FACTORS AFFECTING THE FEASIBILITY OF ULTRAHIGH FREQUENCY ELECTROMAGNETIC ENERGY FOR SOIL PEST CONTROL

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY
ROBERT PATRICK RICE JR.

1974

ABSTRACT

FACTORS AFFECTING THE FEASIBILITY OF ULTRAHIGH FREQUENCY ELECTROMAGNETIC ENERGY FOR SOIL PEST CONTROL

By

Robert Patrick Rice Jr.

Available methods for the control of a variety of soil pests affecting minor acreage crops are often inadequate. These studies were initiated to determine if selected weeds, insects, and nematodes could be controlled with UHF energy (2450 $\pm$ 20 MHz) and to determine factors which affect the efficiency of UHF energy for control of these pests.

Field tests were conducted at three geographically different locations on three soil types to test the effectiveness of UHF energy for both preemergence and postemergence weed control, and control of sugarbeet cyst nematodes (*Heterodera schactii*), root-lesion nematodes (*Pratylenchus penetrans*), and onion maggots (*Hylema antiqua*). Excellent season long weed control was obtained with levels from 671 - 1000 joules/cm^2. The specific energy rate required depended on soil type, seedbed preparation and weed species present. Higher rates were required on muck soils and fresh seedbeds. All rates tested provided weed control equal or superior to standard herbicides.

Quackgrass was not controlled at any of the rates tested. Nematode and onion maggot populations were reduced at all levels tested although control diminished with increasing soil depth.

LD_{50} levels were determined for imbibed and non-imbibed seeds of several different species. The LD_{50} of non-imbibed black medic (*Medicago lupulina* L.) occurred at 183 joules/cc, barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) at 160 joules/cc, common purslane (*Portulaca oleracea* L.) at 139 joules/cc, and redroot pigweed (*Amaranthus retroflexus* L.) at 125 joules/cc. After the seeds imbibed water for 24 hours the LD_{50} declined to 80 joules/cc for common purslane, 117 joules/cc for barnyardgrass, and 161 joules/cc for black medic, but did not decline for redroot pigweed. When seed-soil mixtures were treated, greatest toxicity occurred with the higher moisture levels in muck and clay loam soils with least toxicity occurring in a dry loamy sand soil. Attenuation by dry soil occurred with all types tested but was greatest with a sandy loam soil. Increasing power greatly reduced exposure time necessary for kill of seeds. Less energy was required to kill seeds as the soil temperature was increased from -20 to +18 C.

FACTORS AFFECTING THE FEASIBILITY OF ULTRAHIGH FREQUENCY ELECTROMAGNETIC ENERGY FOR SOIL PEST CONTROL

By

Robert Patrick Rice Jr.

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Horticulture

1974

This thesis is dedicated to my parents, Jane and Bob
who have been a constant source of encouragement
in all of my endeavors.

ACKNOWLEDGMENTS

The author expresses appreciation to Dr. A. R. Putnam for guidance during the conduct of the research and assistance in editing the manuscript. Appreciation is also expressed to the members of my guidance committee, Dr. S. K. Ries and Dr. G. W. Bird.

A special thanks is extended to Kei Erlandson for her invaluable assistance during the laboratory phase of this study. Appreciation is also expressed to Paul Love and Amos Lockwood for technical assistance and to Rose Magistro for typing assistance.

The assistance of Dr. J. R. Wayland and Oceanography International Inc. is also gratefully acknowledged.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In an age of increasing demands for food and a growing concern for the environment, increased use of pesticides has increased yield and quality of crops. Concern about the environment has prompted restrictive legislative controls which make the development and use of pesticides more costly. These two factors work against each other, and have renewed the interest in physical and biological methods of controlling pests.

It has been estimated that weeds result in a greater depression of crop yields than either insects or diseases (8). Weeds compete with crops for water, light, and nutrients and may suppress crops directly through allelopathic exudates (10). By eliminating weed competition, yields can be significently increased. Weeds are controlled by cultural methods such as cultivation, fallowing, crop rotations, or by the use of herbicides. Dependence on herbicides for minor acreage crops has several disadvantages. The high cost of registration does not justify the effort to develop herbicides for many fruit, vegetable, and ornamental crops. This makes it difficult for growers to obtain acceptable weed control with the use of federally approved methods. Another problem associated with herbicides is that organic matter adsorbs and inactivates many of them making high rates necessary on soils such as peats and mucks. As a result of these and other problems such as herbicide residues and drift, alternative weed management techniques must be explored. The use of ultrahigh frequency electromagnetic energy is one of the physical weed control measures being investigated. Apparently it will not require EPA registration and may provide effective pest control on organic soils while being free from drift and residue problems.

Commercial use of UHF energy depends on the ability of microwave energy to compete with current pest control practices on an energy consumption and cost per acre basis. Since efficiency is of utmost importance, the objective of this research is to ascertain the factors which affect the efficiency of UHF energy in controlling weeds.

CHAPTER 1

LITERATURE REVIEW

Microwaves (UHF energy) are the portions of the electromagnetic spectrum which fall between lower frequency radiowaves and higher frequency infrared waves. The basic properties of electromagnetic waves apply to microwaves. Microwaves travel at the speed of light and for each wavelength there is a corresponding frequency (F) obtained by dividing the velocity (c) of light by the wavelength (λ).

$$F = c/\lambda$$

The use of microwaves in the United States is controlled by the Federal Communications Commission which has designated four frequencies for non-communications use. These are 915 megacycles per second (mc/sec), 2450 mc/sec, 5800 mc/sec, and 22125 mc/sec. Penetration of microwaves into organic compounds is greatest at lower frequencies, resulting in 915 mc/sec and 2450 mc/sec being of greatest interest for pest control (4). As frequencies decrease, the quantity of energy contained in the wave also decreases. Although lower frequency waves penetrate deeper into a substance than higher energy waves, they do not contain as much energy. Therefore, 2450 mc/sec is of particular interest because of its adequate penetration characteristics coupled with reasonably high energy capacity.

Microwaves are produced either by magnetron or klystron tubes. Unlike an ordinary vacuum tube which contains two fixed poles, an anode and a diode, a magnetron is a cylindrical diode having resonant cavities which act as the anode. The klystron is a vacuum tube in which an electron beam is alternately accelerated and decelerated to produce oscillations which deliver pulsating energy to a cavity resonator. After microwaves are produced, they travel through metal waveguides to their point of use. The size of the waveguide is precisely determined by the particular microwave frequency. At 2450 mc/sec, the waveguide must be exactly 9.26 x 5.46 cm with walls at least 0.20 cm thick. If waveguides are correctly proportioned, the waves will be directed along the guide with a minimum of reflection. This will allow a uniform distribution of waves and prevent "hot spots" which are common in cavity type chambers due to the reflection from cavity walls and the resulting unequal distribution of energy. As a result of these variations, data obtained from treatments in a cavity will differ substantially from that obtained from waveguide treatments. Since present methods of field application of microwaves employ waveguides with horn type applicators, data obtained from waveguide treatments will be most applicable to field conditions.

Microwaves are capable of producing many and varied effects on substances which enter the field. A primary effect is that of heating. Heating involves the loss of energy from the microwave to the heated substance. This phenomenon is referred to as loss. High loss materials are those which readily absorb UHF energy to produce heat; conversely, low loss materials are those which either reflect the waves (e. g. metals) or allow them to pass through (e.g. silica) with little or no energy absorption. Several factors influence the dielectric characteristics of plant materials, such as moisture content of the tissue, water of hydration of molecules particularly proteins, and presence of interfaces between tissues of different dielectric properties. Moisture content is important in determining the loss characteristics of a particular tissue in that high moisture in a tissue will cause minimum penetration but maximum absorption. On the molecular level, hydrated molecules absorb energy faster than molecules with a lower water content. The presence of interfaces between tissues of different dielectric properties is important because the electromagnetic waves may be reflected from the interface causing the lossy tissue to be exposed to both direct and reflected waves. Copson (3) indicated that when animal fat is superimposed over muscle tissue, energy is transmitted through the fat, reflected at the muscle interface and absorbed by the fat. This phenomenon may further account for localized effects of microwaves.

Microwaves affect biological systems in a variety of ways. The most obvious are those resulting from heating of the tissue. Heat may cause a disruption of cells by denaturing proteins or causing chemical or physical changes in other cell constituents. Because different types of molecules differ in their dielectric loss properties, heating of biological tissues must occur in a non-uniform fashion. Since energy absorbed by the cell cytoplasm, for example, must eventually cross the plasmalemma, it seems that a very high thermal gradient would exist across the membrane (12). In plant cells, a temperature differential of only 0.01 C corresponds to an osmotic pressure of 1.32 atm (9). A change of this magnitude would certainly affect the physiological processes of the cell. Van Everdingen found that at 3000 MHz, microwaves cause a change in the optical activity of starch and glycogens and cause precipitation in starch solutions. It was possible in this case to obtain optimal conditions for microwave interaction by altering the viscosity of the solution rather than by changing the frequency (16). Suspensions of materials may also be affected by the imposition of an electromagnetic field. Microwaves can cause such things as colloidal particles, blood cells and droplets to allign themselves into formations known as "pearl chains" (14). Presumably molecular orientation of dipoles of the supporting medium must occur before "pearl chains" can be formed. The physiological significance of this allignment is not clear, except that the particles concerned would be redistributed (4). Another non-thermal cellular effect exerted by microwaves is that of altering the electrical properties of the plasmalemma. The cell membrane naturally exhibits such properties as separation of electrical potentials and capacitance. Frequencies in the microwave range may induce a loss in functional integrity of the cell membrane, leaving the cell to act essentially as a protein-electrolyte solution. In tests on mesquite and bean seeds in a microwave chamber, mortality of seeds was thought to be due to non-thermal effects (20).

Davis et al. in tests conducted in a microwave cavity (2450 $\pm$ 20 MHz), found that susceptibility of seeds is positively correlated with increasing moisture content, mass of seed, volume per seed, and energy absorbed per seed. Susceptibility is negatively correlated with ether soluble lipid content (18). Selectivity also occurs between species, in that low levels of energy effectively control some while others are unharmed by similiar levels (5). In field tests, Wayland et al. found that at a fixed energy level increased power levels can be substituted for exposure time in the

100 to 1200 W range (19). Field tests have also shown that applications of 1200 joules/cm^2 of microwave energy provided preemergence control of London rocket (*Sisymbrium irio* L.), Japanese millet (*Echinochloa frumentacea* (Roxb.) Link), ridgeseed euphorbia (*Euphorbia glyphosperma* Engelm.), redroot pigweed (*Amaranthus retroflexus* L.), and annual sunflower (*Helianthus annuus* L.) when applied directly to both wet and dry soils. Control of common purslane (*Portulaca oleracea* L.) required 2400 joules/cm^2. These same energy levels applied to dry soil prior to planting increased muskmelon (*Cucumis melo* L.) plant size at 4 weeks and increased yield in irrigated soils of Texas (12). Vela *et al*. reported that herbicidal and insecticidal rates of UHF energy had no effect on soil microorganisms such as heterotrophic bacteria, spores, fungi, and actinomycetes (17).

CHAPTER 2

EFFECTIVENESS OF UHF ENERGY FOR CONTROL OF SEVERAL SOIL PESTS

ABSTRACT

Available methods for the control of soil pests affecting minor acreage crops often are inadequate. The purpose of this study was to determine if selected weeds, insects, and nematodes could be effectively controlled with UHF energy (2450 $\pm$ 20 MHz).

Varying rates of UHF energy (621 - 1856 joules/cm^2) were applied to three geographically different newly prepared seedbeds, a stale seedbed, and a quackgrass sod to assess preemergence and postemergence weed control. Excellent season-long control of annual weeds was obtained with energy levels from 671-1000 joules/cm^2. The specific energy rate required depended on soil type, seedbed preparation, and weed species present. Higher rates were required for newly prepared seedbeds and muck soils. All rates tested produced annual weed control equal or superior to standard herbicides. Quackgrass was not controlled at any of the rates tested.

Onion maggot (Hylema antiqua) pupae, sugarbeet cyst nematodes (Heterodera schactii), and root-lesion nematodes (Pratylenchus penetrans) were placed in 100 cc nylon sacks, buried at 5 and 10 cm depths, and treated with UHF energy (673 - 1480 joules/cm^2). Nematode and onion maggot population densities were substantially reduced at all energy levels tested although control diminished with increasing soil depths.

INTRODUCTION

Soil-borne organisms including weed seeds, nematodes, insects, and fungi all have the potential to seriously reduce crop growth and yield. At present independent control practices and pesticides are usually employed for each of these pests. Each pesticide requires registration on the particular crop and pest, and each is subject to individual or interacting problems of adsorption, inactivation, persistance, etc.

Techniques designed to control more than one of the soil-borne organisms harmful to crops would greatly reduce the quantities of fungicides, nematicides, herbicides, and insecticides used. Broad spectrum soil fumigants are used in certain high value crops to non-selectively control many soil-borne weed seeds, insects, nematodes, fungi and bacteria. Fumigants such as methyl bromide (CH_3Br), carbon disulfide (CS_2), and chloropicrin (CCl_3NO_2) are quite effective in controlling soil pests; however, their use requires utmost caution, they are expensive, and they may kill beneficial microorganisms allowing toxic ammonia levels to accumulate in the soil (4). In addition, chemical fumigants require EPA registration and must be allowed to dissapate from the soil before planting of crops (4). A pest control method which would perform on a variety of soil types and would not require EPA registration certainly could offer additional advantages for minor acreage crops.

Wayland et al. found that seeds of wheat and radish buried in a sandy loam were susceptible to UHF (2450 $\pm$ 20 MHz) exposure. Wheat seeds were more susceptible than radish seeds which was attributed largely to their differences in mass (7). In field tests at several different locations, Wayland et al. found that effective preemergence weed control could be obtained at energy/area levels of between 80 and 160 joules/ cm^2 (7). Menges controlled London rocket (*Sisymbrium irio* L.), Japanese millet (*Echinochloa frumentacea* (Roxb.) Link), ridgeseed euphorbia (*Euphorbia glyptosperma* (Engelm.), redroot pigweed (*Amaranthus retroflexus* L.), and annual sunflower (*Helianthus annuus* L.) with field applications of 1200 joules/cm^2 of UHF energy regardless of soil moisture content on a sandy loam soil (5). On dry soil, 2400 joules/cm^2 was required to control common purslane (*Portulaca oleracea* L.). On similar soils, cantaloupe (*Cucumis melos* L.) yields were increased after preplant applications of 1200 and 4800 joules/cm^2. This was attributed to a reduction in weed competition and reniform nematode (*Rotylenchus reniformis*) populations (5).

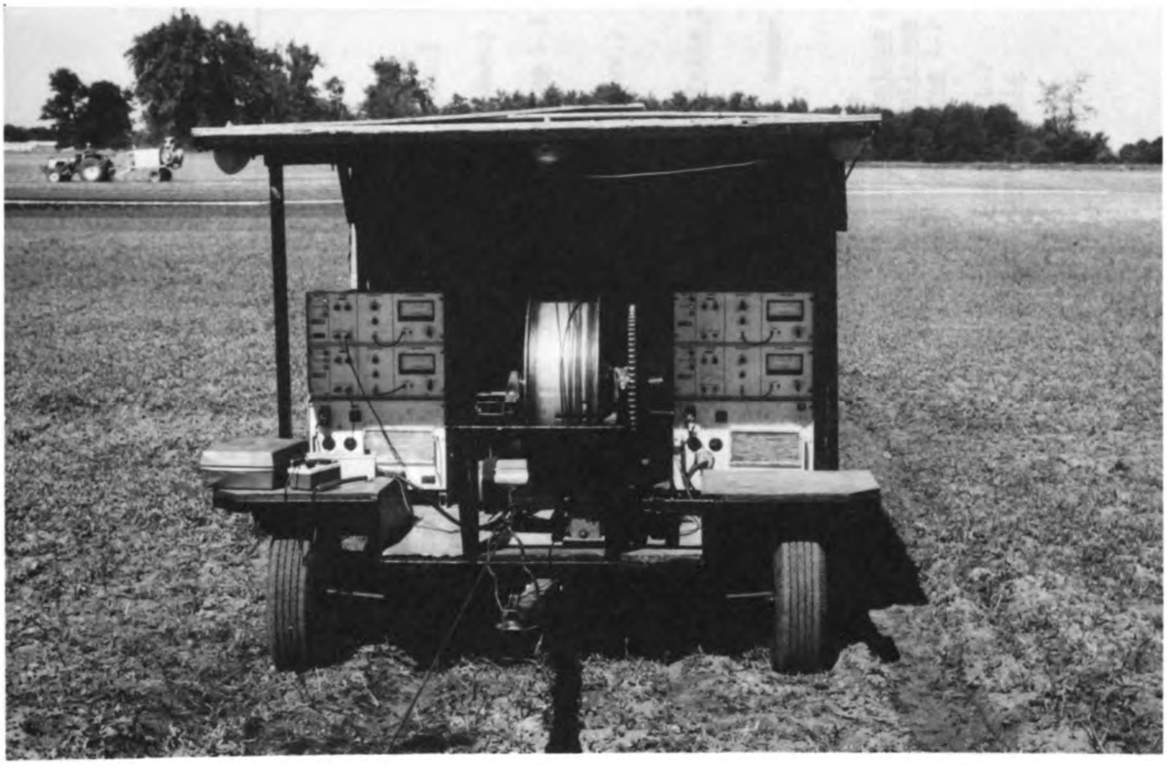
Field and laboratory studies indicate that UHF energy can control a wide spectrum of soil pests. The purpose of this investigation was to determine if important weeds, nematodes, and insects could be controlled by UHF energy applied in the field on a variety of soil types.

MATERIALS AND METHODS

UHF energy (2450 $\pm$ 20 MHz) was applied to the soil by a mobile microwave generating device (Figure 1). It consisted of a gas powered 60 hz electrical generator which provided power to four 1.5 KW microwave generators each containing a magnetron tube. A control panel provided adjustment of microwave power and readings of forward and reflected power. Microwaves were guided through four flexible wave guides to a 20.3 cm square horn type applicator which skimmed over the soil surface. A pyroceram plate with a dielectric constant between soil and air covered the applicator serving mainly as a barrier against the entry of soil into the radiator. The generators were mounted on a trailer which was propelled by means of a variable speed winch.

Efficacy of Microwaves for Weed Control. Newly prepared seedbeds at three different locations with three different soil types (Table 1) were treated with UHF energy at three energy levels, a standard herbicide, and hand weeded control. Different energy levels were obtained by altering the speed of the applicator. In all cases the soil surface was dry at time of application. Plot size was 6.1 m x .2 m and each treatment was replicated three times in a randomized block design. Observations included visual weed control ratings at 30 or 45 days and weed density counts after 60 days. A stale seedbed (prepared 3 weeks earlier) was treated with UHF energy at varying rates, a standard herbicide and a control. An adjacent area containing a severe infestation of quackgrass was also similarly treated but with a plot size of 6.1 m x .4 m. The design was a randomized block

Figure 1.--Mobile microwave field application device.
Top--Frontal view
bottom--Closeup view of horn applicator



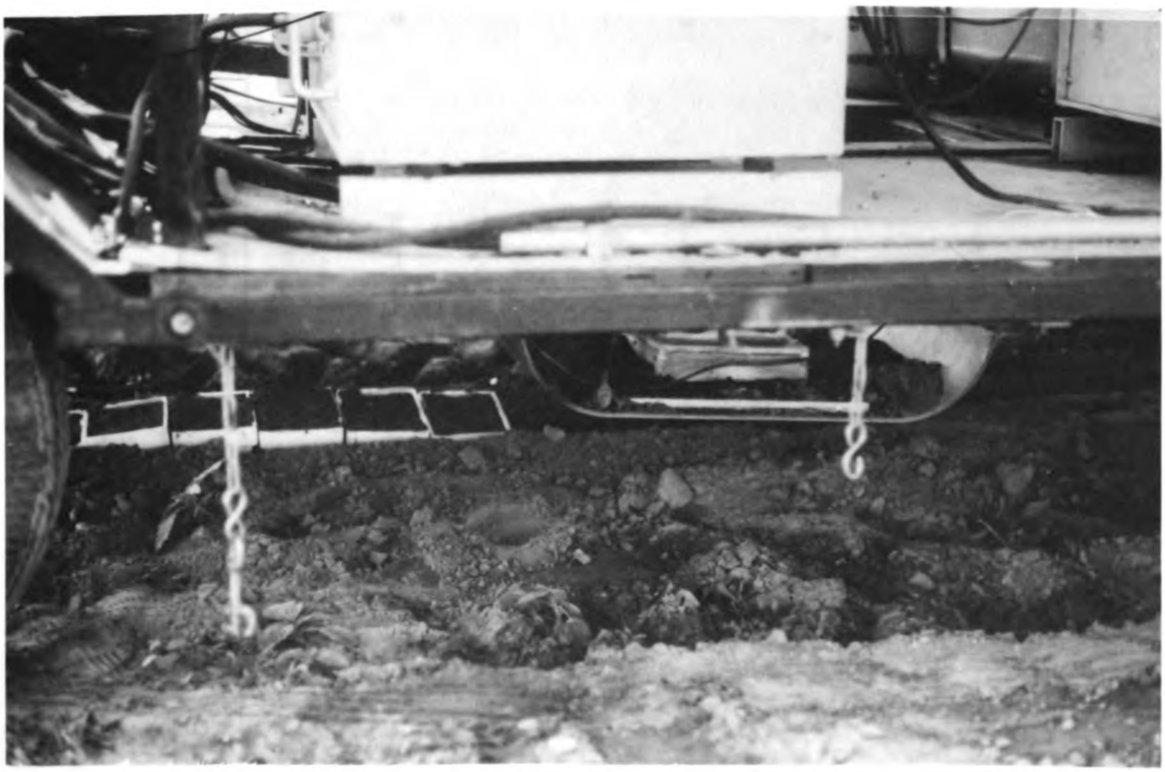


Table 1.--Description of weed control tests with UHF electromagnetic energy on stale seedbeds, newly prepared seedbeds, and quackgrass sod.

Location	Soil type	Site description	crop	Dominant weed species
MSU Horticulture Research Center	Miami Loam	fresh seedbed	cucumber	80% common purslane (*Portulaca oleracea* L.) 5% witchgrass (*Panicum capillare* L.) 15% others
Nobach Farm Aurelius, Mi.	Fox sandy loam	fresh seedbed	tomato	30% flixweed (*Descurainia sophia* (L.) Webb) 30% hoary allysum (*Berteroa incana* (L.) DC.) 15% red clover (*Trifolium pratense* L.) 10% quackgrass (*Agropyron repens* (L.) Beauv.) 10% Pennsylvania smartweed (*Polygonum pennsylvanicum* L.) 5% others
Nobach Farm Aurelius, Mi.	Fox sandy loam	quackgrass sod	---	100% quackgrass (*Agropyron repens* (L.) Beauv.)
Nobach Farm Aurelius, Mi.	Fox sandy loam	stale seedbed	tomato	4-8 cm common ragweed (*Ambrosia artemisifolia* L.) 5 cm common lambsquarters (*Chenopodium album* L.) 18 cm quackgrass (*Agropyron repens* (L.) Beauv.) 3 cm wild mustard (*Brassica kaber* (DC.) L.C. Wheeler) 5 cm Pennsylvania smartweed (*Polygonum pennsylvanicum* L.) 2.5 cm redroot pigweed (*Amaranthus retroflexus* L.) 5 cm wild buckwheat (*Polygonum convolvus* L.)
MSU Muck	Houghton muck	fresh seedbed	carrot	89% common purslane (*Portulaca oleracea* L.) 10% large crabgrass (*Digitaria sanguinalis* (L.) Scop.) 1% others

with three replications on the stale seedbed and two on the quackgrass sod. Observations included visual ratings at 30, 45, and 60 days and weed density counts 90 days after treatment.

Efficacy of Microwaves for Insect and Nematode Control. The potential of UHF energy for control of onion maggots (*Hylema antiqua*), sugarbeet cyst nematodes (*Heterodera schachtii*) and root-lesion nematodes (*Pratylenchus penetrans*) was determined. Ten pupae of onion maggots were placed in cheesecloth sacks and buried at 5 and 10 cm depths in a Miami loam soil. The soil was then treated with UHF energy at two rates. The treatments were replicated three times. After treatment the sacks were removed to the laboratory where the number of adults which emerged after 30 days were recorded. Soils containing the sugarbeet cyst nematodes or the root-lesion nematodes were placed in 100 cc nylon sacks and buried in Fox sandy loam and Houghton muck soils at 5 and 10 cm prior to treatment with microwaves at two energy levels. The treatments were replicated five times at each location. Sacks containing sugarbeet cyst nematodes had an initial population density (P_i) of 64 cysts/100 cc of soil, while sacks containing the root-lesion nematodes had a P_i of 52 adults/100 cc of soil. After treatment the sacks were collected and stored for 60 days at 12.5 C prior to assay by the centrifuge flotation technique.

RESULTS AND DISCUSSION

Efficacy of Microwaves for Weed Control. Treatment of newly prepared seedbeds with UHF energy provided weed control equal to or better than the standard herbicide treatment in all cases (Tables 2,3,4).

Control generally improved as energy levels were increased. Since crops were under a great deal of stress from weeds impinging on the treated area from outside of the plot, meaningful yield data were not obtained. Crop injury did not occur with any treatment and cucumbers appeared to grow better in UHF treated plots than in hand weeded plots. Weed control in UHF treated plots remained acceptable throughout the duration of the growing season.

Table 2.--Weed control with UHF electromagnetic energy on a newly prepared seedbed (Fox sandy loam).

Treatment	joules/cm^2 or lb/A	Weed Control Ratings 30 days	Weed Control Ratings 45 days	Weeds/2 ft^2 (60 days)
UHF energy	621	8.0a	5.3a	5.1
UHF energy	891	9.0a	6.0ab	4.0
UHF energy	1389	9.0a	8.7c	1.5
diphenamid	5	5.0b	5.3a	6.2
Weeded check	-	9.0a	7.0bc	4.2

Means with a column followed by identical letters are not significently different by Tukey's HSD test at the 5% level.

Table 3.--Weed control with UHF electromagnetic energy on a newly prepared seedbed (Miami loam).

Treatment	joules/cm^2 or lb/A	Weed Control Ratings 45 days	Weeds/2 ft^2 (60 days)
UHF energy	671	7.3a	3.5a
UHF energy	854	8.3a	1.5a
UHF energy	1376	9.0a	0.5a
chloramben (methylester)	2	6.7b	1.8a
Weedy check	-	0.0c	13.0c

Means within a column followed by identical letters are not significently different by Tukey's HSD test at the 5% level.

Table 4.--Weed control with UHF electromagnetic energy on a newly prepared seedbed (Houghton muck).

Treatment	joules/cm^2 or lb/A	Weed Control Rating 30 days	Weeds/2 ft^2 (60 days)
UHF energy	879	5.7ab	4.5a
UHF energy	1000	7.3bc	1.8a
UHF energy	1480	9.0c	0.2a
linuron	2	5.7ab	11.5b
Weedy check	-	4.7a	17.0b

Means within a column followed by identical letters are not significently different by Tukey's HSD test at the 5% level.

On Fox sandy loam, red clover was generally the first species to appear in plots treated with the lower energy levels. This may indicate that red clover seed is resistant to UHF energy at levels up to 891 joules/cm^2 on this soil type. Flixweed and hoary allysum emerged sporadically in all plots regardless of energy level applied. Since these species can behave as biennials or perennials, regrowth may have occurred from underground vegetative organs. On the Miami loam and Houghton muck soils, common purslane was the only species to consistently emerge in UHF treated plots; however, common purslane was the dominant species present at both locations so that no conclusion can be drawn concerning relative resistance to microwaves on these soils. Germination of seeds in the plots cannot necessarily be attributed to seeds which escaped treatment since the plots were narrow and could have been contaminated by seeds blown in from adjacent untreated areas. It appears that the energy required to kill weed seeds is somewhat less on sandy loams and loam soils than on muck soils. Definite comparisions are difficult to make since different weed species were present at each location.

On the stale seedbed, all UHF energy levels tested caused immediate loss of turgor and apparent death of emerged weeds (Table 5). Little or no regrowth occurred during the entire season, and after 90 days all UHF treated plots still exhibited commercially acceptable weed control.

Table 5.--Weed control with UHF electromagnetic energy on a stale seedbed

Treatment	joules/cm^2 or lb/A	Weed Control Ratings 30 days	45 days	60 days	Weeds/2 ft^2 (90 days)
UHF energy	771	9.0a	8.0a	9.0a	0.7
UHF energy	926	9.0a	9.0a	9.7a	1.0
UHF energy	1856	9.0a	9.0a	9.3a	0.7
diphenamid + paraquat	5 +0.5	5.3b	0.7b	2.7b	17.7
Weeded check	-	9.0a	9.0a	6.3c	16.3

Means within a column followed by identical letters are not significently different by Tukey's HSD test at the 5% level.

UHF treatment of stale seedbeds appears particularly promising due to the comparative ease of kill of emerged weeds and imbibed seeds (4). With this system, there should be a high percentage of seeds which have either germinated or imbibed water. Seeds capable of germination are primarily those viable seeds located within 1.3 cm of the soil surface. If soil disturbance is minimal, few new seeds should be introduced into this germination zone (4). Besides requiring less energy, stale seedbed treatments would allow the grower more flexibility since treatment date would not be as critical as where treatment must occur immediately after soil preparation and prior to planting.

Treatment of quackgrass at two energy levels tested resulted in immediate death of shoots. Rhizomes were apparently not harmed, as vigorous regrowth occurred within thirty days (Table 6). The translocated herbicide glyphosate gave excellent season long control. UHF energy may be feasible for perennial weed control only at higher rates or as spot treatments.

Table 6.--Quackgrass control with UHF electromagnetic energy

Treatment	$joules/cm^2$ or lb/A	Quackgrass Control Rating 15 days	Quackgrass Control Rating 60 days
UHF energy	502	8.5a	4.0a
UHF energy	952	5.0b	0.0b
glyphosate	2	10.0a	10.0c
check	-	0.0c	0.0b

Means within a column followed by identical letters are not significently different by Tukey's HSD test at the 5% level.

Efficacy of Microwaves for Insect and Nematode Control. UHF treatment at 1480 $joules/cm^2$ reduced final population densities (P_f) of root-lesion nematodes to non-detectable levels at both depths in mineral and muck soils. It is highly probable that UHF treatment at 879 $joules/cm^2$ reduced the P_f of root-lesion nematodes at both depths of each soil; however, natural mortality in nontreated soil was not determined. UHF treatment with 1480 $joules/cm^2$ reduced the P_f of sugarbeet cyst nematodes in muck soil at a 5 cm soil depth, but not at the 10 cm soil depth. It is highly probable that UHF treatment at an energy level of 879 $joules/cm^2$ reduced population densities of the sugarbeet cyst nematode at both depths in mineral soil, however, natural mortality levels in nontreated soil were not measured (Table 7).

Table 7.--Control of *Pratylenchus penetrans* and *Heterodera schachtii* with UHF electromagnetic energy at two depths of each of two soil types.

Energy joules/cm^2	Nematodes recovered per sack							
	Root-lesion nematode				Sugarbeet cyst nematode			
	Muck soil		Mineral soil		Muck soil[1]		Mineral soil[2]	
	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm	5 cm	10 cm
879	1.8	1.2	1.6	1.8	136	241	15.2	4.6
1000	0.0	0.6	5.2	0.2	207	93	14.0	9.0
1480	0.0	0.0	0.0	0.0	18	105	15.0	16.6

1/Survivors are primarily larvae

2/Survivors are primarily cysts. (A cyst contains 250-300 larvae)

Onion maggot pupae were eradicated at the highest energy level at the two depths tested while populations were reduced at the lower level (Table 8).

Table 8.--Toxicity of UHF energy to onion maggot pupae.

Energy joules/cm^2	Adults Emerged (%)	
	5 cm	10 cm
0	100	100
673	0	73
832	0	0

These data indicate that microwaves have excellent potential for nematode and soil insect control. The energy levels necessary for weed control may also effectively control certain insect and nematode populations.

Discussion. UHF energy has the potential to control several major soil pests. The shortage and high cost of energy may be a major obstacle to development of microwave applicators for pest control. Major expenses associated with microwave usage will include fuel, equipment (either purchased or leased), and labor. At 800 joules/cm^2, using a 40% efficient gas powered generator and an 80% efficient magnetron tube, approximately 64 gallons of gasoline per acre would be required to treat 0.3 m bands 1.0 m apart for wave generation alone (1, 3, 6,). Additional power will be required to supply drive motors. In high value crops where soil fumigation is used, UHF energy will be able to compete most effectively. In these crops, costs of fumigation to control weeds, nematodes, fungi, and soil insects generally range from $400 to $600 per acre for a tarped commercial application. In order for microwave energy to be competitive for pest control, application devices must be engineered which will use energy efficiently and will be capable of generating high intensity microwaves that can be applied rapidly. Costs can be further reduced by manipulation of soil conditions and application techniques so that energy requirements can be minimized. A thorough understanding of the factors which affect the efficiency of UHF energy is imperative for UHF energy to be used effectively for pest control.

LITERATURE CITED

1. Baumeister, Theodore. 1967. Standard Handbook for Mechanical Engineers. McGraw Hill Book Co. New York.

2. Davis, F. S., J. R. Wayland, and M. G. Merkle. 1971. Ultrahigh frequency electromagnetic fields for weed control: Phytotoxicity and selectivity. Science 173:535-537.

3. Fink, Donald B. 1968. Standard Handbook for Electrical Engineers. McGraw Hill Book Co. New York. 8:45.

4. Klingman, Glenn C. 1961. Weed Control as a Science. John Wiley and Sons, Inc. New York. pp. 272.

5. Menges, Robert M. Ultrahigh frequency (UHF) electromagnetic energy for weed control in vegetables. Weslaco, Texas. Unpublished.

6. Pimental, David, L. E. Hurd, A. C. Bellotti, M. J. Forster, I. N. Oka, O. D. Sholes, R. J. Whitman. 1973. Food production and the energy crisis. Science 182:443-448.

7. Wayland, J. R., F. S. Davis, and M. G. Merkle. Toxicity of an UHF device to plant seeds in soil. Texas A&M University. Unpublished.

8. Wayland, J. R., F. S. Davis, R. M. Menges, C. Robinson, and M. G. Merkle. Pre-emergence control of unwanted vegetation by use of UHF electromagnetic fields. Texas A&M University. Unpublished.

CHAPTER 3

SOME FACTORS AFFECTING EFFICIENCY OF UHF ENERGY FOR CONTROL OF WEED SEEDS

ABSTRACT

The potential of ultrahigh frequency electromagnetic energy as an alternative weed control method is being investigated. These studies were initiated to determine methods of maximizing the efficiency of UHF energy on weed seeds.

Imbibed and non-imbibed seeds of several different species were treated with UHF electromagnetic energy at varying intensities and for various periods of time. In addition, soil type and moisture influences on phytotoxicity were evaluated. Soil attenuation was measured by inserting a three cm thick soil plug into the wave-guide in front of the target seeds. After treatment, seeds were germinated in an incubator at 27 C to determine viability. The LD_{50} of nonimbibed black medic (Medicago lupulina L.)occurred at 183 joules/cc, barnyardgrass (Echinochloa crus-galli (L.) Beauv.) at 160 joules/cc, common purslane (Portulaca oleracea L.) at 139 joules/cc, and redroot pigweed (Amaranthus retroflexus L.) at 125 joules/cc. After the seeds had imbibed water for 24 hours the LD_{50} declined to 80 joules/cc for common purslane, 117 joules/cc for barnyardgrass, and 161 joules/cc for black medic, but did not decline for redroot pigweed. When seed-soil mixtures were treated, greatest toxicity occurred with the higher moisture levels in muck and clay loam soils with least toxicity occurring in a dry loamy

sand soil. Attenuation by dry soil occurred with all types tested but was greatest with Bellefontaine loamy sand. Increasing the power greatly reduced the time of exposure necessary to kill barnyardgrass seeds but not that necessary to kill corn seeds (*Zea mays* L.). Less energy was required to kill seeds as the soil temperature was increased from -20 to +18 C.

INTRODUCTION

For UHF energy to be used as a weed control tool, the factors which affect the efficacy of the process must be understood. An understanding of these factors will allow weed control with the least amount of energy.

One of the greatest obstacles to the widespread use of UHF energy to control weeds is the high cost of treatment. By manipulating equipment and field conditions so that seeds can be killed at maximum efficiency, significant cost reductions could be obtained.

In tests conducted in a microwave cavity, Wayland *et al*. found that seeds of broadleaf bean (*Phaseolus vulgaris* L.) and mesquite (*Prosopis glandulosa* Torr) were more easily killed after they had imbibed water. Wayland also found that lethal effects of microwaves in plant tissue were not due to average temperature increases but to either selective heating or non-thermal effects (5). Davis *et al*. reported that in a microwave chamber, UHF phytotoxicity is increased in imbibed seeds and young plants and that soil partially attenuates the UHF field but is not opaque to it (2,3). Due to differences in wave patterns and non uniformity of the field in a cavity, results from cavity treatments may not be directly applicable to those obtained with horn type applicators (1).

The objective of this investigation was to study methods for maximizing the efficiency of UHF energy for the control of weed seeds.

MATERIALS AND METHODS

All tests were conducted with a 1.5 KW microwave generator. Microwaves were produced by a magnetron tube and channeled through a metal wave guide. Treatments were made in a quartz test tube which was placed directly into the wave guide (Figure 1). In all cases reflected radiation was minimal. At the distal end of the waveguide, UHF energy was absorbed by water flowing through a cooling chamber separated from the waveguide by a ceramic plate. Power was regulated by a control panel which enabled adjustment of power in the range of 0 to 1500 W. The control panel also housed a gauge which measured forward and reflected power.

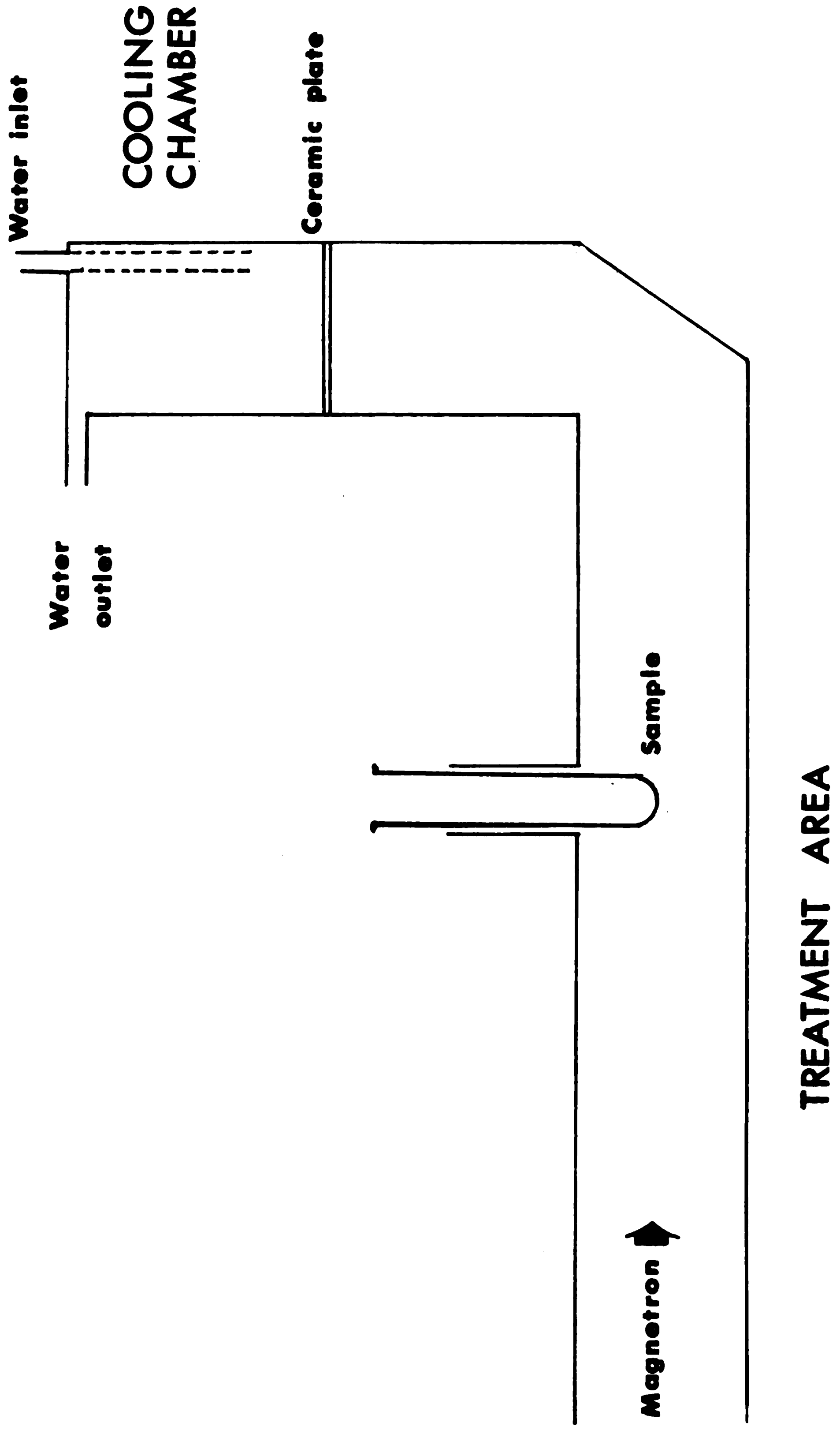
Lethal dose determinations. Laboratory tests were conducted to determine the lethal dosages of UHF energy for non-imbibed and imbibed seeds of several different species (Table 1).

Table 1.--Moisture content of seeds of 4 weed species.

Common name	Scientific name	% H_2O non-imbibed	% H_2O imbibed
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	12.6	54.6
Common purslane	*Portulaca oleracea* L.	13.5	49.5
Redroot pigweed	*Amaranthus retroflexus* L.	13.3	51.6
Black medic	*Medicago lupulina* L.	13.6	----

Moisture content was determined by drying seeds in an oven for one

Figure 1.--Schematic diagram of the waveguide of a UHF laboratory treatment apparatus.


Water inlet
COOLING CHAMBER
Ceramic plate
Water outlet
Sample
TREATMENT AREA
Magnetron

hour at 130 C and weighing (3). Moisture content is expressed as:

$$\% H_2O = \frac{M_i - M_f}{M_f}$$

where M_i is the initial mass, and M_f is the mass after drying(4).

One gram samples of the non-imbibed seeds of six species and of the 24 hour-imbibed seeds of four species were treated with UHF energy at various rates. In all cases, power was 1 KW and rates were altered by adjusting the time of exposure. Energy levels were determined by standard calorimetry in which the seed sample of known mass was placed into 10 ml of water (0 C) contained in a double wall styrofoam calorimeter. Equilibrium temperature was measured with a low mass bead thermister. The specific heat (Cps) of the seed was determined by heating the seed to a known temperature, measuring the equilibrium temperature reached in the calorimeter, and substituting the appropriate values into the following equation where M_w= mass of water, M_s= mass of seeds, T_{wo}= initial water temperature, T_{so}= initial temperature of seeds, and T_f= equilibrium temperature:

$$Cps = \frac{M_w(T_f - T_{wo})}{M_s\ (T_{so} - T_f)}$$

After treatment, the seeds (50/sample) were placed in petri dishes on moist filter paper and allowed to germinate in a dark incubator at 27 C. Each treatment was replicated on five lots of seed. Seed-coats were mechanically removed from large crabgrass seeds after treatment to increase germination and seed viability was observed daily. Emergence of the radicle was used as a criterion for germination.

Soil attenuation of the UHF field. Dry soil of three types was placed in a glass container and inserted into the waveguide between the magnetron and the sample chamber. Corn seed was then placed in the quartz tube and treated with UHF energy at various levels to test the reduction in toxicity which occurred due to the presence of soil. The test was replicated five times with 8 seeds in each sample. Germination was compared to that of corn seeds treated in the absence of soil.

In another series of soil tests, 50 seed samples of common purslane were mixed with 6 g of soil of three types and two moisture levels and treated with UHF energy for 5, 10, 15, 20, 25, 30, and 35 sec in the quartz tube. Soil types were a Bellefontaine loamy sand (3 and 20% H_2O), Miami loam (7.4 and 24% H_2O), and Houghton muck (49 and 55% H_2O). Five replications of seed-soil mixtures were incubated in petri dishes at 27 C and assayed daily.

Field intensity effects. The effects of varying both the duration and intensity of treatment when total energy was kept constant were ascertained. Since total energy is the product of intensity and duration of treatment, if total energy remains constant, changing one factor inversely affects the other.

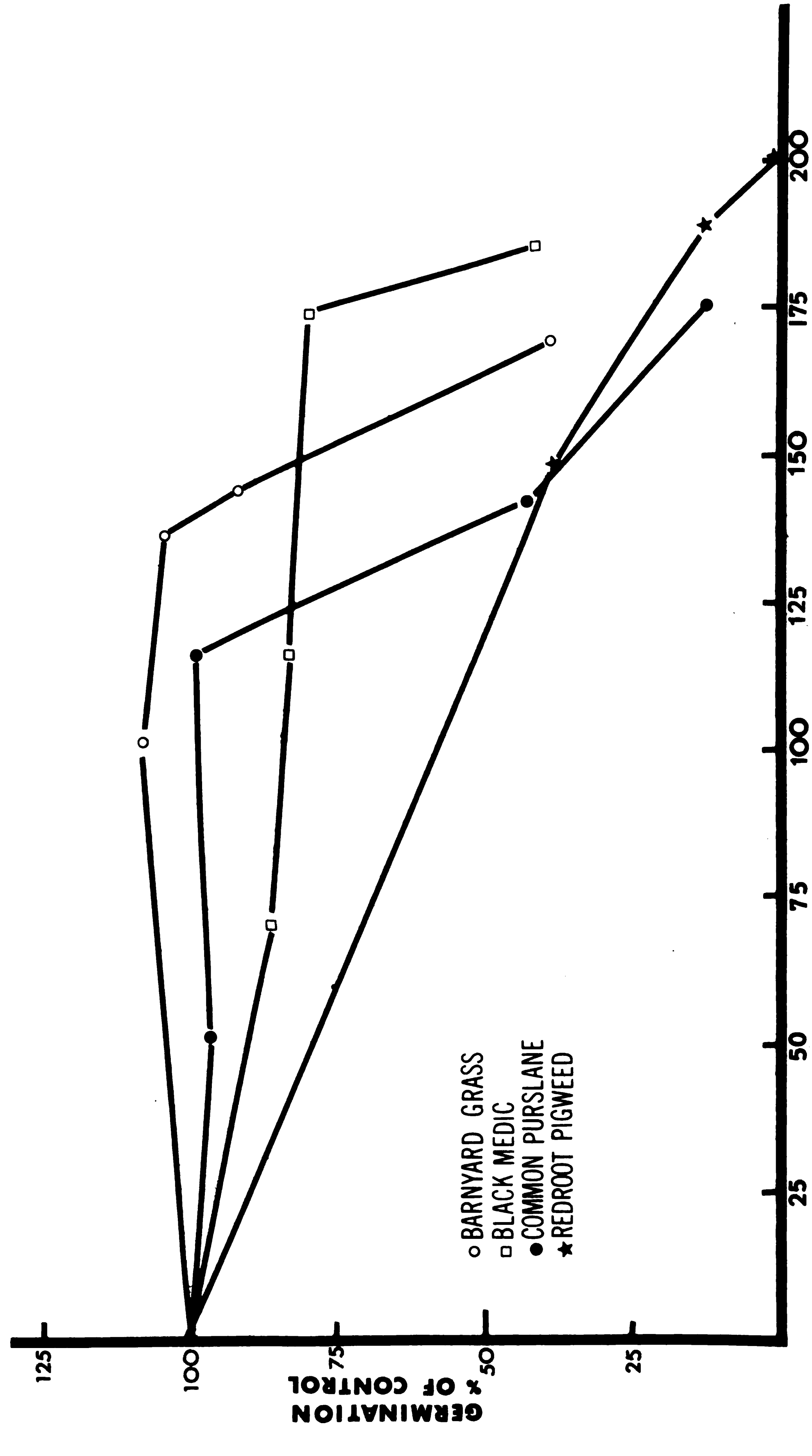
Seeds of barnyardgrass and corn were treated with UHF energy at 5 different total energy levels. Energy intensity was varied to include 0.1 KW, 0.2 KW, 1.0 KW, and 1.5 KW. Duration of exposure was varied so that total energy levels remained constant. Seeds were germinated as previously described with 5 replicates.

Effects of initial temperature on microwave efficiency. Barnyardgrass seeds were mixed with 6 g of Miami loam soil containing 19% moisture, quick frozen in a dry ice-acetone mixture and treated with microwaves for varying lengths of time. Seed-soil temperatures at the time of treatment approximated -20 C. Seed-soil mixtures were also frozen in a freezer for 19 hours at -8 C and treated in the same manner. After treatment at five different energy levels, the sample tube containing the soil-seed mixture was placed in a water bath at 45 C until thawed prior to being placed in petri dishes and germinated at 27 C. Seeds in the same soil at 18 C were also treated in the same manner. The test was replicated 5 times.

RESULTS AND DISCUSSION

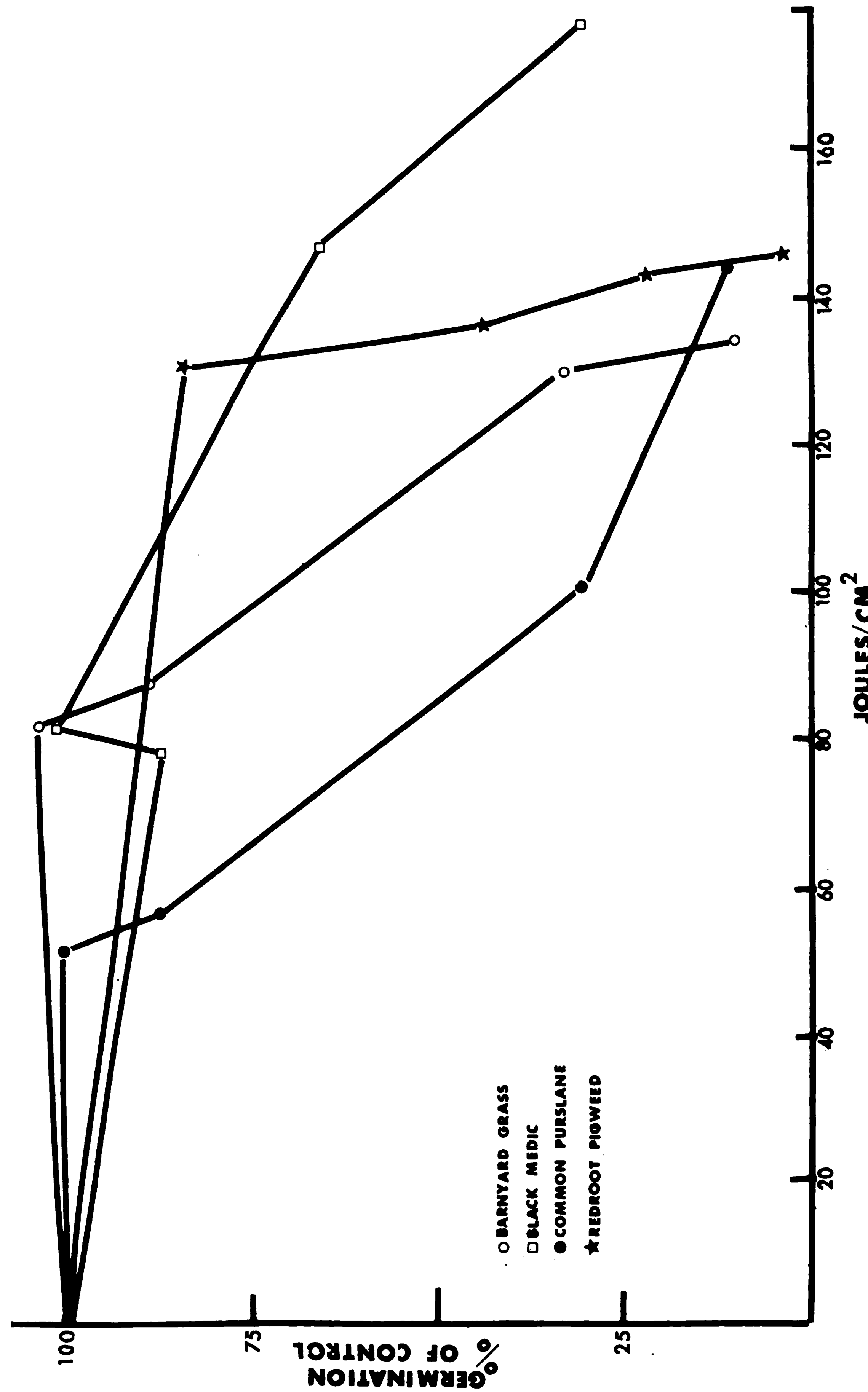
Lethal dose determinations. The UHF energy required for median toxicity varied for each of the species tested. In two of the species, short exposures to UHF energy stimulated germination. In barnyardgrass, germination was not significently increased but with large crabgrass (Digitaria sanguinalis (L.) Scop.) a 180% increase in germination occurred and was reproduced in subsequent tests. The increase occurred only when the seedcoats were mechanically removed. The LD_{50} of non-imbibed black medic occurred at 183 joules/cc, barnyardgrass at 160 joules/cc, common purslane at 139 joules/cc and redroot pigweed at 125 joules/cc (Figure 2). After the seeds had imbibed water for 24 hours the LD_{50} declined to 80 joules/cc for common purslane, 117 joules/cc for barnyardgrass, and 161 joules/cc for black medic, but did not decline for redroot pigweed (Figure 3).

Figure 2.--Effects of increasing UHF energy on the germination of non-imbibed seeds of 4 weed species.



○ BARNYARD GRASS
□ BLACK MEDIC
● COMMON PURSLANE
★ REDROOT PIGWEED
JOULES/CM²
25
50
75
100
125
150
175
200
GERMINATION
% OF CONTROL
125
100
75
50
25

Figure 3.--Effects of increasing UHF energy on the germination of 4 weed species imbibed for 24 hours.



% GERMINATION OF CONTROL
100
75
25
JOULES/CM²
20
40
60
80
100
120
140
160
○ BARNYARD GRASS
□ BLACK MEDIC
● COMMON PURSLANE
★ REDROOT PIGWEED

When radicle lengths were measured, no differences could be ascertained between treated seeds which germinated and non-treated seeds(Table 2).

Table 2.--Effects of UHF energy on radicle growth of barnyardgrass.

Exposure (sec)	Radicle length (mm)
0	22.5
40	22.5
50	21.5
60	0.0
70	0.0
80	0.0

Apparently UHF energy affects seeds by preventing germination but non-lethal doses do not inhibit seedling growth.

Soil attenuation of the UHF field. Wet soil greatly reduced the penetration of microwaves through a soil chamber both by absorption and reflection. As exposure time increased, moisture content of the soil decreased and reflection was reduced to a negligable level (Table 3).

Table 3.--Reflectivity characteristics of Houghton muck soil (H_2O initial = 49%).

Exposure	Reflected Energy (KW)	Exposure	Reflected Energy (KW)
10	0.80	45	0.11
15	0.55	50	0.10
20	0.70	55	0.10
25	0.60	60	0.03
30	0.25	65	0.01
35	0.10	70	0.00
40	0.10		

Attenuation of the UHF field by dry soils varied with soil types (Figure 4). Although all types tested attenuated the field, Bellefontaine loamy sand was most opaque to microwaves. There was no difference in opacity between Miami loam and Houghton muck soils.

When seeds were mixed directly with soil, energy levels required to kill seed varied with species, soil type and moisture content of the soil. In loamy sand with a 3% moisture content, common purslane germination was not reduced at exposures of up to 35 sec (Figure 5). When the same soil with a moisture content of 20% was treated a 60% reduction in purslane germination occurred with a similar exposure. Seeds treated in the Miami loam soil with a 7.4% moisture content were much more susceptible than those in the loamy sand. The threshold injury level occurred at 25 seconds whereas the LD_{50} occurred between 30 and 35 seconds. When water content of the Miami loam was increased to 24%, the injury threshold for purslane occurred at 15 sec and the LD_{50} occurred at 22 sec. In Houghton muck soil the injury threshold occurred at 7 sec for soil with a 55% moisture content and 17 sec for soil with a 49% moisture content. In the soil with a higher moisture content the LD_{50} occurred at 15 sec while in the drier soil it did not occur until 26 sec of exposure. The lower energy levels required in soils with a higher moisture content may be due to the greater temperature increase occurring in these soils. Since water heats rapidly in a UHF field, general heating of the soil is related to moisture content. Sandy soils generally do not absorb UHF energy as efficiently as other soil types primarily because of lower field capacities and high percentages of UHF transparent silica compounds.

Figure 4.--Attenuation of UHF energy by dry soil of three types as indicated by corn germination.

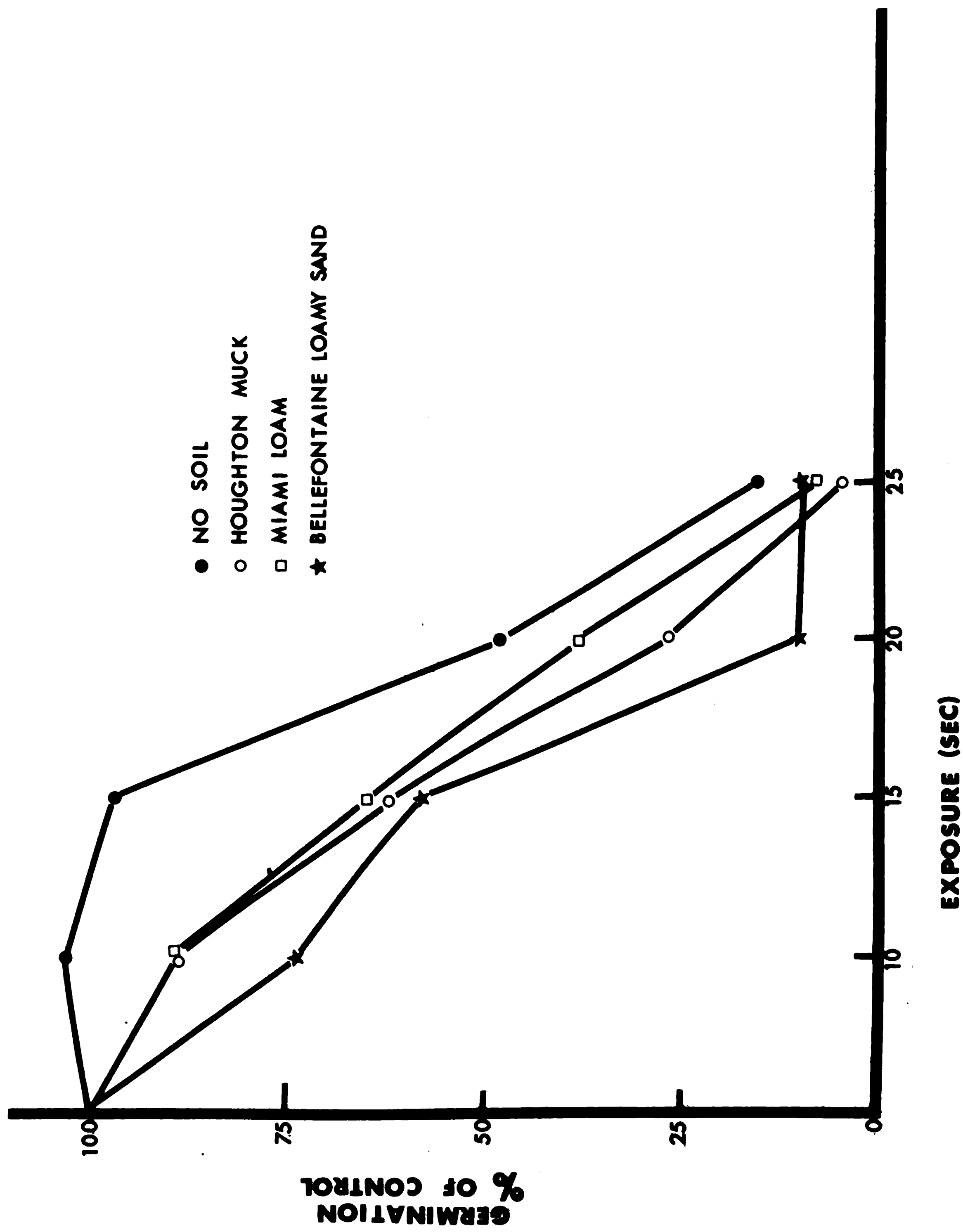
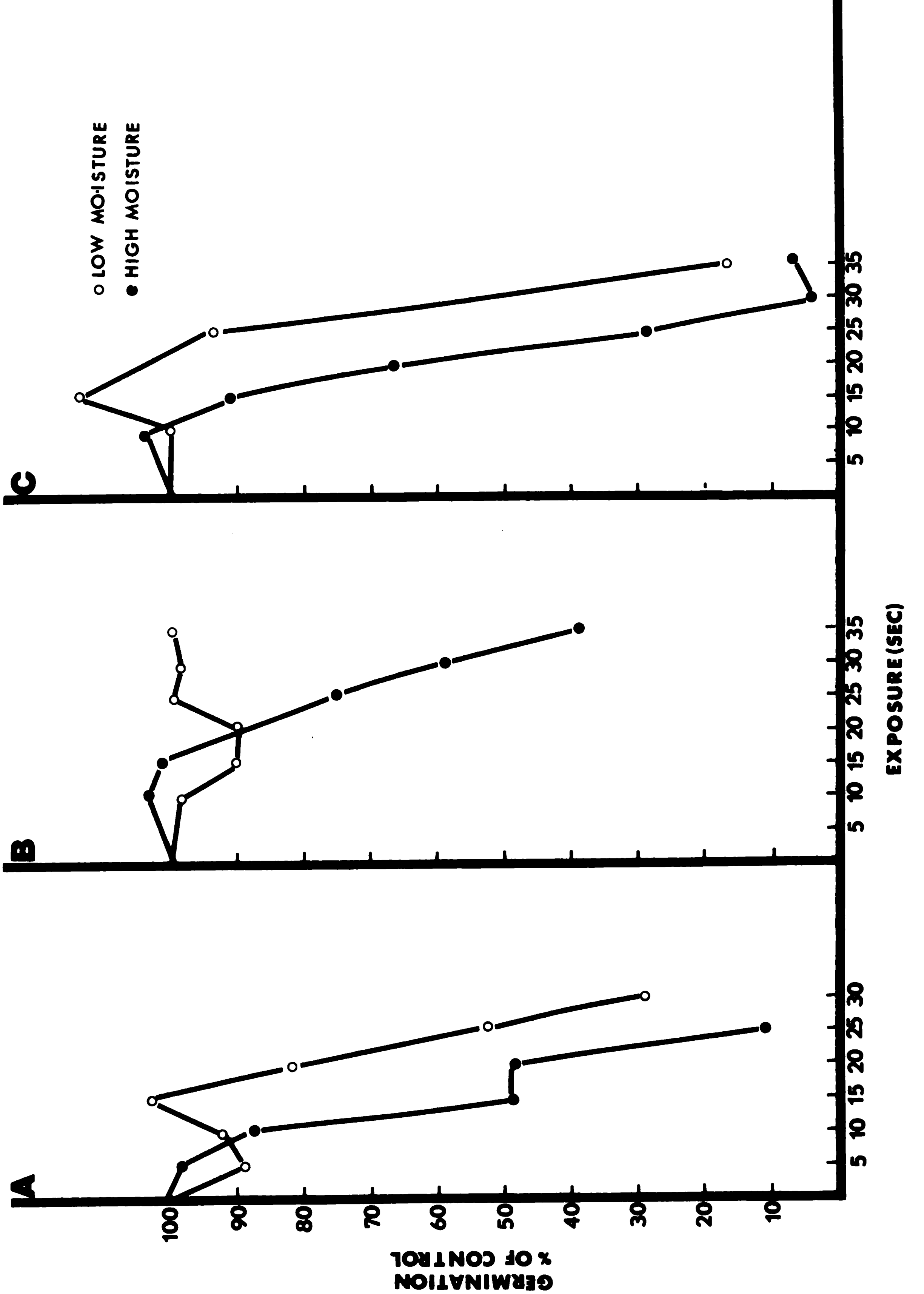

NO SOIL
HOUGHTON MUCK
MIAMI LOAM
BELLEFONTAINE LOAMY SAND
GERMINATION % OF CONTROL
100
75
50
25
0
10
15
20
25
EXPOSURE (SEC)

Figure 5.--Effects of UHF energy on germination of barnyardgrass when seeds were mixed with soil (6 g) of 3 soil types and 2 moisture levels.

A.--Houghton muck (49% and 55% H_2O)

B.--Bellefontaine loamy sand (3% and 20% H_2O)

C.--Miami loam (7.4% and 24% H_2O)


A
B
C
○ LOW MOISTURE
● HIGH MOISTURE
EXPOSURE (SEC)
GERMINATION
% OF CONTROL
100 90 80 70 60 50 40 30 20 10
5 10 15 20 25 30 35

Field intensity effects. The effects of substituting increased field intensity for duration of treatment varied between the species tested. Increased intensity treatments of barnyardgrass were lethal to a higher percentage of seeds than treatments of a longer duration when total energy levels remained constant (Figure 6). At 0.1 KW germination percentages did not significently decrease in any of the treatments. As the field intensity was increased, the germination percentage at any single level decreased. In corn, duration of treatment and field intensity were more nearly interchangeable. Though germination was slightly poorer at any given rate at the higher field intensities, substantial germination reductions were obtained at all intensities tested. Increased field intensity apparently can be substituted for duration of treatment and in the case of barnyardgrass considerable reductions in the total energy required for a lethal dose may result. In order for UHF applications to become commercially feasible, higher intensities will have to be employed so that the speed of treatment can be increased.

Effects of initial temperature on microwave efficiency. UHF treatment of -20 C soil-seed mixtures required much higher energy levels to decrease germination than identical 18 C soil-seed mixtures. Germination of -20 C seeds was not affected at exposures up to 40 sec (Figure 7). When soil-seed mixtures were frozen in a freezer at -8 C for 19 hours and subsequently treated, germination was significantly reduced only at the 40 sec exposures. Germination of 18 C soil-seed mixtures was reduced at all levels tested. Apparently, higher energy levels will be required to kill seeds at lower initial

Figure 6.--Effects of varying the field intensity and duration of treatment when total energy remains constant on germination of barnyardgrass at 5 total energy levels.

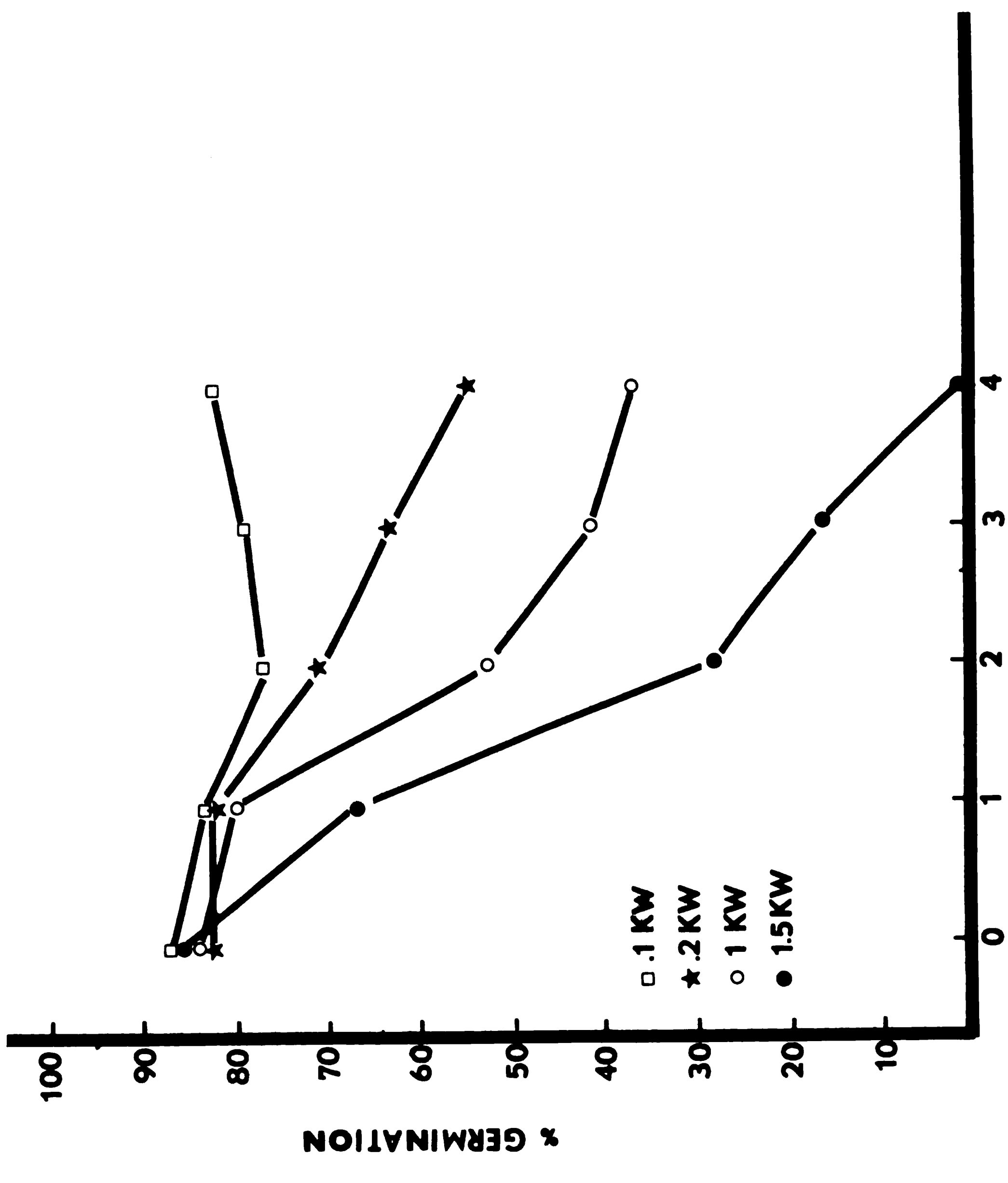
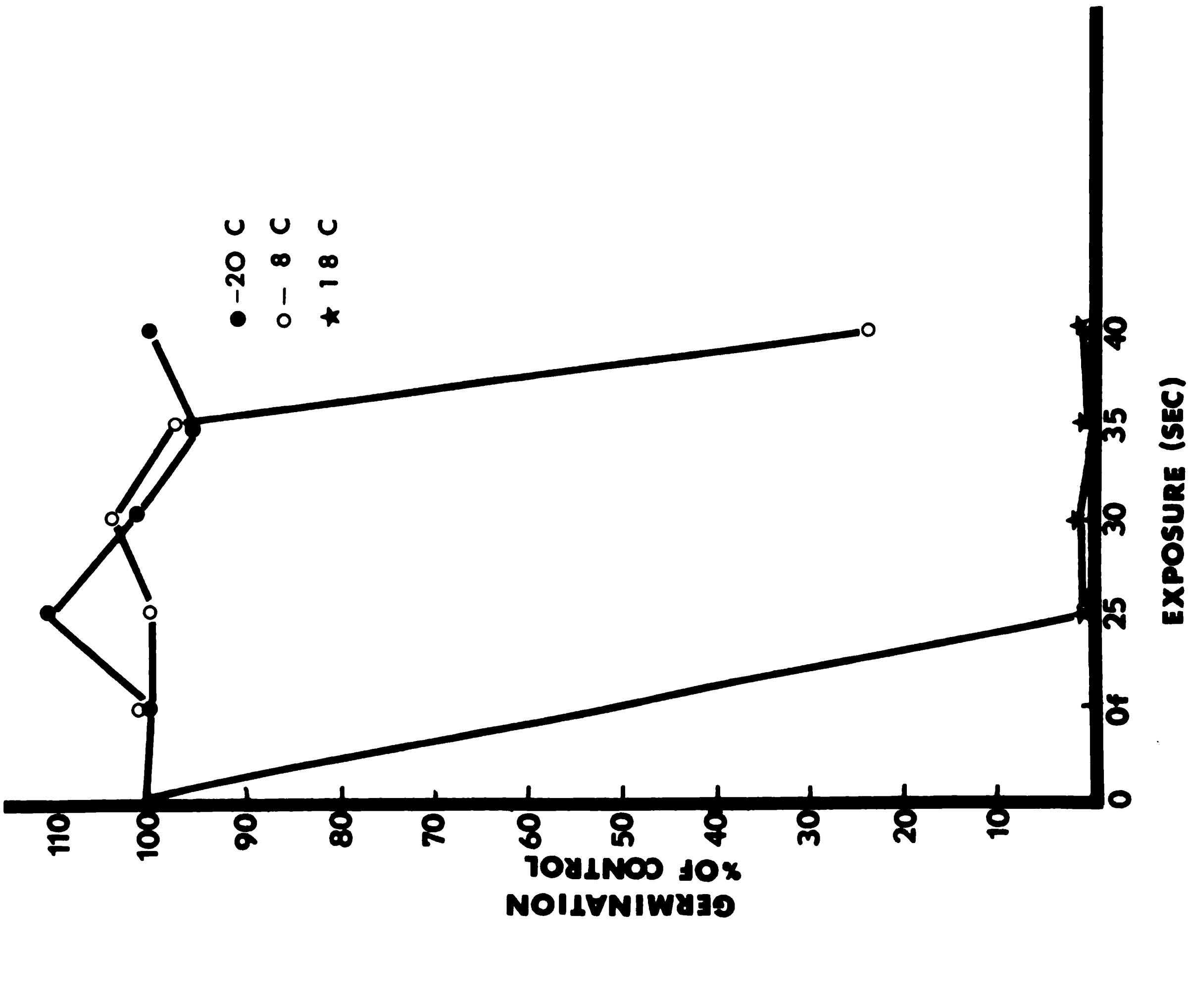

% GERMINATION
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
RATE
.1 KW
.2 KW
1 KW
1.5 KW

Figure 7.--Effects of initial soil-seed temperature on the efficiency of UHF energy for controlling germination of barnyardgrass.


GERMINATION
%OF CONTROL
110
100
90
80
70
60
50
40
30
20
10
0
10
25
30
35
40
EXPOSURE (SEC)
-20 C
— 8 C
18 C

temperatures. Since temperatures after treatment did not approach previously determined thermal LD_{50} levels of 65-70 C in any of the treatments except the 40 sec exposure of -8 C seeds and all the treatments of the 18 C seeds, colder seeds may have failed to absorb enough energy for lethal thermal effects to occur. If thermal effects are the primary cause of death of UHF treated seeds, considerably more energy would have to be absorbed by a frozen seed than one at room temperature for a thermal death point to be reached.

Lethal effects of UHF energy on seeds are apparently affected by many factors. Energy requirements for killing seeds can generally be decreased by increasing the moisture content of the seed and the soil, by using higher intensity microwave fields, and by treating when seed-soil temperatures are high. Highest energy levels will be required on muck and sandy soils.

LITERATURE CITED

1. Copson, David A. 1962 Microwave Heating. The Avi Publishing Company Inc. Westport, Conn.

2. Davis, F. S., J. R. Wayland and M. B. Merkle. 1971. Ultrahigh frequency electromagnetic fields for weed control: phytotoxicity and selectivity. Science 173: 535-537.

3. Davis, F. S., J. R. Wayland, C. W. Robinson, and M. B. Merkle. Some factors affecting differential phytotoxicity of a UHF electromagnetic field. Texas A & M University. Unpublished.

4. Koxlowski, T. T. 1972. Seed Biology. Academic Press, New York. pp. 236-238.

5. Wayland, J. R., F. S. Davis, L. W. Young, M. G. Merkle. 1972. Effects of UHF fields on plants and seeds of mesquite and beans. Journal of Microwave Power 7:4.

LIST OF REFERENCES

LITERATURE CITED

1. Baumeister, Theodor. 1967. Standard Handbook for Mechanical Engineers. McGraw Hill Book Co. New York.

2. Champ, Michael A., Frank S. Davis, J. R. Wayland. 1972. Ultrahigh frequency electromagnetic radiation utilized for aquatic vegetation control. Proceedings of the Southeastern Association of Game and Fish Commissioners.

3. Copson, D. A. 1956. Microwave energy in food procedures. IRE Trans. Prof. Group on Med. Electronics. PGME-4, 27-35.

4. Copson, David A. Microwave Heating. 1962. The Avi Publishing Company, Inc., Westport, Conn. p. 419.

5. Davis, F. S., J. R. Wayland, and M. G. Merkle. 1971. Ultrahigh frequency electromagnetic fields for weed control: Phytotoxicity and selectivity. Science 173:535-537.

6. Davis, F. S., J. R. Wayland, C. W. Robinson and M. G. Merkle. Some factors affecting differential phytotoxicity of a UHF electromagnetic field. Texas A&M University. Unpublished.

7. Fink, Donald G. 1968. Standard Handbook for Electrical Engineers. McGraw Hill, New York. 8:45.

8. Furtick, W. R. 1967. National and international weeds for weed science. A challenge for W.S.A. weeds. 15:291-295.

9. Katchalsky, A., and P. F. Curran. 1967. Nonequilibrium thermodynamics in biophysics. Harvard University Press, Cambridge.

10. Klingman, Glenn C. 1961. Weed Control as a Science. John Wiley & Sons, Inc., New York. pp. 409.

11. Koxlowski, T. T. 1972. Seed Biology. Academic Press, New York pp. 236-238.

12. Lebovitz, Robert M. 1972. The sensitivity of the human central nervous system to "safe" levels of microwave radiation. Rand, Santa Monica, Calif. p.47.

13. Menges, R. Ultrahigh frequency (UHF) electromagnetic energy for weed control in vegetables. Weslaco, Texas. Unpublished.

14. Munger, B. L., and B. S. Reynolds. 1961. The relationship between optical properties of liquids and the behavior of colloidal systems in the microwave range of electromagnetic radiation. Biophys. Soc. 5th Annual Meeting.

15. Pimental, David, L. E. Hurd, A. C. Bellotti, M. J. Forster, I. N. Oka, O. D. Sholes, R. J. Whitman. 1973. Food production and the energy crisis. Science 182:443-448.

16. Van Everdingen, W. A. G., 1946. On molecular and structural changes from irradiation at 16 to 10 cm I. Molecular Transformation. Revue Belge de Sciences Medicales 17, 261-283.

17. Vela, G. R., J. F. Wu, Don Smith, and Frank S. Davis. 1974. Effect of microwaves on populations of soil microorganisms. Abstracts: 1974 meeting--Weed Science Society of America. p. 97.

18. Wayland, J. R., F. S. Davis, R. M. Menges, C. Robinson, and M. G. Merkle. Pre-emergence control of unwanted vegetation by use of UHF electromagnetic fields. Texas A & M University. Unpublished.

19. Wayland, J. R., F. S. Davis, and M. G. Merkle. Toxicity of an UHF device to plant seeds in soil. Texas A & M University. Unpublished.

20. Wayland, J. R., F. S. Davis, L. W. Young, M. G. Merkle. 1972. Effects of UHF fields on plants and seeds of mesquite and beans. Journal of Microwave Power 7:4.