ACROLEIN (2-PROPENAL): A POTENTIAL ALTERNATIVE

TO METHYL BROMIDE

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Jason Lamar Belcher

Certificate of Approval:

Rodrigo Rodríguez-Kábana
Distinguished University Professor
Entomology and Plant Pathology

Robert H. Walker, Chair
Professor
Agronomy and Soils

Elizabeth A. Guertal
Professor
Agronomy and Soils

George T. Flowers
Dean
Graduate School

ACROLEIN (2-PROPENAL): A POTENTIAL ALTERNATIVE TO METHYL BROMIDE

Jason Lamar Belcher

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ACROLEIN (2-PROPENAL): A POTENTIAL ALTERNATIVE TO METHYL BROMIDE

Jason Lamar Belcher

Signature of Author

Date of Graduation

VITA

Jason Lamar Belcher was born November 4, 1970 in and grew up in Auburn, Alabama. He attended Aubun University, receiving his Bachelor of Science degree in Wildlife Science in December, 1993. He then began graduate school in the Agronomy and Soils Department studying weed science, receiving his Master of Science Degree in May, 2001. He continued in his education in weed science at Auburn University, enrolling in a doctorate program in Agronomy and Soils. Jason is married to Ashley and they have three children, Piper, Braden, and Wren.

DISSERTATION ABSTRACT

ACROLEIN (2-PROPENAL): A POTENTIAL ALTERNATIVE

TO METHYL BROMIDE

Jason Lamar Belcher

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Vegetable producers face a variety of pest species that can negatively impact the performance of their crops. Nematodes, plant diseases, and several weed species, notably nutsedges (*Cyperus* spp.), are common problems in most areas where vegetables are commercially produced. Historically, growers have relied heavily on methyl bromide to fumigate their fields. Methyl bromide is a general biocide that effectively controls many fungi, bacteria, nematodes, and weeds. However, methyl bromide has been identified as an ozone-depleting compound. As a result, its use has been restricted as specified in the Montreal Protocol, which went into effect January 1, 1989. Currently there are no alternatives that can replace methyl bromide on a one-to-one basis. With the loss of methyl bromide, growers are forced to rely on compounds that may not be as effective at controlling pest species, and substantial losses in yield and quality can occur.

Research was initiated at Auburn University, Alabama to evaluate the potential for acrolein to be considered a viable methyl bromide alternative. Acrolein currently has registration as an aquatic herbicide (Magnacide H®). It provides excellent control of aquatic vegetation in irrigation canals in many countries, including the United States. The pesticidal properties of acrolein when applied to soils are unknown. Research focused on herbicical efficacy against yellow nutsedge (*Cyperus esculentus* L.) and crop tolerance, focusing on tomato (*Solanum lycopersicum* L.), bell pepper (*Capsicum annuum* L), and strawberry (*Fragaria x ananassa* Duchesne).

Greenhouse and field trials were conducted to evaluate acrolein rates ranging from 0 to 896 kg ai/ha applied as a fumigant application in greenhouse studies or when applied through irrigation drip lines in field experiments. Acceptable levels of control (>70%) for yellow nutsedge were achieved with acrolein rates of 448 kg ai/ha and higher. Enhanced growth of yellow nutsedge was observed at lower rates, indicating control of soil pathogens or a stimulation of beneficial organisms. Crop tolerance for all crops tested was excellent when planting was delayed 2 weeks after application. Earlier planting dates resulted in poorer plant health, particularly at rates higher than 448 kg ai/ha. Tomato yields were equivalent to methyl bromide at rates of 448, 672, and 892 kg ai/ha. Pepper yields with acrolein were equivalent to methyl bromide at 224 and 448 kg ai/ha, the only rates tested. Strawberry tolerance to acrolein was excellent when applied preplant. Strawberry yield was higher in plots receiving 448 kg ai/ha acrolein than with methyl bromide. Acrolein applied to strawberries after transplanting was too injurious at all rates evaluated and would not be advisable in sandy soils with low organic matter.

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Style manual or journal used ___Crop Science

Computer software used Microsoft Word XP, Microsoft Excel, Statistix 9, and SAS v.8

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I. LITERATURE REVIEW

INTRODUCTION

Methyl Bromide

Methyl bromide (CH_3Br) is a colorless, odorless gas that was first introduced as a pesticide in 1932 and registered for use in the United States in 1961 (Gehring 1991). It was one of the most widely used pesticides in the world. This widespread use is due to the range of pests controlled by this compound and includes nematodes, insects, and weeds, particularly *Cyperus* spp., as well as fungi and bacteria that cause plant diseases. Because methyl bromide is odorless, 2% chloropicrin is commonly added as an odorant to aid in detection, but it also supplements disease control at higher concentrations (Noling 2002).

Methyl bromide is used as a post-harvest storage protectant as well as a quarantine treatment to control pests of many crops; however, the majority of methyl bromide's use is for the pre-plant soil fumigation for vegetable crops grown under polyethylene mulch. Batchelor and Alfarroba (2002) reported that approximately 75% of all methyl bromide used was for soil fumigation purposes. In the United States, over 85% of methyl bromide used preplant in vegetable crops was for the production of tomatoes, strawberries, and peppers, with California and Florida accounting for most of this use (NASS 1997).

The Montreal Protocol is an international treaty that went into effect January 1, 1989. It was designed to protect the stratospheric ozone layer, which absorbs ultraviolent-B (UV-B) radiation. This treaty was signed by 191 countries and centers on the regulation and control of compounds that have been shown to deplete the ozone layer. These compounds all contain either chlorine or bromine and are collectively referred to as halogenated hydrocarbons. The ozone depleting potential of chlorofuoromethanes was first reported by Molina and Rowland in 1974. In 1985, scientists involved with the British Antarctic Survey published the results of a study that revealed a “hole” in the ozone layer over Antarctica (Nature). That same year, 20 nations signed the Vienna Convention establishing a framework for regulating ozone-depleting substances. Methyl bromide was added to the list of substances that deplete the ozone at the fourth conference of the parties of the Montreal Protocol in 1991 and was put on a timetable for gradual reduction (Watson et al. 1992). This timetable froze production and consumption of methyl bromide from 1993 to 1998 to a baseline level of that used in 1991. The reduction from baseline levels were as follows: 25% in 1999-2000, 50% 2001-2002, 70% 2003-2004, and complete phase out in 2005 for developed countries.

Methyl bromide is currently still in use. Critical use exemptions (CUE) allow the use of methyl bromide when there are no technically and economically feasible alternatives or substitutes available that are acceptable to the user in terms of the environment and health and are suitable to the crops and circumstances. The loss of methyl bromide to producers could result in the loss of efficiency and increase the costs of crop production unless viable alternatives are found.

Potential Methyl Bromide Alternatives

There has been a great deal of effort in the last several years to identify alternatives to methyl bromide. Various molecules have been proposed as methyl bromide replacements to control soilborne diseases, nematodes, and weeds in polyethylene-mulched crops

(Santos et al. 2006). The fungicide chloropicrin (Pic) has been used to control soil-borne pathogens, but this compound has limited weed and nematode control, thus it is typically applied with other compounds. One of the more promising treatments is the application of the nematicide 1,3-dichloropropene (1,3-D) plus chloropicrin. This combination has demonstrated that it can be an effective means to reduce the incidence of soilborne diseases in tomato (Jones et al., 1995; Locascio et al., 1997) as well as control of small-seeded weeds in horticultural crops (Gilreath et al., 1994; Jones et al, 1995). This combination is labeled and is sold under various trade names including Telone C-35 and Inline. Another product that has limited registration is the combination of iodomethane and chloropicrin, marketed under the trade name Midas®. This product has been reported as providing similar results as those obtained with methyl bromide in strawberry production in California (Ajwa et al., 2005) and tomato in Florida (Olson and Kreger, 2007). Other broad-spectrum fumigants which are registered for use in some crops include metam sodium and dazomet, which are both methyl isothiocyanate (MITC) generators. Both of these compounds have been tested under various conditions and have provided mixed results (Gilreath et al., 1994; Locasio et al., 1997). Metam sodium failed to reach pest control levels of methyl bromide + chloropicrin in one study (Locascio et al., 1997), whereas other research has found it to be a viable methyl bromide alternative (Vaculin and Hochmuth, 2003). Because metam sodium is a relatively low-cost product that can be sprayed on the soil surface or drip-applied, it should still be considered a viable alternative despite the variability in pest control (Santos et al., 2006).

Research on compounds that are not currently registered is ongoing. One potential compound is dimethyl disulfide (DMDS), also known as Paladin™. This compound does not yet have registration in the United States but has been issued an experimental-use permit for 2007-2008 by the U.S. Environmental Protection Agency. Studies conducted in North Carolina have reported that DMDS compares favorably to methyl bromide in tomato production (Welker et al., 2006 and 2007) while research in Florida showed promising results when compared to methyl bromide in terms of weed and disease control (Olson and Rich, 2007). Other chemicals, such as propylene oxide and sodium azide, have been tested with promising results (Belcher et al., 2004, Lopez-Aranda et al., 2004; Norton, 2004; Rodriguez-Kabana et al., 2003) but appear to be far from registration in vegetable crops.

Research continues on potential alternatives to methyl bromide. However, progress in this area can be hindered by a number of things: government restrictions, lack of funding, and a lack of acceptance by the end user, among others. Unless a suitable alternative or combination of alternatives is found, the costs to producers, and ultimately the consumer, will likely only increase as time passes.

ACROLEIN

Physiochemical properties

Acrolein (acrylaldehyde, prop-2-enal) was first recognized by J. Redtenbacher in 1843 during the dry distillation of fats and glycerol (Beauchamp et al, 1985). It is structurally the simplest of the class of α, β-unsaturated aldehydes (Fig. 1.1) and is a colorless, volatile, flammable, highly reactive liquid (Ghilarducci and Tjeerdema, 1995) characterized by a pungent odor. Acrolein is highly soluble in water as well as many organic solvents such as ethanol, acetone, and ether (Beauchamp et al., 1995). The high reactivity of acrolein originates from the conjugation of the carbonyl and vinyl group

(Fig. 1.1) (Ghilarducci and Tjeerdema, 1995), making acrolein a difficult compound to work with. As a result, hydroquinone is added (0.1-.025%) as an inhibitor and commercial acrolein is typically shipped under a blanket of oxygen-free inert gas (Albin, 1962), typically nitrogen. A summary of the chemical and physical properties of acrolein is shown in Figure 1.2. Elaborate and specific conditions are now prescribed for the storage of acrolein and include vents, safety valves, construction materials, fire control, spills, and waste disposal (Beauchamp et al., 1985).

Sources

Acrolein occurs in the environment from a number of sources. These sources are both natural and man-made and include: incomplete combustion of fuels and other organic compounds, industrial and manufacturing processes, photochemical oxidation of airborne hydrocarbons, and cigarette smoke (Eisler, 1994, Ghilarducci and Tjeerdema, 1995). The main source of atmospheric acrolein is incomplete combustion of organic material. Sources such as automobile exhaust, tobacco smoke, the burning of coal, oil and natural gas in power plants, as well as structural and vegetative fire smoke, all contribute to acrolein in the environment (Ghilarducci and Tjeerdema, 1995). Acrolein concentrations found in the exhaust of gasoline engines can contain up to 0.16 g/L while diesel engines may produce as high as 0.20 g/L (Guicherit and Schulting, 1985). Cigarettes have been measured to deliver up to 228 μg/cigarette (Rickert et al., 1980). Second-hand smoke may also expose non-smokers to acrolein as acrolein levels in enclosed areas where smoking occurs may reach 12,400 μg/L (Beauchamp et al. 1985). Many cities and communities have banned smoking in public areas due to the irritating nature of cigarette smoke, which is caused, in part, by acrolein. Some of the highest acrolein concentrations have been reported near forest fires and urban area fires (Beauchamp et al., 1985), exposing firefighters to very high levels of acrolein.

Toxicity

Acrolein is a highly toxic material. As a general plant cell toxicant, it kills cells through its reactivity, the destruction of cell membrane integrity (Ashton and Crafts, 1981), and through its affinity for sulfhydryl groups, causing interruption of vital cell enzyme systems (WSSA, 2007). These characteristics also make this reactive compound an effective general biocide (Ghilarducci and Tjeerdema, 1995).

Aquatic organisms appear particularly sensitive to acrolein. Concentrations (µg/L) resulting in death were: 7 for frog tadpoles, 14-62 for fish, and 34-80 for crustaceans. Several species of submerged aquatic plants have been reported as being controlled with acrolein at rates ranging from 1500-7500 µg/L (Ferguson et al., 1961; Beauchamp et al., 1985). Floating plants appear more tolerant of acrolein and concentrations required for control may be double that of submerged species (Ferguson et al., 1961). Terrestrial plants appear more tolerant of acrolein. Several crop species, including corn (*Zea mays*), cotton (*Gossypium hirsutum*), and tomato (*Lycopersicon esculentum*), have been shown to tolerate concentrations of acrolein in water up to 80,000 µg/L (Ferguson et al., 1961).

Animal and human exposures can cause acute pulmonary and respiratory tract damage, ocular irritation, and, if ingested, nausea, vomiting, collapse, and coma (Ghilarducci and Tjeerdema, 1995). Prolonged exposure may lead to death. Acrolein was lethal to birds at single oral doses of 9,100 µg/kg body weight while 3,300 µg/kg body weight produced signs of acrolein poisoning (Eisler, 1994). In mammals, lethal doses ranged from 4000 µg/kg body weight for guinea pigs to 28,000 µg/kg body weight in mice when administered orally. No dermal sensitization occurred in female guinea pigs after repeated skin exposure to acrolein (Susten and Breitenstein, 1990). In undiluted or vapor form, acrolein produces intense irritation in the eyes and mucous membranes of the respiratory tract and direct contact with the liquid can produce skin or eye necrosis (Beauchamp et al., 1985). Carcinogenicity, embryotoxicity, and teratogenicity are possible when acrolein occurs as a metabolite near the target site, but are not a likely result when it is encountered as an environmental contaminant (Ghilarducci and Tjeerdema, 1995).

Although acrolein can be highly toxic to humans, its irritating odor and lachrymatory properties serve to warn of possible exposure. Humans can begin detecting acrolein at a concentration of 0.07 mg/m^3 and recognize the odor at 0.48 mg/m^3 (Ghilarducci and Tjeerdema, 1995). Because these levels are well below the levels considered toxic to humans, the risk of lethal exposure is limited.

Environmental Fate

Acrolein emitted to air reacts primarily with photochemically generated hydroxyl radicals in the troposphere (Ghilarducci and Tjeerdema, 1995). Other processes that may have a minimal impact on acrolein in the atmosphere are reactions with nitrate radicals, direct photolysis, and reactions with ozone (Atkinson et al., 1987; Haag et al., 1988; Howard, 1989). Additionally, acrolein has been detected in rainwater, indicating it may be removed by wet deposition (Grosjean and Wright, 1983). Atmospheric half-life of acrolein has been calculated as being 3.4-33.7 hours (Atkinson, 1985; Haag et al., 1988, Howard, 1989). The overall reactivity-based half-life of acrolein in air is less than 10 hours (Mackay et al., 1995).

In surface waters, acrolein is removed mainly by reversible hydration, biodegradation, and volatilization (Bowmer and Higgins, 1976; Howard, 1989, Tabak et al., 1981). In groundwater, acrolein is removed through degradation by anaerobic bacteria and hydrolysis (Chou and Spanggord, 1990). The overall reactivity-based half-life of acrolein in surface water is estimated to be 30-100 hours (Mackay et al., 1995). Dissipation half-lives of acrolein applied as a herbicide to water in irrigation canals has been reported as approximately 9 hours (Bowmer and Higgins, 1976, Nordone et al., 1996). In terrestrial environments, acrolein undergoes biodegradation, hydrolysis, volatilization, and irreversible sorption to soil (Howard, 1989; Chou and Spanggord, 1990) with an overall reactivity-based half-life of 30-100 hours (Mackay et al., 1995).

Acrolein's physical and chemical properties, such as high water solubility and high reactivity, suggest low uptake by organisms (Ghilarducci and Tjeerdema, 1995). Studies conducted by Veith et al. (1980) on fish and shellfish found no acrolein in tissue when sampled 1 day after a second exposure to radio-labeled acrolein. The presence of metabolites indicates that these species were able to rapidly metabolize acrolein and its residues (Nordone et al., 1998). Acrolein acts as a contact herbicide on aquatic plants, reacting with sulphydryl groups on a variety of biomolecules, destroying enzyme systems and cell membranes (Bentivegna and Fernandez, 2003). Acrolein has been shown to be poorly absorbed by terrestrial plants (WSSA, 2007).

Uses

Approximately 47,600 lbs. of acrolein were produced in the United States in 1980 (U.S. EPA) with worldwide production being over 113,000 tons (Kroschwitz, 1991).

Acrolein is used as an intermediate in the production of other substances such as animal feed additives, water treatment in many industrial settings and as an intermediate in the formation of other compounds. Oil companies also use acrolein to scavenge hydrogen sulfide from petroleum and to cleanse wells of sulfur-producing bacteria. Acrolein has also been used to control ground squirrels in California (Clark, 1994). The majority of acrolein produced is converted to acrylic acid while 3% is used for aquatic weed control (Beauchamp et al, 1985). Much of the research conducted with acrolein has involved assessing its use as an aquatic herbicide. Since 1960, acrolein has been used to control submerged aquatic weeds in irrigation systems in the United States, Austrailia, and other countries where open channels distribute water for crop production (Hill, 1960; Bowmer and Higgins, 1976). Currently, acrolein is marketed under the trade name Magnacide H®.

POTENTIAL AGRICULTURAL USES OF ACROLEIN

The use of acrolein to control aquatic vegetation in irrigation canals has been well documented (Bowmer and Sainty, 1977; Bowmer, 1979; Bentivegna et al., 2004). In most instances, proper water flow was restored relatively quickly (Bowmer and Sainty, 1979; Bentivegna and Svachka, 1997; Bentivegna et al., 1998) and acrolein was found to be a low-cost alternative for reducing submerged plant biomass (Bentivegna and Fernandez, 2005). Crops treated with irrigation water from canals where acrolein has been applied have shown no adverse effects from acrolein. Studies conducted in peppers (*Capsicum* sp.) (Caldironi et al., 2004) and leaf lettuce (*Latuca* sp.) (Nordone et al., 1997) revealed that acrolein does not accumulate either on or in these crops and that the use of acrolein-treated water on agricultural crops is safe. Crops that have had acrolein-treated water applied to them have also been reported as exhibiting enhanced growth. Acrolein has also been evaluated as a stored product fumigant. Pourmirza (2006) evaluated acrolein for control of several insect species in stored wheat (*Triticum aestivum* L). The results from that study found that acrolein did control all stages of insects in this trial. However, wheat seed viability was diminished. These results indicate that acrolein could be a potential compound for empty-space fumigations.

Little information is available on other agricultural uses of acrolein. Several patents exist that refer to the use of acrolein as a fungicide and a nematicide, with references being made to weed activity (Kreutzer, 1962; Werle et al., 1997; Allan and Schiller, 2007), however, little to no data has been reported as a result of these patents. A study evaluating several compounds for nematode control in a replanted plum tree orchard (*Prunus* spp.) evaluated acrolein applied as a drench at 366 kg/ha (McKenry et al., 1995). One year after treatment nematode control was 50% and considered unsatisfactory. However, plum tree growth was 8.3 times greater than the non-treated trees.

RESEARCH JUSTIFICATION

With the loss of methyl bromide, vegetable growers are faced with the challenge of finding an economical, effective alternative for control of weeds, nematodes, and disease. Currently, there is no one compound that is a replacement for methyl bromide. Research has focused mainly on relatively few compounds. These compounds usually have to be combined in order to achieve the spectrum of pests controlled by methyl bromide. Therefore, research is needed in this area to find alternatives to fill the void left by methyl bromide. Because acrolein has been shown to provide excellent control of aquatic plants, and because there is evidence that it has activity on many of the problem pests in vegetable crops, research is needed to evaluate its potential as an alternative to methyl bromide. Registration of acrolein in vegetable crops may prove to be an easier task than other potential alternatives being researched as acrolein currently has registration with the United States Environmental Protection Agency (U.S. EPA) under the aquatic herbicide Magnacide H®.

GENERAL OBJECTIVES

The general research objectives were:

i) Determine the rate of acrolein needed for acceptable nutsedge (*Cyperus* spp L.) control;

ii) Determine the safe interval for crop planting following acrolein application;

iii) Evaluate tomato and bell pepper response to acrolein applied preplant in terms of plant health and yield;

iv) Evaluate strawberry response to acrolein applied preplant and post-transplant.

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Figure 1.1. Acrolein Structure

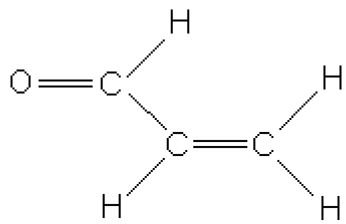
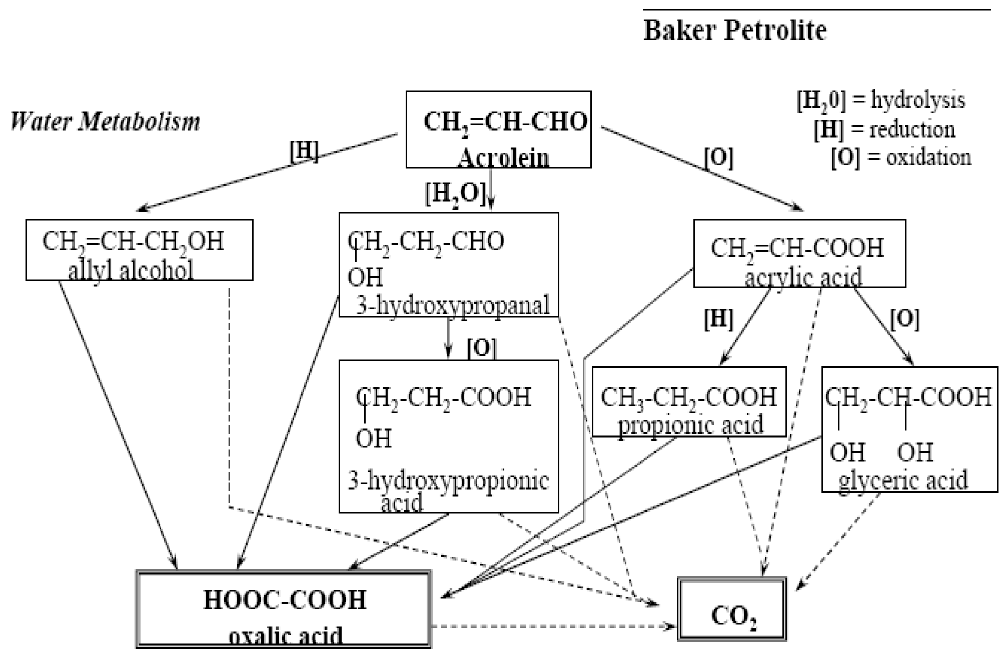


Figure 1.2. Physical and Chemical Properties of Acrolein

Chemical Name	2-propenal **Alternate names**: acraaldehyde, acraldehyde, acrolein, acryladehyde, acrylaldehyde, acrylic aldehyde, allyl aldehyde, aqualin, aquilin, Magnacide H, propenal
CAS Number	107-02-8
Structural formula	CH2=CHCHO
Molecular weight	56.06
Specific Gravity	0.8427 - 0.8442
Color	Clear to yellow liquid
Odor	Extremely irritating and pungent
Boiling Point	52.5 - 53.5ºC
Melting Point	-86.95ºC
Solubility: Water Organic Solvents	 206 - 208 grams/L Miscible
Vapor Pressure	215 - 0220 mm HG at 20 ºC
Explosive limits of acrolein vapor	2.8 - 31% in air

Figure 1.3. Acrolein metabolism in water.



Baker Hughes - Baker Petrolite
12645 West Airport Blvd.
Sugar Land, Texas 77478

II. YELLOW NUTSEDGE CONTROL WITH ACROLEIN (2-PROPENAL)

Abstract

Greenhouse and field studies were conducted to evaluate yellow nutsedge control with several rates of acrolein. Greenhouse experiments evaluated acrolein when applied as a fumigant in sealed chambers. Field experiments were conducted under normal growing conditions with acrolein applied as a drip application under high-density polyethylene (HDPE) mulch. Rates tested in greenhouse studies ranged from 0 – 896 kg ai/ha. Rates tested in the field were 224 and 448 kg ai/ha. Methyl bromide (67% methyl bromide, 33% chloropicrin) was included in field experiments as a standard at a rate of 392 kg ai/ha.

Results from greenhouse studies indicate that as acrolein rate increased, so did nutsedge control. Complete control of nutsedge was obtained with 896 kg ai/ha of acrolein, but this was not significantly higher than control achieved with 448 kg ai/ha. These results suggest that 448 kg ai/ha may be sufficient to provide acceptable nutsedge control under field conditions. Results from field tests varied. In one trial, acrolein provided higher control of yellow nutsedge than methyl bromide, 74% versus 33%, respectively, while another trial showed that control of yellow nutsedge with 448 kg ai/ha of acrolein was equivalent to methyl bromide.

Data from these studies demonstrate that acrolein applied at 448 kg ai/ha or higher provided control of yellow nutsedge that was equivalent to, or better than, methyl bromide.

Introduction

Yellow (*Cyperus esculentus* L.) and purple nutsedge (*C. rotundus* L.) are problematic weed species that commonly occur in vegetable production. They are considered some of the most noxious weeds worldwide based on the number of countries that report nutsedge as a troublesome weed (Holm et al. 1991). Typically, farmers have relied on methyl bromide, a soil fumigant, for control of these species. However, because methyl bromide has now been phased out as a result of the Montreal Protocol, farmers are left with few options. Other compounds exist that may potentially be used in vegetable production as alternatives to methyl bromide. One such compound is 1,3-dichloropropene (1,3-D). Studies have shown that when combined with chlroropicrin, another soil fumigant, the potential for weed control equivalent to methyl bromide is possible (Gilreath et al., 1994). Another material that is commonly used is metam sodium. Metam sodium is a methyl isothiocyanate (MITC) generator that is comparatively cheap when compared to methyl bromide and can be sprayed on the soil surface and incorporated or drip-applied. One problem with this compound is that nutsedge control has been reported as somewhat variable. Studies conducted by Locascio et al. (1997) demonstrated that control levels did not reach those provided by methyl bromide while other studies have reported it to be a viable alternative to methyl bromide (Ajwa et al., 2003; Vaculin and Hochmuth, 2003). Other products have been tested in vegetable crops for nutsedge control, yet few are out of the experimental phase of evaluation.

Acrolein (2-propenal) is a simple aldehyde discovered by Redtenbacher in 1843. It is a pungent-smelling liquid that will volatilize when exposed to air. It is also highly soluble in water. Acrolein is produced from many natural sources anytime organic material undergoes combustion. Forest fires, cigarette smoke, and the burning of fats all are natural sources of acrolein. The majority of acrolein produced in industry goes toward the production of acrylic acid and acrylic acid esters (Beauchamp et al., 1985). Other uses include the control of bacteria, fungi, algae, and molluscs in cooling-water systems (Donahue et al., 1966), a sulfide scavenger in the oil production systems, and a host of other uses in industry. The main agricultural use of acrolein is for the control of aquatic weeds in irrigation canals. Since 1960, acrolein has been used in this manner in the United States, Australia, Argentina, and other countries where open channels distribute water for crop production (Hill, 1960; Bowmer and Higgins, 1976). Acrolein is currently labeled for aquatic weed control under the trade name Magnacide H®. It is a general cell toxicant that reacts with sulfhydryl groups on a variety of biomolecules, destroying enzymes and disrupting plant metabolic pathways (WSSA, 2007). Research has shown that irrigation water treated with acrolein has no detrimental effects on peppers (*Capsicum* spp L.) or leaf lettuce (*Latuca sativa* L.) and does not accumulate in the leaves, roots, or plant surfaces (Caldironi et al., 2005; Nordone et al., 1997). Little data is available on the potential use of acrolein on terrestrial plants, particularly as a soil fumigant for weed control. One study evaluated acrolein in orchard replanting (McKenry et al., 1995) and there are several patents on file regarding the potential for acrolein to be used in agricultural crops to control not only weeds, but nematodes and diseases as well. However, there is little published information on application methodology or results from any experiments that have been done. Therefore, this research was conducted to evaluate acrolein for control of yellow nutsedge in both greenhouse and field settings.

Materials and Methods

Except where noted, all greenhouse experiments consisted of a completely randomized design with four replications for each treatment. Field trials used a randomized complete block design with four replications. Analysis of variance (ANOVA) was conducted on all experiments and means were separated at the $p = 0.05$ level of significance when F values were significant.

Three initial greenhouse studies were conducted in 2005 to determine the rate of acrolein needed to provide an acceptable level of nutsedge control. Acrolein rates tested were: 0, 112, 224, 448, and 896 kg ai/ha. A sandy-loam soil with pH 6.1 was collected from the E.V. Smith Research Center's Plant Breeding Unit for use in these experiments. This soil has a very low organic matter (<1%) and CEC (typically less than 4.6 cmol/kg). One kilogram of soil was place in each fumigation chamber. Fumigation chambers (Figure 2.1.) were constructed of PVC which were capped on the bottom and had a removable plug on the top. Chambers had a diameter of 10 cm and were 30 cm tall. A 7.6 cm long glass tube was inserted 3.8 cm from the bottom of the tube and sealed to allow for injection of acrolein into the chamber. This tube was then plugged after injection. Purchased yellow nutsedge nutlets were used in these studies. Five nutlets were sealed in nylon mesh bags and placed in the chamber with a 5 cm layer of soil covering the bags. The appropriate rate of acrolein was then administered into the chamber through the glass tube, using a micro-syringe to inject the liquid into the soil. Chambers were then left sealed for 6 days. The tops were removed on the 7th day to allow the soil to air. Bags were then removed from treated soil, opened, and nutlets planted into cups containing a sterile mix of sand (90%) and peat moss (10%). These cups were then watered daily and the number of yellow nutsedge shoots was recorded 3 weeks after planting (WAP).

Two additional greenhouse studies were conducted in 2005 to further evaluate acrolein rates. Methodology was similar to previous greenhouse studies, however, rates tested were over a narrower range in order to develop a better understanding of the optimal rate required for acceptable nutsedge control. Rates tested were: 0, 448, 560, 672, and 784 kg ai/ha. Additionally, soil was removed from the fumigation chambers and placed into 1-liter cups. Five soybean [*Glycine max* (L.) Merr.) seeds were then planted into cups in order to determine a safe plantback interval. Soybean seeds were planted into cups 1, 3, and 5 weeks after treatment and the number of germinated seeds was counted and dry weights were recorded 2 weeks after each planting.

Observations made during field studies the previous season indicated that postemergence (POST) control of yellow nutsedge may provide higher levels of control than obtained with preemergence (PRE) applications. As a result, a greenhouse study was carried out in 2006 to compare yellow nutsedge control with acrolein as either a PRE or POST application. Rates evaluated were: 0, 224, 448, 672, and 896 kg ai/ha. The same soil type used in previous studies was also utilized in this study. One kilogram of soil was placed into 1-L cups lined with low-density polyethylene (LDPE) bags. Five nutsedge nutlets were planted in cups receiving POST applications 2 weeks prior to nutlet planting for PRE applications. This was done to allow nutsedge for POST treatments time to begin shoot growth. Acrolein was mixed with a volume of water equivalent to 20,805 L/ha and applied as a drench application to the appropriate cups two days after

PRE nutsedge had been planted. Bags were then sealed for 1 week at which point they were reopened and watered. Shoot numbers were counted and dry weights taken 4 WAT.

A field trial was initiated April 18, 2007 in Brewton, Alabama to evaluate yellow nutsedge control with acrolein compared to other treatments available to growers. Soil at this location is a Benndale fine sandy loam soil with ph = 5.8 and CEC of <4.3 cmol kg^{-1}. Treatments and rates are shown in Table 2.1. Methyl bromide (67% methyl bromide, 33% chloropicrin) was shank-injected (3 shanks with 30.5 cm spacing) while acrolein and metam sodium (Vapam®) were drip-applied in 41,610 L of water/ha. Halosulfuron was sprayed to the bed surface prior to tarping. Each bed (0.75 m wide x 10 cm high) contained 2 drip tapes and were covered with high-density polyethylene mulch (HDPE). Metam sodium was applied to the appropriate beds 1 week after acrolein application. Beds were formed and 3 rows of yellow nutsedge were planted 2.5 cm deep on the bed surface at study initiation. Each plot contained 15 "hills" of nutsedge with each hill receiving two nutlets. Percent nutsedge control was recorded 7 WAT. The number of hills with germinated nutsedge as well as green weights were recorded for each plot.

Results and Discussion

Results from the three initial greenhouse experiments are shown in Table 2.2. The 448 kg ai/ha rate provided a substantial decrease in number of shoots while the highest rate tested, 896 kg ai/ha, provided complete control of yellow nutsedge. Because of the large gap in these rates, further testing was necessary to gain a better understanding of the optimum rate for control of yellow nutsedge.

All acrolein rates tested significantly reduced yellow nutsedge shoots compared to the nontreated in greenhouse studies evaluating acrolein over a narrow rate range (Table 2.2). There were no statistical differences among acrolein rates, although 672 kg ai/ha was required for total control. Plant-back data revealed that all acrolein rates significantly reduced soybean numbers and dry weights when planted 1 WAT (Table 2.3). No significant reduction of soybean number or dry weight was observed at either the 3 WAT plant-back (Table 2.3) or the 5 WAT plant-back (Table 2.3). The data also show that there was a slight trend for enhanced growth with the 448 kg ai/ha rate.

Data analysis from greenhouse research revealed no differences in nutsedge shoot numbers or dry weights between PRE and POST applications of acrolein. Results detailing rate effects on nutsedge shoot number and weights are shown in Table 2.4. Acrolein rates of 448 kg ai/ha and higher significantly reduced yellow nutsedge growth, providing almost complete control.

Results from the field experiment are shown in Table 2.5. Treatments that provided the highest level of nutsedge control and most growth reduction was the 358 kg ai/ha rate of metam sodium, halosulfuron (Sandea ®) + acrolein, and the Vapam + acrolein treatments. Acrolein applied alone outperformed methyl bromide. However, time of planting may have negatively affected methyl bromide's performance as dry nutlets were planted and these may not have begun to actively initiate growth until methyl bromide had dissipated.

Conclusions

Acrolein applied as a fumigant or in drench applications provided acceptable control of yellow nutsedge at rates of 448 kg ai/ha and above in greenhouse and field settings.

Plant-back results indicate that the interval needed for a safe plant-back was between 1 and 3 weeks, well within the range required by other compounds such as metam sodium and 1,3-D. Results from these studies indicate that acrolein should be considered as a viable methyl bromide alternative in terms of nutsedge control and crop safety on soybeans.

Figure 2.1: Fumigation Chamber used in 2005-2006 greenhouse studies.

Table 2.1. Experimental treatment list for 2007 field trial, Brewton, Alabama

Treatment	Application rate	Application method
--------------------------------	kg ai/ha	--------------------------
Methyl Bromide (67%)[a]	392	Shank inject
Metam sodium[b]	358	Drip
Metam sodium	179	Drip
Acrolein	448	Drip
Acrolein + metam sodium	448 + 179	Drip + drip
Halosulfuron[c]	0.392	Spray
Halosulfuron + acrolein	.392 + 448	Spray + drip
Non-treated	0	-

[a]Mix of 67% methyl bromide, 33% chloropicrin

[b]Vapam HL®, Amvac Chemical Corporation LLC, Los Angeles, CA 90023

[c]Sandea herbicide, Gowan Company LLC, Yuma, AZ 85364

Table 2.2. Number of yellow nutsedge shoots/cup[a]

Acrolein rate	2005 Greenhouse Studies 1-3	2006 Greenhouse Studies 4-5
kg ai/ha	--------------------------shoots/cup	--------------------------
0	6.7	5
112	5.8	-[b]
224	5.1	-
448	1.8	0.63
560	-[b]	0.25
672	-	0
784	-	0
896	0	-
LSD (0.05)	**1.9**	**1.2**

[a]Shoot counts taken 3 weeks after treatment at Auburn, AL

[b]Rates not included in these studies

Table 2.3. Soybean germination and shoot dry weight as affected by acrolein rate[a]

Acrolein rate	Soybean plantback timing					
	--------1 WAT--------		------3 WAT------		------5 WAT-----	
kg ai/ha	Number germinated soybeans	Shoot dry weight (g)	Number germinated soybeans	Shoot dry weight (g)	Number germinated soybeans	Shoot dry weight (g)
0	4.63	1.03	4.0	0.72	3.13	0.71
448	0.75	0.06	4.4	0.79	4.38	0.88
560	0	0.00	4.0	0.67	4.38	0.85
672	0	0.00	3.5	0.60	3.88	0.74
784	0	0.00	3.9	0.70	3.86	0.71
LSD (0.05)	0.67	0.09	1.1	0.20	0.86	0.20

[a]Data recorded 2 weeks after planting from 2006 greenhouse studies 4-5 at Auburn, AL.

Table 2.4. Yellow nutsedge control with acrolein applied pre- and postemergence[a]

Acrolein rate kg ai/ha	Number of shoots	Dry weight (g)
0	5.50	0.90
448	3.60	0.31
560	0.00	0.00
672	0.38	0.01
784	0.00	0.00
LSD (0.05)	**1.21**	**0.25**

[a]Data collected 4 WAT from a greenhouse study at Auburn, AL; data summed over timings.

Table 2.5. Effect of treatments on percent yellow nutsedge control, number, and green weight.[a]

Treatment	Rate	---------------Yellow Nutsedge---------------		
	kg ai/ha	% Control	Shoot Number	Green weight (kg)
Methyl Bromide	392	32.50	10.25	7.52
Metam sodium	358	93.75	0.75	1.83
Metam sodium	179	47.50	4.50	8.01
Acrolein	448	73.75	3.75	3.83
Acrolein + metam sodium	448 + 179	90.75	1.00	1.72
Halosulfuron	0.392	21.25	11.25	6.69
Halosulfuron + acrolein	0.392 + 448	95.00	1.50	0.04
Non-treated	0	16.25	14.00	11.73
LSD (0.05)		**21.86**	**4.07**	**1.80**

[a]Visual estimates control taken 7 WAT, shoot number and green weights recorded 10 WAT from a 2007 field trial at Brewton, AL.

III. TOMATO AND PEPPER RESPONSE TO ACROLEIN (2-PROPENAL)

Abstract

With the loss of methyl bromide, vegetable growers are forced to use newer compounds for preplant pest control. Acrolein is one experimental compound being evaluated as a potential methyl bromide alternative. Research was conducted to evaluate tomato (*Lycopersicon esculentum* Mill.) tolerance to acrolein at rates of 0, 112, 224, 448, 672 and 896 kg ai/ha when planted 1, 7, 14, and 21 days after treatment (DAT). Additional research was conducted evaluating acrolein at 224 and 448 kg ai/ha applied at varying concentrations in irrigation water to tomato and bell pepper (*Capsicum annuum* L). Methyl bromide (67/33) was applied at 392 kg ai/ha as a standard. The safe plantback interval for rates of 448 kg ai/ha and higher was determined to be at least 14 days after treatment. Tomato vigor and yield were equivalent to methyl bromide under these conditions. Earlier plant-back resulted in decreased vigor, growth, and yield. Acrolein concentration in irrigation water did not affect vigor or yield for either tomato or bell pepper.

Introduction

Tomatoes (*Lycopersicon esculentum* Mill.) and bell pepper (*Capsicum annuum* L.) are two of the most important vegetable crops grown in the United States. Worldwide, tomato production in the United States accounted for 10% of the worldwide area planted for tomato production with a gross value of $1342 million (FAO, 2005; USDA 2005).

Unfortunately, climatic conditions that tomatoes are grown in also support a host of pest problems including nematodes, diseases, and weeds. Often, pressure from these pest species is severe enough to cause significant reductions in the quality and amount of yield. As a result, growers are forced to adopt management practices to combat these problems. Typically, growers combine several methods to manage pest species, including the use of polyethylene mulch, fumigation, and herbicides (Gilreath and Santos, 2004).

Methyl bromide has traditionally been the fumigant of choice as it controls a wide range of nematode, fungal, bacterial, and weed species. However, methyl bromide has been identified as an ozone-depleting compound and is being phased out worldwide as called for in the provision of the Montreal Protocol (Watson et al., 1992). As a result, alternative compounds are being researched for use in vegetable crops to prevent yield losses due to the aforementioned pest species.

One of the more promising treatments is a combination of 1,3-dichloropropene (1,3-D) with chloropicrin. This combination has been reported as being effective against soilborne diseases and nematodes (Noling and Gilreath, 2001) and is among the most promising methyl bromide alternatives (Locacascio et al, 1997). Metam sodium (Vapam®) is another alternative that has been shown to be effective preplant soil fumigants. Both 1,3-D + chloropicrin and metam sodium are registered for use in vegetable crops. However, weed control with these compounds has provided mixed results (Gilreath et al., 1994; Locacascio et al, 1997). Other compounds that are being researched and have shown some promise include propylene oxide (Belcher et al., 2004) and sodium azide (Rodriquez-Kabana et al., 2003), however, data for these compounds are limited and have not been tested on a large scale.

Acrolein (2-propenal) is a simple aldehyde discovered by Redtenbacher in 1843. It is a pungent-smelling liquid that will volatilize when exposed to air. It is also highly soluble in water. Acrolein is produced from natural sources when organic material undergoes combustion. Forest fires, cigarette smoke, and the burning of fats all are natural sources of acrolein. Some of the uses of acrolein include the control of bacteria, fungi, algae, and molluscs in cooling-water systems (Donahue et al., 1966), a sulfide scavenger in the oil production systems, and many other industrial uses. The main agricultural use of acrolein is for the control of aquatic weeds in irrigation canals. Since 1960, acrolein has been used in this manner in the United States, Australia, Argentina, and other countries where open channels distribute water for crop production (Hill, 1960; Bowmer and Higgins, 1976). Acrolein is currently labeled for aquatic weed control under the trade name Magnacide H®. Acrolein is a general cell toxicant that reacts with sulfhydryl groups on a variety of biomolecules, destroying enzymes and disrupting plant metabolic pathways (WSSA, 2007). Research has shown that irrigation water treated with acrolein has no detrimental effects on peppers (*Capsicum* spp) or leaf lettuce (*Latuca sativa* L.) and does not accumulate in the leaves, roots, or plant surfaces (Caldironi et al., 2005; Nordone et al., 1997). This research indicated that acrolein may have the potential to be used as a fumigant in vegetable production. However, research is limited on the potential for acrolein to be used in this manner. One study evaluated acrolein in orchard replanting for control of nematodes (McKenry et al., 1995). Nematode control was considered unacceptable, but researchers did note an increase in plant growth with the use of acrolein. Additionally, there are several patents on file regarding the potential for acrolein to be used in agricultural crops to control not only weeds, but nematodes and diseases as well. However, there is little published information on application methodology or results from any experiments that have been done. Therefore, this research was conducted to evaluate the response of tomato and bell pepper to preplant applications of acrolein.

Materials and Methods

All experiments consisted of a randomized complete block design with four replications for each treatment. Except where noted, all acrolein treatments were drip-applied in 41,610 L/ha with two drip tapes per bed. Beds were covered with HDPE (high density polyethylene mulch) and were 10 cm high and 0.75 m wide. Standard fertility and cultural recommendations for tomato production were followed. Methyl bromide (67% methyl bromide, 33% chloropicrin) was applied in all experiments as the standard at 392 kg ia/ha. Analysis of variance (ANOVA) was conducted on all experiments and means were separated at the p = 0.05 level of significance when F values were significant.

A field experiment was initiated April 26-27, 2006 at the Brewton Experiment Field in Brewton, Alabama. This area is a 'Benndale' fine sandy loam soil with the main pest being root-knot nematode (*Meloidogyne* spp.). The purpose of this experiment was to determine the safe plant-back interval for tomato following acrolein application. Acrolein rates tested were: 0, 112, 224, 448, 672 and 896 kg ai/ha. Tomatoes were planted at 1, 7, 14, and 21 days after treatment (DAT). Vigor ratings as well as percent dead plants were taken 6 WAT. Stem diameters were also measured on the 14 and 21 day plantings only, 7 WAT. Measurements were taken with electronic calipers 2.5 cm above the point where tomato stems emerged from the soil. Yield data include total number and total marketable weight for each treatment in each plant-back interval.

A second field trial was established at Shorter, Alabama at the E.V. Smith Horticultural Research Unit and was initiated May 22-23, 2006. This location has a 'Orangeburg' sandy loam soil with the main pests being a sedge species (*Cyperus strigosus*) and *Fusarium* crown and root rot (*Fusarium oxysporum*). Acrolein rates tested were: 0, 112, 224, 448, 672 and 896 kg ai/ha. Due to phytotoxicity recorded in the 1-day plantback in Experiment 1, this plant-back interval was dropped at this location. Therefore, only the 7, 14, and 21-day plant-back were evaluated. Vigor ratings as well as percent dead plants were taken 7 WAT. Yield data included the number and weight of tomato fruit in each treatment for each plant-back interval.

A field experiment was initiated April 18-19, 2007 at the Brewton Experiment Field in Brewton, Alabama.to evaluate the effects of acrolein concentration on tomato and bell pepper. Soil at this location is a Benndale fine sandy loam soil with ph = 5.8 and CEC of <4.3 cmol kg^{-}1. Typically, chemical applications are applied in 41,610 L/ha. This study was conducted to determine the effects of higher concentrations of acrolein. Therefore, three rates of acrolein, 0, 224, and 448 kg ai/ha, were applied in 41,610 L/ha of water over a 3-hour period, the time usually required to put this volume of water on at this location. Concentrations were tested by applying rates at 100%, 75%, and 50% of the standard time, giving a low, medium, and high concentration. Methyl bromide was included at 392 kg ai/ha. Treatments are listed in Table 3.1. Tomatoes were planted either 14 or 21 DAT while peppers were planted 21 DAT. Data was collected for plant vigor and growth as well as yield. Vigor was rated on a scale of 0-10 with 0 being the best.

Results and Discussion

Results from the 2006 study at the Brewton, Alabama location indicated that as rate increased, longer intervals were needed to avoid loss of vigor (Table 3.2) and increased mortality (Table 3.3). However, it must be noted that tomatoes in the 1- and 7-day plant-back date were damaged by a hailstorm, and may have resulted in poorer observations for these timings. In general, plant vigor and tolerance was excellent for all treatments in both the 14 and 21-day plant-back timings, some differences were noted in stem diameters (Table 3.4). This trend followed when inspecting yield results (Tables 3.5-3.8). All acrolein rates were significantly lower than either the nontreated or methyl bromide at the 1 and 7-day plantings. However, yields were equivalent for all treatments except the nontreated at the 14 and 21-day plant-back timings.

Results from the study conducted in 2006 at the Shorter, Alabama location were affected both by improper application of glyphosate and the onset of bacterial leaf spot, forcing an early harvest of green tomatoes. As a result, any inferences made from the data must take these facts into consideration. Plant vigor and percent dead plants are shown in Tables 3.9 and 3.10, respectively. Due to high variation within plots, no patterns were discernible among planting dates or treatments. Yield data (Table 3.11) from this study were also misleading, although the 224 and 448 kg ai/ha rates of acrolein provide yields equivalent to methyl bromide and significantly higher than the nontreated.

Results from the 2007 study conducted at Brewton, AL indicated that concentration had little effect on tomato growth in terms of stem diameter or vigor (Table 3.12).

Similarly, pepper vigor was not affected by acrolein concentration (Table3.13), although some differences were noted among individual treatments. Tomato yield was unaffected by acrolein concentration (Table 3.14). All concentrations within the tested rates were equivalent. No differences were noted within plant-back intervals, although there was a trend for the 14 day plant-back to have higher yields. No differences were found among concentrations for pepper yield (Table 3.15).

Conclusions

Results from these studies indicate that tomato and pepper tolerance to acrolein was excellent. A plant-back interval of 14 days was required to ensure crop safety at acrolein rates of 448 kg ai/ha and higher. This is well within the suggested times for other compounds used for preplant treatments in tomato and pepper. Additionally, the acrolein concentration applied does not appear to negatively impact tomato or pepper growth and yield. This allows for flexibility in application times in differing soil types, for example, where sandy soils may require longer drip times to ensure complete wetting of the bed.

Table 3.1. List of experiment treatments, rates, and concentrations at Brewton, AL.

Treatment	Rate (kg ai/ha)	Concentration (ppm)	Water time[a] (hrs.)	Water + acrolein[b] (hrs.)
Non-treated	0	0	3.0	0.0
Acrolein	448	2104 (low)	0.0	3.0
Acrolein	448	4208 (med)	1.5	1.5
Acrolein	448	8418 (high)	2.3	0.8
Acrolein	224	1052 (low)	0.0	3.0
Acrolein	224	2104 (med)	1.5	1.5
Acrolein	224	4209 (high)	2.3	0.8
MeBr[c]	392	NA	3.0	NA

[a]Time that water alone was drip-applied through irrigation lines.

[b]Time that water and acrolein was drip-applied through irrigation lines.

[c]MeBr shank-injected through 3 shanks spaced 30.5 cm apart.

Table 3.2. Tomato vigor 6 WAT as affected by plantback interval and treatment.[a]

Treatment	Rate	---------------------Plantback interval--------------------			
	kg ai/ha	1 day	7 days	14 days	21 days
Non-treated	0	0.00	2.50	1.00	0.67
Acrolein[b]	112	5.70	2.20	0.83	1.50
Acrolein	224	6.20	2.00	1.00	1.20
Acrolein	448	9.30	3.60	1.00	2.20
Acrolein	672	9.80	5.10	2.50	1.80
Acrolein	896	10.00	5.80	2.40	1.30
MeBr[c]	392	5.20	1.00	0.50	0.17
LSD (0.05)		**1.83**	**2.30**	**1.20**	**1.15**

[a]Visual ratings for vigor taken in 2006 at Brewton, AL; vigor scale 1-10 where 1 = best.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.3. Percent dead tomatoes 6 WAT as affected by plantback interval and treatment.[a]

Treatment	Rate	------------------Plantback interval------------------			
	kg ai/ha	1 day	7 days	14 days	21 days
Non-treated	0	2.1	0.0	6.3	0.0
Acrolein[b]	112	35.4	4.2	0.0	0.0
Acrolein	224	43.8	4.2	0.0	0.0
Acrolein	448	89.6	2.1	0.0	0.0
Acrolein	672	97.9	12.5	0.0	0.0
Acrolein	896	100.0	18.8	0.0	0.0
MeBr[c]	392	25.0	0.0	0.0	0.0
LSD (0.05)		**20.3**	**12.1**	**4.7**	**-**

[a]Percent dead plants taken in 2006 at Brewton, AL.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.4. Tomato stem diameter (mm) 7 WAT as affected by plantback interval and treatment.[a]

Treatment	Rate	-----------Plantback interval-----------	
	kg ai/ha	14 days	21 days
Non-treated	0	13.1	12.4
Acrolein[b]	112	13	11.7
Acrolein	224	12.6	11.9
Acrolein	448	12.7	11
Acrolein	672	12.8	11.1
Acrolein	896	12.2	12
MeBr[c]	392	14.2	13
LSD (0.05)		**0.9**	**1.1**

[a]Stem diameters taken from 3 plants in each planting at Brewton, AL in 2006.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.5. Treatment effects on total marketable tomato number and weight; 1-day plantback interval.[a]

Treatment	Rate	-----Marketable tomato totals-----	
	kg ai/ha	number	weight (kg/plot)
Non-treated	0	72.3	17.6
Acrolein[b]	112	54.0	11.8
Acrolein	224	68.3	14.9
Acrolein	448	0.0	0.0
Acrolein	672	0.0	0.0
Acrolein	896	0.0	0.0
MeBr[c]	392	96.0	21.7
LSD (0.05)		**24.3**	**5.7**

[a]Yield data collected at Brewton, AL in 2006.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.6. Treatment effects on the total marketable tomato number and weight; 7-day plantback interval.[a]

Treatment	Rate	-----Marketable tomato totals-----	
	kg ai/ha	number	weight (kg/plot)
Non-treated	0	71.8	16.0
Acrolein[b]	112	83.2	17.8
Acrolein	224	86.8	20.2
Acrolein	448	95.3	21.5
Acrolein	672	82.8	18.7
Acrolein	896	91.7	20.2
MeBr[c]	392	112.7	30.1
LSD (0.05)		**26.5**	**7.7**

[a]Yield data collected at Brewton, AL in 2006.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.7. Treatment effects on total marketable tomato number and weight; 14-day plantback interval.[a]

Treatment	Rate	-----Marketable tomato totals-----	
	kg ai/ha	number	weight (kg/plot)
Non-treated	0	80.0	18.2
Acrolein[b]	112	101.5	22.8
Acrolein	224	104.2	23.8
Acrolein	448	128.7	28.0
Acrolein	672	122.0	31.3
Acrolein	896	134.7	30.5
MeBr[c]	392	133.8	32.8
LSD (0.05)		**25.1**	**6.4**

[a]Yield data collected at Brewton, AL in 2006.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.8. Treatment effects on total marketable tomato number and weight; 21-day plantback interval.[a]

Treatment	Rate	-----Marketable tomato totals-----	
	kg ai/ha	number	weight (kg/plot)
Non-treated	0	94.5	21.6
Acrolein[b]	112	122.9	26.7
Acrolein	224	122.0	26.7
Acrolein	448	126.8	27.9
Acrolein	672	142.5	30.9
Acrolein	896	141.0	30.9
MeBr[c]	392	130.3	29.9
LSD (0.05)		**20.0**	**4.0**

[a]Yield data collected at Brewton, AL in 2006.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.9. Tomato vigor 7 WAT as affected by plantback interval and treatment.[a]

Treatment	Rate	------------------Plantback interval------------------		
	kg ai/ha	7 days	14 days	21 days
Non-treated	0	6.5	6.6	4.6
Acrolein[b]	112	3.3	5.8	2.8
Acrolein	224	5.1	5.8	3.0
Acrolein	448	3.1	3.5	2.6
Acrolein	672	5.8	4.0	3.8
Acrolein	896	9.5	5.5	2.3
MeBr[c]	392	6.5	5.0	2.4
LSD (0.05)		**3.7**	**2.5**	**1.9**

[a]Visual ratings for vigor taken in 2006 at Shorter, AL; vigor scale 1-10 where 1 = best.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.10. Percent dead tomatoes 7 WAT as affected by plantback interval and treatment.[a]

Treatment	Rate	------------------Plantback interval------------------		
	kg ai/ha	7 days	14 days	21 days
Non-treated	0	56.2	40.6	47.0
Acrolein[b]	112	43.8	59.4	50.0
Acrolein	224	40.6	46.9	62.5
Acrolein	448	40.6	37.5	50.0
Acrolein	672	75.0	50.0	72.0
Acrolein	896	93.8	59.4	62.5
MeBr[c]	392	46.9	59.4	78.0
LSD (0.05)		**36.0**	**26.0**	**43.5**

[a]Percent dead plants taken in 2006 at Shorter, AL.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

Table 3.11. Effects of treatment and plantback interval on total marketable tomato number and weight.[a]

Treatment	Rate	Total marketable tomatoes	
	kg ai/ha	Number	Weight (kg/plot)
Non-treated	0	16.8	3.2
Acrolein[b]	112	36.3	8.2
Acrolein	224	49	11.2
Acrolein	448	47.8	12.4
Acrolein	672	17.5	6.4
Acrolein	896	18.5	6.9
MeBr[c]	392	47.8	12
LSD (0.05)		29.7	8.1

[a]Yield data pooled across dates; taken in 2006 at Shorter, AL.

[b]Acrolein applied in drip irrigation lines over 3-hour period.

[c]Methyl bromide shank injected through 3 shanks.
spaced 30.5 cm apart.

Table 3.12. Treatment effects on tomato stem diameter and vigor 8 WAT.[a]

Treatment	Rate	14-day plantback		21-day Plantback	
	kg ai/ha	Vigor[b]	Stem dia. (mm)	Vigor	Stem dia (mm)
Non-treated	0	2.10	11.87	1.88	10.52
Acrolein[c]	448 (low)	1.75	13.30	1.63	10.61
Acrolein	448 (med)	1.50	12.63	1.13	10.68
Acrolein	448 (high)	1.75	12.57	1.38	10.68
Acrolein	224 (low)	1.63	12.98	1.38	10.74
Acrolein	224 (med)	2.00	11.83	1.50	10.91
Acrolein	224 (high)	1.63	12.52	1.50	10.71
MeBr[d]	392	2.00	12.89	1.50	9.91
LSD (0.05)		**0.63**	**0.88**	**0.73**	**0.95**

[a]Plant data collected in 2007 at Brewton, AL.

[b]Vigor rated on 1-10 scale where 1 = best.

[c]Acrolein drip-applied through irrigation lines over 3-hour period.

[c]Methyl bromide shank-injected through 3 shanks spaced 30.5 cm apart.

Table 3.13. Treatment effects on bell pepper vigor 8 WAT.[a]

Treatment	Rate kg ai/ha	Vigor[b]
Non-treated	0	1.25
Acrolein[c]	448 (low)	2.25
Acrolein	448 (med)	2.33
Acrolein	448 (high)	1.25
Acrolein	224 (low)	1.25
Acrolein	224 (med)	2.13
Acrolein	224 (high)	1.13
MeBr[d]	392	1.38
LSD (0.05)		**0.77**

[a]Plant data collected in 2007 at Brewton, AL.

[b]Vigor rated on 1-10 scale where 1 = best.

[c]Acrolein drip-applied through irrigations over 3-hour period.

[d]Methyl bromide shank-injected through 3 shanks spaced 30.5 cm apart.

Table 3.14. Treatment effects on total marketable tomato number and yield.[a]

Treatment	Rate	14-day plantback		21-day plantback	
	kg ai/ha	number	weight (kg/plot)	number	weight (kg/plot)
Non-treated	0	129.0	23.6	96.5	17.8
Acrolein[b]	448 (low)	144.8	28.5	113.5	20.9
Acrolein	448 (med)	131.5	25.8	117.5	22.4
Acrolein	448 (high)	125.8	23.6	109.5	21.9
Acrolein	224 (low)	135.3	25.2	120.5	23.2
Acrolein	224 (med)	130.5	26.2	113.3	22.6
Acrolein	224 (high)	135.0	25.6	122.8	23.4
MeBr[c]	392	127.8	24.5	101.0	19.4
LSD (0.05)		**21.5**	**4.3**	**16.6**	**3.6**

[a]Yield data collected in 2007 at Brewton, AL.

[b]Acrolein drip-applied through irrigation lines over 3-hour period.

[c]Methyl bromide shank-injected through 3 shanks spaced 30.5 cm apart.

Table 3.15. Treatment effects on total marketable bell pepper number and yield.[a]

Treatment	Rate	,---------------Total marketable---------------	
	kg ai/ha	number	weight (kg/plot)
Non-treated	0	73.8	20.0
Acrolein[b]	448 (low conc.)	52.8	13.1
Acrolein	448 (med. conc.)	68.8	17.8
Acrolein	448 (high conc.)	69.3	18.1
Acrolein	224 (low conc.)	81.8	21.1
Acrolein	224 (med. conc.)	109.3	26.5
Acrolein	224 (high conc.)	75.5	19.1
MeBr[c]	392	71.8	19.2
LSD (0.05)		**37.6**	**8.2**

[a]Plant data collected in 2007 at Brewton, AL.

[b]Acrolein drip-applied through irrigation lines over 3-hour period.

[c]Methyl bromide shank-injected through 3 shanks spaced 30.5 cm apart.

IV. STRAWBERRY RESPONSE TO ACROLEIN (2-PROPENAL)

Abstract

Greenhouse and field studies were conducted to evaluate the response of strawberries to acrolein when applied pre- and post-transplant. Greenhouse studies evaluated acrolein applied to strawberries after transplanting. Rates tested were 0, 28, 56, 112, and 224 kg ai/ha. Rates higher than 56 kg ai/ha significantly decreased plant vigor and shoot dry weights in the greenhouse. Rates tested in the field experiment for post-transplant applications were 0, 24, 47, 71, and 94 kg ai/ha. All rates applied post-transplant to strawberry significantly reduced strawberry growth and yield. Acrolein applied preplant to strawberry at 448 kg ai/ha improved both vigor and total yield when compared to methyl bromide. These results indicate that acrolein has excellent potential to be considered as a methyl bromide alternative in strawberry production when applied 21 days prior to transplanting.

Introduction

Strawberries (*Fragaria* × *ananassa* Duchesne) are a high value commodity in the United States. California is the leading state for strawberry production, accounting for over 80% of total production with gross sales valued at over $1 billion (NASS, 2007). As a result, much attention has been given to optimizing production in this state. However, practices utilized in California are generally practiced throughout areas where strawberries are grown.

Effectively managing weeds and soilborne pests, particularly diseases, is imperative for achieving high strawberry yields. Soil fumigation with methyl bromide in combination with chloropicrin has been the basis for preplant pest management in strawberry production for over 40 years (Wilhelm and Paulus, 1980). This treatment provides consistent control of soilborne diseases, nematodes, and weeds. Soil fumigation with methyl bromide consumes 15.9 million kilograms each year; approximately 50% being used in California and 35% in Florida (Manning and Fennimore, 2001). Methyl bromide, both natural and man-made, contributes to the depletion of the stratospheric ozone layer (Watson et al., 1992). As a result, the use of methyl bromide has been phased out in developed countries in accordance with the Montreal Protocol (U.S. EPA, 2005). Some use is still allowed under critical use exemptions (CUE) in situations where no viable alternatives are available. Alternatives to methyl bromide that have been used in strawberry production include chloropicrin, 1,3-dichloropropene (1,3-D), and metam sodium. None of these fumigants alone controls soilborne pathogens and weeds to the level of methyl bromide in combination with chloropicrin (Ajwa and Trout, 2004). Chloropicrin has high activity against insects and fungi, but less activity against nematodes and weeds than methyl bromide (Johnson and Feldmesser, 1987). The fumigant 1,3-D has high activity against nematodes but low to moderate activity on fungi and weeds (Noling and Becker, 1994). Metam sodium has shown activity against all pests affecting strawberry, however, control of nutsedge has been reported as not being equivalent to methyl bromide (Locascio et al., 1997). Because no one compound can provide pest control at the level of methyl bromide, producers are forced to utilize more than one fumigant, or settle for less than desirable control of problem species if only one chemical is used.

Acrolein (2-propenal) is a simple aldehyde discovered by Redtenbacher in 1843. It is a pungent-smelling liquid that will volatilize rapidly when exposed to air, and is highly soluble in water. Incomplete combustion of organic materials is one source of acrolein. Forest fires, automobile exhaust, and cigarette smoke are among some of the sources of acrolein. Acrolein has been used for control of bacteria, fungi, algae, and molluscs in industrial cooling water systems (Donahue et al., 1966), in the production of acrylic acid, and as a sulfide scavenger in oil production systems. Acrolein has also been used for aquatic weed control in irrigation canals to control plant species that reduce or block the flow of water (Hill, 1960; Bowmer and Higgins, 1976). Since 1960, acrolein has been used in this manner in the United States, Australia, Argentina, and other countries where open channels distribute water for crop production. Acrolein is currently labeled for aquatic weed control, its main agricultural use, under the trade name Magnacide H®. Acrolein is a general cell toxicant that reacts with sulfhydryl groups on a variety of biomolecules, destroying enzymes and disrupting plant metabolic pathways (WSSA, 2007). Research has shown that irrigation water treated with acrolein has no detrimental effects on peppers (*Capsicum* spp) or leaf lettuce (*Latuca sativa* L.) and does not accumulate in the leaves, roots, or plant surfaces (Caldironi et al., 2005; Nordone et al., 1997). Results from these experiments indicate that acrolein has the potential to be used on vegetable crops in terms of crop safety. However, research is limited on the potential for acrolein to be used in this manner, particularly regarding the level of control on weeds, nematodes, and disease. One study evaluated acrolein in orchard replanting for control of nematodes (McKenry et al., 1995). Nematode control was reported as unacceptable 1 year after treatment, but researchers did note an increase in plant growth with the use of acrolein, potentially indicating control of soil-borne pathogens. Several patents have also been filed regarding the potential for acrolein to be used in agricultural crops to control not only weeds, but nematodes and diseases as well. However, there is little published information on application methodology or results from these patents. Therefore, this research was conducted to evaluate strawberry tolerance and soil-borne disease control with acrolein.

Materials and Methods

Two greenhouse experiments were conducted to evaluate strawberry tolerance to acrolein when applied after strawberry planting. Fungicides are often needed to help prevent or control soil-borne diseases following soil fumigation in the fall. It was hypothesized that postplant applications of low rates of acrolein could potentially help manage these diseases.

'Chandler' strawberries were separated into two groups based on size: small-rooted plants and large-rooted plants. Plants in the small group had an average weight of 7 grams while plants in the large group weighed an average of 30 grams. Bare root plants were then transplanted into 1-L Styrofoam cups. These cups contained 1 kilogram of a sandy-loam soil with pH 6.1 that was collected from the E.V. Smith Research Center's Plant Breeding Unit in Tallassee, Alabama for use in these experiments. This soil has a very low organic matter (<1%) and CEC (typically less than 4.6 cmol/kg). Acrolein rates evaluated were 0, 28, 56, 112, and 224 kg ai/ha. Acrolein was mixed with a volume of water to equate to a half-acre inch of water per acre (20,805 L/ha) and applied as a drench application to the appropriate cups either 1, 7, or 14 days after the strawberries were planted (DAP). Plant health was recorded 27 DAP using a visual rating scale (1-10, 1 = best; 10 = plant death). Plant shoots were harvested 37 DAP and dry weights were recorded. Only live shoots were harvested. Both experiments consisted of a completely randomized design with four replications. Data were subjected to ANOVA and means separated with LSD (0.05) when differences were detected to allow for all possible comparisons.

Field experiments were conducted at the Brewton Experimental Field in Brewton, Alabama. Soil at this location is a Benndale fine sandy loam soil with ph = 5.8 and CEC of <4.3 cmol kg^{-1}. Beds (10 cm high x 0.75 m wide) were formed and covered with high-density polyethylene mulch (HDPE) with two drip tapes on each bed. Two rows of 10 bare root, 'Camarosa' strawberry plants were planted for a total of 20 plants in each plot October 24, 2007. The experiment design was a randomized complete block with four replications. Data were subjected to ANOVA and means separated with LSD (0.05) when appropriate to allow for all possible comparisons.

The first field trial was initiated to evaluate strawberry tolerance to acrolein applied after transplanting. Acrolein was applied after transplanting either in the fall (8 DAP) or in the spring (155 DAP). Preliminary greenhouse studies indicated that rates over 56 kg ai/ha were detrimental to strawberry growth. Therefore, a lower range of acrolein rates were tested in the field. Acrolein rates tested were: 0, 24, 47, 71, and 94 (kg ai/ha). Acrolein was mixed with 11.36 liters of water in a stainless steel spray container to facilitate application. These mixes were then applied in 41,610 L/ha over approximately a 3-hour period through drip irrigation lines.

Visual vigor ratings (1-5 scale; 5 being best) were taken 4 weeks after each application. Marketable as well as total yield data were recorded (kg/plot). Unmarketable fruit was those considered small and those that were blemished. Data were subjected to ANOVA and means separated with LSD (0.05) when appropriate to allow for all possible comparisons.

A second field trial was conducted to evaluate strawberry tolerance and yield to acrolein applied preplant. Treatments in this study were: acrolein at 448 kg ai/ha, methyl bromide (67% methyl bromide/33% chloropicrin) at 392 kg ai/ha, fungicides only, and a non-treated control. The fungicides-only treatment received applications as deemed necessary by the station superintendent and consisted of contact-only materials for the control of any airborne diseases. This was done to avoid any systemic fungicides that could potentially allow good plant growth despite any soilborne diseases that may occur. Methyl bromide was shank injected while acrolein was drip-applied in 41,610 L/ha through drip irrigation lines over approximately a 3 hour period 34 days prior to transplanting. Visual ratings for plant vigor (1-5 scale; 5 is best) were taken 12 and 28 weeks after treatment (WAT). Both marketable and total yields (kg/plot) were recorded at study termination. Data were subjected to ANOVA and means separated with LSD (0.05) when appropriate to allow for all possible comparisons.

Results and Discussion

Results from the first greenhouse study evaluating small-rooted strawberry are shown in Table 4.1. No differences were detected among acrolein applications made either 1, 7, or 14 day after planting, therefore data from these treatments were pooled and reported together. At rates of 56 kg ai/ha and greater, acrolein significantly reduced plant health, with complete plant death at 224 kg ai/ha. A similar trend was evident with shoot dry weights. Shoot dry weight significantly decreased as rates increased to 56 kg ai/ha and above, with no shoot weight being recorded for the 224 kg ai/ha rate.

Results from the second greenhouse study evaluating large-rooted strawberry are shown in Table 4.2. For plant vigor, no differences were detected among timing of acrolein application; therefore data for these observations were pooled. Plant health ratings were significantly reduced at the 112 and 224 kg ai/ha rates. Both the 28 and 56 kg ai/ha rates were not significantly different from the non-treated plants. Analysis of shoot dry weight revealed differences in timing of acrolein application therefore results from the different application timings are reported separately (Table 4.2). The highest numeric dry weight was determined to be from the 28 kg ai/ha rate; however, no differences were detected among acrolein rates for applications made 1 day after transplanting. Both the 112 and 224 kg ai/ha rates resulted in significantly lower dry weights than the lower rates tested. Again it was noted that the highest dry weight was recorded for the 28 kg ai/ha rate, although this was not significantly higher than the 0 or 56 kg ai/ha rate. Applications made 14 days after transplanting followed similar patterns as earlier application timings. Lowest dry weights were recorded at 112 and 224 kg ai/ha. The 28 kg ai/ha rate produced the highest dry weight, yet was not significantly different from either the nontreated or 56 kg ai/ha rate.

Results from these studies indicate that post applications to strawberry may be possible at rates lower than 56 kg ai/ha without adversely affecting plant growth. There were also indications that plant growth may actually be increased at rates of 28 kg ai/ha or lower.

Analysis of the data from the field experiment evaluating POST applications of acrolein on strawberry revealed a significant difference between fall versus spring applications. Post-transplant applications made in the fall had higher marketable and total yields than applications made in the spring. This potentially indicates that strawberries had recovered more from fall-applied treatments than those in plots receiving spring applications. Results from the two timings are reported separately.

Results from fall applied post-transplant treatments are shown in table 4.3. All rates of acrolein greater than 24 kg ai/ha significantly reduced vigor ratings taken 4 WAT compared to the non-treated plots. Marketable and total yields were significantly reduced by all rates of acrolein applied post-transplant when compared to the non-treated. Spring post-transplant treatments resulted in observations similar to those from fall post-transplant treatments. All rates of post-transplant acrolein applied 155 DAP reduced vigor as well as marketable and total yields when compared to the non-treated plots (Table 4.4). Because post-transplant spring applications were made closer to flowering, it is likely that flowering and fruit set were negatively affected, resulting in lower yields.

Results from the second field experiment evaluating preplant treatments on strawberry are shown in Table 4.5. Analysis of vigor ratings taken 12 WAT reveal that plots receiving acrolein had significantly higher vigor than the non-treated plots and vigor equivalent to those receiving fungicides and methyl bromide. At 28 WAT, acrolein had higher vigor than the fungicide-only treatment, with all other treatments being equivalent. Analysis of yield data reveal that plots receiving acrolein had a higher total yield than any other treatment. Marketable yield was equivalent for acrolein and methyl bromide, yielding 42.05 and 35.96 kg/plot, respectively. Marketable yield from acrolein-treated plots was significantly higher than the non-treated and fungicides-only treatment.

Conclusions

Results from greenhouse studies indicated that post-transplant applications of acrolein in strawberry have the potential for use in the field at rates of 56 kg ai/ha and lower. Post-transplant applications conducted in the field, however, did not support the findings from greenhouse experiments. In general, all applications made to strawberries after transplanting were detrimental to plant vigor and yield. Strawberries receiving fall applications fared better than those receiving spring applications. This was likely due to the longer period for recovery for those receiving fall treatments. Additionally, there were problems with bed formation (unlevel) that may have contributed to some of the injury observed. Despite this, it appears that applying acrolein after transplanting, even at low rates, negatively impacted strawberry health and fruit production.

Acrolein applied 21-days prior to strawberry transplanting at 448 kg ai/ha resulted in increased vigor and yield. Yield results from all treatments was good, indicating that pest pressure may have been limited. However, because yield was increased in plots receiving acrolein, it is theorized that acrolein provided disease control, improved soil health, or a combination of the two, resulting in increased plant growth and vigor. Acrolein appears to enhance *Trichoderma* spp. (Simmons 2008). Some species of *Trichoderma* are known to improve plant health and this may be a factor in the improved plant growth and yield observed with plots treated with acrolein. Results from these studies indicate that acrolein has good potential to be used as an alternative to methyl bromide in strawberry when applied 3 weeks prior to transplanting.

Table 4.1. Effects of acrolein[a] on vigor (27 DAP) and dry weight (37 DAP) when applied to small-rooted strawberry.[bc]

Rate (kg ai/ha)	Vigor[de]	Shoot dry weight[e] (g/cup)
0	1.58	2.18
28	2.08	1.72
56	3.50	1.45
112	7.92	0.40
224	9.75	0.00
LSD (0.05)	**1.28**	**0.46**

[a]Acrolein applied as a drench application in a half acre-inch of water.

[b]Study conducted at pesticide research greenhouse in Auburn, AL in 2006.

[c]Roots had an average weight of 7 grams.

[d]Vigor ratings visually estimated on a 1-10 scale where 1 = best.

[e]Vigor and shoot dry weight pooled across 1, 7, and 14 DAP timings.

Table 4.2. Effects of acrolein[a] on vigor (27 DAP) and dry weight (37 DAP) when applied to large-rooted strawberry[b] either 1, 7, or 14 days after planting.[c]

Rate (kg ai/ha)	Vigor[de]	Shoot dry weight (g/cup)		
		-----Time of application after planting-----		
		1 day	7 days	14 days
0	1.67	1.99	2.18	2.11
28	1.58	3.15	2.42	2.86
56	2.42	1.68	2.07	1.66
112	6.42	2.08	0.50	0.24
224	7.67	2.19	0.00	0.00
LSD (0.05)	**2.05**	**1.54**	**1.39**	**1.37**

[a]Acrolein applied as a drench application in a half acre-inch of water.

[b]Roots had an average weight of 30 grams.

[c]Study conducted at pesticide research greenhouse in Auburn, AL in 2006.

[d]Vigor ratings visually estimated on a 1-10 scale where 1 = best.

[e]Vigor pooled across application timings.

Table 4.3. Effects of acrolein[a] on vigor[b] and yield when applied to strawberry in a field setting 8 days after planting.[c]

Rate (kg ai/ha)	Vigor 4 WAT	Marketable yield	Total yield
		------------------------kg/plot----------------------	
0	4.00	30.63	33.4
28	3.13	22.18	23.87
56	2.50	20.81	22.29
112	2.50	17.46	18.84
224	2.38	19.76	20.84
LSD (0.05)	**1.34**	**7.43**	**8.08**

[a]Acrolein mixed with 11.36 L of water and applied through irrigation lines.

[d]Vigor ratings visually estimated on a 1-5 scale where 1 = worst.

[c]Study conducted in Brewton, AL fall 2006 through spring 2007.

Table 4.4. Effects of acrolein[a] on vigor[b] and yield when applied to strawberry in a field setting 155 days after planting.[c]

Rate (kg ai/ha)	Vigor 4 WAT	Marketable yield	Total yield
		------------------------kg/plot----------------------	
0	4.38	30.63	33.4
28	1.83	12.22	14.09
56	1.19	10.25	11.38
112	0.64	4.60	5.56
224	0.63	8.89	10.06
LSD (0.05)	**0.46**	**8.72**	**9.22**

[a]Acrolein mixed with 11.36 L of water and applied through irrigation lines.

[d]Vigor ratings visually estimated on a 1-5 scale where 1 = worst.

[c]Study conducted in Brewton, AL fall 2006 through spring 2007.

Table 4.5. Effects of preplant treatments on strawberry vigor and yield.[a]

Treatment	Rate	Vigor[b] 12 WAT	Vigor 28 WAT	----Yield (kg/plot)----	
	kg ai/ha			Marketable	Total
Non-treated	0	4.00	4.38	30.63	33.40
Fungicides[b]	NA	4.13	4.05	33.29	35.64
Methyl bromide[c]	392	4.75	4.58	35.96	38.94
Acrolein[d]	448	4.88	4.81	42.05	47.49
LSD (0.05)		0.85	0.73	6.57	8.00

[a]Study conducted in Brewton, AL fall 2006 through spring 2007.

[b]Received contact-only fungicides.

[c]Methyl bromide shank injected through 3 shanks spaced 30.5 cm apart.

[d]Acrolein drip-applied over 3-hour period through irrigation lines.