Radio-frequency electromagnetic radiation alters the electric potential of *Myriophyllum aquaticum*

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**Abstract**

Electric signaling pathways are important for rapid and long-distance communication within a plant. Changes in the electric potential (EP) inside plants have been observed during the propagation of electric signals. Increasing radio-frequency electromagnetic radiation (EMR) in the environment raise the question about possible effects of EMR on the EP of plants. In the present experiment, we investigated the effect of 2, 2.5, 3.5, and 5.5 GHz EMR with a maximum field intensity of 23 - 25 V m⁻¹ on the EP in emergent *Myriophyllum aquaticum* plants. The 2 and 5.5 GHz exposures caused significant (16 and 13 %) decreases in the standard deviation of rapid fluctuations observed in the EP. The greatest change was caused by 2.5 GHz EMR (23 % increment), although it was not statistically significant. A recovery of the EP was only after 2.5 GHz EMR exposure. The temperature of the plants was not changed by the EMR exposure. These findings confirm the frequency-dependent non-thermal effects of EMR on the EP of plants.

**Additional key words**: communication technology, electric field, microelectrodes, parrot feather, plant signaling.

**Introduction**

Plants growing in their natural environment are exposed to both abiotic and biotic stimuli. To respond to or resist these stimuli, different signaling pathways operate to allow communication among plant organs (Mancuso and Mugnai 2006, Ilić et al. 2010). These signaling pathways can be subdivided into three main categories: chemical (Seo et al. 1997, León et al. 2001, Gechev et al. 2006), hydraulic (Comstock 2002, Christmann et al. 2007), and electric (Fromm and Lautner 2007, Oyarce and Gurovich 2010). The electric signaling pathway transmits long-distance signals at a relatively high rate (Fromm and Bauer 1994, Stanković et al. 1997, Volkov and Ranatunga 2006). Usually, these signals are subclassified in terms of the action potential (AP) and the variation potential (VP) based on the mode and rate of transmission (Stahlberg and Cosgrove 1997, Fromm and Lautner 2007). In addition to these two categories, another electrical signal type called the system potential (SP) has been discussed by Zimmermann et al. (2009). Collectively, AP, VP, and SP signals propagate as change in the electric potential (EP) inside plants. These signals can contain encoded information that is determined by the shape of the signal (Krol et al. 2006, Fromm and Lautner 2007). Therefore, if the EP of a plant is altered or manipulated due to external factors, it is possible to transmit incorrect information to the destination of the signal or to disturb the electric signaling system. The wounding response of tomato plants evoked by the external application of electrical stimuli (Stanković and Davies 1997) and the activation of the Venus flytrap by an electric charge (Volkov et al. 2008) are examples of the external manipulation of the plant electrical signaling system.

The use of mobile phones and wireless broadband access base stations has greatly increased the radiated power of radio-frequency electromagnetic radiation (EMR) in the environment (Hyland 2005). Frequencies from 800 MHz to 2.5 GHz are primarily used for communication networks, and frequencies above 2.5 GHz are increasingly used due to increased band width demands in technology. Even higher frequencies are...
anticipated for broadcasting networks as spectrum allocation tables list increasingly higher frequencies that are allocated to broadcasting purposes (Australian communications and media authority 2009, Electronic communications commission 2011, Federal communications commission 2012). When EMR propagates in space, it generates electric fields that depend upon the power density of the wave. Due to the sensitivity of plants to electrical stimuli, it is possible to manipulate the electric signaling or EP of plants with these EMR electric fields. If such an effect exists, it will affect the capacity of plants to adapt and respond to external stimuli. In contrast, if EMR exposure causes stress in plants (Tkalec et al. 2005, 2007, Roux et al. 2006, Sharma et al. 2009), this stress can then be reflected by the EP due to the change in physiological status (Fromm and Lautner 2007). However, evidence for such effects in plants is lacking, and investigating the problem will broaden understanding the environmental impacts of the extensive use of EMR. Therefore, we conducted this study to investigate the existence of EMR effects on the EP of plants. For this purpose, we exposed emergent parrot feather plants (Myriophyllum aquaticum) to 2, 2.5, 3.5, and 5.5 GHz EMR with 23 - 25 V m⁻¹ field intensity, and studied the effect on the EP. To the best of our knowledge, this study represents the first attempt to investigate the effect of EMR on the EP of plants.

Materials and methods

Plant preparation: Parrot feather (Myriophyllum aquaticum Verdc.) plants were grown in cubic glass tanks half-filled with river sand and a 35 % (v/v) Hoagland solution to a height of 5 cm above the sand. Healthy, vertical, emergent stems with roots in a submerged region were cut from a culture and individually planted in the glass tanks. The cuttings were allowed to further develop their roots and to grow to at least 10 cm above the top of the tank. The water level was maintained by adding distilled water every 2 - 3 d, and once a week, the water level was adjusted with the 35 % Hoagland solution. The plants were grown at temperature of 26 - 27 ºC, irradiance of 55 to 60 µmol m⁻² s⁻¹ (photosynthetically active radiation), a 12-h photoperiod, and air humidity of 70 - 75 %. To allow acclimation after the mechanical shock to the plants, a tank with a plant greater than 10 cm in height was placed inside an EMR-shielded anechoic chamber (specially designed Faraday cage used in the present experiment to separate plants from environmental EMR and to prevent the internal reflection of the transmitted EMR) one day prior to the experiment. The chamber doors remained open until the beginning of the experiment. Inside the chambers, the environmental conditions were the same as mentioned above.

EMR-shielded anechoic chamber: It was necessary to prevent the exposure of the plants to environmental EMR during the experiment because the environment contains a wide mixture of EMR emitted from terrestrial television stations, mobile phone networks, wireless broadband access, and internal WiFi links. The presence of these EMR sources affects the measurements obtained for an individual frequency. For these reasons, all of the experiments were performed in a specially designed anechoic chamber 100 (H) × 75 (W) × 75 (L) cm in size. The chamber was covered with a 3 mm² stainless steel mesh with a thickness of 0.8 mm (18 AWG). All of the vertical walls were internally covered with flat, 6 cm thick ferrite EMR-absorbing foam (PFP F, Riken, Tokyo, Japan), the bottoms of the chambers were covered with 20 cm pyramidal-type EMR-absorbing foam (PFP 30, Riken). The purpose of the application of EMR-absorbing foam was to prevent the internal reflection of EMR from forming standing waves which could affect the EMR treatment. The chambers were capable of reducing EMR penetration by more than 95 %.

EMR exposure and EP measurements: Plants were exposed to continuous-wave EMR at 2, 2.5, 3.5, and 5.5 GHz (the experiment repeated four times for each frequency). The maximum electromagnetic field at the top of the plant was maintained at 23 - 25 V m⁻¹ for every frequency. EMR was broadcast from above the plant, and the distance between the top of the plant and the...