Academic Journal of Physics Research

Juniper Publishers
key to the Researchers

Review Article
Volume 1 Issue 1 - March 2025

Academic Journal of Physics Research

Physical Pressures *Vs* Biological Pressures by Using Plant Cell as an Intrinsic Model

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Submission: January 04, 2025; **Published:** March 11, 2025

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Abstract

This review discusses the relation between physical pressures represented at atmosphere, gravity and tension against biological pressures as osmosis and hydraulic conductivity by using plant cell structure as a model. There is a mutual effect between them with different laws and equations. Positive and negative values are present according to the direction and magnitude of forces. This review emphasizes on the necessity of study any real or virtual system on basis of abiotic and biotic factors.

Keywords: Atmosphere; Gravity; Tension; Osmosis; Hydraulic conductivity

Root Pressure

It is pressure exerted by root plant cells downwards through soil particles as a positive pressure against the gravity and at the inverse, the water content moves upwards through xylem cells. This pressure is generated as a chemical potential presented in water solution.

Factors affecting on root pressure

There are different factors influenced on root pressure and represent the main forces in water movement:

Osmotic Pressure (π)

It is the pressure that is arisen from transfer the water from low conc. solution to high conc. solution through semi-permeable membranes. It can be written as a law that is called **Van't Hoff's Law** as following: [1]

$$\pi = i \cdot C \cdot R \cdot T$$

Where:

- π = Osmotic pressure (atmospheres, atm)

- i = Ionization constant (number of ionic particles dissociated in the solute dissociates)

- C = Concentration of the solute (mol/L)

- R = Ideal gas constant (0.0821 L·atm/(mol·K))

- T = Temperature in Kelvin (K)

This equation is used for ideal conditions as there is not any interruption pressure between two standard solutions. Really, water flow through plasma membrane (semi-permeable membrane) inside the plant cell interfaces with another pressure that maintain the rigidity of plant cell. It is reverse pressure that exerted from cell wall to inhibit more water flow in. This reversed pressure is called turgor pressure [2]. Osmotic Pressure in the plant's roots is responsible for water uptake from the soil by drawing water into the plant through osmosis. Osmotic pressure is determined by the concentration of solutes in the plant cells and helps maintain water balance in the plant.

Atmospheric pressure and osmotic pressure are indirectly related in that they both influence the overall water balance in the plant, but they do so through different mechanisms. Atmospheric pressure affects the rate of water loss, while osmotic pressure affects the rate of water uptake. Atmospheric pressure influences water movement out of the plant (through transpiration), while osmotic pressure primarily influences water movement into the plant (from the soil). Both pressures work together to maintain the plant's water balance, but they operate through different processes. Reduction of pressure reduces the unavoidable losses of gases by leakage and also can reduce the weight of structures necessary to maintain growing units in whole plant. In instance, increments in the rate of transpiration or photosynthesis are explained by reduction of coefficient diffusion of gases. The model shows the relation between pressure and plant volume at constant weight based on leakage of O_2 and N_2 gases (Figure 1). From previous studies, If the total pressure decreases 80%, oxygen and nitrogen level more than 80%, weight of shoots increases with more than 21%, roots more than 41%, total more than 26%. [3].

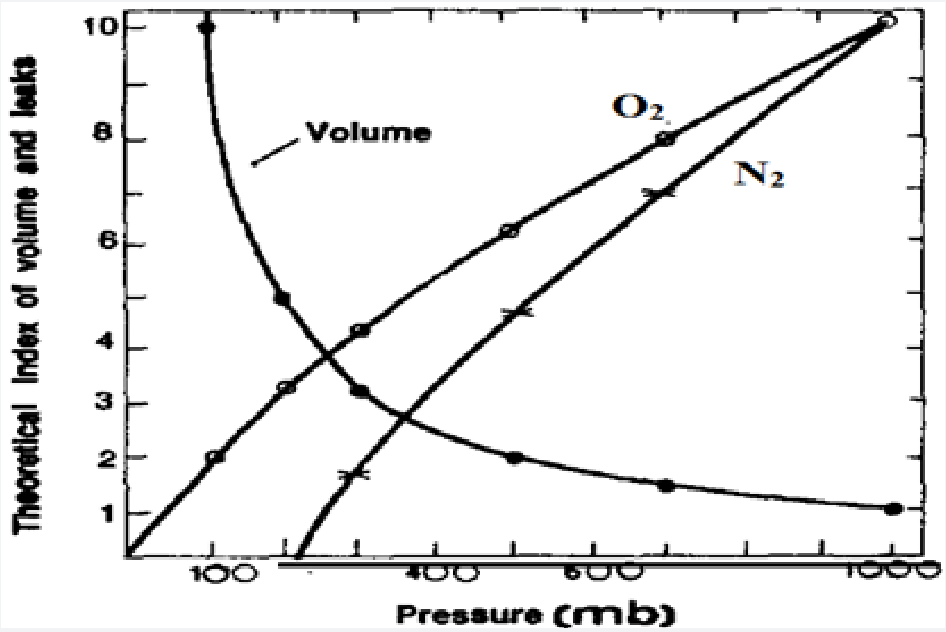

Figure 1: Diagram represents the relation between pressure and plant volume in presence of leakage gases

- **For non-ideal solutions (Water Potential)**

Water is the main substance induces pressure inside the plant. The degree of pressure depends on the concentrations of chemical ions dissolved or colloidal in it. The term chemical potential refers to the energy exerted due to chemical constituents within the solute. It is difficult with regular methods to calculate it so the difference between standard potential water (pure water, μ_ω^*) and water in cell sap (μ_ω) divided by the partial molal volume of water ($\bar{v}_\omega$ m^3 $mole^{-1}$):

can be compensated the difficulty in chemical potential calculation to be water potential (Ψ_w): [4]

$$\Psi_\omega = \frac{\mu_\omega - \mu_\omega^*}{\bar{v}_\omega}$$

Actually, water potential included other component potentials that influenced on all water pressure. So, water potential can be determined by another equation:

$$\Psi_w = \Psi_\pi + \Psi_p + \Psi_g$$

Where, Ψ_π = osmotic or solute potential, Ψ_p = turgor or pressure potential, and Ψ_g = gravitational potential.

The gravitational component potential is regarded as a physical parameter that link between physical and biological inducers where the gravitational component potential varies with variation of biological parameter as plant height by 0.1 MPa for each 10 m increment displacement upwards. Hence, there is a concept combine between physical and biological pressures in one model like a plant cells that is called the Soil-Plant-Atmosphere Continuum (SPAC). It emphasizes on mass flow of water within a conducted system like electricity and can be represented by the following equation: [5]

$$Flow = \frac{\text{difference in } \Psi_w}{\text{resistance}}$$

resistance Where, movement of water within plant through semi-permeable membranes as plasma membranes in different forms as from cell to cell, ascent of saps, evaporation in the form of water vapors from plant openings like stomata causes random motion of molecules for water solution forming own kinetic energy at the process called diffusion. The resistance faces water flow represented at plant cell wall, moving upwards against gravity, exposed to outside through openings against atmospheric pressure [6]. This water circuit resembles flow of electricity in closed circuit that can be appeared at (Figure 2).

How to cite this article: A El-Shabasy, Mohammad S. Physical Pressures Vs Biological Pressures by Using Plant Cell as an Intrinsic Model. Academic Journal of Physics Research. 2025; 1(2): 555558.

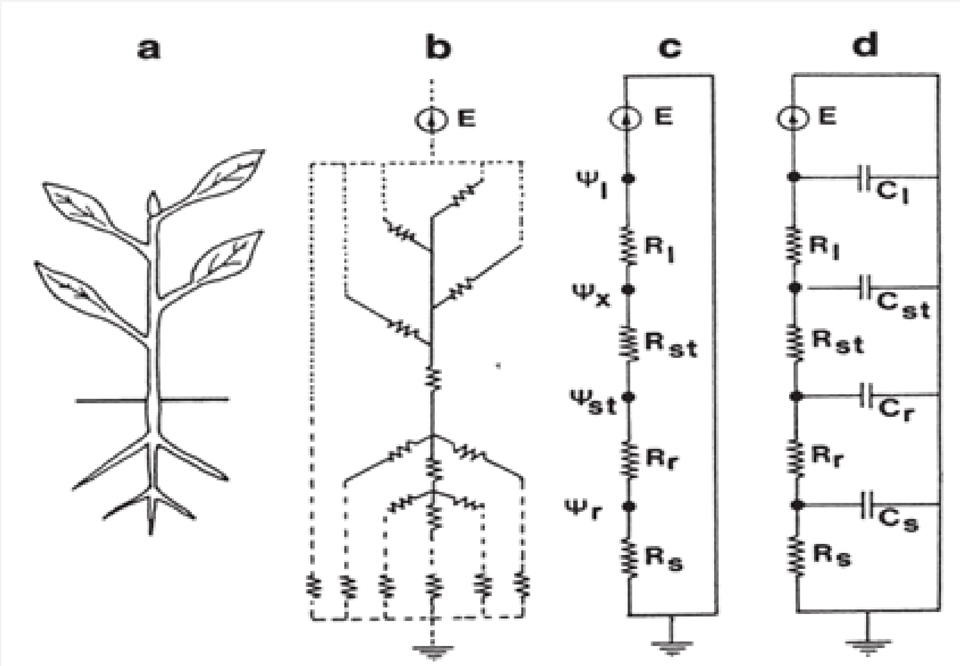

Figure 2: Scheme represents the Soil-Plant-Atmosphere Continuum (SPAC) like electrical circuit, a; the whole plant, b; the vascular system like electrical circuit, c&d; imaginary electrical circuit inside plant as : power, l: leaf, x: xylem, st: stem, r: root, s: soil, R: resistance, C: conductivity.

Hydrostatic Pressure (P)

It is the pressure generated through water flow within vascular bundles containing xylem (moving water upwards). So, root pressure can be calculated with accordance to resistance coming from physical pressures as following:

P_root = π _root - P_resistance

Where:

- P_root = Root pressure (in pascals, Pa, or atmospheres, atm)

- π _root = Osmotic pressure in the root (calculated above)

- P_resistance = Resistance pressure from the plant's vascular system (e.g., friction and gravity) [7].

Hydraulic Conductivity (K)

The rate of water movement from the roots to the xylem is influenced by **the hydraulic conductivity** of the plant's vascular tissues. This is the efficiency with which water moves through the plant's xylem. Hydraulic conductivity (K) can be calculated as:

J_v = K ·Δ P

Where:

- J_v = Water flux (volume of water per unit time, e.g., L/s)

- K = Hydraulic conductivity (in units of L·s^-1·atm^-1·m^-2)

- Δ P = Pressure gradient (in atm or Pa) between the roots and the xylem

Atmospheric Pressure vs Osmotic Pressure

Although atmospheric pressure and osmotic pressure act through different phenomenons, they can influence each other directly and indirectly on water movements as following:

Transpiration and Osmotic Pressure

Transpiration creates a negative pressure (tension) in the plant's xylem that is partly counteracted by the osmotic pressure as evaporation from plant opening on leaves called stomata.

As transpiration increases (due to low atmospheric pressure or dry conditions), the plant may experience a greater pull-on water from the roots, increasing the movement of water through the plant. The osmotic pressure in the roots helps ensure that water can continue to enter the plant to replenish what is lost through transpiration [8].

Water Uptake and Atmospheric Pressure

If the atmospheric pressure is high and transpiration is low (e.g., on a cool or humid day), osmotic pressure will still continue to draw water into the plant, but the rate of water loss through transpiration will be slow, while during dry conditions with low atmospheric pressure (high transpiration rates), the plant will lose more water, and the osmotic pressure in the roots will continue to draw in water to compensate for the loss.

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The Effect of Atmospheric Pressure on Guttation

Guttation is the process where water is exuded from the tips of leaves at special openings called hydathodes, evaporating water as droplets often seen in plants at night. It occurs due to root pressure, which is generated by osmotic pressure in the roots [9]. Atmospheric pressure may indirectly affect guttation. For example, when atmospheric pressure is high and transpiration is low (e.g., at night), root pressure can push excess water out through the leaf tips. In this case, the atmospheric pressure does not directly interact with osmotic pressure but affects the overall water balance in the plant.

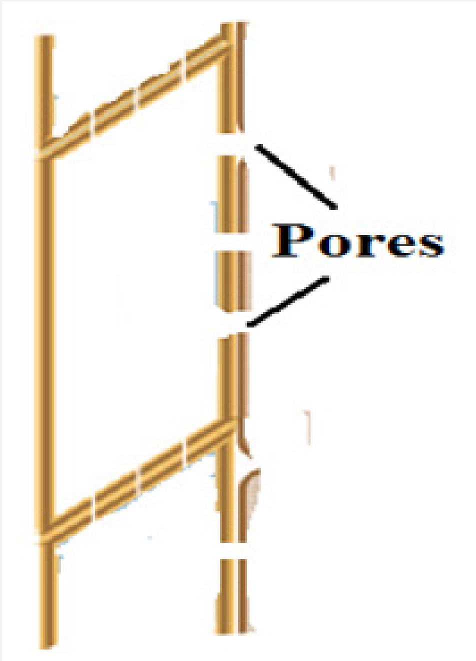

Figure 3: Pores appeared at vessel and tracheids

Air Embolism and Xylem Blockage

It is rupture of water column in xylem due to invading air gases through pores represented naturally on xylem or induced by excessive transpiration, drought and winter freezing. Air is aspirated into vessels or tracheids that disturbed the atmospheric pressure and arises another physical pressure is called water tension where it exerts negative pressure collecting adjacent water molecules together against other physical pressures like atmospheric and gravitational pressure [10]. The major effect of tension appears on pores between vascular bundles as surface tension arises. Hydraulic conductivity can be reduced by increasing external gas pressure on xylem segments under tension, thereby presumably increasing the pressure difference across pores (Figure 3).

Conclusion

The present review focus on the importance of studying abiotic (represented at chemical and physical parameters) factors correlated with biotic factors (represented at plant, animal or microorganism) to obtain the real picture for any studied system. Physical pressures have a large effect on biological pressures internally and externally like a plant cell model. If one wants to collect the optimized results from any living organisms, abiotic factors (chemical and physical parameters) should be obeyed to standard and optimum levels

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