Chapter 5

# Sand Electrification Possibly Affects the Plant Physiology in Desertification Land

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Additional information is available at the end of the chapter

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**Abstract**

At present, the researchers mainly focused on the degradation of vegetation caused by the sand burial, the sand flowing, and the loss of soil moisture and nutrients but never considered the impact of strong environmental electric field, which caused by the moving sand particles, on the physiological process of plants. In this chapter, we briefly introduced the research progress of wind-blown sand electrification and proposed a coupling prediction model to explain the contact electrification phenomenon of moving sand. At last, based on the rigid conduit model and the root-water-uptake model, we discussed the effect of wind-blown sand electric field, which maximum value can reach to 200 kV/m, on the speed of plant sap flow, the water potential of root, and the cell membrane permeability, respectively. The numerical simulation results showed that the wind-blown sand electric field directly accelerates the sap flow rate and indirectly decreased the water potential of plant root, which finally affects the plant physiological processes. These results can explain why the effect of wind-blown sand on the plant is obvious than that of the clean wind. From these discussions, we effectively illustrate the impact mechanism of wind-blown sand on the plant physiology in the desertification land.

**Keywords:** wind-blown sand electric field, water transport velocity, root-water uptake, cell membrane permeability

## 1. Introduction

Desertification is one of the major environmental disasters in the world [1, 2]. Desertification not only leads to the loss of agriculture and threat to the human survival but also can increase the aerosol concentration, degrade the atmospheric quality, and then lead to some negative impacts on the environment and human health [1, 3, 4]. In general, land desertification is accompanied by the degradation of vegetation [5] and accelerated by the climate anomalies and drought. Some researchers studied the reason of vegetation degradation and its restoration techniques under the various environmental stresses, for example, the drought [6], the high temperature [7, 8], the wind blowing [9], the sand burial [10, 11], the sand flowing [12, 13], the dust deposition on plant leaf [14], and so on.

In addition, some scholars also discussed the influence of various electric fields on the biological system [15]. Murr firstly discussed the physiological influence on plant growth of the electric field environment, and the author found that sufficiently high electric fields have a definite effect on plant growth and the growth response. Andersen and Vad [16] investigated the growth of *Serratia marcescens* and *Escherichia coli* at various filed strengths. Some researchers also considered the effect of environmental electric field on the seed germination, plant growth, respiration, and tolerance [17–22].

On the other hand, the soil grain and the sand particles incompactly distribute on the surface of desertification land, which can be driven by the strong wind and eventually formed the wind-blown sand flowing. Some particles will deposition on the earth, but others can enter into the air with the turbulent process and even develop to the dusty weather [23, 24]. A lot of experiments show that the moving sand is charged, which induced a strong electric field in the air [25–27]. As mentioned above, some experimental results have shown that with the increasing of the applied electric field, the electrostatic field has some negative or positive influence on the plant physiological processes. The wind-blown sand electric field must also work on the similar process.

However, there is no any related report published on the effect of wind-blown sand electric field on the plant physiological processes. In view of this situation, this chapter firstly introduced the research status of sand electrification phenomenon and then proposed some physical models to analyze the effect of environmental electric field on the physiological processes of plants, for example, the root-water absorption process, the water transport processes in the stem, the permeability of cell membranes, etc. Through these discussions, we want to furtherly demonstrate the influence of sand flow on plant growth.

## 2. Contact electrification of moving sand

Knowledge on the phenomenon of sand electrification also stems from a few experimental measurements. For example, friction was performed between the glass rod and the filter paper, whose main components were similar to the sand particles, and then the charge on the glass rod was measured by an electroscope and a Faraday cup [28], or blasting sand were measured [29, 30]. These experiments showed that the larger particles tend to be charged positively, but the smaller particles are charged negatively [31]. In addition, they also find that the atmospheric pressure [32], the ambient humidity [33, 34], and the components [35, 36] all have some significant impact on the particle's charged process [36].

With the development of experimental devices, some scholars found that the polarity of the charge on a particle is related to its grain size. Greeley and Leach [37] analyzed the wind tunnel experimental results, and he finds that the critical particle size is 60 μm. But Zheng et al. found that the negative charge is gained when the diameter is smaller than 250 μm and positive charge is gained if the diameter is larger than 500 μm [38, 39], which have been proven by Forward et al. [40]. Of course, the critical particle size for the charged polarity of sand maybe varies with the incoming wind velocity, the height from the sand surface, and the grain size, as well as its size distribution [25].

It should be specially pointed out that the above researches only obtained the average charge on particles. Due to the limitations of experimental techniques, the experimental devices, and other objective factors, we cannot precisely obtain the quantitative relationship between the charge on single particle and the particle size, the incoming wind speed, the temperature, the humidity, and so on. However, these results have played a positive role in promoting the understanding of the electrification phenomenon of wind-blown sand and enlighten scholars on its physical mechanism.

On the mechanism of contact electrification of sand, the highly accredited conjecture is the contact electrification and the polarization-inducing process [25, 41]. For the contact electrification mechanism, which contains the static contact and the friction, an asymmetric transfer of tiny charged ion or substance is the primary source of it. In addition, it just concerns what these metastatic substances are and why and how many are transferred. But the polarization-inducing process is more intuitive. This mechanism suggests that the particle is polarized by the environmental electric field and the excess charges are repelled to the two sides of the particle. When the moving particle contact with each other, charges with opposite polarity cancel out and then will charge itself after separation. This theory firstly explained the reason of the thunderstorm. Considering that the natural sand is wrapped by a water film [42, 43], some researchers also believed that it also worked in the electrification of wind-blown sand [41]. However, there is still a lack of physical model which is formed by the fusion of those two physical processes. In here, I want to introduce a simple coupling model for it.

### 2.1. Contact electrification from ion transfer

Xie et al. [44] proposed a contact electrification model of glass sphere, which can precisely predict the effect of particle size and the impact velocity on the electric quantity. So here, we directly used it to express the contribution of ion transfer to the contact electrification process. Of course, you can replace it with other suitable models, which have more precision. The model can be expressed as follows:

$$Q_1 = \rho P_D (1 - P_D)(\mathrm{A}_2 - \mathrm{A}_1) \tag{1}$$

where $\rho$ is the charge density and $P_D$ is the probability of any position on the particle surface as a donor; the reference suggests that it is 0.5. $A_i(\mathrm{i} = 1, 2)$ is the contact area in the collision process, which can be expressed as follows:

$$A_1 = 2\pi R_1^2 \left(1 - \sqrt{R_1^2 - 2R\delta_{\max}^1}/R_1\right) A_2 = 2\pi r_1^2 \left(1 - \sqrt{r_1^2 - 2R\delta_{\max}^2}/r_1\right)$$

$$\delta_{\max}^1 = \frac{R_1}{R_1 + r_1}\left(\frac{5}{4}\frac{M}{K}v_r^2\right)^{0.4} \delta_{\max}^2 = \frac{r_1}{R_1 + r_1}\left(\frac{5}{4}\frac{M}{K}v_r^2\right)^{0.4}$$

$$R = \frac{r_1 R_1}{r_1 + R_1} \; M = \frac{m_1 m_2}{m_1 + m_2} \; E = \left( \frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2} \right)^{-1} \; K = {}^{4ER^{0.5}}/_{3}$$

In here $m_1, m_2$ is the mass of two particles with radius $R_1, r_1$, $E_i, \nu_i$ is its elastic modulus and Poisson's ratio, and $v_r$ is the collide velocity.

### 2.2. Polarization-inducing process

The atmospheric electric field is 100–200 v/m, but it may be up to hundreds of kilovolts per meter in the thunderstorm or dust storm [45]. Under the polarization of the electric field, the conductor particles also can be charged after being separated from contact. Latham and Mason [46] deduced the contact electrification of two conductive spheres under the electrostatic field:

$$\Delta q_0 = \gamma_1 E r^2 \cos\theta + \gamma_2 q_1 R_1^2 / r_1^2 \tag{2}$$

Here, E is the environmental electric field. $r$ is the particle radius and $\theta$ is the angle between the two particles' centers and the electric field line. $q_i(i = 1, 2)$ is the initial net charge on the particle before they collide. The first term in Eq. (2) represents the contribution from the polarization, and the last one is the charge redistribution on the charged sphere. Here, we just keep the first term. Those meanings of the charge after two spheres collide in the electric field can be calculated through the last equation:

$$\Delta q_1 = \gamma_1 E r^2 \cos\theta \tag{3}$$

If two particles all are charged before they contact, the charge may redistribute on each surface. Davis [47] and Ziv and Levin [48] proposed a simple relation:

$$\Delta q_2 = (\omega - 1) q_1 + \omega q_2 \tag{4}$$

here, $\omega$ is the transfer fraction, which means how many charges on the smaller particle transfer to the relative larger particle. $\gamma_1$ is a parameter related to the radius ratio of two particles. And, we set $\alpha = r/R$, and then the values of $\gamma_1$ and $\omega$ have been shown in **Table 1**.

To simply, we obtain a fitting relationship used the MATLAB software, and it is shown as follows:

$$\gamma_1 = 1.915\alpha^2 - 6.132\alpha + 4.894$$

$$\omega = 0.5152\alpha^3 - 0.8769\alpha^2 - 0.1397\alpha + 1.003$$

| | | | | | | |
|---|---|---|---|---|---|---|
| $\alpha$ | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| $\gamma_1$ | 4.93 | 3.9 | 3.1 | 2.55 | 2.06 | 1.64 |
| $\omega$ | 1 | 0.948 | 0.838 | 0.714 | 0.6 | 0.5 |

**Table 1.** Values for the parameters $\gamma_1$ and $\omega$.

So, the charge on the smaller particles after it contacts another sand in a strong electric field can be obtained:

$$\Delta Q_1 = \Delta q_1 + \Delta q_2 \tag{5}$$

Considering that the sand is not an imperfect conductor, and the contact time is finite, so we have to add the impact of relaxation time [48]. Then, Eq. (6) is replaced by the following equation:

$$Q_2 = \left[1 - \exp(-\mathrm{t}_c/\tau)\right]\left(\Delta q_1 + \Delta q_2\right) \tag{6}$$

$\beta = 1 - \exp(-\mathrm{t}_c/\tau)$, $t_c$ is the contact time, while particles collide each other. $\tau$ is the surface conductivity of sand, which is connected with the thickness of water film, denoted as $n$, on the sand:

$$\tau(\mathrm{n}) = \begin{cases} 3.0 \times 10^{-18} \times 10^{0.44n} & n > 0 \\ 6.5 \times 10^{-18} & n = 0 \end{cases}$$

If the air humidity is $H$, the thickness of water film can be calculated by the following equation:

$$n = -1.588 \times 10^{-6}x^4 + 2.567 \times 10^{-4}x^3 - 0.01193x^2 + 0.2999x + 0.02099$$

Based on the above equations, the electrification of sand contact in a strong electrostatic field can be forecasted.

### 2.3. Electrification of sand in sand flowing

Under the real conditions, both of the above two processes occurred when the particles contact each other. So, the total charge on sand can be calculated through Eq. (7):

$$Q = Q_1 + Q_2 \tag{7}$$

### 2.4. Discussions

We supposed the particles are colliding along its center line; the radius of larger sand is 6 mm, the radius ratio is 0.5, the humidity of sand is 0.1, the collision velocity is 0.5 m/s, and $E_i, v_i$ are all 15 GPa and 0.4. Taking into account these parameters, we discussed the effect of environmental electric field on the contact electrification of sand. The simulation results are shown in **Figure 1**. From it, we can see that while the environmental electric field is up to 100 kv/m, the charge increased by 10%. Considering that the wind-blown sand electric field may be up to 200 kV/m, we believe that the polarization-induced electrification mechanism plays a very important role in the phenomena of wind-blown sand electrification.

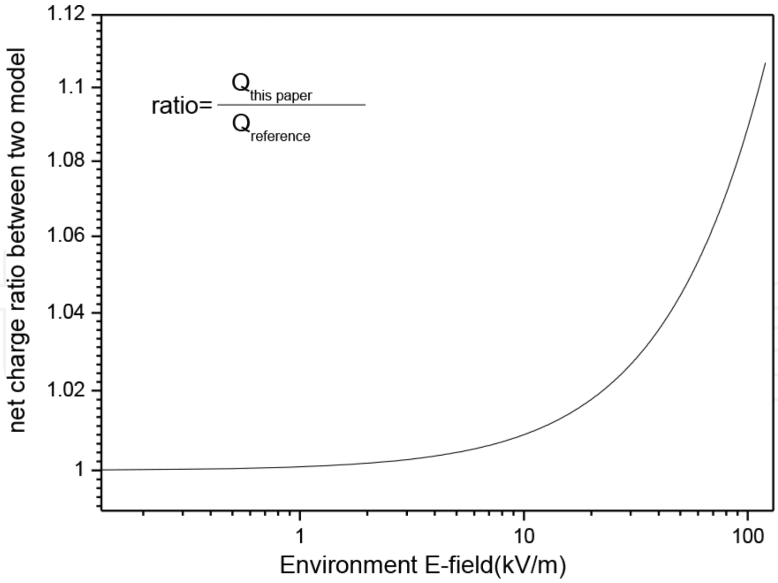


**Figure 1.** The effect of environmental electric field on the sand's electrification.

## 3. Wind-blown sand electric field

On the research of wind-blown sand electric field, Rudge firstly found that the atmospheric electric potential is obviously enhanced in the dusty weather and the direction is reversed [49]. Gill found the strong electric field and the spark phenomenon in the dust storm [50]. Freier found that the electric field in strong dust storm can be up to 60 kV/m [51]. Schmidt et al. measured the electric field in sand flow, and they found the electric field up to 160 kV/m at a distance of 5 cm from the ground [52]. These researchers just measured the vertical electric field. Jackson and Farrell found that the horizontal electric field of dust devil can be up to 120 kv/m [53]. Bo and Zheng found that the horizontal electric field is much larger than the vertical electric field [27]. Zhang et al. measured the electric field range from 0 to 30 m, in the sand

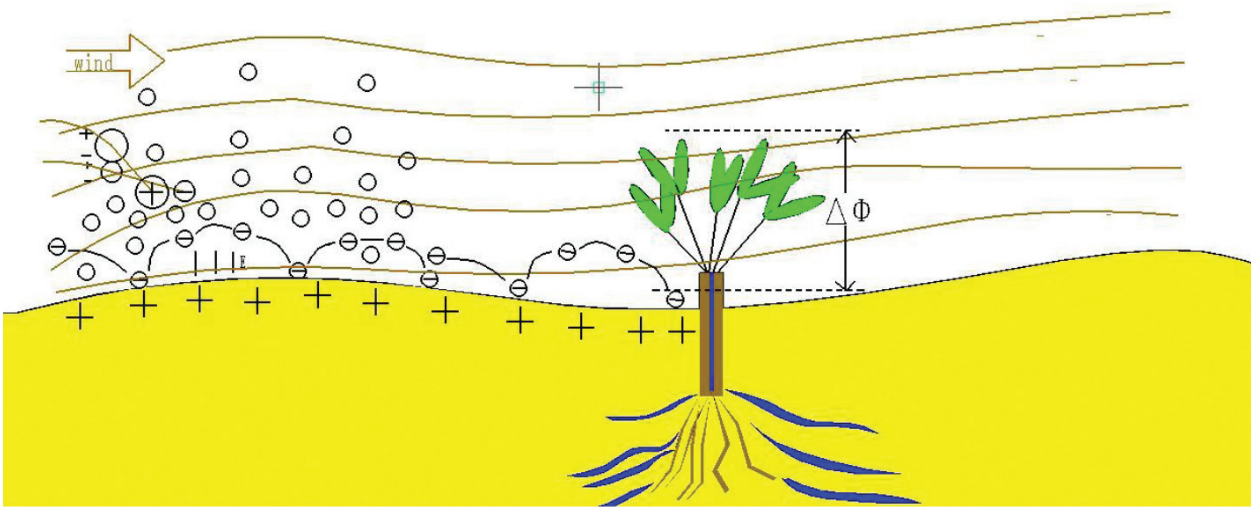


**Figure 2.** The effect of wind-blown sand electric field on plant.

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storm, and they found that the electric field is no-monotonic changed with the increase of height in the process of sandstorm and the direction may reverse [54]. These studies further revealed the complexity of wind-blown sand electric field, but they all reported that the magnitude of electric field is generally tens of kilovolts per meter, and it is even up to more than a hundred kilovolts per meter, which is sufficient to affect the physiological processes of plant (**Figure 2**).

## 4. Effects of sand electrification on plants

Numerous studies have shown that the electric fields, as a physical stimulus, have a wide range of effects on the physiological processes of plant; for example, an appropriate strength of the electric field can affect cell proliferation, enzyme activity, biofilm permeability, and DNA synthesis, which will have an impact on plant growth and even improve the plant tolerance [21]. Some experiment also reported that the high-level electric field accelerated the drying of the hydrous plants [21]. In general, plants used to adapt a couple of abiotic effects like drought, ice, and sandstorm causing spectacular physical damage in plant tissues, especially the psammophyte. However, the psammophyte is the product of evolution, but others are more common, which would not adapt the damage from electric field, for example, the crop on the desertification land. In my knowledge, no any references concerned about the impact of wind-blown sand electric field on plant's physiological processes. In this chapter I want to discuss the effect of environmental electric field on the plant sap flow, the potential root water, and the cell membrane permeability.

### 4.1. Effect on plant sap flow and root absorption

For the part between the crown and the root, which also named as xylem duct system, Parlange et al. proposed a theoretical model to simulate the sap flow of plant, and he suggest that the Poiseuille equation can be used to describe the sap flow in the stalk [55]. The driving force of the sap flow is the water potential differences between the plant root and the soil water. We set it as $\Delta p$. The water flux in a duct of the stem can be calculated through the Poiseuille equation:

$$Q = \frac{\pi r^4}{8\eta L}(\rho g \Delta h + \Delta p) \tag{8}$$

here, $Q$ is the water flux, $r$ is the duct radius, $L$ is the duct length, $\Delta h$ is the height difference of the duct, $\eta$ is the fluid viscosity coefficient, and $\rho g \Delta h$ represents the gravity of water in the duct.

It is clear that Eq. (8) does not consider the effect of environmental electric field. The plants in desertification land are located in a strong wind-blown sand electric field. The duct of the stem can be equivalent to tubules, the water in the duct can be simplified to a tiny conductor rod,

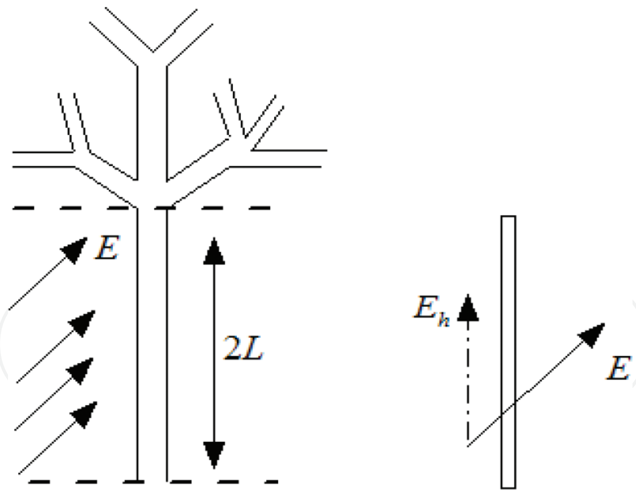


**Figure 3.** The plant in wind-sand electricity field.

and it must be affected by the electrostatic field force. So, we need to add one term in Eq. (8) to describe the effect from electric field (**Figure 3**).

If we set the vertical height of stem as $2L$, the electric field is $E_h$, $\sigma_h$ is the polarization charge density, and the electric field force can be calculated through Eq. (9):

$$F_E = \int_{-L}^{L} \sigma_{\mathrm{h}} E_h dh \tag{9}$$

$\Delta h = 2L$. To simplify, we set that the environment electric field is equivalent to the field in the stem duct, and we directly use the experimental results of wind-blown sand electric field reported by Schmidt et al. [52]:

$$E_{\mathrm{h}} = E_0 h^{-0.6} \tag{10}$$

here, $E_0$ is a constant and $h$ is the height from the ground. The charge on the water rod is [56]:

$$\sigma_h = \frac{E_h h}{\ln\left(4\left(L^2 - h^2\right)/_{a^2}\right) - 2} \tag{11}$$

Now, we can obtain the electric field force on the water rod:

$$F_E = \int_{-L}^{L} \frac{{E_0}^2 h^{-0.2}}{\ln\left(4\left(L^2 - h^2\right)/_{a^2}\right) - 2} dh \tag{12}$$

Then, we can modify Eq. (8) to contain the effect of electric field:

$$Q = \frac{\pi \mathrm{r}^4}{8\eta L}\left[\rho g \Delta h + \Delta p + \mathrm{sign}(E) * F_E\right] \tag{13}$$

The corresponding flow velocity is

$$v = Q/\left(\pi r^2\right) = r^2(8\eta L)^{-1}[\rho g \Delta h + \Delta p + \mathrm{sign}(E) * F_E] \tag{14}$$

Based on Bernoulli's theory, the change of fluid velocity can induce the change of pressure. Those meanings of the electric field also can influence the root absorption process. Therefore, we need to find a related model to describe it.

Supposedly, the resistance of radial direction and the one of axial direction for root absorption are $R_R$ $R_X$, and they all keep constant. In addition, supposedly the water potential inside and outside the root is $\psi_s(z)$, $\psi_X(z)$, the water flux from soil to root is $q_R(z)$, the radial resistance for the root absorption is $R_R$, and the following relation is established:

$$R_R q_R(z) = \psi_s(z) - \psi_X(z) \tag{15}$$

here, $z$ is the distance to the root tip; for the root tip, $z = 0$.

The water potential gradient along the root equals to the axial flux of root water in unit length: so,

$$\frac{d\psi_X(z)}{dz} = -R_X q_X(z) \tag{16}$$

$q_X(z)$(mm$^{-3}$-s$^{-1}$) is the volume flux of water from soil to root, which can be calculated through the van den Honert's constant flow equation:

$$\frac{dq_X(z)}{dz} = 2\pi a q_R(z) \tag{17}$$

here, $a$ can be thought as the radius of stem duct.

After some mathematics calculation, we can obtain

$$\frac{d^2\psi_X(z)}{dz^2} = \frac{2\pi a R_X}{R_R}\left[\psi_X(z) - \psi_s(z)\right] \tag{18}$$

Eq. (18) can be used as the control equation of root suction model.

The water potential function $\psi_s$ must vary with the research region. For example, the linear function can be used for the region where plant with shallow roots and well irrigation, and the exponential function can be used to describe the region with large changes in geological condition and climatic conditions and the plant with deep roots.

(A) Soil water potential is linear function.

We supposed the soil water potential is

$$\psi_s(z) = \mu z + \psi_0 \tag{19}$$

In here $\mu$ is an experimental constant, and we set it as 0.5. $z$ is the distance from the soil surface. The water potential at root cap $\psi_X(L)$ is

$$\psi_X(z)\big|_{z=L} = \psi_X(L) \tag{20}$$

At the influence of environmental electric field, the sap flow is accelerated. Considering the Bernoulli equation, the parameter $\psi_X(L)$ can be predicted as follows:

$$\psi_X(L) = k/v^2 \tag{21}$$

In here $v$ is the velocity of the stem flow at $z = L$, which can be calculated by Eq. (14). $k$ is an experimental constant, and we set it as 0.5.

In addition, considering the cross section of root tip is too small, we set.

$$q_X(0) = 0 \tag{22}$$

Now, we can obtain that the water potential in root is

$$\psi_X(z) = \left[\psi_X(L) - \left(\mu z + \psi_0\right)\right]\frac{\cosh(\alpha z)}{\cosh(\alpha L)} + \frac{\mu}{\alpha}\frac{\sinh(\alpha L - \alpha z)}{\cosh(\alpha L)} + \left(\mu z + \psi_0\right) \tag{23}$$

(B) Soil water potential is exponential function.

We supposed the soil water potential is as follow:

$$\psi_s(\mathrm{z}) = \psi_s(0)\mathrm{e}^{-\mu z} \tag{24}$$

$\mu$ is a constant. Then, we can obtain the water potential function in root:

$$q_X(z) = \mathrm{A}\mathrm{e}^{\alpha z} + B\mathrm{e}^{-\alpha z} - \frac{2\pi a\mu}{\left(\mu^2 - \alpha^2\right)R_R}\Psi_s(0)e^{-\mu z}$$

$$\frac{dq_X(z)}{dz} = \mathrm{A}\alpha\mathrm{e}^{\alpha z} - B\alpha\mathrm{e}^{-\alpha z} + \frac{2\pi a\mu^2}{\left(\mu^2 - \alpha^2\right)R_R}\Psi_s(0)e^{-\mu z}$$

$$\psi_x(\mathrm{z}) = \psi_x(0)\mathrm{e}^{-\mu z} - \frac{R_R}{2\pi a}\left[\mathrm{A}\alpha\mathrm{e}^{\alpha z} - B\alpha\mathrm{e}^{-\alpha z} + \frac{2\pi a\mu^2}{\left(\mu^2 - \alpha^2\right)R_R}\Psi_s(0)e^{-\mu z}\right] \tag{25}$$

$$G = \frac{R_R}{2\pi a}\left(\alpha e^{-\alpha L} + e^{\alpha L}\right) \quad M = \frac{\mu\psi_s(0)}{\mu^2 - \alpha^2}\left(\mu e^{-\mu L} + e^{\alpha L}\right)$$

$$A = \frac{2\pi a\mu}{\left(\mu^2 - \alpha^2\right)R_R}\psi_S(0) - B \quad B = \frac{1}{G}\left[\psi_s(\mathrm{L}) - \psi_s(0)\mathrm{e}^{-\mu L} + M\right]$$

Now, we want to make some discussion on them.

Firstly, we showed the effect of electric field on the stem flow speed, which is shown in **Figure 4**. From it we can see that the velocity of stem flow obviously increased when we consider the effect of the environmental electric field, and it also increases with the stem radius increasing, but it decreases with the stem length increasing.

**Figure 5** showed the effect of electric field on the speed of stem flow, and we can see that the stem flow increases exponentially with the electric field increasing. From these two results, we can see that the effect of wind-blown sand on the plant is obvious than that of the clean wind.

### 4.2. Effect on the permeability of the cell membrane

For the dielectric response of the cell media under the electric field, the weak conductor-coated spherical model proposed by Prodan et al. can be used directly [57]. We used it to simplify expression derived by Di Biasio A. [57]:

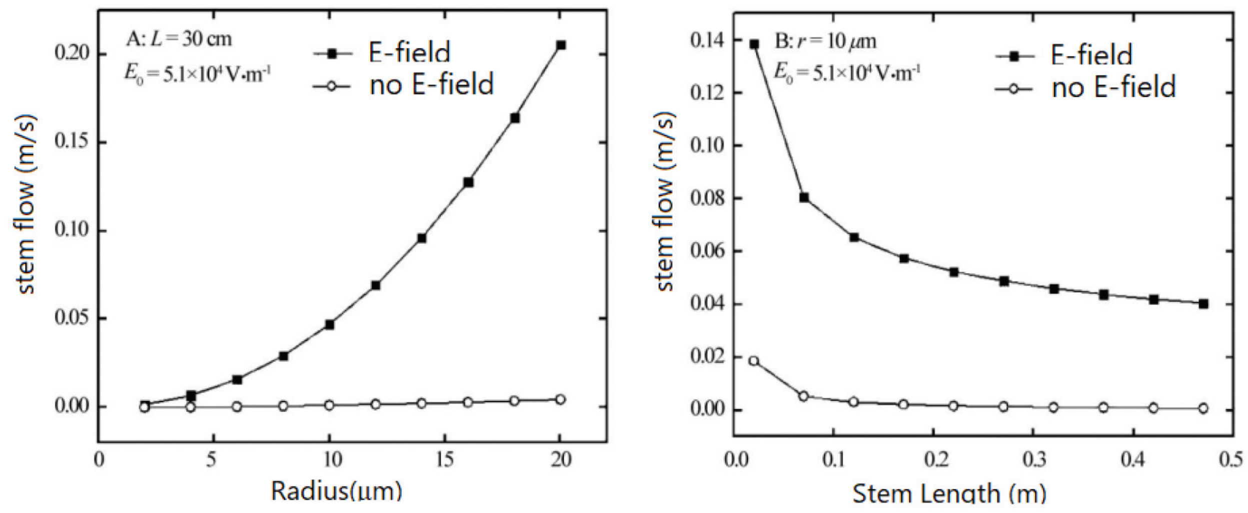


**Figure 4.** The effect of stem parameters on the stem flow.

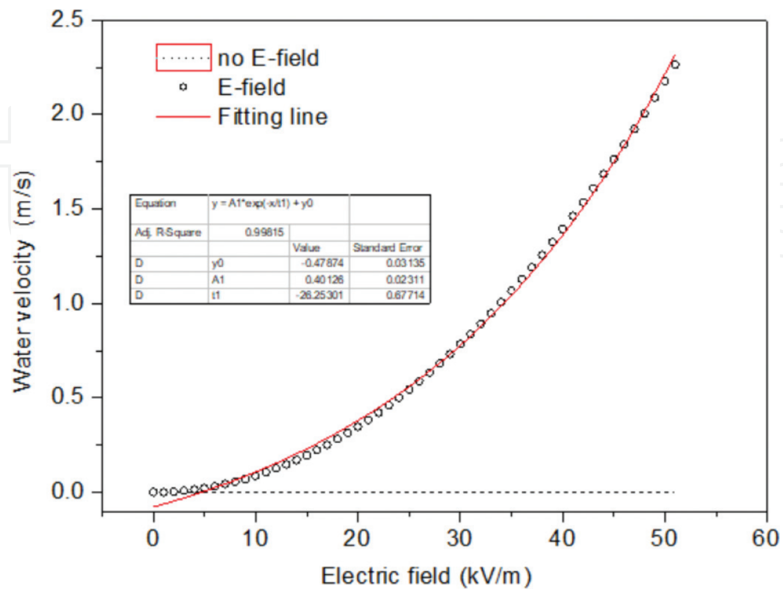


**Figure 5.** The effect of environmental electric field on the speed of stem flow.

$$\psi(r,\theta) = \left\{-rE_0 + 3R_1^2E_0\left[p_1\nu(r,R_1) + p_2\nu(r,R_2)\right]\right\}\cos\theta \tag{26}$$

In here $p_1 = \frac{C-B}{AC-B}, p_2 = \frac{A-1}{AC-B},$ and $D_k^{'} = 2D_k + i\omega R_k^2,\ \ k = 1, 2$. This expression is based on the spherical coordinates, $r$ is radial component, and $\theta$ is azimuth angle (**Figure 6**):

$$A = \frac{1 + \frac{D_1^{'}}{2R_1\gamma_1}\left(\varepsilon_1^* + 2\varepsilon_0^*\right)}{1 + \frac{D_1^{'}}{2R_1\gamma_1}\left(\varepsilon_1^* - \varepsilon_0^*\right)}\ B = \frac{R_2}{R_1}\frac{1\text{-}2\frac{D_1^{'}}{2R_1\gamma_1}\left(\varepsilon_1^* - \varepsilon_0^*\right)}{1 + \frac{D_1^{'}}{2R_1\gamma_1}\left(\varepsilon_1^* - \varepsilon_0^*\right)}\ C = \frac{R_1^2}{R_2^2}\frac{1 + \frac{D_2^{'}}{2R_2\gamma_2}\left(\varepsilon_2^* + 2\varepsilon_1^*\right)}{1 + \frac{D_2^{'}}{2R_2\gamma_2}\left(\varepsilon_2^* - \varepsilon_1^*\right)}$$

$$\nu(r,R_1) = \frac{R_1}{3r^2} \quad \nu(r,R_2) = \frac{R_2}{3r^2} \quad (r > R_1)$$

$$\nu(r,R_1) = \frac{r}{3{R_1}^2} \quad \nu(r,R_2) = \frac{R_2}{3r^2} \quad (R_1 > r > R_2)$$

$$\nu(r,R_1) = \frac{r}{3{R_1}^2} \quad \nu(r,R_2) = \frac{r}{3{R_2}^2} \quad (r < R_2)$$

The electric potential difference between inside and outside of the cell is

$$\begin{aligned}\Phi &= \psi(R_1,\theta) - \psi(R_2,\theta)\\ &= 3R_1^2\left[p_1\left(\frac{R_2}{3R_1^2} - \frac{1}{3R_1}\right) - p_2\left(\frac{1}{3R_2} - \frac{R_2}{3R_1^2}\right)\right]E_0\cos\theta + E_0(R_1 - R_2)\cos\theta\end{aligned}$$

After further simplification, we obtain

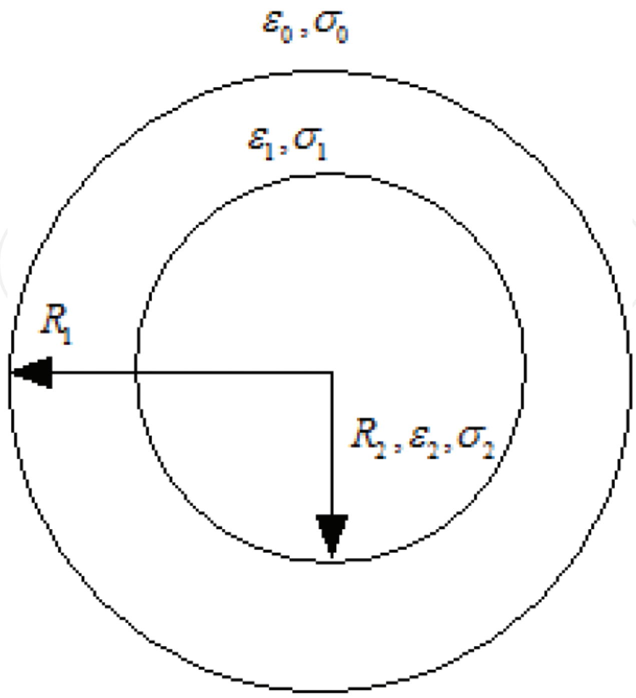


**Figure 6.** The coated spherical cell model and its physical parameters.

$$\Phi = 3\left[p_1\left(\frac{R_2}{3} - \frac{R_1}{3}\right) + p_2\left(\frac{R_2}{3} - \frac{R_1^2}{3R_2}\right)\right]E_0\cos\theta + E_0(R_1 - R_2)\cos\theta \tag{27}$$

The charged ion can be partially transported across the cell membrane and exchanged inside and outside the cell. For the $j-th$ ion, the net flux is

$$J_j = \frac{u_jRT}{\gamma_j}\frac{\partial\gamma_jc_j}{\partial x} - u_jc_jz_jF\frac{\partial E}{\partial x} \tag{28}$$

here, $u_j$ is the ion mobility, R is the thermodynamic constant, $T$ is the temperature, $\gamma_j$ is the active coefficient in a solution, $c_j$ is the ion concentration, $z_j$ is the number of valence electron, $F$ is the Faraday constant, and $\frac{\partial E}{\partial x}$ is the potential gradient.

In general, the first term repressed the ion flux originate from the concentration gradient, and the second term is stem from the potential gradient.

If we supposed that the active coefficient inside and outside the cell keeps a constant, then Eq. (28) can be changed:

$$J_j = u_jRT\frac{\partial c_j}{\partial x} - u_jc_jz_jF\frac{\partial\phi}{\partial x} \tag{29}$$

The thickness of cell membrane is $\Delta x$:

$$\frac{\partial E}{\partial x} = \frac{\Delta\phi}{\Delta x} = \frac{\Phi}{\Delta x}$$

Then, the last equation can be changed as follows:

$$\frac{z_jF\Phi}{RT\Delta x}dx = -\frac{dc_j}{c_j + \frac{J_j\Delta x}{u_jz_jF\Phi}}$$

Do some mathematic operation:

$$\int_0^{\Delta x}\frac{z_jF\Phi}{RT\Delta x}dx = -\int_{c_j^0}^{c_j^i}\frac{dc_j}{c_j + \frac{J_j\Delta x}{u_jz_jF\Phi}}$$

Then

$$\frac{z_jF\Phi}{RT} = \ln\frac{c_j^0 + \frac{J_j\Delta x}{u_jz_jF\Phi}}{c_j^i + \frac{J_j\Delta x}{u_jz_jF\Phi}}$$

And then

$$c_j^0 + \frac{J_j\Delta x}{u_jz_jF\Phi} = \exp\left(\frac{z_jF\Phi}{RT}\right)\left[c_j^i + \frac{J_j\Delta x}{u_jz_jF\Phi}\right]$$

So, we obtain the ion flux:

$$J_j = \frac{u_j z_j F\Phi}{\Delta x} \frac{1}{\left[\exp\left(\frac{z_j F\Phi}{RT}\right) - 1\right]} \left[c_j^0 + c_j^i \exp\left(\frac{z_j F\Phi}{RT}\right)\right] \tag{30}$$

Now, we will discuss the effect of environmental electric field on the ion flux in and out of the cell. The cell radius $R_1 = 1\mu m$, the thickness of cell membrane $d = 7nm$, its dielectric constant, and conductivity are $\varepsilon_1 = 150$, $\varepsilon_2 = 50$, $\varepsilon_0 = 80$, $\sigma_1 = 0.15$, $\sigma_2 = 0.2$, and $\sigma_0 = 0.1$; then the complex permittivity $\varepsilon_i^* = \varepsilon_i + \sigma_i/(i\varepsilon_m\omega)$, $i = 1, 2$, and $\varepsilon_m = 8.857 \times 10^{-12}$; the frequency of incident electric field $\omega = 10^3 Hz$, and the temperature $T = 300\text{K}$. In **Figure 7** we just showed the results, while $\theta = 0$. From it we can see that with the increasing of electric field, the negative ion flux increased, but the positive ion flux decreases, and the number of valence electron is larger; the influence is more obvious.

**Figure 8** showed that the ion flux changed with the azimuth angle; from it we can see that with the increasing of azimuth angle, the net flux of positively charged ion became increased, but the one for negative valence ions decreases. In addition, with the increase of the number of valence electrons, the net flux of negative ions in the upper part of the cell is increasing, but the net flux of positive ions is constantly disappearing, which is opposite for the lower part of the cell. This is due to the opposite polarization charge in the upper and lower parts of the cell.

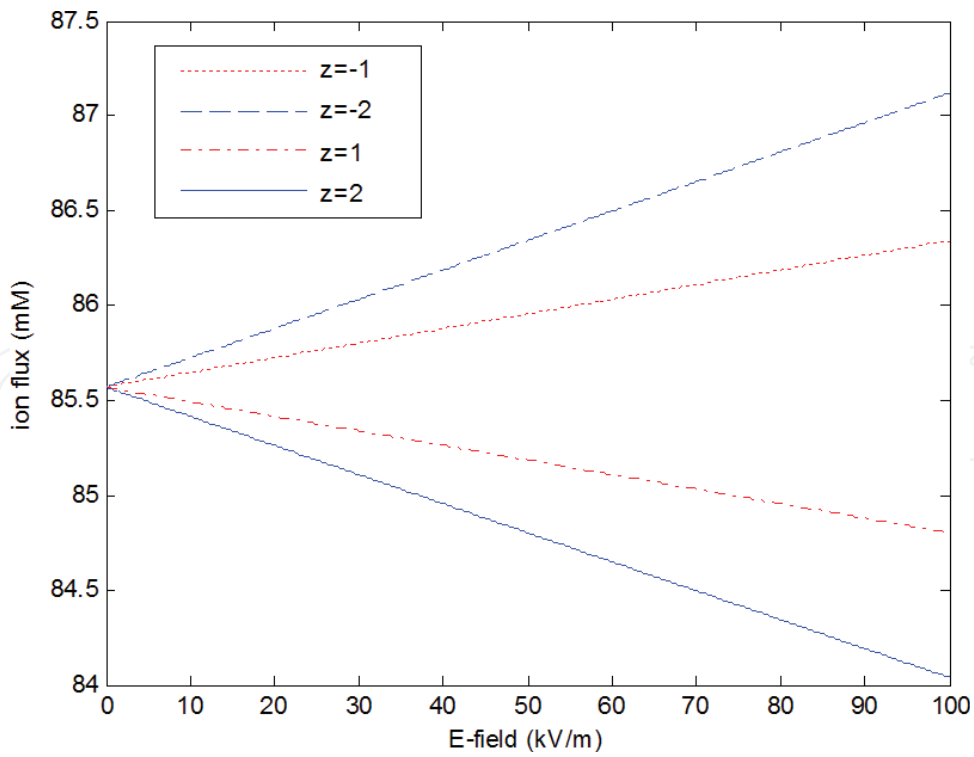


**Figure 7.** Effect of electric field on ion flux while it is with different polarity charges.

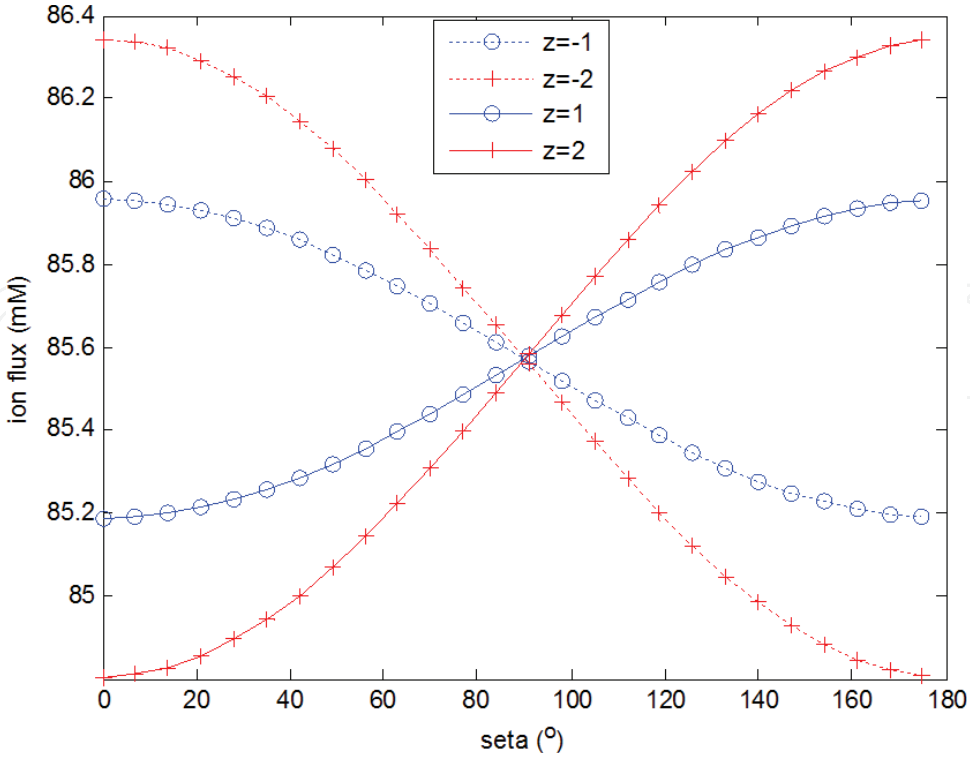


**Figure 8.** Ion flux changed with the azimuth angle ($\theta$) of cell in spherical coordinate.

## 5. Conclusions and perspective

This chapter discussed the electrification of sand flow and proposed a simple physical model to reveal the mechanism of it. In addition, we also further discussed the effect of wind-blown sand electric field on the physiological process of plants. The simulation results showed that the electric field strongly enhanced the sap flow and root-water-uptake rate, and the permeability of the cell membrane also changed and then influences the growth of plants. However, these results are derived from the theoretical model, so we hope someone can carry out a series of relevant experimental studies to verify them. In addition, there is a lack of detailed experiment and discussion on the frequency of wind-blown sand electric field and on the effect of frequency of electric field on the plant physiology process.

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