Using Pressure-Volume Analysis to Determine the Effect of the Hydrostatic Gradient on Cell Turgidity

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Abstract. The physiological effects of the force of gravity on the water column of different aged and sized trees were examined. Pressure-volume techniques were utilized in order to distinguish and study the component potentials of the various tree samples. Evidence of osmotic regulation among the older trees was found. Further research is required to ascertain how such regulation relates to growth mechanisms and carbon assimilation.

Introduction

Availability of water is an important factor affecting terrestial plant production on a global scale. Water is essential for maintenance of turgidity of cells and tissues and thus plays a crucial role in the processes involved in growth, such as cell enlargement and stomatal regulation.

The driving force behind water movement is a water potential gradient. Water potential is proportional to chemical potential, which is related to the free energy of a system and refers to the capacity of a system to do work. Water moves along gradients of decreasing free energy--from higher to lower water potential.

Water potential (Ψ_w) can be defined as the sum of the following components:

$$\Psi_w = \Psi_p + \Psi_s + \Psi_g$$

Ψ_p = Pressure or Turgor Potential

Ψ_s = Osmotic or Solute Potential

Ψ_g = Gravitational Potential

The osmotic component is due to dissolved solutes and the lowered activity of water near charged surfaces.

Pressure potential arises from xylem tension (negative pressure) or the positive pressure found inside living cells as water presses against the cell walls.

Gravitational potential varies with height at a rate of 0.1 MPa per ten meters.

This project is part of a larger overall study of age-related changes in trees. One of the goals is to determine what role hydraulic limitation plays in growth and aging mechanisms. More specifically, in this study, we investigate whether the hydrostatic gradient (the effect of gravity on the water column) causes differences in cell turgor in different canopy positions and in trees of different heights.

Experimental Methods

The Wind River Canopy Crane (Figures 1 and 2) in southern Washington provides access to trees more than 60 meters tall at almost all canopy levels . It is thus an ideal place to study height-related differences in trees.

Our study involved two different-aged stands in the Wind River Experimental Forest. The older stand (450 years old) is located in the 70m radius crane circle. We extracted samples from five trees in this stand at three different heights (bottom, middle, and top) for each tree. We also gathered samples from the tops of five trees in the younger stand (24 years old).

Xylem water potentials were measured using a pressure chamber (Figure 3). We assumed that water equilibration had been achieved (i.e. that no water potential gradient existed within the sample) as the twigs were collected pre-dawn. We could therefore also assume that the water potential in the xylem was the same as the water potential of all the tissue in the chamber.

In other words, the balancing pressure is approximately equal to the tissue water potential in the sample. Given these total water potentials, how do we determine the effect of gravity on the cells at different heights? Pressure-volume analysis helps us examine the component effects.

In order to obtain a pressure-volume (P-V) curve (Fig. 4), we repeat the pressure chamber measurement, periodically measuring the balancing pressure and the mass of the sample, while allowing the sample to dry in the air. We ultimately arrive at a P-V curve, which is the reciprocal of the balancing air pressure versus the relative water deficit (RWD). Because P-V curves can be used to estimate symplastic and apoplastic water volume, osmotic potential, pressure potential, the point of incipient plasmolysis, and the volumetric elastic modulus, they have played a prominent role in the study of plant water relations.

We used P-V curves to estimate osmotic potentials at full and zero turgor and pre-dawn and mid-day turgor (Figures 5-8). Mid-day water potentials were estimated at
-2.6 MPa for old trees and -2.1 MPa for young trees using previous years' data.

Fig. 1. The canopy crane provides unique access to levels of the canopy that had previously been out of reach.

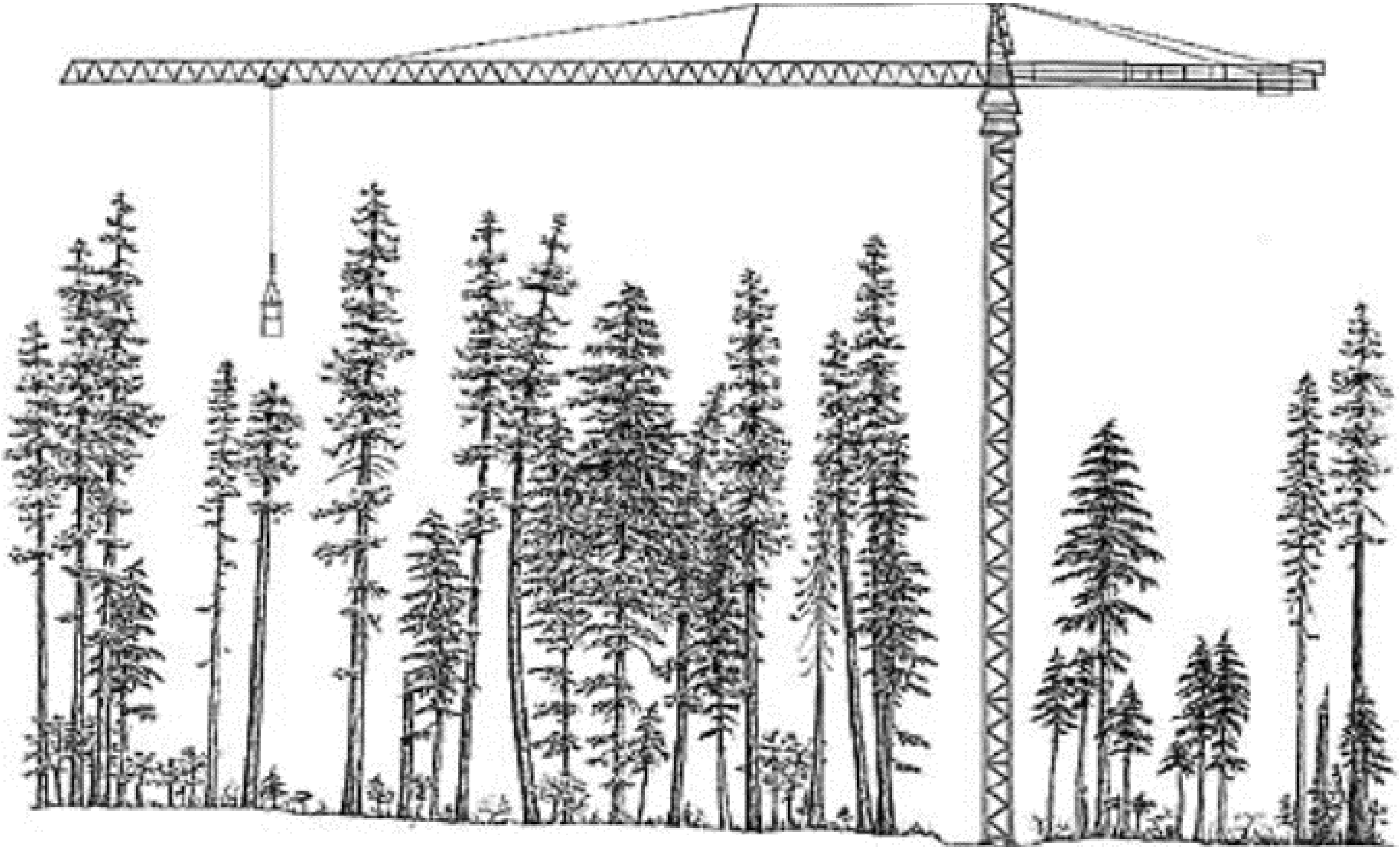


Fig. 2. Measuring Ψ_w at the top of the canopy.

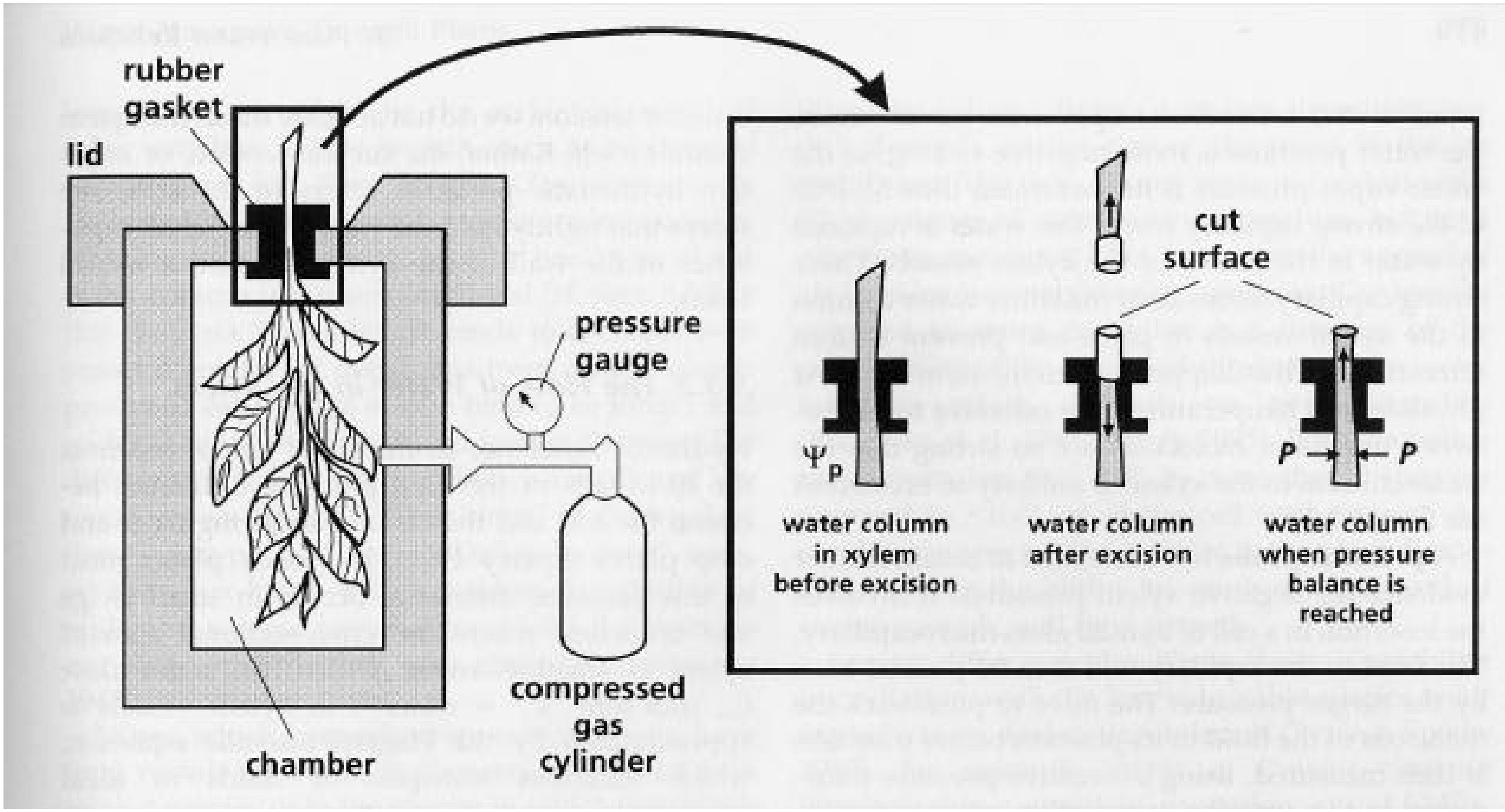


Fig. 3. The pressure chamber (or pressure bomb) measures negative hydrostatic pressure in xylem (averaged over the material placed in the chamber). A severed part of a plant is placed in a sealed chamber, with the freshly cut end protruding from the gasket. Positive pressure is applied to the sample, until xylem fluid just appears at the surface of the cut end. At this point, the positive pressure (balancing pressure) equals the negative water potential in the xylem. If Ψ_s can be ignored, then the pressure in the xylem is approximately equal to xylem water potential.

Fig. 4. Example of a pressure-volume curve (Tree 2120low) illustrating the relationship between $1/\Psi_w$ and relative water deficit (RWD).

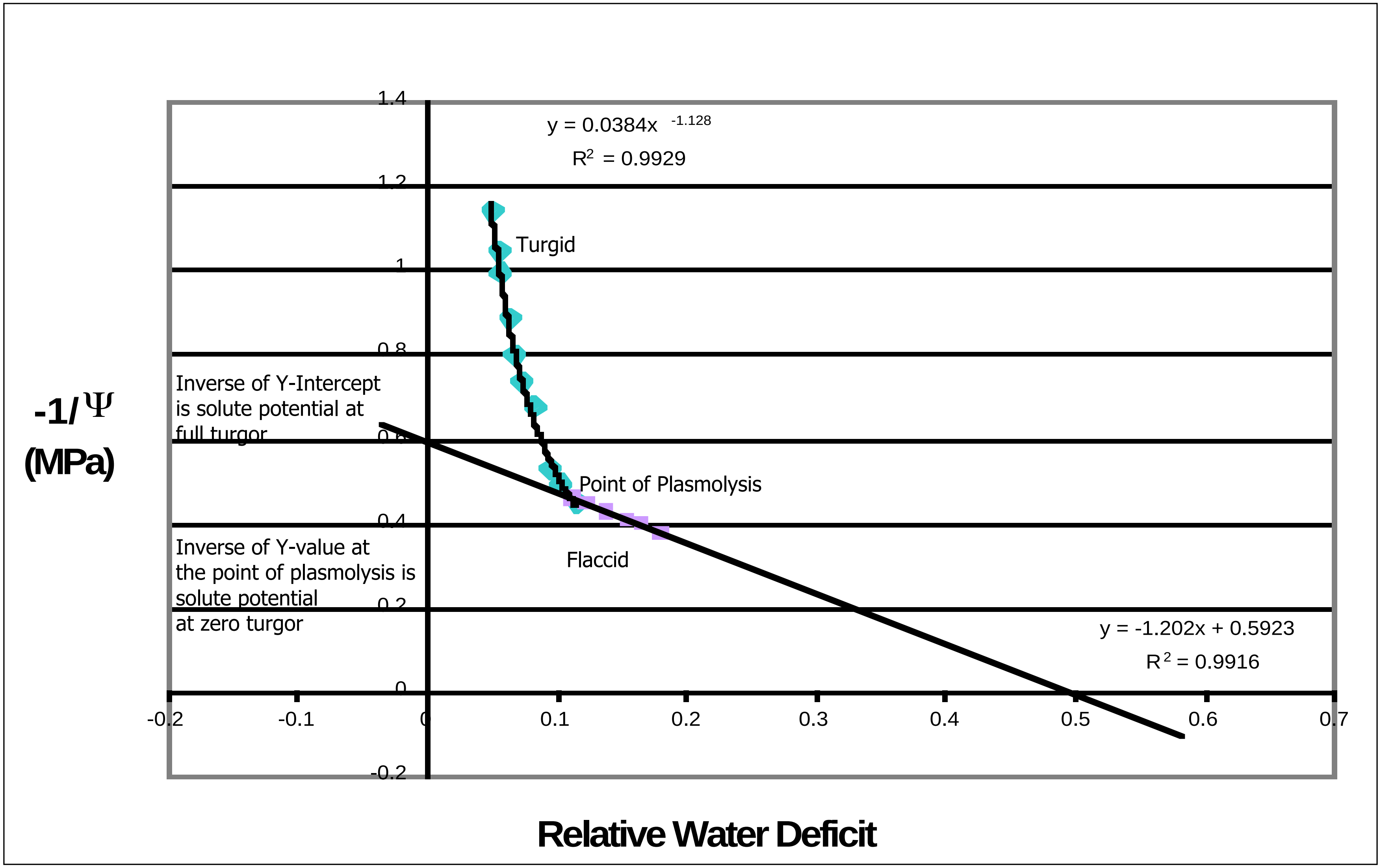


Fig. 5. Osmotic Potential (MPa)
Full Turgor

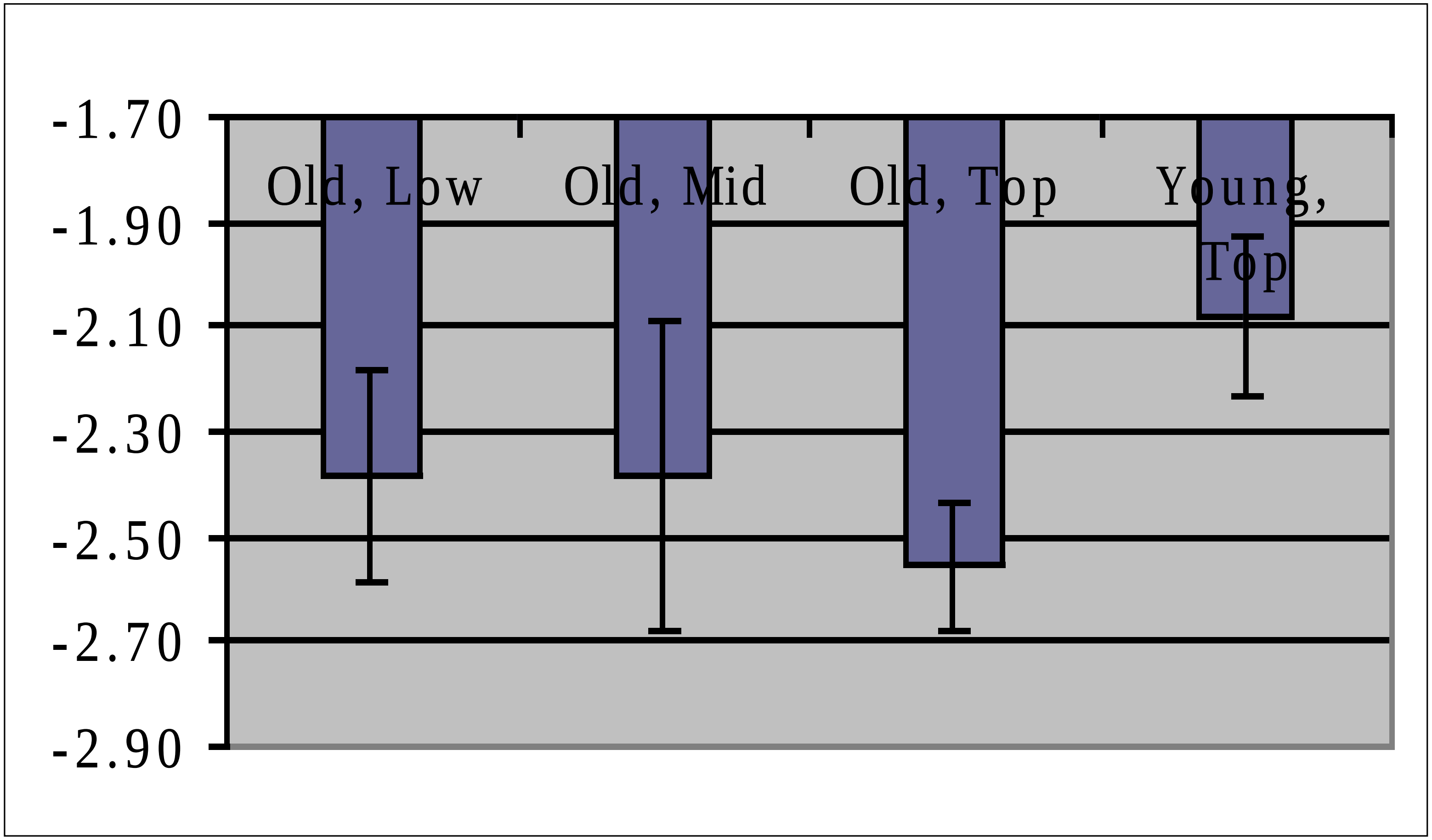


Fig. 6. Osmotic Potential (MPa) Zero Turgor

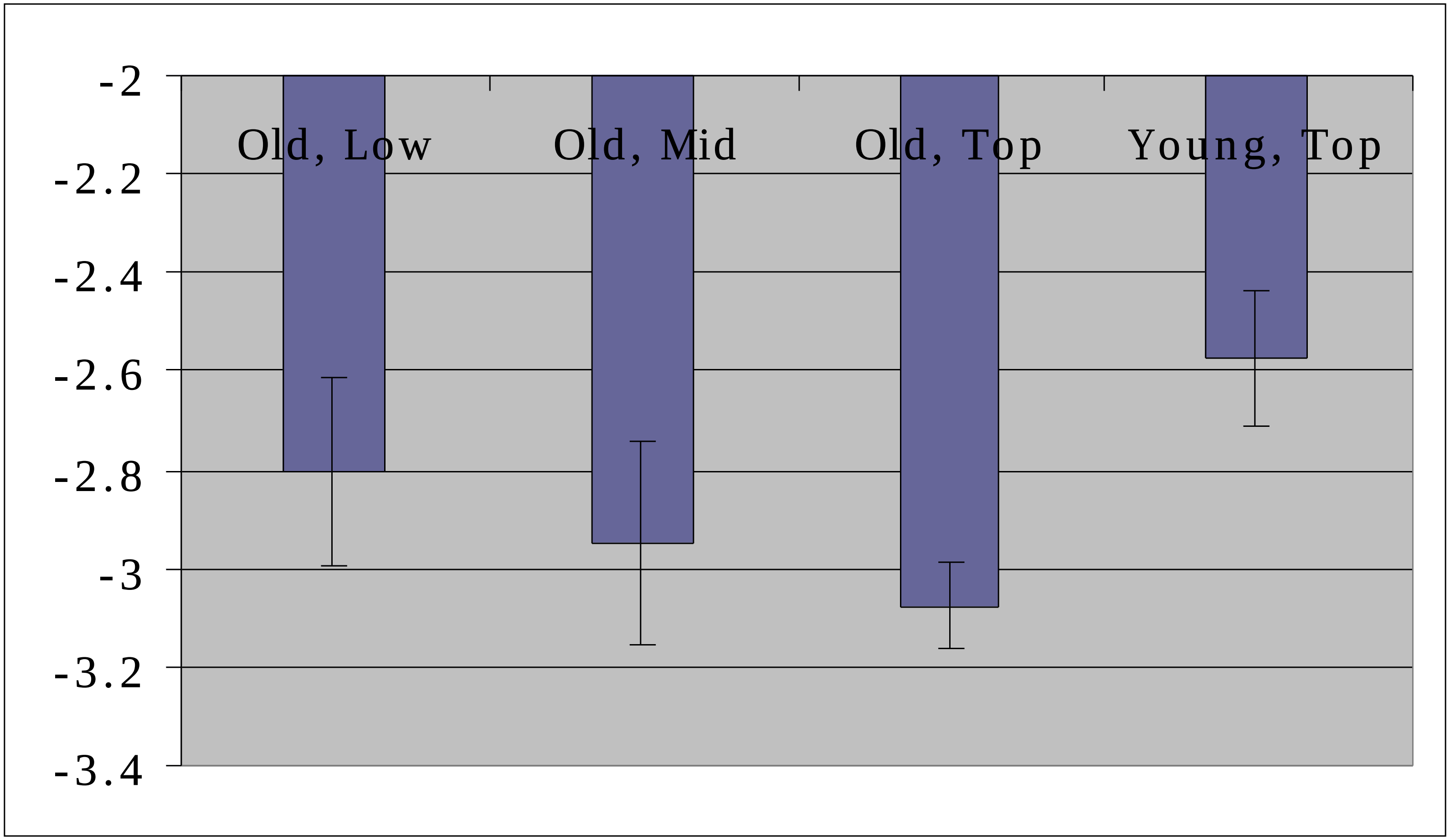


Fig. 7. Pre-dawn Turgor (MPa)

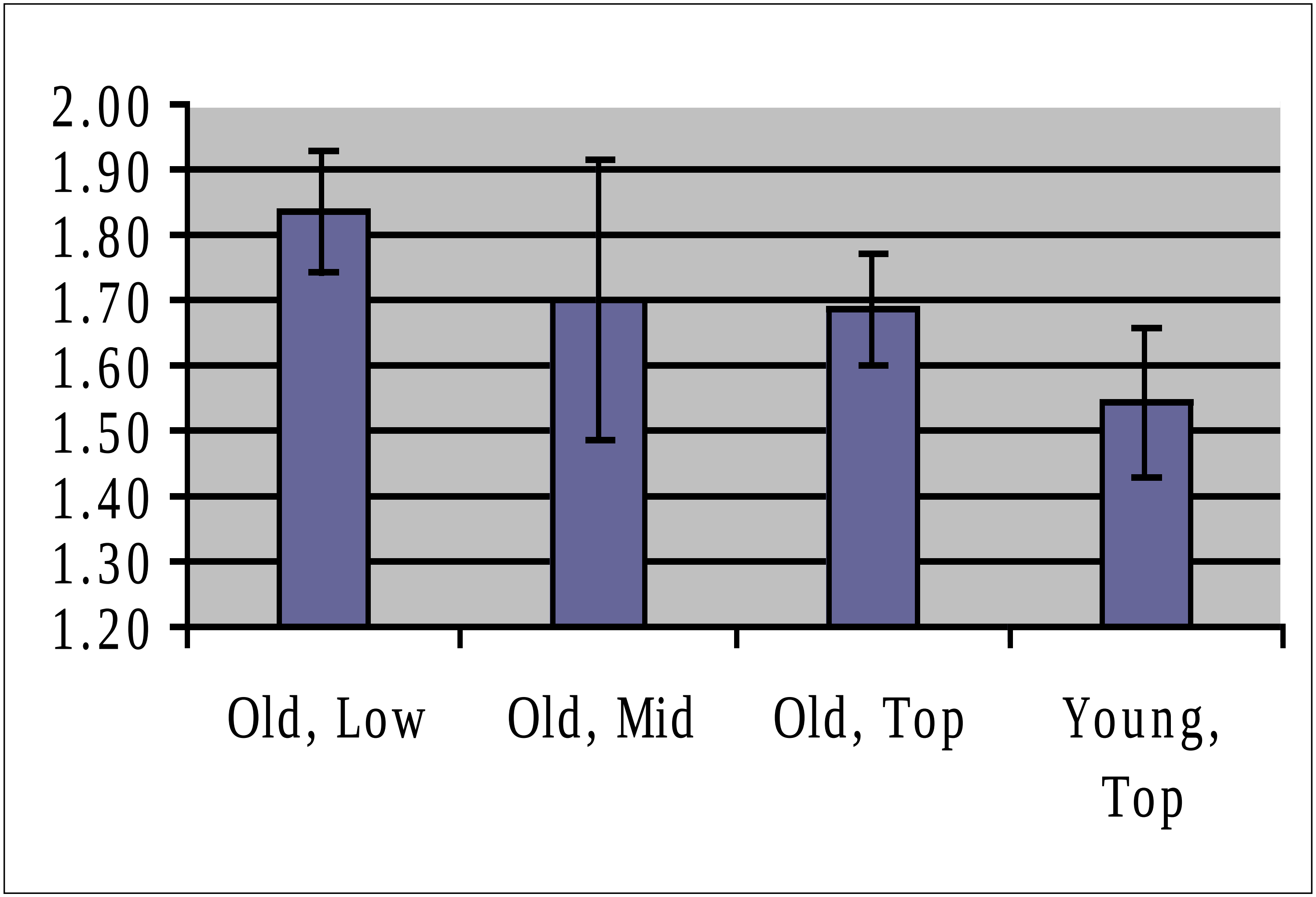
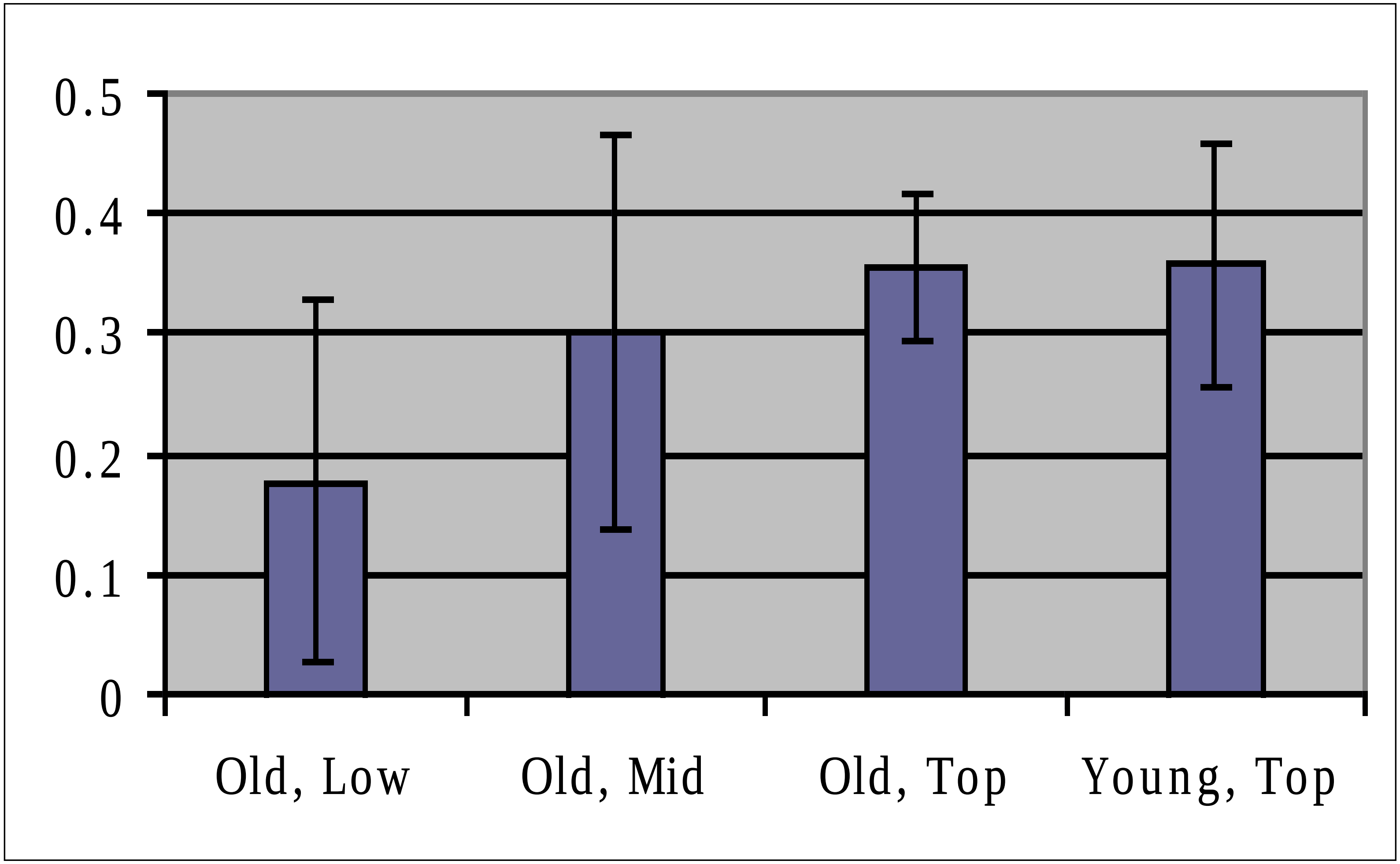


Fig. 8. Mid-day Turgor (MPa)



Results and Implications

After evaluating the osmotic potentials at various canopy positions (Figures 5 and 6), it seems that the older (and taller) trees are osmotically regulating themselves in order to maintain turgor. That is, the cells appear to be adjusting their water status by accumulating osmotically active compounds, which reduces Ψ_s (makes it more negative) and therefore helps to maintain turgor. In fact, it seems that they are more than compensating for the effect of gravity, as evidenced by the higher pre-dawn turgor (Fig. 7) in the old trees as compared to the young. Further research will examine how cell physiology is affected due to the increased concentration of solutes. Grafting studies will be conducted to investigate whether genetic changes

Other results, such as how the pre-dawn and mid-day turgors (Figures 7 and 8) relate to growth, show some trends but the meaning behind the trends is uncertain as of yet (especially given the large standard errors). The experiment will be replicated this month and the results of both experiments will be compared to each other and contrasted with data taken last spring.

As mentioned previously, this study is part of a broader examination of water relations in general. The results from these cell water relations studies will ultimately be compared to investigations at the tree level (e.g., sap flow measurements), at the stand level (e.g., soil moisture measurements), at the ecosystem level, and globally.

If size and age related differences do exist, it will be interesting to ascertain how (and if) the differences relate to carbon sequestration by forests of varying ages. If old trees grow less (because of stomatal regulation caused by water potential gradients), they will need less carbon for biomass and therefore won’t fix as much. It seems clear that age and size related differences should be considered when modeling carbon dynamics in mixed-age forests.

References

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