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Ultrahigh-Frequency Electromagnetic Fields for Weed Control: Phytotoxicity and Selectivity

Abstract. *An ultrahigh-frequency electromagnetic field (2450±20 megahertz) is lethal to plants and seeds of several species after relatively short exposure times. Some species are highly susceptible; others are relatively resistant to a given field intensity. Phytotoxicity is increased in imbibed seeds and young plants. It is decreased in dry seeds and sometimes decreased in mature plants. Soil partially attenuates the field but is not opaque to it.*

The use of ultrahigh-frequency (UHF) electromagnetic field of frequency 2450 ± 20 Mhz for vegetation control and its potential to discriminate between species are considered in this report. The influence of imbibition of the seed, the stage of development of the plant, and presence or absence of soil on phytotoxicity may be important parameters in the effective use of UHF fields for weed control. Accordingly, the following work investigates the influence of each of these on phytotoxicity.

The frequency used in this experiment is in the microwave region of the radio-frequency band (*1*). In this region the absorption occurs principally by changes in the rotational energies of molecules in the object being exposed. The absorption of electromagnetic energy by rotations is the result of an interaction of the molecular dipole moment with the electromagnetic field. The molecule must have a permanent dipole moment to exhibit absorption in this frequency range.

Various workers have reported that macrowave, or lower-frequency fields (10 to 100 Mhz), increase germination and alter subsequent growth of crop species (*2*). It is interesting to note that application of macrowave fields to insects results in a method of control. Nelson (*3*) states that the mechanism of lethal action has not been explained with any certainty, and there may be physiological lesions other than thermal effects that contribute to the death of insects in a radio-frequency field. Two investigations on effects of low-frequency fields on weed seeds were reported in 1950 and 1954 (*4*), but the methods used did not permit conclusive results.

The UHF range has not previously been studied for weed control. Recently UHF fields have been studied for

Table 1. Relative germination or seedling survival* of several species after exposure to radiation at three stages of development. Numbers followed by the same letter are not significantly different at $P < .05$ by Duncan's test.

Species	Dry seed (%)		Wet (4-hour imbibed) seed (%)		Germinating (46-hour) seed (%)	
	At 45 joule/g	At 270 joule/g	At 23 joule/g	At 45 joule/g	At 23 joule/g	At 45 joule/g
Corn (*Zea mays*)	73abc	15f	26bcd	1	52ab	1
Cotton (*Gossypium hirsutum*)	73abc	72ab	13cd	1	21abc	0
Soybean (*Glycine max*)	71abc	70abc	28bcd	0	31ab	0
Sorghum (*Sorghum vulgare*)	88a	54bc	22bcd	1	62a	15
Wheat (*Triticum vulgare*)	100a	48cde	37bc	0	48ab	15
Peanut (*Arachis hypogaea*)	100a	83a	53ab	0	46ab	0
Honey mesquite (*Prosopis juliflora*)	59c	48bc	1d	1	16c	0
Cucumber (*Cucumis sativus*)	93a	69ab	47b	1	31ab	1
Mustard (*Brassica* spp.)	79ab	83a	9cd	0	48ab	0
Curled dock (*Rumex crispus*)	72abc	100a	19bcd	0	56ab	21
Jungle rice (*Echinochloa colonum*)	71abc	75cd	74a	0	48ab	0
Pigweed (*Amaranthus* spp.)	74abc	35ef	12cd	0	0c	0

* $\frac{\text{Germination of treated}}{\text{Germination of control}} \times 100$.

Table 2. Plant damage index* of several 14-day-old species to an electromagnetic field of 2450 ± 20 Mhz at the indicated absorbed energies. Numbers followed by the same letter are not significantly different at $P < .05$ by Duncan's test.

Species	Plant damage at absorbed energy:			
	9 joule/g	18 joule/g	23 joule/g	36 joule/g
Mustard	3a	7a	0a	25a
Jungle rice	5ab	7a	25ab	25a
Sorghum	7a	38b	48bc	70bc
Honey mesquite	10a	20ab	52bcd	60ab
Cucumber	12a	23ab	28ab	72bc
Wheat	20ab	37b	45abc	63b
Peanut	37b	80cd	75cde	90bc
Soybean	77c	67d	92de	100c
Cotton	100d	100cd	100e	100c

* Percentage of necrotic tissue 5 days after treatment.

control of microorganisms in plant materials and nematodes in soil (5).

The source of radiation for these studies was a Litton (6) cavity-type chamber (38 by 30 by 23 cm) which contained a magnetron tube as a source for a 2450 ± 20 Mhz field with a nominal power output of 600 watts. Energy intensities used in these studies are reported as energy absorbed by an equivalent volume of water. For example, the chamber had an absorbed energy level of 270 joule/g for a 50-ml water sample exposed for 60 seconds.

For treatment, samples were placed on a raised glass shelf that was 1.5 cm above the chamber floor. In all studies, replications to be compared were treated in identical positions within the chamber to avoid confounding effects due to nonhomogeneity of the field within the chamber. Environmental conditions before and after treatment were as follows: day and night temperature, 32° and 29°C, respectively; relative humidity, 75 percent; light, 16,050 lu/m^2 (1500 foot-candles); and day length, 15 hours.

Effects on germination were compared in several species (Table 1) by exposing seeds in glass petri dishes. Ten replications of ten seeds were used for each species, and a seed was considered germinated if it had 3-mm root elongation after 5 days. Germination percentages were calculated on the basis of the percentage of germination of untreated controls. All lots of seed used had at least 50 percent germination under our conditions. Selected weed and crop species were exposed in the dry, imbibed (4 hours), and germinated (46 hours) states to 270, 135, and 135 joules of absorbed energy per gram, respectively, to determine the susceptibility in relation to stage of development.

Response to the radiation levels varied widely (Table 1). Corn, sorghum, and jungle rice were more susceptible than were cotton, mustard, and soybean.

Both selectivity and resistance decreased when the seeds were permitted to imbibe water for 4 and 46 hours (Table 1). These data suggest that internal moisture or other changes associated with imbibition of the seeds is an important factor governing susceptibility. However, there was a tendency for germinating seeds to be somewhat more resistant than imbibed seeds, which suggests that internal moisture content is not the only factor governing susceptibility of the various species.

In other studies, seeds of two species were exposed to 45 joule/g at 0, 30, 60, 120, 180, 240, 510, 2160, and 4020 minutes after wetting the seeds to further establish the relation of stage of development to susceptibility. Resistance to 45 joules of absorbed energy per gram decreased markedly within a short time after seeds of sorghum and honey mesquite were wet. Mesquite was more sensitive in the imbibed state than was grain sorghum. The principal change occurred during the first 60 minutes (7).

To determine whether soil moisture or moisture in the imbibed seed is more important in the phytotoxic effect, the field was applied to two species under four conditions: dry seeds, 4-hour imbibed seeds, 4-hour imbibed seeds in dry sand, and dry seeds in wet sand. Germination percentages for sorghum and mesquite, respectively, after receiving 45 joule/g of radiation were as follows: dry seeds, 88 and 69 percent; dry seeds in 2 cm of wet sand, 98 and 77 percent; 4-hour imbibed seeds, 1 and 0 percent; 4-hour imbibed seeds in 2 cm of dry sand, 75 and 22 percent. These data indicate that internal seed condition is a more important factor influencing the phytotoxic effect than is soil moisture. Sand clearly causes some attenuation of the field but is not opaque to it.

To establish susceptibility of growing plants of various species, 14-day-old plants were exposed to levels of radiation from 9 to 36 joule/g. The experiment was replicated three times, and the effect of the radiation was determined by damage ratings made 5 days after treatment. The phytotoxicity of the UHF field to 14-day-old plants of several species varied widely. At 23 joule/g, the range of susceptibilities among species was 0 to 100 percent tissue damage (Table 2). Relatively resistant species (less than 50 percent damage at 23 joule/g) were sorghum, jungle rice, cucumber, mustard, and wheat. Cotton was quite susceptible at all absorbed energy levels employed. Jungle rice and mustard were the only species having less than 50 percent damage at 36 joule/g. In general, all species were many times more sensitive in the seedling stage than as seeds.

Effect of plant age on relative susceptibility was studied in two species by exposing 8- and 28-day-old bean and 8-, 45-, and 360-day-old mesquite plants to levels of radiation from 4.7

Table 3. Influence of age of plant damage index* of bean (*Phaseolus vulgaris*) and mesquite plants after exposure to the indicated radiation.

Bean			Mesquite			
Radiation (joule/g)	Damage at		Radiation (joule/g)	Damage at		
	8 days	28 days		8 days	45 days	360 days
9	15	20	90	100	56	20
13.5	45	40	180	100	100	38
18	51	45	270			61
23	100	90	360			98
27	100	100	540			95
90	100	100	1080			100

* Percentage of necrotic tissue after 5 days (bean) and 20 days (mesquite).

to 540 joule/g. Damage ratings (percentage of leaf and stem necrosis) were made after 5 and 20 days, and the experiments were replicated three times. Aging had little effect on the susceptibility of bean plants, but in honey mesquite resistance to damage increased with aging (Table 3). After 8 days, bean was several times more susceptible than was honey mesquite.

The mechanism creating toxicity is not clear. Energy absorbed by organic molecules can result in internal heating or even disruption. On the other hand, water molecules or other noncritical molecules can be excited and transfer their energy to the molecules that are critically involved in growth. This is, obviously, a complex problem that requires extensive investigation.

Our studies have demonstrated differential phytotoxicity of radio-frequency energy at 2450 ± 20 Mhz to several species at various stages of development. The findings have broad implications for the current crises in agricultural production and environmental quality. Widespread practical application of radio-frequency energy for vegetation control will depend on location of particular frequencies of radio-frequency fields with specific species effects (the range from 300 to 300,000 Mhz is available for study), on development of equipment for focusing energy to a particular zone, and on a much better understanding of the mechanism of phytotoxicity of radio-frequency fields in plants.

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7. Detailed studies with several species have shown that, although sensitivity increases markedly during imbibition, there is a poor correlation between increasing moisture content and increasing sensitivity to the field. More detailed studies will be reported by F. S. Davis, J. R. Wayland, C. R. Robinson, and M. G. Merkle ("Weed science," in preparation).

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Free Radical Inhibitory Effect of Some Anticancer Compounds

Abstract. *Conventional tests for polymerization initiated by free radicals indicate that alkylating agents vary in free radical inhibitory activity from negligible to moderately strong; antimetabolites from negligible to weak; hormones, steroids, and phenolics from very weak to very strong; and antibiotics from moderate to very strong. Vitamins A and C and copper, which potentiate the biological activity of some anticancer compounds, are relatively strong free radical inhibitors.*

The several classes of anticancer compounds are generally believed to operate by a variety of mechanisms. In recent years, the possible role of enzymes in cancer has received increased attention. Because of the presence of free radicals (unstable molecules with unpaired electrons), some enzymes exhibit electron spin resonance (ESR) signals, and the signals from neoplastic cells generally differ very significantly from those from normal cells (*1*). I undertook this investigation to determine whether some typical anticancer compounds were also free radical inhibitors that might block biological reactions involving free radicals.

During the past 20 years, we have studied various classes of inhibitors of the polymerization of monomers initiated by free radicals. I now report results obtained by the use of vinyl acetate as the monomer and benzoyl peroxide as initiator at 70°C since my co-workers and I had already established with this system correlations (*2, 3*) between the chemical structures of inhibitors and their inhibition factors (*4*). We have previously described our "test tube" test (*2, 3*). Some anticancer compounds have a very low solubility in vinyl acetate, and it was necessary to add up to 2 percent by volume of methanol or ethanol or up to 0.2 percent of water to the monomer to increase their solubilities (Table 1).

Whether my inhibition factors (Table 1) have any quantitative significance in biological systems has yet to be established. However, Emanuel and co-workers have found that certain phenolic compounds which are strong inhibitors of free radicals in my test system and which exhibit antitumor and antileukemic activity in mice reduce the ESR signals because of free radicals in cancer cells (*5*). There is experimental and theoretical evidence to suggest that biological systems are much more sensitive than my test system to a given concentration of free radical inhibitor. This is due to the lower reaction temperature and the much higher concentration of water in biological systems (which increase the stability of inhibitor free radicals), and the lower concentrations of free radicals in them.

Data in Table 1 indicate that the free radical inhibition factors of various alkylating agents vary over a wide range. Nitrogen mustard is moderately strong for an aliphatic amine; such amines are generally weak. Calculations indicate that, at concentrations theoretically obtainable from clinical doses [0.1 to 0.4 μg/g per day (*6*)], free radical inhibition may be perceptible but short in duration because of rapid catabolysis. Where local concentrations are high, substantial inhibition is possible.

L-Phenylalanine mustard (Melphalan) has a relatively low free radical inhibition factor consistent with its *N,N*-disubstituted aniline structure, which is known to exhibit weak inhibition (*7*). The para form of Melphalan is used clinically while the meta is almost inactive. This is analogous to the activity of phenolics and aromatic amines in conventional free radical polymerization systems, in which the para and ortho isomers are relatively strong inhibitors while the meta is weak.

Cytoxan (cyclophosphamide) has almost no free radical inhibitory activity, a property consistent with the widely held view that this compound must be activated in biological systems before it will act as an anticancer agent. ThioTepa contains three cyclic ethyleneimine groups and one sulfur atom. It has a very low inhibition factor, which nevertheless is five times as great as that of Cytoxan. The contribution of the imine groups or of the sulfur to the inhibition factor appears significant but very small. Oxophenarsine is a phenol with a para-substituted arseno group and an ortho-substituted amine, which enhance the inhibitory effect. Therefore, it is not surprising that oxophenarsine is one of the strongest free radical inhibiting alkylating agents. Busulfan (Myleran) was the only alkylating agent studied that showed no measurable free radical inhibitory activity at all.

Antimetabolites do not appear to be free radical inhibitors, except when they