EFFECTS OF ELECTROSTATIC FIELDS, ULTRASONIC VIBRATIONS AND ULTRAVIOLET LIGHT ON SPINACH SEED

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I N T R O D U C T I O N

Seedsmen, farmers, and agricultural scientists have been concerned with low and uneven germination for many years. Different varieties of seed possess different germination characteristics. Some varieties germinate almost 100% and retain their viability for several years. Other varieties germinate very poorly and deteriorate rapidly. The hard seed coat of alfalfa and red clover gives these seeds a long storage life but causes them to germinate slowly and produce an uneven stand. Wheat and corn are seeds that germinate readily immediately after harvest. Most vegetable seeds have immature embryos and exhibit post-harvest dormancy.

Dormancy is the term applied to live seeds that fail to germinate even though they are placed in an environment conducive to germination. Dormancy may be due to either of several causes; seed coats being impermeable to water or oxygen, seed coats being strong enough to prevent growth and expansion of the embryo, partially developed embryos, or the presence of chemicals which inhibit germination.

Dormancy of most hard seeds can be broken by scarification in which the seed coat is scratched or broken. Mechanical treatments such as hydraulic pressure, sandpapering, and scraping; acid treatments; and alternating freezing and thawing have been used to promote early germination. Seeds that have immature embryos are usually stored for several weeks or until the next growing season before being placed on the market. Scientists, in efforts to speed up research, may want to produce two crops in one season. A shortage of seed of cool season

spring and fall crops, such as spinach, may make it desirable to plant the new crop seed almost immediately after harvest. Treatments have been tried in an effort to stimulate more rapid maturity. A freezing treatment of pine seed improves viability and shortens the time needed for germination (14)*. Earlier, as well as increased, germination of new and old spinach seed was induced by sulfuric acid treatments (21).

Seeds live from a few months to many years. Under usual storage conditions, the seed of the majority of crops remain viable only one to three years. Those in storage respire and, consequently, deteriorate. Seeds store better in a low-temperature, low-moisture environment where respiration is reduced.

Seeds that germinate below the minimum percentage set by law cannot be sold for planting. Low germination is a problem of great economic importance whether it be due to dormancy or deterioration. Higher cost of seed production, storage, insect and fungus control, packaging, and seedbed preparation justify research that would lead to improved germination characteristics. If one could develop economical seed treatments that would break dormancy of new or hard seeds or stimulate old seeds, he would make an important contribution to the agricultural economy.

*Numbers in parenthesis refer to the Bibliography.

REVIEW OF LITERATURE

It has been known for some time that electromagnetic energy has an effect on living things. In 1936 Duggar (8) edited two volumes in which investigators presented papers on the effects of radiation on biological materials. Ark and Parry (1) presented a comprehensive review on high frequency electrostatic fields. They reported effects of gamma rays, X-rays, Roentgen rays, radium emanation, ultraviolet rays, visible light, infrared rays, and other treatments on living matter. In attempting to explain the phenomena relating to high frequency energy, they speculated that various factors, including heating, may have been involved.

Because of the practical as well as the scientific interest in the problems of seed germination, large numbers of investigations have been carried out. Some of the more intense treatments that have been tried in recent years are gamma rays, cathode rays, and X-rays. Solderholm and Walker (24,25) found that wheat kernels subjected to cathode ray doses of 10,000 to 200,000 reps (roentgens equivalent physical) for 45 seconds were not limited in germination. After germination, however, a detrimental effect was observed. The number of seedlings continuing to grow was progressively reduced with treatment doses ranging from 10,000 to 30,000 reps. Doses above 40,000 reps not only reduced emergence but caused degeneration and death of seedlings after emergence.

In more recent work, Younis and Hammouda (29) were unable to find any significant stimulating effect on growth when dry cotton seeds were subjected to gamma irradiation doses of 1.17 to 29.92 kr (kilo-roentgens).

While low dosages produced no noticeable effect, high dosages caused reduction in emergence and inhibition of growth which resulted in greatly reduced yields.

Cherry, et al, (5) found that X-rays reduced the rate of germination of corn but did not reduce total germination. Those doses ranging from 0 to 1000 kr also reduced seedling and plant growth. According to Morris and Frolik (18), corn seed exposed to X-ray doses ranging from 4000 r to 32,000 r units or thermal neutron doses ranging from 5.8×10^{12} to 5.1×10^{13} thermal neutrons per square cm exhibit reduced stands, abnormal pollen production, and mutations.

A few investigators experimented with alternating current fields with varying degrees of success. Some of the studies with radio-frequency heat were concerned with devitalizing weed seeds or killing insects in grain. In 1950 Lambert, et al, (16) found that the radio-frequency heat treatments required to devitalize weed seeds reduced the germination of the cereal seeds. Death was attributed to swelling caused by the heat. Additional study with less intense treatments revealed an increase in germination of the seeds.

Soderholm (25) was interested in determining the damage that might be expected when grain is heated to destroy insects. Dielectric heating of wheat at 14% moisture content to about 150°F. with a frequency of 40 mc per second did not reduce germination. A slight stimulation of germination and greater vigor of seedlings was noticed when the treatment produced a final mass temperature of 100 to 140°F.

Nelson, working with Whitney (20), studied radio-frequency treatments for insect control in grains. They found that treatments required for 100% insect mortality produced momentarily mass temperatures of 140 to 150°F. in wheat. These temperatures may reduce germination unless the grain moisture content is below 14%. In 1960 Nelson and Walker (19) reported that wheat exposed to 39 mc with 3.6 kv per inch from 4 to 37 seconds showed no significant increase in germination. Attempts to duplicate the work of Soderholm were unsuccessful. Alfalfa seed produced very noticeable increases in germination after treatment with radio-frequency energy. This increase is attributed to the reduction in the percentage of hard seed. Seeds were treated with field intensities ranging from 2 to 4 kv per inch. Optimum treatments produced seed mass temperatures between 153 and 183°F. Corn at 9% and 12% moisture contents treated for five seconds at 40 mc germinated earlier than untreated corn. Ten-kernel samples were exposed to 8 kv, rms across electrodes spaced 3/4 inch apart. Small scale field plots indicated a significant increase in field emergence to about 95% as compared to about 90% for the controls. In a later test, field emergence of both treated and untreated seeds was very high and no significant differences could be found. Red clover and unhulled vetch also showed beneficial results of radio-frequency treatments. Sweet clover showed no response to treatments. Inconclusive results of tests with grain sorghum indicated that r-f treatments may increase germination of seeds exhibiting post-harvest dormancy.

When seeds are placed in an electrostatic field, the electrons of the seeds oscillate at the frequency of the imposed field. According to Nelson and Walker this oscillation causes heat to be generated within the seeds. The increase in temperature is a function of the electrical characteristics of the seeds, the field intensity, the frequency of the field, the electrode spacing, the sample size and shape, and the density and thermal capacity of the sample.

Eglitis and Johnson (9) reported an increase in germination and a reduction in hard seed of alfalfa when seeds were treated between two horizontal electrodes of a 5 kw supply at 27 mc. Seeds were brought to the optimum temperature of 133°F., where the highest percentage germination occurred, with an exposure of 25 to 30 seconds. Treated seeds continued to have a higher germination after one year of storage. The treatments were believed to have increased the water absorption capacity of the seed.

In 1952 Jonas (12) found that seeds of carrots, onions, lettuce, and tomatoes germinated better when exposed to radio-frequency energy at 43 and 44 mc for short periods. In 1953 similar results were obtained with carrots, onions, and celery with a frequency of 44.5 mc (13). Infrared irradiation produced smaller increases in the germination rate. He concluded that germination is dependent on voltage gradient across the seed, energy input, frequency, time of exposure, and condition of the seed. The period of exposure had to be limited to a few seconds to prevent damage. Exposures from 10 to 11 seconds at 44.5 mc with 340 to 360 volts rms per cm produced temperatures as high as 122°F. The

effectiveness of the r-f irradiations was not reduced when planting was delayed 12 weeks after treatment.

Iritani and Woodbury (11) concluded that radio frequency heat was not significantly effective in increasing early or total germination of beans, garden peas, and onions. Seeds were treated at 10 mc with voltages ranging from 1000 to 2800 volts and with exposure times ranging from about 2-1/2 minutes to about 10 minutes. Germination was slightly increased at the lower voltages and decreased at higher voltages. Similar tests with hard seed alfalfa and red clover showed that treatments of 4000 to 4500 volts for two minutes, 37 seconds increased the germination. These radio-frequency heat treatments were not as effective as chipping the seed coats, however.

Kinard and Wiant (15) exposed young chickens to electromagnetic fields of 6, 16, and 32.5 mc for several weeks. They were unable to find any differences in gain or feed conversion efficiency. A rise in body temperature and increased heart and respiratory activity were noticed during treatment, however. This study disagreed with Baker (2) (original not available for examination) who had previously reported that high frequency electric treatments to young chickens caused them to grow 1/3, or more, faster with a more efficient feed conversion.

Baker, Wiant, and Tabouda (3) presented the laws involving the effects of electromagnetic energy on plants and animals. Their summary indicates that primarily heating effects are produced by wave lengths longer than about 2880 A. This includes radio-frequency dielectric heating, infrared rays, and the visible spectrum.

Wave lengths shorter than about 2880 A cause mostly ionization of atoms which produces chemical effects. As the wavelength decreases, the heating effects decrease and the ionization effects increase so that there is no sharp dividing line between the two effects.

Ben Zeev (4) reported the results of some high temperature treatments on seeds. Seeds preheated for three hours at 140°F. and heated for 16 minutes at temperatures of 250 to 280°F. were able to survive. Such treatments produced inhibition of germination for four months.

Rincker (22, 23) studied the effects of infrared heat on hard seeds. His results showed that heat supplied by infrared bulbs produced the same scarifying effect on hard seeds as dry oven heat and in a shorter time. Hard seeds of alfalfa and red clover were made permeable by an application of infrared heat for four minutes during which the seeds were heated to 220°F. Sweet clover did not respond to treatments. He later decided that for alfalfa an exposure time of 1-1/2 minutes is the optimum. By increasing the temperature to 280°F. the exposure time can be reduced to 8.6 seconds. In his later report he did not include data for clover or other seeds.

According to Downs, et al, (7), different varieties of seeds have different degrees of sensitivity to visible light. Some seeds do not germinate at all in darkness while others appear to be inhibited by light. No information was found that presents effects of ultraviolet light on seeds.

Williams (28) concluded that d c electrostatic fields of 75 or 115 volts do not have any effect on wheat, corn, soybean, and oat

germination. His data indicate a beneficial effect on soybeans, but the study was limited in scope. Some treatments increased the germination of soybeans from 92% to 99%. Seeds that have a high initial germination are hardly able to show beneficial effects.

Landes (17) exposed spinach seed to a c electrostatic fields. Earlier and increased germination were observed when seeds were exposed to a 110 volt source at 60 cps for 15 and 60 seconds. The scope of this study was also limited.

In summary, oven and infrared heat treatments are effective on some hard seeds. Of the high energy treatments that increased germination, none appear economically feasible for commercial applications. Few of the researchers have presented emergence and crop effects of the treatments. This review of literature indicates that very little work has been done with low-frequency, low-energy fields as they relate to seed germination and plant growth.

O B J E C T I V E S

To evaluate the effects on germination, emergence, and plant production resulting from the following treatments on spinach seed:

1. Electrostatic fields in the range of 60 to 1000 cps (cycles per second).
2. Ultrasonic vibrations of 20,000 cps, and
3. Ultraviolet radiations of 3129 and 3654 Angstroms.

FACILITIES AND PROCEDURES

General

The equipment and facilities for treating and germinating the seed were made available by the Agricultural Engineering Department. The Horticulture Department furnished land, greenhouse space, and materials for the field and greenhouse plots. Labor, tillage machinery and tools were supplied by both departments. Dr. Howard Massey of the Horticulture Department, Dr. Clyde Y. Kramer of the Statistics Department, and Professor U. F. Earp of the Agricultural Engineering Department were available for consultation during the study.

Spinach was selected because of its adaptability to this problem. Spinach is a 55 day cool season crop that can be planted in late summer. Of the seeds that have a low germination, spinach seed are large enough to be treated, counted, and planted easily. It would be difficult to plant individual lettuce seeds for example. Beet seed were rejected because it would have been difficult to remove the seeds that had two seeds per seed coat.

For statistical purposes, all the seeds in each test were from the same lot. The seed used were of the Old Dominion variety. These Holland grown seeds were treated with Dupont Arasan and packed by the Corneli Seed Company of St. Louis, Missouri. They were from lot No. 4809-4 and tested at 90% germination in November, 1959. Low germination was expected at the time of treating, since the seeds were almost three years old. Weed seeds, trash, and large seeds that had two seeds per seed coat were removed before the seeds were treated.

Preliminary Study

While the field work was being planned, a preliminary study was conducted. The purpose of this study was to gain experience so as to reduce mistakes in the field work. Okra seed were treated and planted in randomized plots in a greenhouse in three replications of four treatments and a check. The treatments consisted of: (1) exposure for one minute to 60 cps electrostatic field from a 119 volt line source, (2) the same exposure from a 238 volt line source, (3) exposure for five minutes to ultraviolet light of 3129 A (angstrom unit or angstrom, 1×10^{-8} cm), and (4) exposure to ultrasonic vibrations of 20,000 cps for one minute. Seven seeds were planted 12 inches apart in each of the 15 rows. Rows were 2.5 feet apart.

Four seeds came up in the check row near the end of the plot. At least six plants emerged in the other rows. Since the two rows on each end of the plot were considerably retarded relative to the others, a statistical analysis of the crop yield data is invalid. Two of the check replications happened to be on one end of the plot. Plants of the check row near the center appeared at least six inches shorter than the others, with the exception of the four retarded rows. The crop yield of an ultrasonic treated row was less than that of the others. The check row produced the next larger yield. In general, this pilot study indicated that differences in response may be obtained by using the treatments.

After reviewing literature and doing the prelininary work with okra, it was decided to limit the study to an investigation of the following treatments:

1 - 150 volt rms, 60 cycle ac field, 30 second exposure
2 - 150 volt rms, 60 cycle ac field, 60 second exposure
3 - 150 volt rms, 60 cycle ac field, 90 second exposure
4 - 150 volt rms, 500 cycle ac field, 30 second exposure
5 - 150 volt rms, 500 cycle ac field, 60 second exposure
6 - 150 volt rms, 500 cycle ac field, 90 second exposure
7 - 150 volt rms, 900 cycle ac field, 30 second exposure
8 - 150 volt rms, 900 cycle ac field, 60 second exposure
9 - 150 volt rms, 900 cycle ac field, 90 second exposure
10 - Dry check
11 - Wet check - soak in water - 60 second exposure
12 - Ultrasonic vibrations - 60 second exposure
13 - Ultraviolet light - 3129 Angstroms - 5 minute exposure
14 - Ultraviolet light - 3654 Angstroms - 5 minute exposure

A. C. Fields

The ac electrostatic fields were studied to obtain conclusive data on germination effects as well as to obtain emergence and crop data. The ultrasonic vibrations and the ultraviolet light treatments were added because of the great interest now being shown in these phenomena.

Figure 1 shows the variac and the transformer used to obtain the 150 volt rms, 60 cycle field. Conductors from the transformer were soldered to the brass condenser plates. The six-inch by six-inch condenser plates were spaced one inch apart in the plastic frame. Seeds were placed on the bottom plate and spread out one layer deep. This set-up was used for treatments 1, 2, and 3, of 30, 60, and 90 second exposures respectively.

To obtain 500 cycle and 900 cycle fields, the signal generator and step-up transformer shown in Figure 2 were used. Since the signal generator had a maximum output of about ten volts, the transformer was necessary to get 150 volts across the condenser plates. Seeds were treated for 30, 60, and 90 seconds at 500 cps for treatments 4, 5, and 6 and at 900 cps for treatments 7, 8, and 9.

FIGURE 1

VARIAC, TRANSFORMER, AND CONDENSER
PLATES FOR 60 CPS TREATMENTS

FIGURE 2

SIGNAL GENERATOR, TRANSFORMER, AND
CONDENSER PLATES FOR 500 AND 900 CPS
TREATMENTS

The exposure times of 30, 60, and 90 seconds were selected because studies by Landes (17) indicated that the optimum time is around 60 seconds. The 150 volt potential across the fields was selected because it was almost the maximum that could be obtained with the signal generator set-up.

For all nine of the electrostatic fields, a Triplett Model 666R volt ohm meter was used to measure the voltage across the plates. An oscilloscope was used to compare the height and shape of the nine waveforms of the three frequencies used. Figures 3, 4, and 5 are the oscillograms of the voltages applied to the plates. When changing from 500 cps to 900 cps, the generator output had to be reduced to maintain 150 volts rms across the plates. It can be seen from the figures that the peak to peak voltage varied slightly when this adjustment was made. It can also be seen that the peak to peak voltage of the 60 cycle curve is slightly less than that of the 500 and 900 cycle curves.

Ultrasonic Vibrations

The 10th and 11th group of seeds were dry and wet checks with which to compare the treatments. Soaking the wet check for 60 seconds was done to compare the wetting effect of the ultrasonic treatment.

Seeds of treatment 12 were enclosed in a 3-1/2 inch by 1-inch deep galvanized screen container, submerged in three inches of tap water in an ultrasonic cleaner and vibrated at 20,000 cps for 60 seconds. Figure 6 shows the ultrasonic cleaning system used. The cleaner was tuned to obtain maximum visible and audible activity.

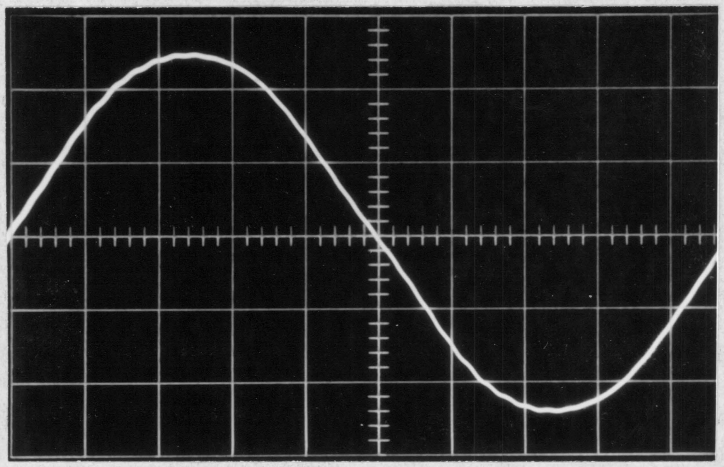

FIGURE 3. OSCILLOGRAM OF 60 CPS VOLTAGE

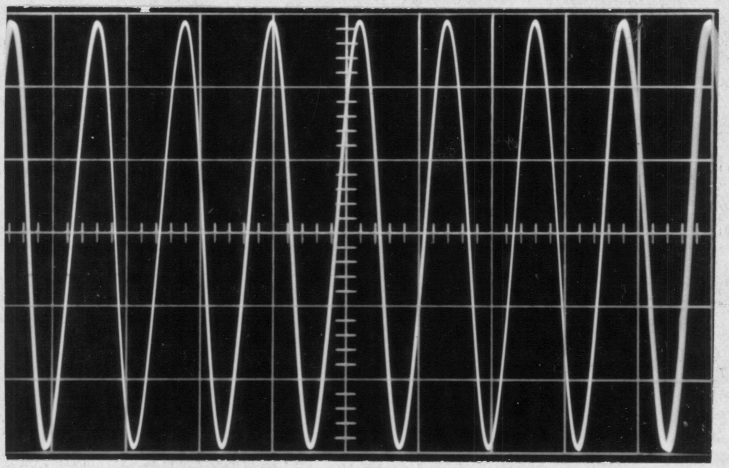

FIGURE 4. OSCILLOGRAM OF 500 CPS VOLTAGE

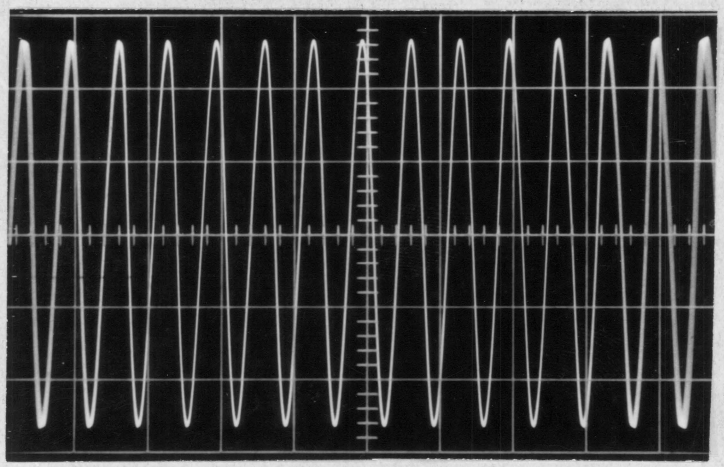

FIGURE 5. OSCILLOGRAM OF 900 CPS VOLTAGE

FIGURE 6

ULTRASONIC GENERATOR AND CLEANING
UNIT SYSTEM

Ultraviolet Light

The equipment for the ultraviolet light treatments is shown in Figure 7. Seeds of treatments 13 and 14 were exposed for five minutes to ultraviolet energy of 3129 and 3654 Angstroms respectively. Figure 7 shows a mercury vapor lamp, the Bausch and Lomb grating monochromator, a mirror and frame apparatus, and a container of seed. In this study a hydrogen arc illuminator was used instead of the mercury vapor lamp. Light from the illuminator passed through the grating monochromator and was reflected down onto the seed by the mirror. The entrance and exit slits of the monochromator were set at one cm and the vee-slide handle was in the open position. The rectangular enclosure under the mirror held about 200 seeds. Seeds were exposed on one side only.

Germination Study

A germination test gives an index of the ability of seeds to grow. For each treatment more seeds were treated than were needed for germination and planting. Excess seeds were discarded. Figure 8 shows the seeds in four 10-inch by 15-inch trays after germination had begun. Emerged rootlets appear white. All 14 treatments of 100 seeds each were germinated in one tray so that there would be no moisture differences within reps. Seeds were put in the trays the same day they were treated. The location of the treatments within the tray was not randomized. Two germination blotters were used under the seeds and one was cut into five strips and placed on top of the seeds.

FIGURE 7

MONOCHROMATOR WITH MERCURY VAPOR LAMP,
MIRROR AND SEEDS

FIGURE 8

GERMINATING SEEDS IN TRAYS

The blotter paper was wetted every two days. On the 9th day after germination was started and every two days thereafter, seeds which had a visible sprout were removed and counted. This method of counting gives an indication of the speed of germination as well as the total germination.

Seeds were treated at three different times for germination tests. The first test gave invalid results because only one replication was used. The original plan was to compare emergence of plants in the field study. The germination test was to be used to compare germination with emergence. In the second test four reps were germinated in an air tight insulated cabinet. A thermostatically controlled heater was used to keep the temperature from dropping below 70°F. As the seeds germinated heat was given off and the temperature in the chamber rose to above 90°F. This was not anticipated. In an open room the blotter papers dried out too rapidly. Spinach seed will germinate well at lower temperatures, but take longer. In the third test seeds were germinated in a refrigerator at 45 to 50°F. Because the temperature was controlled, the data were more reliable. Less difficulty may have been encountered in this study had the seeds been germinated in moist soils in a greenhouse flat. Uniform moisture can be obtained by placing a flat of soil on blocks in another flat and flooding the lower flat. A sheet of plastic in the lower flat will hold the water.

Field Study

Because of the cost involved, considerable planning was done to insure a statistically valid crop study. The land was plowed, disked,

staked off and formed into eight beds five feet wide. Efforts were made to follow commercial practices. Soil samples indicated a high primary plant nutrient content and a Ph of 6.2. Both the Ph and the fertilizer content were within the range recommended for spinach production. The entire area used had been in orchard grass and clover for the previous two years. Soil color and texture varied in the direction perpendicular to the beds. The beds were parallel to the slope.

To eliminate weeding and to insure against diseases, the beds were fumigated. Figure 9 shows the plastic covering on two of the beds being fumigated. Diofume M-C2 was used as recommended by the manufacturer. The soil was left loose after the beds were formed so that the fumigant would penetrate readily. After fumigation and subsequent aeration, the seedbeds were prepared with a roto-tiller. Clods were raked off and the beds were smoothed just before planting (Figure 10). The frame and planting jigs shown in Figures 10 and 11 were used to plant 102 seeds individually in each plot. Seeding was done the day after treatment. Seventeen seeds were planted 3/4-inch deep and 5 inches apart in each of 6 rows spaced 10 inches apart for each test plot. Treatment locations were randomized within replications. There were seven plots per bed and two beds per replication. After all plots were seeded, extra seeds were planted between the rows of the first rep for transplanting.

Irrigation was desired but not obtainable at the time of planting. An idea to use straw or peat moss for a mulch was ruled out because mulch is not used commercially.

FIGURE 9

TWO BEDS BEING FUMIGATED

FIGURE 10. PREPARING PLOT FOR PLANTING

FIGURE 11. SEEDING FIELD PLOT

Greenhouse Study

After obtaining discouraging results with the field crop, it was decided to plant a crop in flats in the greenhouse. A 13-inch by 18-inch by 3-inch flat was used for each plot. Fifty-six flats were used for four replications of the 14 treatments. Topsoil was shredded and mixed with peat moss and sand. The mixture was screened through 1/2-inch mesh hardware cloth. Soil was filled loosely in the flats, packed into the corners by hand, and leveled and packed uniformly with the packer shown in Figure 12. The flats were steamed in a cabinet for about one hour to kill weed seeds, insects, and diseases.

Seeding was done the day after treatment. Five rows were made 1/4-inch deep and two-inches apart. A strip of wood with holes drilled one-inch apart was used to space the 16 seeds in the row. A total of 80 seeds were used per flat. Uniform spacing was done so that each seed could be accounted for when making emergence observations. After the seeds were covered, the soil was packed for firm contact.

Flat locations were randomized within the replications. Figure 13 shows the four rows of flats in the greenhouse. Water was applied every two days. After 28 days the plants that emerged and survived in each flat were counted and the flats were thinned to ten plants each. These ten plants were allowed to grow to maturity so that yield data could be obtained. Malathion was sprayed on the plants occasionally to control aphids. After 108 days in the greenhouse, the plants were cut at the root and weighed individually. Dead leaves were removed before weighing.

FIGURE 12

SEEDING GREENHOUSE FLATS

FIGURE 13

FLATS IN THE GREENHOUSE

RESULTS AND DISCUSSION

Germination Study

Germination data from the third test are presented on Table 1. Since 100 seeds were used in each observation, the figures given represent total as well as percent germination. It can be seen from the table that there is considerable variation in the number of seeds germinated after 9 or 11 days in the refrigerator. The totals become more uniform as germination progresses. After 31 days all except three of the 56 groups germinated above 85% which was higher than expected.

Tables of analysis of variance of the 9th, 13th, 17th, 19th, and 31st day totals are given in Appendices I through V. The 9th day data gave a high F value for replications and treatments. Significant differences were at the 1% level. Data for subsequent days gave progressively lower F values. On the 17th day the difference among treatments was significant at only the 5% level. From the 19th day to the 31st day there were no significant differences among treatments. Differences between the reps can be noted through the 19th day and disappear before the 31st day. An explanation for these differences is not readily apparent. Since water was applied to the trays by inspection, moisture differences may have affected germination.

TABLE 1

Total Seeds Germinated - % Germination

Days After Treatment	Treatment 1				2				3				4				5			
9	42	27	27	46	31	27	33	46	35	31	45	42	47	29	39	42	35	36	41	43
11	55	50	44	60	48	44	49	60	53	54	49	56	60	45	57	56	49	53	50	62
13	67	63	62	71	70	58	64	69	69	64	71	70	69	56	67	65	59	61	62	68
15	76	79	73	81	80	71	76	79	76	78	82	82	78	75	76	79	68	70	75	75
17	83	82	78	84	84	73	81	85	81	81	88	83	83	78	82	85	76	73	82	78
19	86	86	80	86	86	81	83	88	84	81	90	85	85	83	84	88	82	79	84	84
23	89	89	82	88	90	87	84	90	87	88	92	91	86	87	88	91	87	84	87	86
27	91	91	84	93	91	88	86	91	89	89	92	91	88	89	89	93	90	86	88	90
31	93	92	84	96	91	88	88	94	89	91	93	91	90	91	90	93	91	89	91	91

Days After Treatment	Treatment 6				7				8				9				10			
9	33	25	36	42	32	33	38	43	35	24	39	50	34	39	35	43	33	38	32	44
11	55	46	53	60	52	47	52	57	54	46	53	58	49	56	51	57	49	47	56	62
13	67	61	67	70	67	58	63	65	70	55	68	72	61	65	65	71	59	54	67	74
15	80	70	82	77	82	71	75	73	76	66	79	85	73	76	78	81	67	68	74	81
17	86	78	86	82	85	79	80	76	82	73	82	88	81	81	81	82	76	71	80	83
19	86	82	87	84	88	83	84	78	84	77	86	89	83	82	84	83	78	77	85	89
23	91	85	90	85	90	86	87	85	86	79	92	92	84	85	86	86	82	81	86	91
27	92	88	90	87	91	88	89	89	90	81	94	93	88	88	91	87	85	84	88	94
31	93	91	91	87	91	89	90	89	90	83	94	94	88	90	92	87	86	85	89	94

Days After Treatment	Treatment 11				12				13				14			
9	52	50	60	52	55	48	53	50	38	41	53	56	33	37	34	44
11	70	61	64	65	65	64	66	60	55	63	74	64	50	55	57	58
13	76	67	73	74	74	73	75	71	67	75	85	75	62	61	66	72
15	82	74	86	80	80	78	82	80	76	83	87	82	72	68	75	76
17	85	80	89	80	84	81	84	84	82	87	90	86	76	77	82	81
19	90	80	91	84	89	86	84	86	84	87	91	87	80	79	86	85
23	92	84	92	86	91	89	88	89	89	89	92	90	83	82	89	90
27	93	87	94	88	91	90	90	89	91	90	95	93	85	86	92	92
31	93	89	95	90	93	92	91	89	93	90	95	94	87	89	95	93

TABLE 2

Separation of Germination Means at the 5% Level

9th Day	T_6	T_2	T_1	T_7	T_{10}	T_8	T_{14}	T_9	T_3	T_5	T_4	T_{13}	T_{12}	T_{11}
	34.0	34.3	35.5	36.5	36.8	37.0	37.0	37.8	38.3	38.8	39.3	47.0	51.5	53.5
13th Day	T_5	T_7	T_{10}	T_4	T_2	T_{14}	T_9	T_1	T_6	T_8	T_3	T_{11}	T_{12}	T_{13}
	62.5	63.3	63.5	64.3	65.3	65.3	65.5	65.8	66.3	66.3	68.5	72.5	73.3	75.5
17th Day	T_5	T_{10}	T_{14}	T_7	T_2	T_8	T_9	T_1	T_4	T_6	T_3	T_{12}	T_{11}	T_{13}
	77.3	77.5	79.0	80.0	80.8	81.3	81.3	81.8	82.0	83.0	83.3	83.3	83.5	86.3

Separation of the means of the 9th, 13th, and 17th day germination data, as done by Duncan's method at the 5% level, gave the results presented in Table 2 (Appendices I, II, and III). Any two means not underscored by the same line are significantly different. Any two means underscored by the same line are not significantly different. The data indicate that seeds of treatments 11, 12, and 13 germinated significantly earlier than the others including the dry check. This is indicated by the better germination of these seeds at the 9 day count and the tendency for all groups to germinate about the same before the 19th day. Note the longer overlapping underscoring of the 17th day means. Treatments 11 and 12 are the wet check and the ultrasonic vibration treatment. Treatment 13 is the 2936 A ultraviolet light. It is interesting to note that on the 17th day, treatments 6, 3, 12, 11, and 13 germinate significantly greater than the dry check, treatment 10. Treatments 3 and 6 are electrostatic fields of 60 cps and 500 cps for 90 seconds. It is also interesting to note that the 2936 A ultraviolet treatment, T_{13}, germinated earlier than the 3654 A treatment, T_{14}.

Since there were no significant differences between the wet check and the ultrasonic vibration treatment, it appears that the earlier germination is due to the wetting effect. After treatment the vibrated seeds were darker in color and appeared wetter than the wet check. The pink coloring, that had been applied previously with the Arasan, colored the water in the generator during the ultrasonic treatment.

Field Study

Data from the field study were not reliable enough to use in comparing the treatments. However, the data obtained are presented in Table 3. Location of treatments in the beds was randomized as shown. The number of plants that emerged decreased from plot to plot down the bed from north to south especially in the southern-most half of the bed. This can be seen in Figure 14.

The poor emergence was attributed to adverse weather. The first rain occurred two weeks after planting. Some plants came up. There was no more rain for several weeks. Silt and clay particles that washed down the bed with the first rain dried and formed a hard crust. Some plants were observed breaking through the crust. The plants that survived produced a poor stand. A better stand would have been produced if the seeds had been planted 1/4 to 1/2-inch deep, or if irrigation had been used.

When irrigation equipment became available, efforts were made to salvage the plants that did emerge. To obtain crop data, 12 plants in each plot were selected for continued growth. Only six plants could be used for treatment eight of rep four. Other plants were transplanted around these 12 plants so that all would have the same competition. Figure 15 shows the beds after transplanting. The plants that were transplanted wilted and failed to grow well. Figure 16 shows the beds at harvest. Weights of 12 plants of each plot is also presented in Table 2. The weight of the 6 plants in R-4, T_8 was doubled. One plant of the 12 in R-4, T_2; R-4, T_{11}; and R-2, T_8 died before harvest. Another

TABLE 3

Field Plot Randomization, Emergence, and Crop Yield

Field Layout:

Replication	4		3		2		1	
Treatments	4	12	11	7	6	3	13	5
	13	5	10	4	12	11	11	1
	14	1	12	14	4	9	7	9
	7	3	2	13	1	14	6	3
	10	9	6	1	2	7	12	10
	8	2	3	9	10	5	14	8
	6	11	5	8	13	8	4	2
Number of Plants per Plot Emerged and Surviving 28 Days After Planting	32	48	44	39	48	62	59	64
	51	56	62	52	61	55	69	64
	42	54	45	57	45	58	75	55
	46	58	58	54	59	62	71	58
	46	29	51	30	65	59	61	59
	27	21	25	33	31	42	46	61
	10	18	24	20	22	21	36	49
Weight of 12 Plants - Grams	426	435	335	515	616	320	357	398
	448	326	528	501	728	770	455	207
	416	302	590	404	364	766	476	413
	249	500	289	303	724	789	457	459
	274	361	541	448	609	621	371	471
	348	366	270	322	615	514	531	551
	306	282	270	227	328	441	491	492

Weight of 12 Plants - Grams

	T_1	T_2	T_3	T_4	T_5	T_6	T_7
R1	207	492	459	491	398	457	476
R2	724	609	320	364	514	616	621
R3	448	289	270	501	270	541	515
R4	302	366	500	426	326	306	249
T	1681	1756	1549	1782	1508	1920	1861

	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}
R1	551	413	471	455	371	357	351
R2	441	766	615	770	728	328	789
R3	227	322	528	335	590	303	404
R4	348	361	274	282	435	448	416
T	1567	1862	1888	1842	2124	1436	2140

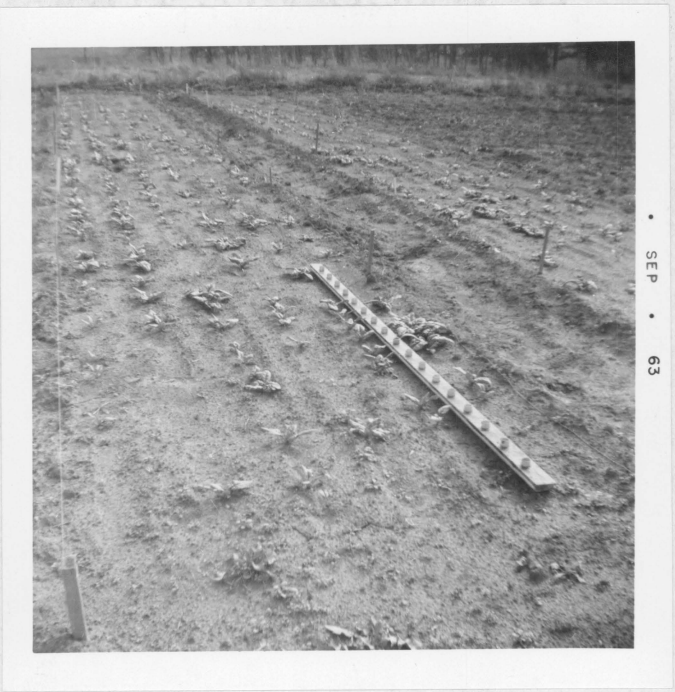

FIGURE 14

FIELD CROP STAND.
NOTE THE POORER STAND DOWN THE BED.

FIGURE 15

FIELD CROP AFTER TRANSPLANTING.
NOTE THAT PLANTS THAT WERE MOVED HAVE
WILTED AND DEAD LEAVES.

FIGURE 16

FIELD CROP AT HARVEST. NOTE DIFFERENCES IN PLOTS AND DECREASED GROWTH DOWN THE BEDS.

plant from the same plot was weighed to give equivalent data. An analysis of variance (Appendix VI) indicated that there were no significant differences between any of the treatments. This was an interesting point after observing the erratic stands.

Greenhouse Study

Emergence

Emergence data are presented in Table 4-A. The data represent the number of plants per flat that emerged and survived 28 days after the seeds were planted. Since 80 seeds were planted per flat, the average percentage emergence was calculated by comparing these percentages with the germination percentages of Table 1, it appears that about 10% of the seeds that were able to germinate died before emergence or soon thereafter.

Seeds of T_{13}, 2936 A ultraviolet light, had the lowest emergence of 68% while seeds of T_4, 500 cps electrostatic field - 30 second exposure, had the highest emergence of 81%. However, an analysis of variance (Appendix VII) indicated no significant differences between any of the treatments. The results of this 28 day emergence test agreed with the results of the 31 day germination test.

Early Growth

In Table 4-B the weights of the plants that were removed from the flats when the flats were thinned are given. These weights gave an indication of early growth. Even though there appeared to be considerable differences between the totals, a statistical analysis (Appendix VIII) indicated that the differences were not significant at the 5% level.

TABLE 4-A

Total Plants Emerged and Surviving in Greenhouse Flats 28 Days After Planting

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Rep 1	69	64	66	70	63	68	73	38	63	58	69	61	39	69
2	70	62	71	67	67	49	69	64	66	65	64	67	62	60
3	65	70	62	66	62	63	63	64	60	66	59	63	62	52
4	64	69	60	67	61	62	58	59	61	71	69	65	55	63
Avg.	67	66	65	68	63	61	66	56	63	65	65	64	55	61
% Emergence	83	83	81	84	79	76	82	70	78	81	82	80	69	76

TABLE 4-B

Weight of the Plants Thinned - Grams

	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	T_{13}	T_{14}
Rep 1	39.6	28.1	51.1	38.7	42.3	49.7	41.5	14.0	38.6	35.1	57.0	55.8	10.6	33.6
2	36.8	44.0	42.0	46.4	42.7	18.3	47.1	36.7	37.4	43.2	38.7	44.4	44.1	35.3
3	23.3	27.8	23.2	20.4	17.5	23.0	28.0	27.7	21.0	32.5	37.5	40.4	28.3	15.9
4	28.2	25.5	19.2	18.8	20.7	23.3	19.7	19.5	25.0	28.7	25.8	20.3	22.1	22.2
T	128	125	136	124	123	114	136	98	122	140	159	161	105	107

Crop Yields

The mature greenhouse plants are shown in Figure 17 and the crop yields are presented in Table 5. The individual weights for each of the ten plants and the total for each flat is given. One plant in each of four flats failed to survive. To make the statistical analysis the average weight of the nine surviving plants was used as the 10th plant. These weights are given in parenthesis. In several flats one or more plants grew slowly and were crowded so that their growth was retarded severely. The weights of these small plants are given in the table.

The analysis of variance of these data (Appendix IX) indicated a significant difference among the replications at the 1% level and among the treatments at the 5% level. The analysis also indicated that the sampling error was greater than the experimental error. This might be expected since there was a large variation in the weights of the ten plants.

Separation of the means at the 5% level gave the following results: (Appendix IX)

T_4	T_{13}	T_6	T_7	T_{14}	T_2	T_{10}	T_8	T_{12}	T_1	T_3	T_5	T_9	T_{11}
550	561	572	578	582	602	613	635	655	657	675	725	774	810

Any two means not underscored by the same line were significantly different. Means of T_3, T_5, T_9, and T_{11} were significantly greater than the mean of the dry check, T_{10}. These treatments were electrostatic fields of 60 cps for 90 seconds, 500 cps for 60 seconds, and 900 cps for 90 seconds, and ultraviolet light of 2936 A. T_{11} produced

FIGURE 17

PLANTS IN FLATS BEFORE HARVEST

TABLE 5

Weight of Spinach Plants Grown in Greenhouse - Grams

Treatment		1				2				3				4			
Replication		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Plant	1	91	113	53	30	138	86	81	47	73	80	46	26	120	55	29	44
	2	16	21	54	77	28	70	75	22	91	29	25	25	19	37	38	27
	3	112	118	67	4	148	37	6	54	58	27	87	121	103	28	58	57
	4	86	55	39	9	24	50	114	58	89	100	15	95	16	29	68	56
	5	32	30	39	18	78	21	37	47	82	100	43	83	24	103	32	23
	6	133	17	76	108	39	25	54	62	29	75	49	40	58	120	42	89
	7	52	24	116	143	48	26	49	54	65	53	31	27	55	88	136	46
	8	82	24	72	67	134	36	41	34	129	104	49	103	70	73	52	24
	9	102	156	46	101	87	126	56	46	52	46	25	78	12	33	81	26
	10	10	113	109	15	45	108	57	60	162	118	122	47	48	112	31	36
Totals		716	671	671	572	769	585	570	484	830	732	492	645	525	678	567	428
Treatment Totals			2630				2408				2699				2198		

Treatment		5				6				7			
Replication		1	2	3	4	1	2	3	4	1	2	3	4
Plant	1	92	143	95	76	164	30	64	53	97	99	170	28
	2	33	46	85	46	46	97	20	36	35	19	39	83
	3	216	157	79	83	27	20	60	87	36	59	39	20
	4	57	51	66	23	62	24	16	14	78	57	34	14
	5	53	50	76	17	62	130	101	29	12	124	11	21
	6	17	27	6	129	109	52	22	93	118	105	73	22
	7	88	33	19	17	145	36	22	32	38	31	97	58
	8	28	18	90	82	86	13	67	23	61	62	25	108
	9	41	104	228	43	23	4	54	102	43	108	62	55
	10	16	165	8	197	126	72	34	29	13	95	24	39
Totals		641	794	752	713	850	478	460	498	531	759	574	448
Treatment Totals			2900				2286				2312		

TABLE 5 (Continued)

Weight of Spinach Plants Grown in Greenhouse - Grams

Treatment		8				9				10				11			
Replication		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Plant	1	157	56	57	23	71	134	35	23	91	64	58	24	332	229	99	33
	2	54	50	7	69	70	110	150	22	40	8	44	22	82	69	93	46
	3	111	130	14	46	112	113	32	17	64	125	78	72	23	37	59	54
	4	48	30	99	23	76	98	44	83	28	37	21	49	102	59	61	94
	5	121	65	19	99	60	38	61	70	85	52	26	202	11	61	65	56
	6	122	118	55	100	8	194	76	60	130	108	38	34	75	38	13	26
	7	14	58	66	37	12	110	35	49	20	8	105	58	105	38	17	23
	8	26	25	77	52	199	99	36	163	59	37	55	8	83	137	128	207
	9	7	103	34	21	70	4	172	68	39	74	139	23	19	157	52	73
	10	112	130	(48)	58	138	(100)	36	48	115	42	20	148	267	2	102	14
Totals		772	765	476	528	816	1000	677	603	671	555	584	640	1099	827	689	626
Treatment Totals			2541				3096				2450				3241		

Treatment		12				13				14			
Replication		1	2	3	4	1	2	3	4	1	2	3	4
Plant	1	137	60	29	25	118	51	32	17	158	122	106	54
	2	39	12	84	24	48	45	30	16	49	17	25	18
	3	73	45	32	9	32	50	66	41	60	28	50	11
	4	90	119	104	54	39	50	98	76	86	52	46	59
	5	7	108	43	79	42	33	34	41	85	131	31	118
	6	67	37	125	54	36	38	56	85	17	32	92	36
	7	90	20	80	25	35	30	81	20	15	58	12	95
	8	107	168	25	53	228	107	31	177	64	50	52	5
	9	54	110	120	146	45	47	54	44	75	33	70	62
	10	7	67	(71)	22	18	59	89	4	66	(58)	119	9
Totals		671	746	713	491	641	510	571	521	675	581	603	467
Treatment Totals			2621				2243				2326		

a high mean as it did in the germination test. T_{13} produced a low mean which did not agree with the germination results. T_4, T_{13}, T_6, T_7, and T_{14} were indicated to produce a detrimental effect on crop production. If the crop had been harvested earlier, or if fewer plants had been left in the flats during thinning, these erratic results may not have been obtained.

An analysis of variance of a factorial arrangement of the data of the first nine treatments of the greenhouse crop yields is presented in Appendix X. The F values indicated no significant differences among the three frequencies and no significant differences among the three exposure times used. An interreaction effect at the 5% level did exist, however, between the frequency and time factors and was probably due to the non-systematic responses of the 60 and 500 cps treatments.

C O N C L U S I O N S

The following conclusions are based on the results of this study:

1. Electrostatic fields of 150 volts per inch in the range of 60 to 1000 cps had no appreciable effect on germination of three year old spinach seeds.
2. Ultrasonic vibrations at 20,000 cps of spinach seeds in water for 60 seconds produced an increase in early germination. However, the increase was not greater than that produced by soaking seeds for 60 seconds.
3. Spinach seeds exposed to ultraviolet light of 3129 Angstroms for five minutes germinated earlier than untreated seeds and seeds exposed to 3654 Angstrom light.
4. None of the treatments had any effect on the percentage of plants that emerged and survived or on early growth.

RECOMMENDATIONS

The following recommendations are presented for future study:

1. Hard seeds, new seeds that have post-harvest dormancy, and old seeds that germinate below the legal minimum should be included in future investigations of this nature.
2. Variables that should be studied with electrostatic fields include seed varieties, plate spacings, plate potentials, frequencies, and exposure times. Since 60 cps fields are readily obtainable, these fields should be investigated further.
3. Further study of ultraviolet light at different frequencies and exposure times is suggested.
4. Because wet seeds are not desired, ultrasonic treatments may be studied with newly harvested seeds which will be dried and then treated chemically.

S U M M A R Y

Low seed germination is a problem of great economic importance, whether it be due to dormancy or deterioration in storage. The purpose of this study was to determine the effects of some low-energy, low-frequency treatments on spinach seeds. The seeds were exposed to the following treatments:

1. Electrostatic fields of 60, 500, and 900 cps at 150 volts rms for time intervals of 30, 60, and 90 seconds,
2. Ultrasonic vibrations of 20,000 cps for one minute, and
3. Ultraviolet radiations of 3129 and 3654 Angstrom units for five minutes.

Four replications were used for each test to find germination, emergence, and yield effects of the treatments. The electrostatic fields had no appreciable effect on germination. Ultrasonic vibrations produced the same earlier germination as soaking in water. The 3129 A ultraviolet radiation treatment caused seeds to germinate earlier while 3654 A treatment had no effect. None of the treatments affected emergence or early growth. Crop yield data were inconclusive.

A C K N O W L E D G E M E N T S

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APPENDICES

APPENDIX I

Analysis of Variance of 9-Day Germination

Correction factor, $C = (Sx)^2/N = 2228^2/56 = 88,642.571$
SS Rep. $= \Sigma Ri^2/n - C = 937.714$
SS Treat. $= \Sigma T_i 2/n - C = 2012.928$

SS Total $= S(x)^2 - C = 92.606.000 - 88,642.571 - 3963.429$

Summary of Analysis

Source	DF	SS	MS	F
Rep.	3	937.714	312.57	12.04**
Treat.	13	2012.929	154.84	5.96**
Error	39	1012.786	25.97	
Total	55	3963.429		

Standard error of mean: Sm $\sqrt{25.97/4} = 2.55$

Significant studentized ranges for 39 degrees of freedom at 5% level:

(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
2.86	3.01	3.10	3.17	3.22	3.27	3.30	3.33	3.35	3.37	3.39	3.40	3.42	3.43

Least significant ranges:

7.29	7.67	7.90	8.08	8.20	8.33	8.41	8.48	8.54	8.59	8.64	8.68	8.71	8.74

RESULTS:

T_6	T_2	T_1	T_7	T_{10}	T_8	T_{14}	T_9	T_3	T_5	T_4	T_{13}	T_{12}	T_{11}
34.0	34.3	35.5	36.5	36.8	37.0	37.0	37.8	38.3	38.8	39.3	47.0	51.5	53.5

**Indicates significant differences at the 1% level.

APPENDIX II

Analysis of Variance of 13-Day Germination

Correction factor, $C = (S_x)^2/N = 3750^2/56 = 251,\ 116.071$
SS Rep. $= \Sigma R_i^2/n - C = 512\ 786$
SS Treat $= \Sigma T_i^2/n - C = 835.929$

SS Total $= S(x)^2 - C = 253,106.000 - 251,116.071 = 1,989.929$

Summary of Analysis

Source	DF	SS	MS	F
Rep	3	512 786	170.93	10.40**
Treat	13	835.929	64.30	3.91**
Error	39	641 214	16.44	
Total	55	1989.929		

Standard error of mean: $Sm = \sqrt{16.44/4} = 2.03$

Significant studentized ranges for 39 degrees of freedom at 5% level

(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
2 86	3.01	3 10	3.17	3 22	3.27	3.30	3.33	3.35	3.37	3.39	3.40	3.42	3.43

Least significant ranges:

5 80	6.10	6 28	6 43	6 53	6 63	6.69	6.75	6.79	6.83	6.87	6 90	6.93	6.95

RESULTS:

T_5	T_7	T_{10}	T_4	T_2	T_{14}	T_9	T_1	T_6	T_8	T_3	T_{11}	T_{12}	T_{13}
62 5	63 3	63 5	64.3	65.3	65 3	65.5	65.8	66 3	66 3	68.5	72.5	73.3	75.5

**Indicates significant differences at the 1% level

APPENDIX III

Analysis of Variance of 17-Day Germination

Correction factor, $C = (S_x)^2/N = 4560^2/56 = 371,314.285$
SS Rep $= \Sigma Ri^2/n - C = 217.572$
SS Treat $= \Sigma T_i^2/n - C = 313.715$

SS Total $= S(x)^2 - C = 372,244.000 - 371,314\ 285 = 929.715$

Summary of Analysis

Source	DF	SS	MS	F
Rep	3	217 572	72.52	7.10**
Treat	13	313.715	24 13	2.36*
Error	39	398.428	10.22	
Total	55	929 715		

Standard error of mean: $Sm = \sqrt{10\ 22/4} = 1\ 60$

Significant studentized ranges for 39 degrees of freedom at 5% level:

(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
2.86	3.01	3 10	3.17	3.22	3 27	3.30	3 33	3 35	3 37	3.39	3.40	3.42	3.43

Least significant ranges:

4 57	4.82	4 96	5 07	5 15	5.23	5.28	5 33	5 36	5.39	5.42	5.44	5.47	5.49

RESULTS:

T_5	T_{10}	T_{14}	T_7	T_2	T_8	T_9	T_1	T_4	T_6	T_3	T_{12}	T_{11}	T_{13}
77 3	77 5	79.0	80.0	80 8	81 3	81.3	81.8	82.0	83.0	83.3	83.3	83.5	86.3

*Indicates significant differences at the 5% level.
**Indicates significant differences at the 1% level.

APPENDIX IV

Analysis of Variance of 19-Day Germination

Correction factor, $C = (S_x)^2/N = 4723^2/56 = 398,334\ 446$

SS Rep. $= \sum R_i 2/n - C = 143.482$

SS Treat $= \sum T_i^2/n - C = 128.304$

SS Total $= S\ (x)^2 - C = 398,991\ 000 - 398,334.446 = 656.554$

Summary of Analysis

Source	DF	SS	MS	F
Rep.	3	143.482	47 83	4.84**
Treat.	13	128 304	9 87	1.00
Error	39	384.768	9.87	
Total	55	656 554		

**Indicates significant differences at the 1% level

APPENDIX V

Analysis of Variance of 31-Day Germination

Correction factor, $C = (S_x)^2/N = 5077^2/56 = 460,284.446$

SS Rep $= \Sigma R_i^2/n - C = 46\ 482$

SS Treat $= \Sigma T_i^2/n - C = 62\ 304$

SS Total $= S(x)^2 - C = 460,719\ 000 - 460.284.446 = 434.554$

Summary of Analysis

Source	DF	SS	MS	F
Rep	3	46.482	15.49	1.86
Treat	13	62.304	4.79	0.57
Error	39	325.768	8.35	
Total	55	434.554		

APPENDIX VI

Analysis of Variance of Field Crop Weights

Correction factor, $C = (S_x)^2/N = 24,916^2/56 = 11,085,840.285$

SS Rep. $= \Sigma R_i^2/n - C = 414,376.572$

SS Treat. $= \Sigma T_i^2/n - C = 150,187.715$

SS Total $= S(x)^2 - C = 12,228,126.000 - 11,085,840.285 = 1,142,285.715$

Summary of Analysis

Source	DF	SS	MS	F
Rep.	3	414,376.572	138,125.52	9.33**
Treat	13	150,187.715	11,552.90	0.78
Error	39	577.721.428	14,813.37	
Total	55	1,142,285.715		

**Indicates significant differences at the 1% level.

APPENDIX VII

Analysis of Variance of Emergence in Flats

Correction factor, $C = (S_x)^2/N = (3534)^2/56 = 223,026.428$

SS Rep. $= \Sigma Ri^2/n - C = 37.429$

SS Treat. $= \Sigma T_i^2/n - C = 777.072$

SS Total $= S(x)^2 - C = 225,462.000 - 223,026,428 = 2432.572$

Summary of Analysis

Source	DF	SS	MS	F
Rep.	3	37.429	12.48	0.30
Treat.	13	777.072	59.77	1.44
Error	39	1,621.071	41 57	
Total	55	2,435.572		

APPENDIX VIII

Analysis of Variance of Early Growth of Greenhouse Plants

Correction factor, $C = (S_x)^2/N = 1,778.3^2/56 = 56,470.551$

SS Rep. $= \Sigma R_i^2/n - C = 3,059.316$

SS Treat. $= \Sigma T_i^2/n - C = 1,106.501$

SS Total $= S(x)^2 - C = 63,486.850 - 56,470.551 = 7,016.299$

Summary of Analysis

Source	DF	SS	MS	F
Rep.	3	3,059.316	1,019.77	13.95**
Treat.	13	1,106 501	85.11	1 16
Error	39	2,850.482	73.09	
Total	55	7,016.299		

**Indicates significant differences at the 1% level

APPENDIX IX

Analysis of Variance of Greenhouse Crop

Correction factor, $C = (S_x)^2/N = 35,951^2/560 = 2,307,990.001$
SS Rep. $= \Sigma R_i^2/n - C = 29,043.620$
SS Treat. $= \Sigma T_i^2/n - C = 33,803.824$
SS Subtotal $= \Sigma C_{ij}^2/n - C = 103,112.498$
SS Total $= S(x)^2 - C = 3,432,307.000 - 2,307,990.001 = 1,124,316.999$

Summary of Analysis

Source	DF	SS	MS	F
Rep.	3	29,043.620	9,681 20	9.37**
Treat.	13	33,803.824	2,600.29	2.52*
Error	39	40,265.054	1,032.43	
Subtotal	55	103,112.498		
Sampling error	500	1,021,404 501	2,042.81	
Total	555	1,124.516.999		

Standard error of mean: $Sm = \sqrt{1,032.43/40} = 16.06$

Significant studentized ranges for 39 degrees of freedom at 5% level:

(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
2.86	3.01	3.10	3.17	3.22	3.27	3.30	3.33	3.35	3.37	3.39	3.40	3.42	3.43

Least significant ranges:

45.9	48 4	49.8	50.9	51.7	52.5	53.0	53.5	53.8	54.1	54.5	54.6	54.9	55.1

RESULTS:

T_4	T_{13}	T_6	T_7	T_{14}	T_2	T_{10}	T_8	T_{12}	T_1	T_3	T_5	T_9	T_{11}
550	561	572	578	582	602	613	635	655	657	675	725	774	810

*Indicates significant differences at the 5% level
**Indicates significant differences at both the 1% level

APPENDIX X

Analysis of Variance for a Factorial Arrangement of Treatments One Through Nine of Greenhouse Crop Data

Source	DF	SS	MS	F
Rep.	3	21,637.7	7,212.5	6.55**
Treat.	8	17,952.6	2,288.1	2.08
a - frequency	2	1,357.7	678.9	0.62
b - time	2	4,005.5	2,002.8	1.82
ab - interaction	4	12,589.4	3,147.4	2.86*
Error	24	26,419.4	1,100.8	
Subtotal	35	66,019.7		
Sampling Error	322	571,307.8	1,777.4	
Total	357	637,327.5		

*Indicates significant differences at the 5% level.
**Indicates significant differences at the 1% level.

EFFECTS OF ELECTROSTATIC FIELDS, ULTRASONIC VIBRATIONS, AND ULTRAVIOLET LIGHT ON SPINACH SEED

By

THOMAS M. ROANE

ABSTRACT

Man has been concerned with low seed germination for many years. If one could develop economical seed treatments that would break dormancy of new or hard seeds or stimulate old seeds, he would make an important contribution to the agricultural economy. The purpose of this study was to determine the effects of some electrically produced treatments on spinach seed.

Seeds were treated between two 6-inch by 6-inch plates, 1-inch apart, at approximately 150 volts rms. Frequencies were 60, 500, and 900 cycles per second. Exposure times were 30, 60, and 90 seconds for each frequency. One sample was treated in an ultrasonic generator at 20 kc for one minute. Another sample was soaked in water for one minute for the wet check. Ultraviolet light at 3654 A and 3129 A was used on other treatments.

Four reps consisting of 100 seed each were germinated in a refrigerator at about 45°F. After 9 days and 13 days the germination of those treated ultrasonically, the wet check, and those exposed to 3129 A was significantly greater than for the other treatments including the dry check. After 31 days all of the treatments germinated above 82% and there were no significant differences for any of the treatments.

A field study was conducted in which 102 seeds were planted individually five inches apart in beds with rows ten inches apart.

Adverse weather conditions caused poor stands which gave unreliable data.

Four reps of 80 seeds each were planted in flats in a greenhouse. After 28 days they were thinned to 10 plants per flat. There were no significant differences in the 28 day emergence or in early growth. Data regarding differences in crop yield were inconclusive.