Communications

Weak Electric Fields Affect Plant Development

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Abstract—High-strength electric currents and fields can alter plant physiology by the production of heat within the plant tissue and by the ionization of air molecules at the plant tips. It has been suggested that weak low-frequency electric and magnetic fields may alter germination and early plant development [4], [5], but the question has not been resolved. Our aim was to determine the possible existence of weak electric-field effects on sunflower germination and to calculate the electric-field threshold inside the seed for any such effects. We found that an applied electric field of 5 kV/m, 60 Hz, produced an internal electric field of 7.5×10^{-4} V/m in a seed in moist soil and resulted in a statistically significant decrease of about 5 percent in germination rate. No effect was found for an applied field of 1 kV/m (1.5×10^{-4} V/m inside the seed). These results established for the first time that electric fields can affect plants by a nonthermal mechanism other than air ionization.

There have been many reports of the effects of high-strength electric currents and electromagnetic fields on plants that are attributable to the production of heat in the plant tissue itself. In contrast, comparatively few studies involving nonthermal currents or fields have been performed. Murr [1], [2] showed that electrostatic fields on the order of 50 kV/m inhibited growth in grass seedlings, and Sidaway [3] reported about a 5 percent decrease in germination of lettuce following exposure to 36 kV/m. In both cases, it seems likely that the observed effects were due to air ionization produced at the plant tips where the electric field would be concentrated. Of more interest are the reports of apparent effects associated with exposure to weak fields. In a pilot study, an apparent increase in germination of sunflower seeds was reported following exposure to simultaneous fields of 10-20 V/m and 1-2 G at 45-75 Hz [4]. In a follow-up study, Rosenthal studied the germination and early growth of sunflowers and seemed to find small effects on germination, seedling mortality, and root length following exposure to 1-10 V/m and 1 G at 75 Hz [5].

It would be important to know whether weak fields can affect plant growth because an affirmative answer would point to the existence of presently unknown mechanisms of interaction between fields and plants. Our aim was to resolve the question in such a way as to permit a mathematical determination of the actual field strength inside the plant tissue.

Sunflower seeds were exposed to a 60-Hz field of 1 or 5 kV/m during germination. The exposure assembly consisted of a lower plate of stainless steel and an upper plate of aluminum screening (each 61 × 122 cm) to permit the entry of light into the region between the plates. The electric field was determined from the applied voltage and the plate separation (38 cm). No detectable ozone was produced by the system.

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TABLE I
GERMINATION PERCENTAGES IN MULTIPLE REPLICATE EXPERIMENTS INVOLVING SUNFLOWERS EXPOSED TO 5 kV/m

EXPERIMENT NO.	GERMINATION PERCENT	
	Experimental Group	Control Group
1	*77	85
2	*75	84
3	79	80
4	79	79
5	81	86
6	81	84
7	84	87
8	*79	86
9	*73.5	80.5
10	75.5	78
11	85.5	81
OVERALL AVERAGE	*79.0 ± 3.7	82.8 ± 3.2

Statistical comparison between the groups within each experiment was based on the chi-square test (2 × 2 contingency table with continuity correction); comparison between the overall averages was based on the two-tailed paired t-test using the data listed in Table I. Every group up to and including those in Experiment 8 initially contained 100 seeds; thereafter, every group contained 200 seeds.
$* = p < 0.05$.

Eight 40-W fluorescent bulbs provided approximately 400 lm at the plane of the soil surface. The control assembly was identical except that the plates were grounded. Both assemblies were housed in a vented windowless room in which the air was constantly circulated by two large fans. To eliminate the possibility that unknown environmental differences could influence the results, the positions of the control and exposure assemblies were interchanged daily. The average temperatures inside the control and exposure assemblies were identical to within less than 0.1°C in each individual experiment. During the five-day exposure period it was generally necessary to water the plants twice; in all cases, both the volume of water and the watering pattern used in each assembly were identical.

A 2.5-cm layer of potting soil was placed in an 28 × 42 cm plastic tray and the seeds were laid on the soil surface—equidistant from their nearest neighbors—with the thinnest dimension in the vertical direction. The seeds were then covered with 2.5 cm of soil, watered, and germinated (defined as emergence of the plant sprout within five days of planting when viewed with the unaided eye). The observation of emergence was not made blindly, but there was virtually no ambiguity in such determinations when made at five days post-planting. At 5 kV/m, the germination percentage of the field-exposed seeds was generally smaller than that of the control seeds (Table I). In four of the replicate experiments this difference was statistically significant; additionally, the overall average germination percentage of the field-exposed seeds was significantly smaller than that of the control seeds. At 1 kV/m, however, the corresponding overall average germination percentage of the exposed seeds was not different from that of the controls, and only one of the six replicates exhibited a significantly smaller germination percentage in the exposed group.

To establish that the observed difference in the overall germination percentage at 5 kV/m did not arise from an unknown environmental factor associated with one of the assemblies, we replicated the entire procedure six times with no electric field present in either assembly. The overall average germination percentages of the two groups were identical, thereby establishing that the effects seen at 5 kV/m may be attributed to the field alone.

The electric field inside the seed may be calculated using the ellipsoidal model described elsewhere [6]. Although the electrical properties of sunflower seeds have not been reported in the literature, they may be estimated from published values for other seeds [7]. At 60 Hz, the dielectric constant K_1 and conductivity g_1 should be on the order of 4 and 3.3×10^{-9} S/m, respectively, for seeds with a moisture content of about 6 percent.

The electric field in the soil far from the seeds is determined primarily by the electrical properties of the soil itself, which depends in turn on its moisture content. The dielectric constant of the soil K_2 can be estimated from its low-frequency conductivity g_2 [8]. The conductivity of the soil in the present study was measured and found to be 10^{-6} S/m before and 0.5 S/m after watering. The corresponding dielectric constants would be on the order of 10^2 and 10^5. For both wet and dry soil the ratio $g_2/2\pi f K_2 \epsilon_0 \gg 1$ where f is the frequency and ϵ_0 is the permittivity of free space. Hence, the bulk field in the soil at 60 Hz was determined by its conductivity. Regarding the air space between the electrode plates as a capacitor and the soil as a pure resistor, one finds that the field in the soil E_s is related to the field in the air E_a by $E_s = 2\pi f \epsilon_0 E_a / g_2$.

Before watering, the seeds are surrounded by dry soil (Case 1). In this situation $K_2 \gg K_1$ and $g_2 \gg g_1$. The field in the seed E is related to the field in the soil by $E = (1 - 1/R)\, E_s$ where R is a geometrical factor related to the shape of the seed [6]. Hence, the field inside the seed depends only on the shape of the seed and is essentially independent of the seed's electrical properties [6]. The field approximates that of a hollow ellipsoidal cavity embedded in a conductor. For sunflower seeds (average dimensions, $0.45 \times 0.69 \times 1.48$ cm) oriented with the smallest dimension in the direction of the field, $E = 2.3 E_s$.

Shortly after watering the seeds are still dry, but they are surrounded by wet soil (Case 2). Again, $K_2 \gg K_1$, $g_2 \gg g_1$ and $E = 2.3 E_s$. Eventually the seeds themselves become moist and are surrounded by wet soil (Case 3). Although the electrical properties of dry sunflower seeds (about 6 percent water) could be readily estimated at 60 Hz, comparable data do not exist for the moist seeds (about 50 percent water). Although the dielectric constant and conductivity both increase with moisture content, these values probably do not approach those of the surrounding soil [7]. Under this assumption, we again expect that $E = 2.3 E_s$.

The field inside the seed is then related to the field in the air by $E = 4.6\pi f \epsilon_0 E_a / g_2$. With an applied field of 5 kV/m at 60 Hz, $E = 37.5$ V/m for Case 1 and 7.4×10^{-4} V/m for Cases 2 and 3.

The results show that at 60 Hz an electric field as high as 37.5 V/m (immediately after planting) and as low as 7.5×10^{-4} V/m (the fully moisture-laden seed immediately prior to germination) is associated with a decrease of approximately 5 percent in the germination percentage: the threshold for the effect is no more than a factor of five below these values. The effect is small and can be masked by the normal variation in germination from experiment to experiment. The significance of the observation, however, lies in the finding that plant physiology can be altered by weak fields because it raises a possibility that stronger, more desirable, effects may be found under different exposure conditions.

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