NEW SOIL WATER TENSION SENSORS: THE DIHEDRAL AND IGstat SENSOR

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INTRODUCTION

- Soil water sensors qre grouped in water content and water potential sensors and both are important for practical applications and fundamental processes studies in agriculture, hydrology and environment.
- Diverse soil water content sensors (SWCS) are available, covering the full range of WC (dry to saturation), different soils and conditions (field, laboratory, cost, accuracy). However, soil water potential sensors (SWPS) are more limited in terms of operation range, cost, maintenance and commercial availability. Therefore, there are still interest in developing new SWCS for different applications.
- Two new sensor concepts have been introduced for measuring soil water tension with a good potential for sensor technology development, named Dihedral (patent: PCT/BR2011/000001) and IGstat sensor (patent: PCT/BR2014/000128).
- The IGstat sensor is composed of particles with known size-distribution (e.g. glass beads) that retains or release water as the soil wets or dries (Calbo et al. 2013). During the drying process air permeates the medium and different systems can be used to detect changes in the hydraulic, optical or electrical properties of the medium. In this work we present IGstat sensors using an optical transducer operating at the reflection mode.
- In the dihedral sensor two rectangular hydrophilic flat glass plates and/or fine porous flat plates are fixed in angle, defining the dihedral angle. The system is fixed in a porous element and the distance between the vertex and the water meniscus is proportional to the soil matric potential (Calbo 2011; Vaz et al. 2013).
- We present and discuss here the basic concepts of these two technologies and some results obtained with some manufactured devices.

THE DIHEDRAL TENSIOMETER

Basic concepts

- The dihedral tensiometer is comprised of two glass plates attached in a dihedral configuration (two nonparallel plates) with a water film between the plates. The distance from the vertex to the water meniscus (L_i) and the distance between the plates at the meniscus position (a_i) are related by the tangent of the dihedral angle (α), as shown in Fig. 1.

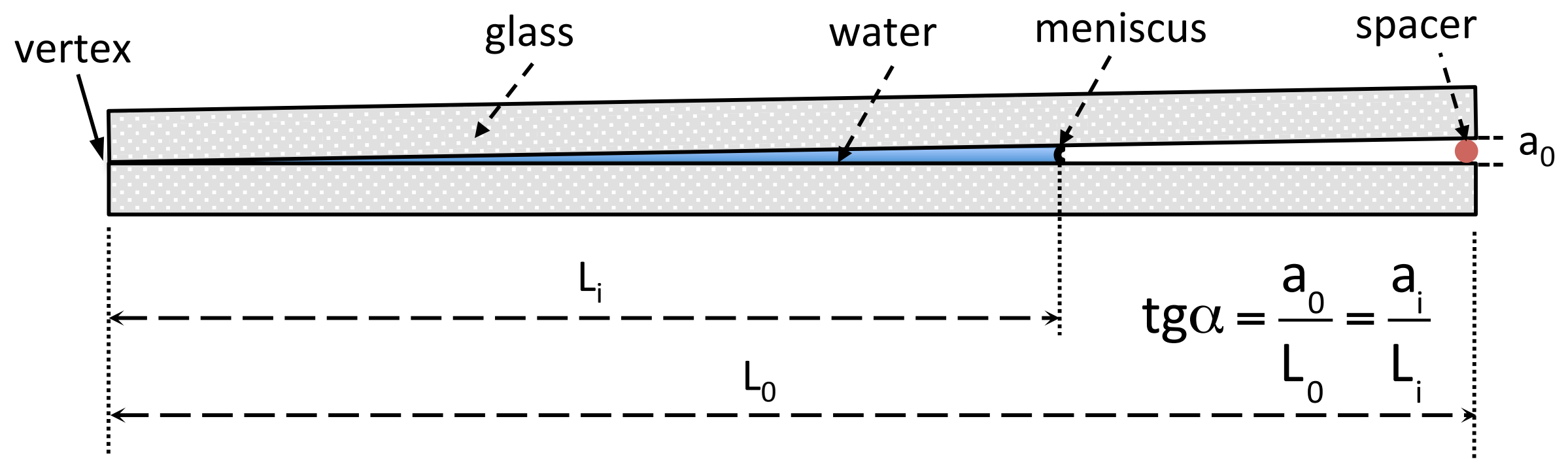
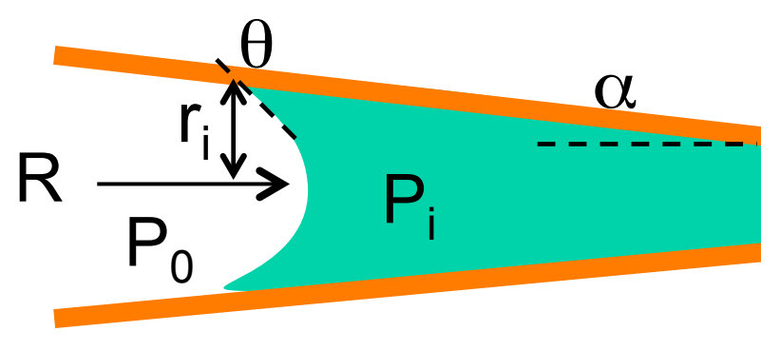


Figure 1. Sketch of the dihedral tensiometer with a dihedral angle α.

- The pressure between two nonparallel plates can be derived from Young-Laplace's law that links the curvature of a liquid-gas interface to the pressure differences across the interface (Eq. 1) and the radius curvature R can be expressed by Eq. 2 (e.g. Berthier and Silberzan, 2010), where γ is the water surface tension (0.0728 Nm^{-1} at 20 °C), r_i is the radius, θ the wetting angle and α the dihedral angle.
- Substituting Eq. 2 in Eq. 1 and considering $P_0=0$ (open chamber dihedral), $\cos(\alpha+\theta)\cong 1$ and writing the distance $a_i=2r_i$, provides Eq. 3, which relates the pressure in the liquid-gas curvature interface with the distance between the plates at the interface position.
- The two plates separation distance at the liquid-air interface can be expressed as $a_i=L_i tg\alpha$, allowing the determination of the pressure P_i or the soil water tension (ψ_i) when the vertex is in contact with a soil, by simply measuring L_i, since $tg\alpha$ is known for a fixed dihedral angle ($tg\alpha= a_0/L_0$).



$$\boxed{P_0 - P_i = \frac{\gamma}{R}} \quad (1) \qquad \boxed{R = \frac{r_i}{\cos(\alpha+\theta)}} \quad (2) \qquad \boxed{P_i = -\frac{2\gamma}{a_i}} \quad (3) \qquad \boxed{P_i = \psi_i = -\frac{2\gamma}{L_i tg\alpha}} \quad (4)$$

Dihedral tensiometer evaluation

- A dihedral tensiometer was made of two 4 cm long glass plates, spaced 30 μm (a_0), glued with gypsum and cement at the top of a gypsum rod (cut in a 30° angle to better visualize the water meniscus).
- A suction chamber was used to evaluate the dihedral tensiometer (Fig. 2) consisting of glass container with a ceramic tube (high bubbling pressure) filled with glass beads (diameter < 100 μm), connected to a vacuum pump and a mercury manometer. Suctions, from 5 to 50 kPa were applied in steps and L_i (mm) was measured at equilibrium condition.
- Water tension measured with the dihedral tensiometer were very close to the applied suction (Fig. 3B), with a root means errorn of about 1 kPa and equilibration time of 30 min. for each suction step applied.

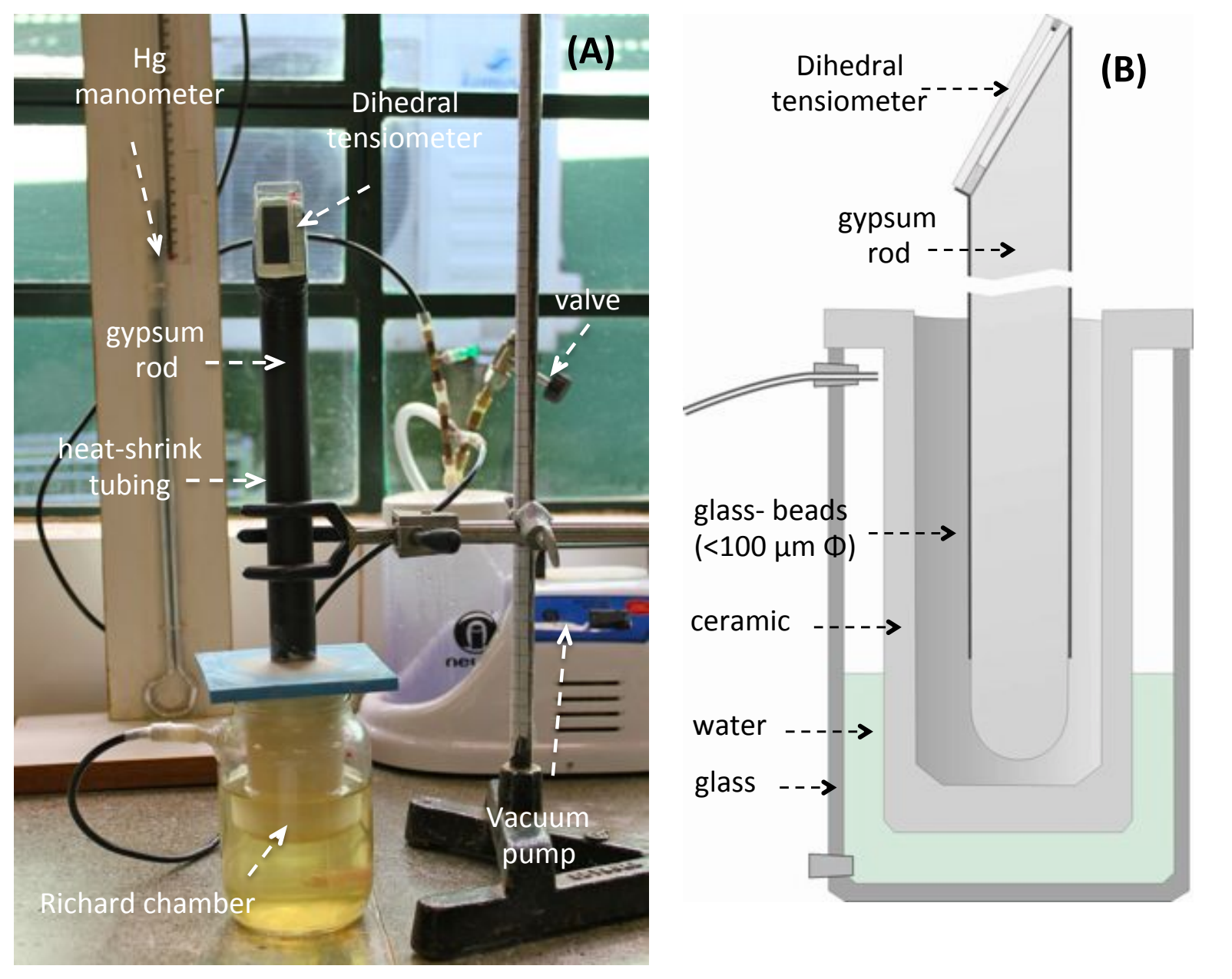


Figure 2. Experimental setup to test the dihedral tensiometer.

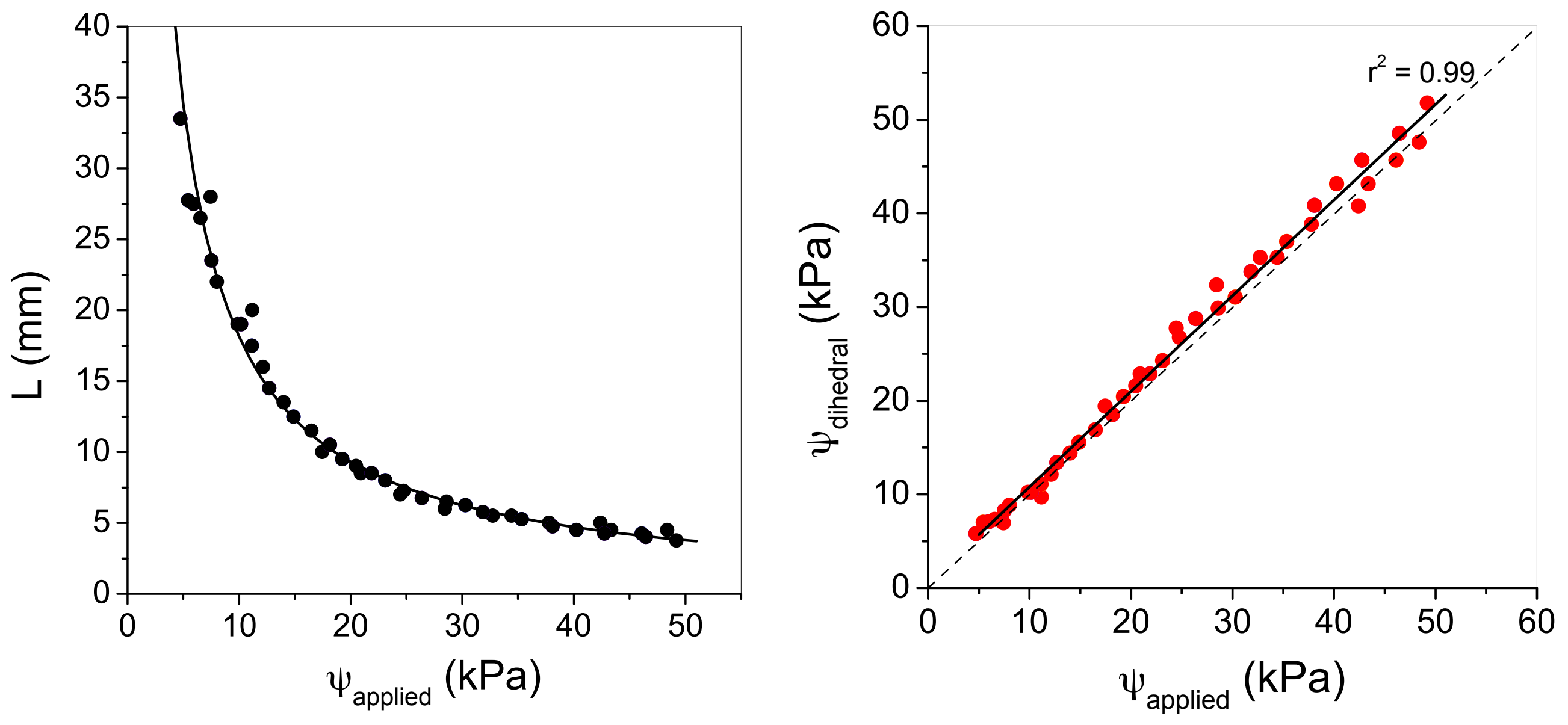


Figure 3. Measured distance between vertex and meniscus (L_i) as a function of applied suction (ψ) (A) and correlation between the dihedral response (Eq. 4) and the applied suction (B).

THE IGstat SENSOR

Basic concepts

- The IGstat sensor principle is illustrated in Fig. 3, where non-sintered glass beads particles (GB) are packed into a ceramic cup with bubbling pressure (BP) higher than BP of the glass beads porous medium. When soil around the IGstat sensor dries to a matric potential higher than the air entry value of the GB medium, a low air pressure air applied in the tube enter (1) will flow through the porous medium and the tube out (2).
- Using GB with diameters from 1 to 100 μm can ideally produce media with air entry values from about 3 to 300 kPa and IGstat sensors with different thresholds for irrigation (critical values). This is the pneumatic mode for the IGstat sensor, but other transducing mode can be used as the light reflection shown in Fig. 4.

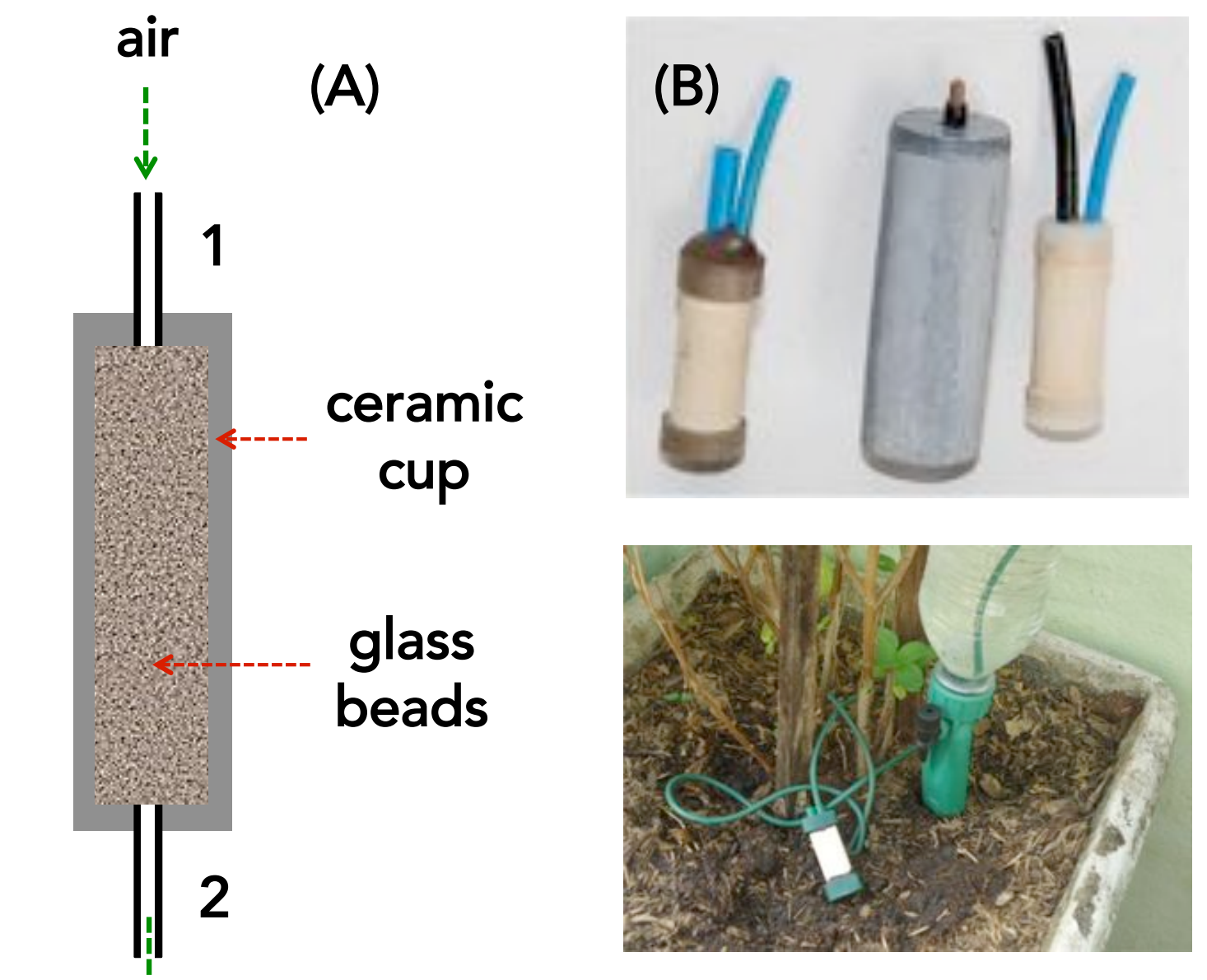


Figure 3. Illustration of a IGstat sensor operating in the pneumatic mode (left) and some prototypes (B).

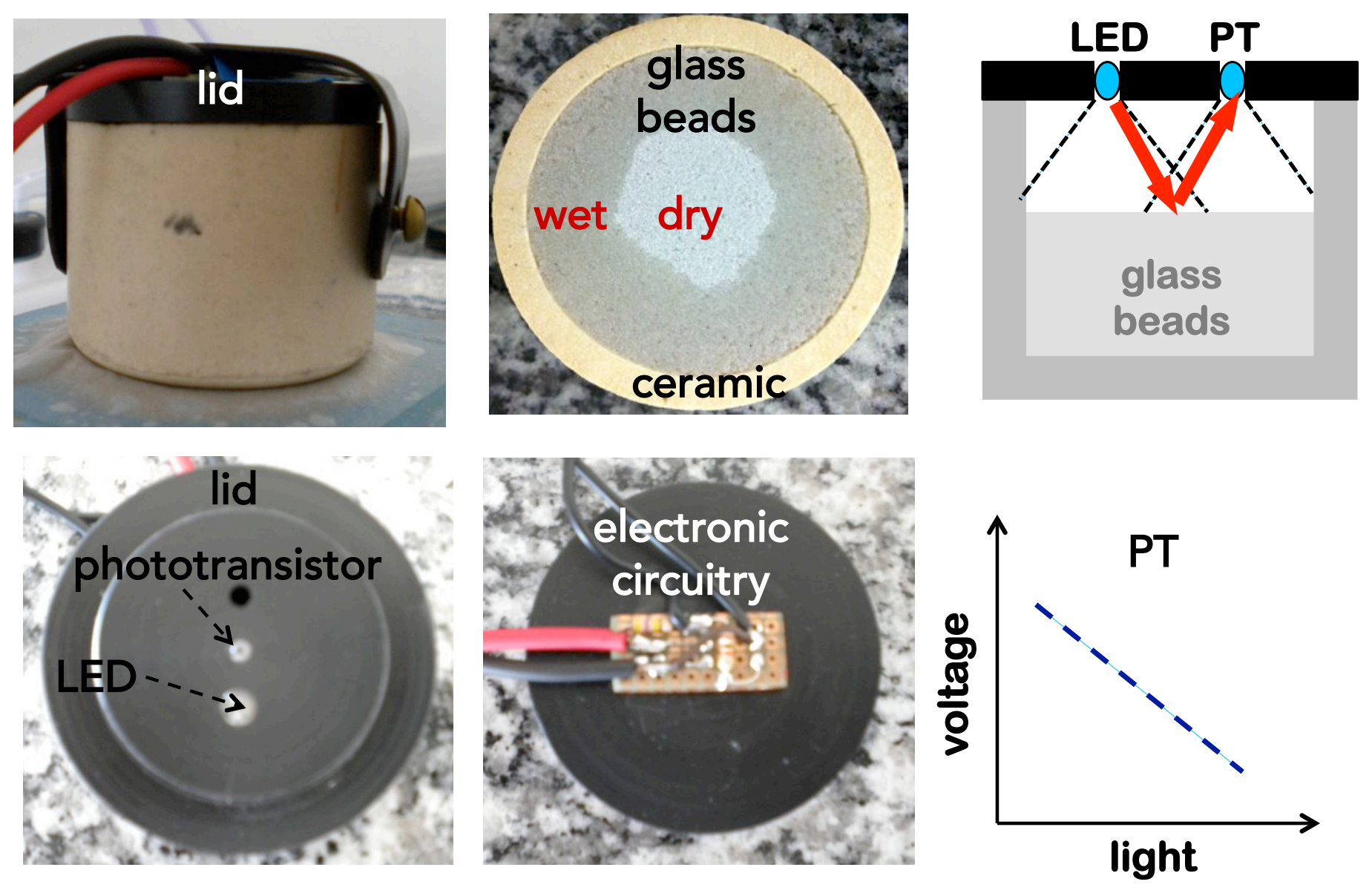


Figure 4. IGstat sensor working in the light reflection mode. PT: phototransistor light detector.

IGstat sensor evaluation

- The IGstat prototype (Fig. 4) uses a white light emissor, that is reflected by the GB surface and captured by the PT light detector. The PT output voltage is approximately linear with the reflected light intensity. IGstat sensors with different GB diameters were evaluated using the experimental setup shown in Fig 2.
- As water suction increases (medium dries) the IGstat output voltage increases (less reflected light reaching the PT) for corase GB (100-250 μm) and decreases (more reflected light reaching the PT) for fine GB (10-100 mm) (Fig. 5). This behavior results from a complex interation of light with GB and water, which includes external and internal reflection, refractive indexes (Grosges, 2008), GB diameter and water film thickness.
- Although not linear, the characteristic relationship between water tension and voltage can be used for irrigation (critical values) and possibly for continuous soil water tension determination using the linear range of the "S-shape" characterist curve obtained.
- The water tension in the inflection point and the linear range of the S-shape curve increased as GB diameters decreases, showing interesting potential for soil water tension sensor developments.

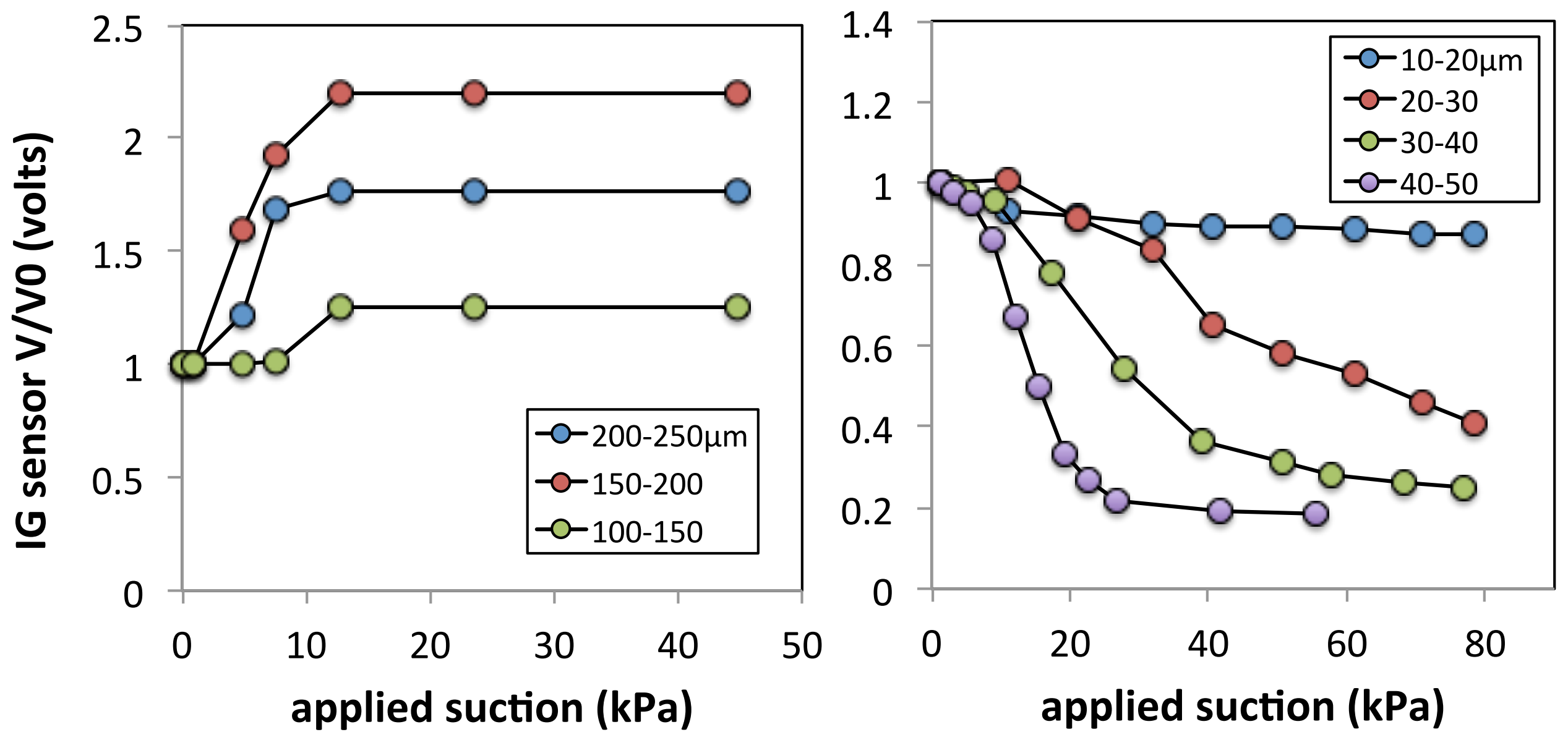


Figure 5. IGstat sensor output voltage as a function of the applied suction (water tension) for different GB diameters.

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