FOOD AND AGRICULTURE APPLICATIONS OF PULSED POWER TECHNOLOGIES AS ALTERNATIVES TO METHYL BROMIDE. Manuel C. Lagunas-Solar[1], James D. MacDonald[2] and Jeffrey Granett[3]. [1]Crocker Nuclear Laboratory, [2]Department of Plant Pathology, and [3]Department of Entomology, University of California, Davis, CA 95616, USA.

Food preservation and control of agricultural pests and pathogens are important issues in U. S. and world wide commerce. Existing sanitation, heating and cooling techniques for food preservation and control of pests in stored foods are insufficient and existing standards require chemical inputs. Chemical inputs, however, are under fire because of the public perception of safety hazards they pose. In addition, the chemical inputs used to protect crop plants from pests and pathogens during production are suspect of impacting human and environmental safety and are being phased out. The limitations on our abilities to preserve foods and control pests, particularly quarantined pests, limit access to international and domestic markets. Therefore, new, efficient, economically viable and reliable technologies are needed for non-chemical agricultural pest and disease control, food preservation, water treatment and environmental. protection. Research conducted at UC Davis indicates that several, seledive, high-efficiency, tunable, pulsed energy delivery systems may provide effective, non-chemical alternatives. Energy delivery systems utilizing pulsed, monochromatic ultraviolet (uv) radiation, tuned microwave (mw) radiation, and electronic (radiofrequency, r-f) power have proved to be useful or potentially useful for many applications. Additionally, some of these energy delivery technologies present opportunities for novel applications.

Narrow-band, well-focussed energy sources provide opportunities for selective energy input to targeted chemicals. Therefore, selective chemical interactions are possible with energy sources such as monochromatic uv and with mw heating of targeted dipole molecules. Furthenore, if energy is delivered in ultra-short pulses, an enhacement of the targeted chemical response results due to kinetic effects. If energy is delivered selectively and in a pulsed mode, a high energy use efficiency results. In addition, ultra-short pulses of electric (rf) power have been proven to degrade cellular activity, providing with new opportunities to control pests and pathogens in certain applications.(*)

Because, current environmental needs are focused on reducing or eliminating the impact of invasive, additive chemical technologies, various pulsed power systems have the potential to provide new, non-chemical approaches to solve or minimize food, agriculture, water and other environmental contamination problems. At UC Davis, these new approaches are in various stages of development and some are ready for commercialization.

Methyl bromide is being phased out as a soil fumigant, presenting a substantial economic problem to production agriculture because none of the available chemical options are as effective as methyl bromide. Biological controls are expensive and of limited efficacy to control pests and pathogens. We are studying the use of electrical systems for heat-treating nursery/greenhouse soils based on conventional microwave or radiofrequency energy. We have shown that this approach can be more energy efficient than soil steaming, the current alternative.

We are also evaluating new microwave technologies for pasteurization and disinfestation of agricultural field soils through selective heating. Conventional heating processes have not been used for bulk soils, because of the costs for the large amounts of energy needed. We believe we can make electronic heating a viable process by using pulsed power and selected microwave frequencies different from those which are absorbed by water. The high-power pulsed technology we propose to use will increase efficiency by overwhelming heat dissipation kinetics of living organisms treated with extremely high instantaneous power; however, the total energy used will remain low because of the extremely short duration of the pulses and the comparatively low mass needing energy (heat) input. Increased energy efficiency can be obtained by selecting frequencies to be absorbed preferentially by pests and pathogens rather than heating the entire soil/water mass.

In the current work we are developing concepts and laboratory- and field-testing prototypes that should lead to both stationary and portable machines for soil pasteurization and disinfestation. The conventional microwave and radiofrequency technology are also being tested as they need no extensive research for application. However, we are determining the conditions for optimal treatments of different types of soil and moisture conditions and test prototypes. We have tentatively identified industrial partners for building pmtotypes and agricultural collaborators for commercially sized tests of the machinery. However, for *in* situ field agriculture, we must do the basic research to-identify the microwave frequencies which will have the absorption and depth penetration characteristics needed.

Research at UC Davis since 1990, has demonstrated that the growth of microbes (bacteria, fungi, etc.) and the presence of insects (eggs, larvae, pupae, adults) and mites on the surface of many commercially important fresh fruits (i.e. table grapes, citrus and stone fruits) and vegetables (i.e., tomatoes, potatoes, Carrots, etc.) can be controlled rapidly and efficiently using high-power, pulsed, monochromatic UV (US patent pending). These results justified the investigation of existing excimer (laser and lamp) technologies used in medical and industrial applications, for commercial-level applications to production agriculture. Practical uses include non-chemical food preservation and quarantine treatments (i.e., an alternative to methyl bromide fumigation). The combination of pulsed UV with other technologies (i.e. sterile packaging, refrigeration, controlled atmosphere, etc.) shall result in a considerable reduction of the use of chemical pesticides and fumigants and decrease' residues in foods and in the environment. We will establish the technical and economic viability' of newly-available monochromatic, high-power pulsed UV energy sources for treating agricultural wastewater. Our research has shown that these sources disinfect microbially contaminated water, and combined with advanced oxidation processes, break down residues of organic chemicals in water.

Finally, we are developing the use of electronically-based water treatment processes that will eliminate pathogenic microbes and organic (e.g., pesticide and petroleum-based) residues in agricultural wastewater. Currently, chlorine is the most widely used water disinfectant. However, at normal doses, some organisms are resistant to chlorine. At higher doses, chlorine can be acutely toxic to aquatic organisms, so chlorinated waters must be chemically dechlorinated before discharge. The dechlorinating chemicals (usually sulfur dioxide) also are toxic and their dosages must be precisely controlled so that they do not become toxic hazards themselves. Chlorination and dechlorination require extensive and costly facilities, and add substantial amounts of salts (chlorides, sulfates) to the reclaimed water. Furthermore, there are no economical, environmentally-friendly methods for eliminating organic chemical residues from agricultural wastewater. We are studying the integration of new large-scale, high-efficiency photochemical processes for simultaneous microbial and chemical decontamination of water. Photochemical processes are not a new concept -- UV radiation has been used for decades as an antimicrobial water treatment process and is currently used to degrade Volatile Organic Compounds (VOC) in groundwater. However, our efforts center around newly-available high-power pulsed UV (monochromatic and/or narrowband) sources as energy delivery systems. We have shown that pulsed UV is highly lethal (a! 248 nm) to fungal and bacterial propagules in wastewater, and that it effectively degrades organic compounds via direct photolysis (at 248 nm) or indirectly via advanced oxidation processes (AOP) (at 172, 193 and/or 222 nm). These systems are electronically-based (nonchemical), energy efficient, and adaptable to high throughput, modular designs.

(*) "Food Preservation with Pulsed, Monochromatic Ultraviolet Radiation", US Patent Pending..

ELECTRONIC HEATING OF SOILS AND POTTING MEDIA TO ELIMINATE ROOT PATHOGENS. J. D. MacDonald[1], M. Lagunas-Solar[2], J. Granett[3], J. Stites[1] and M. Farnsworth[1]. [1]Department of Plant Pathology, [2]Crocker Nuclear Laboratory, and [3]Department of Entomology, University of California, Davis, CA, 95616.

The scheduled loss of methyl bromide poses serious disease problems for growers of ornamental and nursery crops. Methyl bromide has been widely used for sterilizing ground beds and the potting media used in containen. Indeed, for some diseases (e.g., Fusarium wilt of carnation), methyl bromide has been the only effective control. Additionally, as more and more landfills reject "green waste', nurseries are being pressed to retain dead or nonsalable plants and ultimately recycle the potting media. Since many of the plants culled from production have root diseases, there is an obvious risk associated with recycling the potting media.

Among the potential alternatives to methyl bromide, many ornamental and nursery growers are considering thermal energy. This stems quite naturally from the industry's long tradition of steaming soils to eliminate pathogens (1). However, "live" steam is a relatively inefficient means of delivering thermal energy to soil and, in the case of ground beds,. is only modestly effective, To treat ground beds, some growers have begun to adopt solarization practices. However, solarization has some seasonal and geographic limitations (4), and is not well-suited to the year-round "production line" practices used in large container nurseries. Hence, we have been exploring electronic methods for delivering thermal energy to soil-borne pests and pathogens in an effort to develop efficient, broadly-applicable treatment processes. We have focussed our efforts on conventional microwave and ohmic heating processes which, while not new concepts (2. 3, 5), have never been fully explored as commercial possibilities.

Microwave heating of soil: Our microwave experiments have utilized relatively small (900-1200 Watt) devices operating at a fixed frequency of 2,450 Mhz. This frequency is widely used in heating because it interacts with the dipole moment of water molecules, causing rapid changes in molecular orientation and generating heat by friction between the molecules. In soils, the water molecules of interest are those within the soil mass or within the cells of living organisms.

To determine how quickly microwaves could heat potting media to pasteurization temperatures, we exposed a commercial peat:sand potting medium to a 2,450 Mhz microwave. The moisture content of the medium was 20% by weigh! (a typical planting moisture). The medium was placed into a 30-cm-dia : • 15-cm-high plastic container and was loosely consolidated by dropping the container several times onto a bench from a height of 30-35 cm. Final volume of the medium in the container was adjusted to 3.5 liters. Eight replicate containers were prepared for each experiment, and each was placed individually into the microwave cavity and heated for a measured length of time. At the end of the timed microwave exposure, each container was removed from the cavity and a fixed array of thermocouples was immediately inserted to measure soil temperature at various points.

We found that these relatively small volumes of potting media heated very quickly, reaching a temperature of 70" C in approximately 100 sec. (Fig. 1). However, when we dried the medium to 3% moisture (to reduce the heat capacity of the medium and the amount of water available to absorb the microwave energy), heating was much more rapid. In this case, the medium was heated to 70° C in approximately 50 sec. (Fig. 1).

To determine the effect of such rapid heating on the survival of fungal resting structures, we placed small amounts of potting medium infested with *Fusarium oxysporum* f.sp. *dianthi* into small, thin mesh pouches, and buried them in containers of potting medium. The pouches were placed in the containers of medium approximately 12 hours before microwave treatment to allow moisture equilibration with the bulk medium. Following treatment, the pouches were recovered from the soil and their contents were suspended in measured volumes of sterile, distilled water.

These suspensions were pipetted onto agar medium to quantify the numbers of surviving propagules. *Fusarium* was killed within 60-90 seconds in these treatments (Fig. 2).

Because a microwave at 2,450 Mhz generates heat by affecting water molecules, the rate of soil heating will be strongly influenced by moisture content and bulk density. We have been characterizing and quantifying these effects through a series of experiments in which we 1) varied the moisture content of a medium held at constant bulk density, and 2) varied the density of media-held at constant moisture contents. These experiments showed that the time required to achieve temperatures of 70° C increased as both moisture and bulk density increased (Fig. 3).

To adapt microwave technologies to production-level pasteurization systems, we are beginning to experiment with a device (fabricated for us by a company specializing in microwave technologies) that allows continuous-flow processing of potting media. Infested media are fed into the microwave: transit times through the cavity are varied to control temperature: and treated samples are assayed for surviving propagules. These experiments are in progress.

Ohmic heating of soil. Our ohmic (conductive) soil heating experiments have utilized commercially-available and custom-fabricated components. The devices consist essentially of power supplies that provide AC (60 Hz) current to electrodes buried in soil. As current passes through the soil from the cathode to the anode, heat is generated due to the soil's inherent electrical resistance. Initial experiments utilized a 50 volt, 4-7 amp power source (i.e., 200-350 watts) and passed current through a 0.216 m^3 volume of potting mix (60 cm X 60 cm X 60 cm). This apparatus heated the potting medium to 70° C in approximately 24 hr (Fig. 4). A second system was fabricated around a 488 volt, 0.5-1.5 amp power source (i.e., 244-730 watt), and has been used to heat smaller volumes (28 Liter) of soil in the laboratory. We found that this power source heated soil samples much more quickly that the lower-voltage, higher-amperage source, and achieved soil temperatures of 70° C in l-3 hr, depending upon soil conditions (Fig. 5).

As with the microwave, we conducted a series of experiments with the ohmic heater in which soil density was held constant and moisture was varied, or soil moisture was held constant and density was varied. We found that ohmic heating differed from microwave heating in its response to both physical variables: the time required to reach 70° C decreased sharply with increasing soil moisture and less sharply with increasing density (Fig. 6).

Experiments with ohmic heating of ground beds are in progress. Initially, we are using steel rods, driven into the soil to a depth of 60 cm, as electrodes. The rods are arrayed as two parallel lines, 40 cm apart. One line is wired in series as the cathode array, and one as the anode array.- Our first experiment yielded temperatures of 50-55° C to a depth of 60 cm in approximately 6 hr. Work is continuing to optimize the system.

References:

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Fig. 4. Heating profile of an 8 cu. ft. mass of potting medium using a 50 volt, 4-7 amp power supply. A temperature lethal to *Fusarium oxysporum* f.sp. *dianthi* (65° C) was achieved in approximately 24 hr. “Top”, “Middle” and “Bottom” refer to temperatures at various depths within the mass of soil.

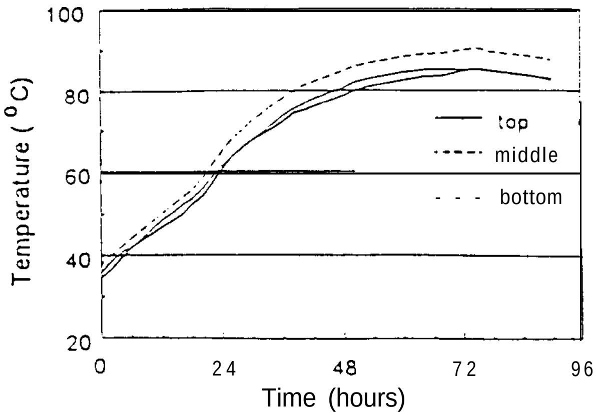

Fig. 5. Heating profile of a 1 cu. ft. mass of potting medium using a 488 volt, 0.5-l .5 amp power supply. Medium A had a moisture content of appx. 27%. Medium B was the same medium, but with a moisture content of appx. 30%. The higher moisture content increased the rate of heating. Experiments showed that a temperature of 65° C is lethal to *Fusarium oxysporum* f.sp. *dianthi.*

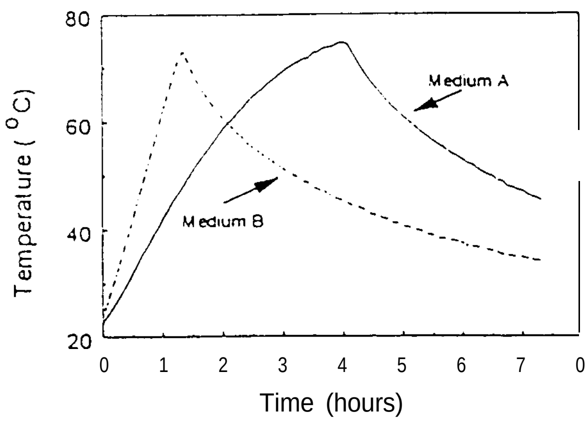

Fig. 6. Influence of soil moisture (dashed line) and bulk density (solid line) on the time required to heat a fixed volume of potting medium to 70° C using a 488 volt, 0.5 amp power supply and solid plate electrodes.

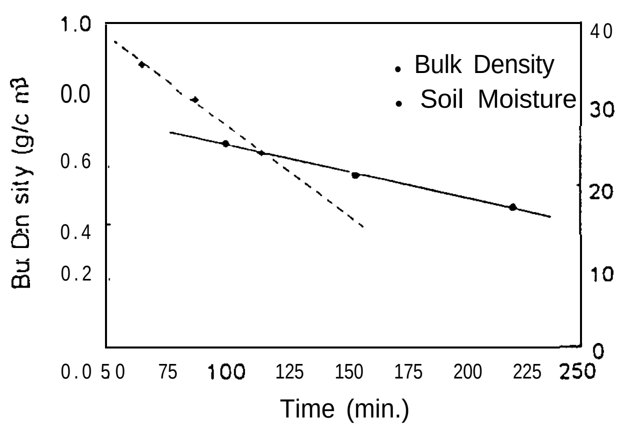

Fig. 1. Heating profiles of a commercial potting mix exposed to microwave radiation. The sample with 20% (by weight) moisture was at a water content ready for planting. The drier sample was air-dried for 24 hr. The lower moisture content allowed more rapid heating of the peat-sand medium.

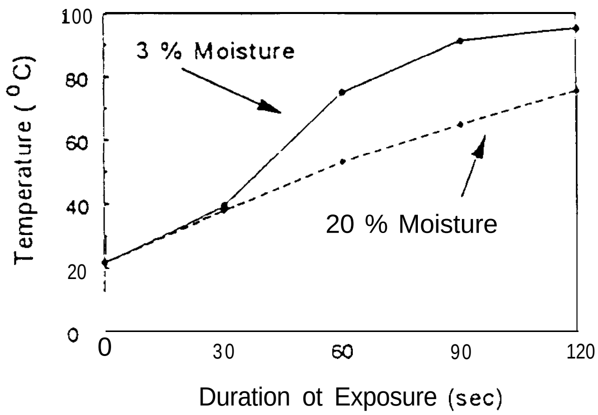

Fig. 2. Survival of *Fusarium oxysporum* f.sp. *dianthi* spores in potting medium exposed to microwave radiation. Survival is shown as a percent of initial population. Corresponding temperatures of the potting medium are indicated in Fig. 1.

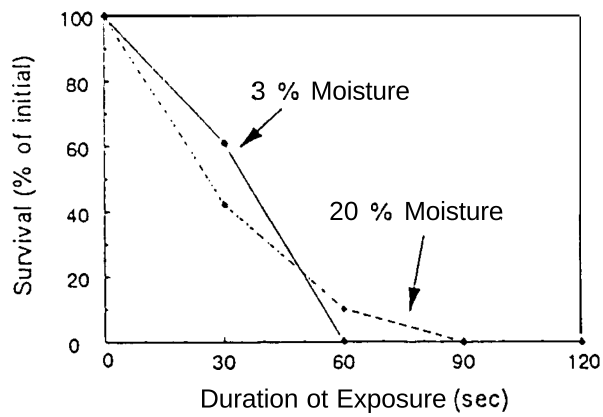

Fig. 3. Influence of soil moisture (dashed line) and bulk density (solid line) on the time required to heat a fixed volume (3.5 Liters) of potting medium to 70° C in a microwave.