the buds abscise. [2]
Boston Fern	+++	1 ppm	Extensive defoliation [6]
Bouganvillea	++		Flower and bract drop [7, 10]
Cactus: Christmas, Easter	++		Flowers and flower buds drop [10]
Caladium	+++	1 ppm	Bending of petiole
Calceolaria	++		Flowers drop [10]
Campanula	+		Premature flower aging [7]
Carnation	+++	Less than 1 ppm, 0.5 ppm for 12 hrs, or 0.03 to 0.06 ppm for 48 hrs	Flowers wilt rapidly, leaves bend downward and petals fold downward- termed "sleepiness" [1, 13]
Celosia	++	5 ppm for 3 days	Leaf curl, severe downward bending [2]
Chrysanthemum	+	1 to 2 ppm	Termed "crown budding" because the bud grows to 1/8 to 3/16 inch, then stops and the new side buds grow out and around the center bud. Thickened stems, short internodes and abortion of the center bud. [3]
Cineraria	++		Wilt like appearance [10]
Clerodendrum	++		Flower [10] and leaf [16] drop
Coleus	++	1 ppm for 24 hrs	Leaf drop [2]
Crossandra	++		Flower drop [10]
Cucumber	++	0.1 ppm	Loss of chlorophyll [12]
		10 ppm	Softening fruit [12]

Table 1. continued.

Crop	Ethylene: Sensitivity Range[z]	Ethylene: Concentration and Exposure Time[y]	Visual Symptoms and Reference[y]
Cyclamen	++		Flowers will wilt and drop [10]
Dahlia	++	1 ppm	Reduced flower life [13]
Delphinium	+++	3 ppm for 24 hrs	Reduced flower life [13]
Dieffenbachia maculata	++	5 ppm for 3 days	Leaves become chlorotic [6]
Eggplant	++	0.8 ppm for 2 days	Fruit abscission [15]
Eremurus hybrids	++	3 ppm for 24 hrs	Reduced flower quality [13]
Exacum	+		Abscission of flowers and buds [7]
Freesia	++		Flower abscission [10, 13]
Fuchsia	++	1 to 3 ppm for 24 hrs	Flower abscission [7] and leaf abscission [16]
Geranium	+++		Flowers fail to open, petal shatter and leaf chlorosis
Gerbera	+	3 ppm	Causes little flower damage [13]
Gladiolus	-		
Gypsophila	++		Flowers fail to open [13]
Hibiscus, Chinese	++		Flower abscission
Hyacinth	++		Flower abscission
Hydrangea	+	1000 to 3000 ppm	*For defoliation purposes prior to subjecting the plants to dormancy breaking cold treatment.*
Impatien	+++	1 ppm for 1 hr	Leaf curl [2]
		1 ppm for 6 hrs	Almost total buds abscission [2]
Impatiens, New Guinea	+++		[7]
Iris	++	3 ppm for 1 day	Shorter flower life and forced flower unfolding [13]
Ivies (*Hedera helix*)	++		Wilt like appearance (epinasty) of young growth [7]
Jade plant	++	5 ppm	Leaf loss [6]
Jerusalem cherry	++		[7]
Kalanchoe	+++		Buds will not open, petal fading and desiccation, and closing of florets [7, 10]
Larkspur	+++		
Lettuce	+++	0.05 to 0.01 ppm	Reduced leaf size and weight [9]
		0.1 ppm	Russet spotting on leaves [9]
Lily: Asiatic, Oriental	++		
Lily, Easter and Hybrids	+++	0.05 to 0.1 ppm	Premature floral bud abscission, buds are abnormally curved, flower numbers are reduced [5]
Marigold	+	10 ppm for 48 hrs	Leaves droop, stems bend downward, curling, tips downward, roots cover entire top of substrate surface [2]
Marigold (African)	+++	0.005 ppm	Leaf curl, severe downward bending, wilt like form
Melons	++	0.1 ppm	Loss of chlorophyll [12]
Mosaic plant (*Fittonia verschaffeltii*)	++	5 ppm for 3 days	Leaf abscission [6]
Nephthytis (*Syngonium podophyllum*)	++		Epinasty [6]

Table 1. continued.			
	Ethylene		
Crop	Sensitivity Range[z]	Concentration and Exposure Time[y]	Visual Symptoms and Reference[y]
Orchid, Cattleya	+++	0.04 to 0.1 ppm for 8 hrs	Termed "dry sepal"
		0.002 to 0.02 ppm for 24 hrs	Dying and bleaching of the sepals [13]
Pansy	+		[7]
Peperomia	++	1 ppm	Leaf abscission [6]
Pepper	++	0.5 ppm for 72 hrs or 1.0 ppm for 12 hrs	Abscission of leaves, flower buds, and immature fruit. Younger plants are more sensitive than more mature plants. [8]
Petunia	+++		Wilt like appearance (epinasty) [7]
Philodendron	++	5 ppm for 3 days	Leaf abscission and chlorosis [6, 7]
Poinsettia	++	10 ppm	Poinsettias demonstrate an interesting wilt like appearance (epinasty). Epinasty can be observed on poinsettia plants when they are held in shipping sleeves for a prolonged time. [14] Flower buds and leaves may abscise. [16] Growth can also be slowed at concentrations less than 10 ppm.
Pothos	++	>2 ppm	Foliage discoloration [6]
Primula	+++		Wilt like appearance of flowers [7]
Rose	++	0.5 ppm for 3 days	Premature flower senescence and bud abortion [7, 11]
Salvia	+++	1 ppm for 6 hrs	50% bud abscission [2]
Schefflera compacta	++		Leaf abscission [16]
Snapdragon	+++		Flower abscission
Spider plant	++	5 ppm with prolonged exposure	Wilt like appearance (epinasty). Plants recover after removal from ethylene source. [6]
Streptocarpus	++		Flower wilting and drop [10]
Sunflower	+++	0.005 ppm	Wilt like appearance [3]
		1 ppm	Reduced flower life [7]
Sweet pea	+++		Petal drop [13]
Tomato	+++	0.05 to 0.01 ppm	Epinasty, reduced leaf area, failture of plants to set fruit [4]
		1 ppm in 3 hrs	Epinasty (leaves pointed downward as if wilted, but the leaves are turgid)
Tulip	+++		Inhibits stem elongation, floral bud abortion and abnormalities [10, 13]
Vinca minor	++		Flower and flower bud abscission [16]
Zinnia	-	1 ppm for 6 hrs	No bud abscission [2]

lead to poorer plant growth, unless a distribution tube is installed to dilute the flue gas and mix the air, thus, reducing the concentration of harmful gases like ethylene.

Vented heaters also produce ethylene in the exhaust, but the difference is that the exhaust flows to the outside through a vent stack. Vent stacks should be located away from trees and nearby buildings and should extend 2 feet or more above the top of the greenhouse. They

References:

[z] Sensitity of plants to ethylene was adapted from Dole, J.M. and H.F. Wilkins. 1999. Floriculture principles and practices. Prentice Hall, Upper Saddle River, NJ. pp. 613.
"-": no effect; "+": slightly sensitive; "++": moderately sensitive; "+++": very sensitive

[y] Values and symptoms were adapted from (shaded areas indicate no data are available):
[1] Applied Science Associates. 1976. Diagnosing vegetation injury caused by air pollution. p. 10-14.
[2] Armitage, A.M.1993. Bedding plants: prolonging shelf performance. Ball Publishing. Batavia, Ill. pp. 69.
[3] Ball, V. 1980. Beware of unvented heaters, p. 67-69. In: V. Ball (ed.). The Ball Red Book., 13th ed., Geo. J. Ball Publishing, Batavia, IL.
[4] Blankenship, S.M. and J. Kemble. 1996. Growth, fruiting, and ethylene binding of tomato plants in response to chronic ethylene exposure. J. Hort. Sci. 71:65-69.
[5] Blankenship, S.M., D.A. Bailey, and J.E. Miller. 1993. Effects of continuous low levels of ethylene on growth and flowering of Easter lily. Scientia Horticulturae. 53: 311-317.
[6] Blessington, T.M. and P.C. Collins. 1993. Foliage plants: prolonging quality. Ball Publishing. Batavia, Ill. pp. 203.
[7] Dole, J.M. and H.F. Wilkins. 1999. Floriculture principles and practices. Prentice Hall, Upper Saddle River, NJ. pp. 613.
[8] Høyer, L. 1990. Developmental stage of *Capsicum annuum* 'Janne' determines the critical ethylene exposure. Acta Horticulturae 272:109-114.
[9] Mortensen, L.M. 1989. Effect of ethylene on growth of greenhouse lettuce at different light and temperature levels. Scientia Horticulturae 39:97-103.
[10] Nell, T.A. 1993. Flowering pot plants: prolonging shelf performance. Ball Publishing. Batavia, Ill. pp. 96.
[11] Piersol, J.R. 1974. Effect of ethylene on rose growth. Colo. Fl. Growers Assoc. Bull. 286:5-6.
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[13] Sacalis, J.N. 1993. Cut flowers: prolonging freshness. Ball Publishing. Batavia, Ill. pp. 110.
[14] Saltveit, M.E, D.M. Pharr, and R.A. Larson. 1979. Poinsettia epinasty: cause is known, cure is not. J. Amer. Soc. Hort. Sci., 104:452-455.
[15] Schouten, S.P. and H.W. Stork. 1977. Ethylene damage in eggplants. Do not keep with tomatoes! Groenten-en-fruit. 32:1688-1689.
[16] Woltering, E.J. 1987. Effects of ethylene on ornamental pot plants: a classification. Scientia Horticulturae 31:283-294.

should be terminated with at least 3 feet of vertical pipe equipped with a suitable cap. Vent pipes should be tight to reduce the chance of leaks and should be supported against the wind. Vent stacks should be checked periodically to make sure they are not blocked.

Oxygen Levels and Intake. Providing enough ventilation and intake of fresh air from outside the greenhouse is also critical. There should be 14 cubic feet of air for each cubic foot of gas burned (Flood, 1999) or 1 square inch of vent cross-sectional area of opening from outside air should be provided for every 2,500 Btu capacity of the heater (Nelson, 1991). The flame of the burner must be a clear blue. Yellow or orange flames indicate that there are impurities in the fuel or a wrong furnace setting. Some growers seal the ventilators completely at night in order to save heat. However, pollutant concentrations can rapidly build up without night venting. The installation of a pipe which takes in air when the furnace burner is ignited is advised.

Without enough oxygen, complete combustion does not occur. This results in dangerous levels of ethylene, sulfur dioxide, and other gases. Without fresh air, burners shut off when oxygen levels are ≤ 18.9%. Humans begin to experience discomfort at ≤ 17% oxygen. Oxygen can become depleted in 2 to 3 hours and lead to incomplete combustion when there is no venting and cold night temperatures require continual heater operation (Bartok, 1992).

Oxygen levels in the greenhouse are of primary concern when temperatures become cold and growers tend to seal their houses tightly for heating efficiency. Whether a grower is burning gas, oil, coal, or wood, a complex mixture of gases will be produced such as carbon monoxide, ethylene, nitrogen dioxide, or nitric oxide. If the fuel contains sulfur, sulfur dioxide is also produced. Plants are 5,000 times less sensitive to carbon monoxide than to ethylene (Post, 1950), but humans are highly sensitive to carbon monoxide poisoning. Sulfur dioxide can cause chlorotic spots and bleaching of interveinal areas. Cigarette smoking is a source not only of ethylene, but also of carbon monoxide and should not be allowed in the greenhouse.

Checklist. A check (Table 2) of all switches, belts, valves, bearings, motors, fans, thermostats, filters, pipes, and gas lines should be conducted to ensure everything is working correctly.

Determining Ethylene Levels. There are a number of methods, which can be used to determine ethylene levels. Indicator plants like tomatoes can be observed for drooping leaves and flower abscission, symptoms that detrimental levels of ethylene are present. Collecting a sample for testing on a gas chromatograph (GC) can also be used to measure the level of ethylene. (Consult the following article, entitled Ethylene Sampling Protocols for Greenhouse-Grown Crops, for steps to follow for testing ethylene by the NC State University Plant Disease and Insect Clinic.) Commercially available indicator tubes for ethylene can also be used, but they are usually not accurate enough to make a definitive diagnosis. When ethylene pollution is suspected or confirmed, check the items listed in Table 2 or call a furnace maintenance firm to inspect your unit.

For Further Reading:

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Bartok, J.W. 1992. Check your furnace when air pollution injury is suspected. Connecticut Greenhouse Newsletter. No. 170. p. 13-15.

Flood, David. 1998. Ethylene injury in floriculture. http://www.agf.gov.bc.ca/croplive/plant/horticcult/Ethylene.htm. 29 Mar. 1999.

Nelson, P.V. 1991. Greenhouse operation and management, 4th ed. Prentice-Hall, Englewood Cliffs, New Jersey. 612 pp.

Post, K. 1950. Florist crop production and marketing. Orange Judd, New York. p. 87-112.

Rodgers, M.N., 1980. Air pollution problems affect bedding plant producers, pp. 77-88. In: V. Ball (ed.). Ball Red Book. 13th Edition. Geo J. Ball, Inc.

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Table 2. Annual heating unit checklist.

Item	To do:
1. Heat Exchanger	Check for cracks. While the furnace is running inspect for light penetration.
2. Furnace	Check for leaks. Place a smoke bomb or furnace candle within the firebox.
3. Gas Lines	Check for leaks. Painting soapy water on the joints and seams.
4. Exhaust Chimney	Check for leaks and obstructions.
5. Pilot Light	Clean pilot and orifice.
6. Flame	Make sure the burner flame is clear blue. Yellow or orange flames represent impurities or a wrong setting.