Ecophysiological processes underlying soybean mineral nutrition under individual or combined heat and water stresses

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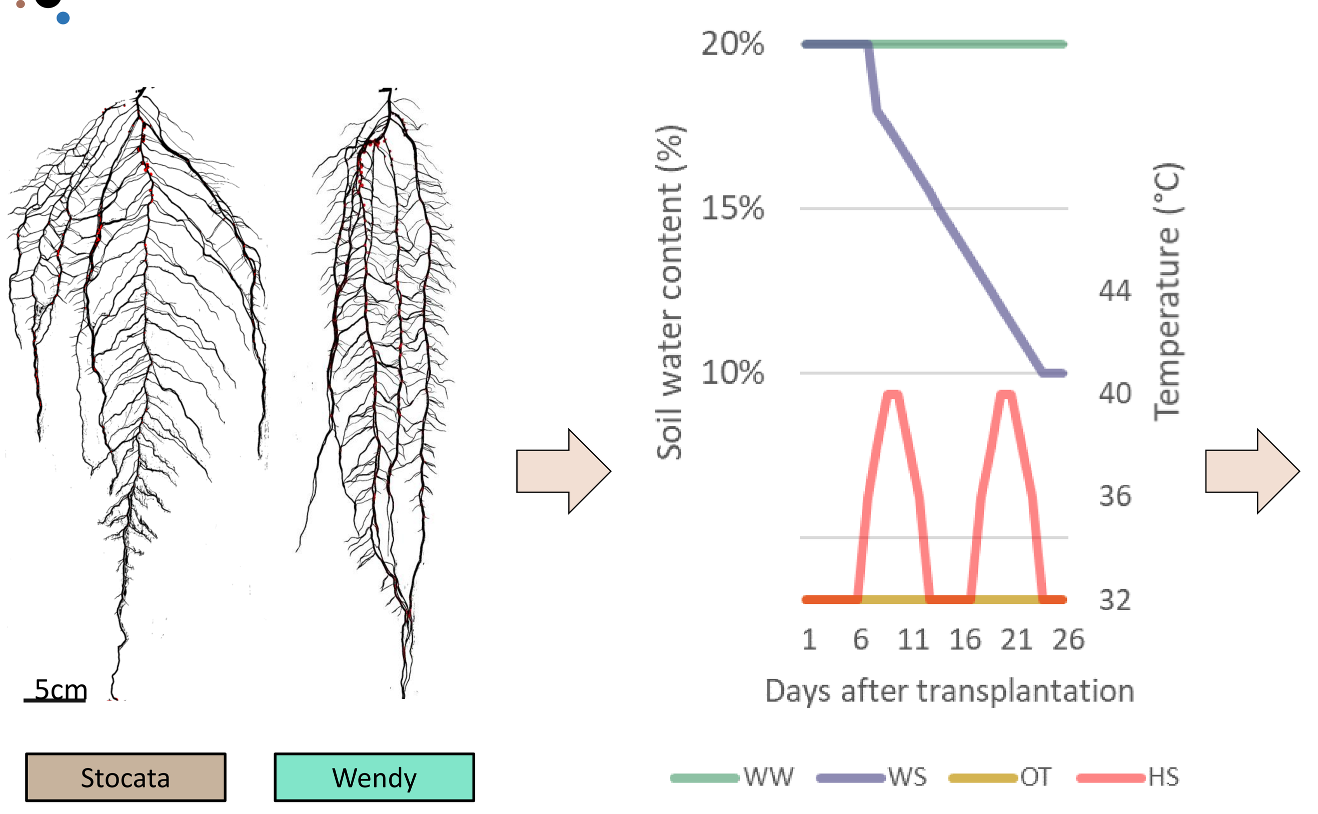
Introduction

In the context of climate change, characterized by more frequent water stress events and heatwaves, it is predicted that soybean yields will drastically decrease in the near future. Because soybean is the most widely grown legume crop in the world, there is an urgent need to improve its ability to sustain its growth under such conditions in order to guarantee high levels of productivity.

The hydro-mineral nutrition of the plant depends both on its morphological modifications during stresses, but also on its capacity to take up mineral elements. This nutrition can also be affected by the architecture of the root system which influences the direct interactions with the soil and with microorganisms.

Our approach consisted in the comparison of two contrasting genotypes for their root architecture in order to identify the strategies promoting soybean growth under these two stresses and offered new perspectives for crop adaptation to climate change.

1. Experimental design



Two genotypes : Use of two soybean genotypes with contrasted architecture[1]

4 climatic conditions : Well Watering (WW) ; Water stress (WS) Optimal temperature (OT) ; Heat Stress (HS)

At the end of the experiment, (26 days), plants were characterized for :

Root architecture and morphology
- Width (cm), depth (cm), projected root surface area (cm²),…etc.

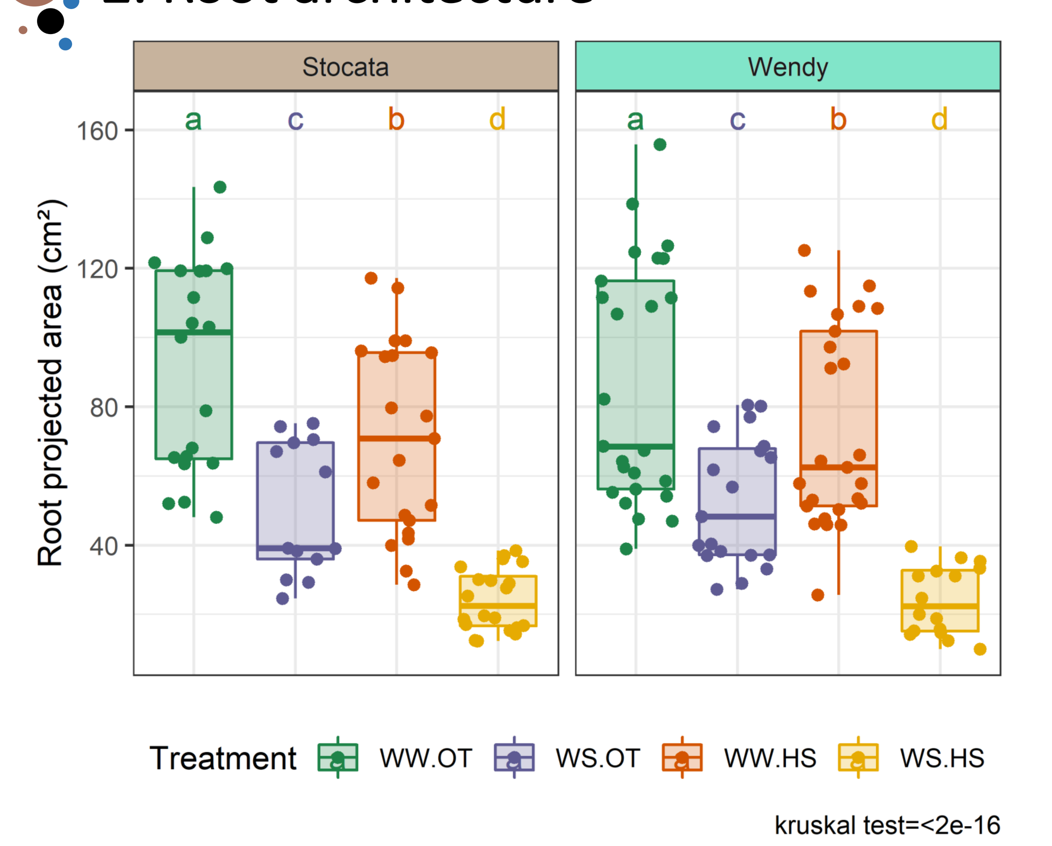
Water-related variables
- Water Use Efficiency ($g.gH_2O^{-1}$);
- Specific Root Water Uptake ($gH_2O[gBM_{root}day^{-1}]^{-1}$)
- Evapotranspiration ($mm.h^{-1}$)

Carbon related variables
- Biomass (mg)
- Leaf area (cm²)
- Photosynthesis ($\mu mol\ CO_2.m^{-2}.s^{-1}$)
- Stomatal conductance ($mol\ CO_2.m^{-2}.s^{-1}$)
- Radiation Use Efficiency ($g.cm^{-2}.Days^{-1}$)
- Leaf Water potential (MPa)

Mineral related variables
- Element Use Efficiency ($g.g_{Element}^{-1}$)
- specific Element Uptake Efficiency ($g_{Element}.gBM_{root}^{-1}.day^{-1}$)

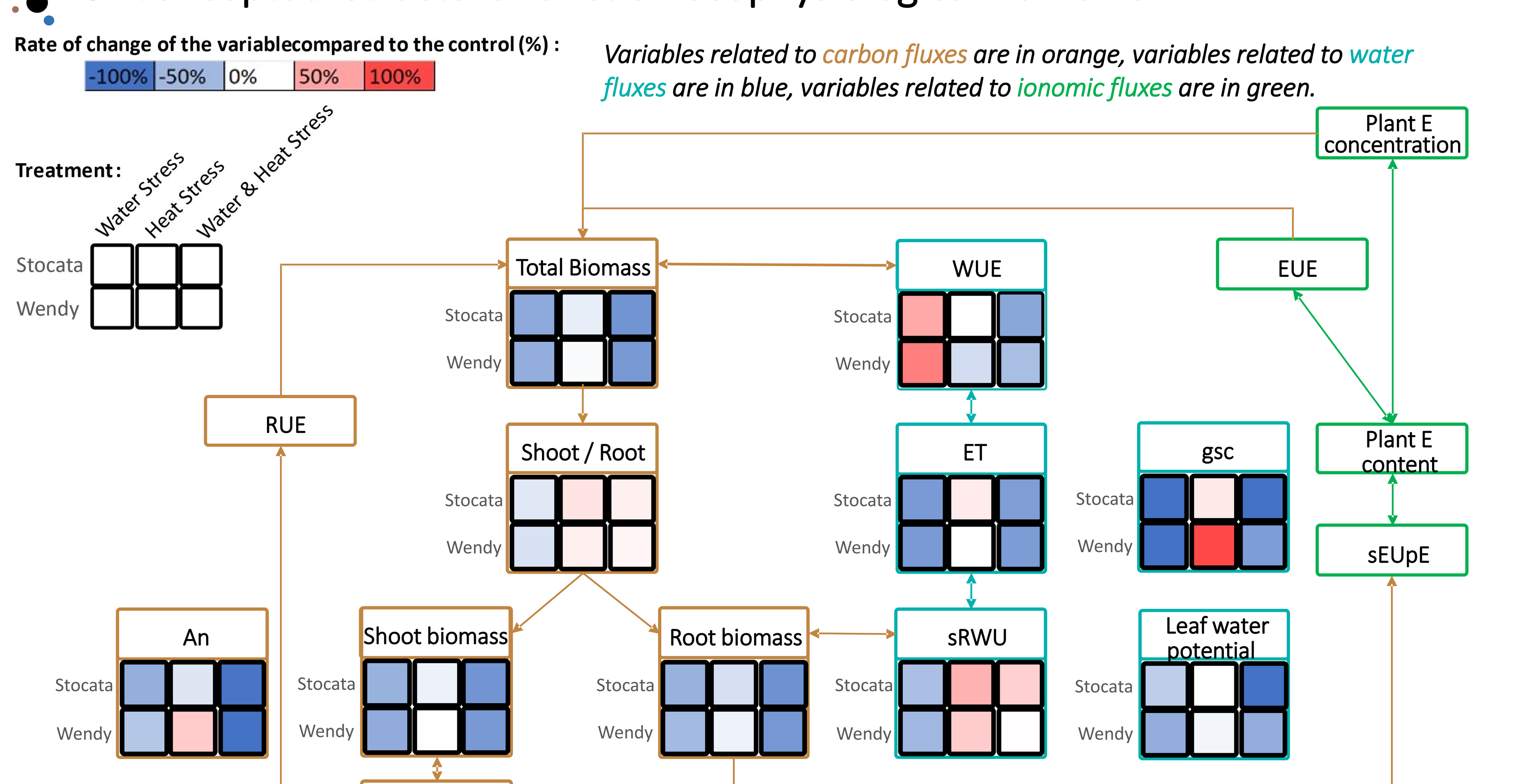
RhizoTube® [2]

2. Root architecture



Whatever the genotype, the root area in contact with the soil remained unchanged after a heat stress, decreased after a water stress, and was extremely decreased after combined water and heat stresses. What are the consequences on the uptake of mineral elements ?

3. Conceptual structure-function ecophysiological framework

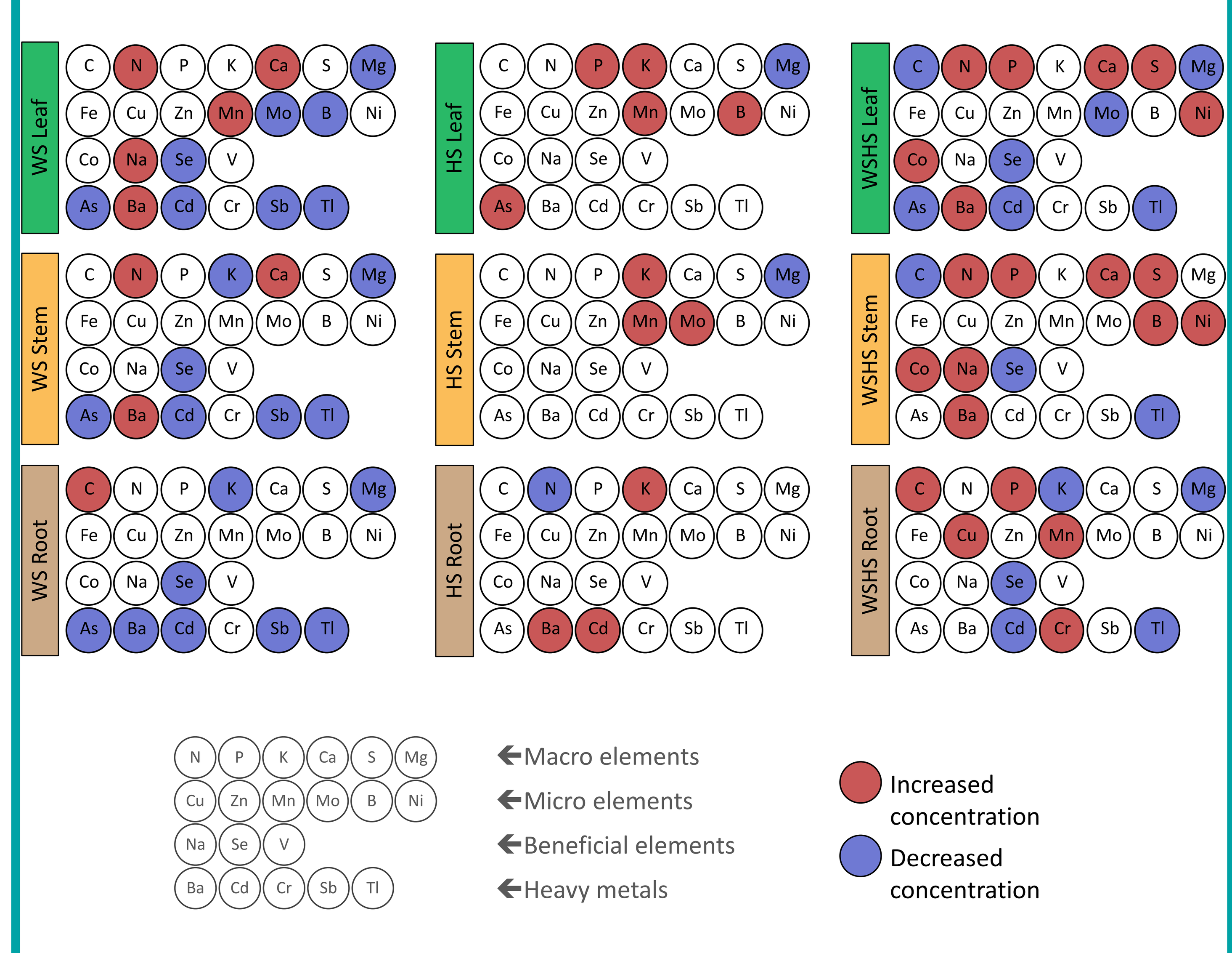


Biomass (mg) ; An : Photosynthesis ($\mu mol\ CO_2.m^{-2}.s^{-1}$) ; gsc : Stomatal conductance ($mol.H_2O.m^{-2}.s^{-1}$) ; WUE: Water Use Efficiency ($g.gH_2O^{-1}$); sRWU: specific Root Water Uptake ($gH_2O[gBM_{root}day^{-1}]^{-1}$); ET : Evapotranspiration ($mm.h^{-1}$) ; EUE: Element Use Efficiency ($g.g_{Element}^{-1}$); sEUpE : specific Element Uptake Efficiency ($g_{Element}.gBM_{root}^{-1}.day^{-1}$) ; RUE: Radiation Use Efficiency ($g.cm^{-2}.day^{-1}$) ; Leaf Area (cm²) ; Water potential (Mpa)

Whatever the genotype, heat stress slightly modified water and carbon fluxes within the plant, compared to the water stress and combined water and heat stresses that drastically impacted plant functioning.

Moreover, for the same amount of root biomass, under heat stress and combined with water stress, the Stocata genotype tended to lose more water by evapotranspiration than Wendy (ET, gsc). This could explain the increased sensitivity to combined stresses as well as the increased water potential in Stocata compared to Wendy under heat and water stresses.

4. Plant mineral concentration in both genotypes



Compared to the control, heat stress had less impact on the change in elemental concentration than water or combined stress. These changes were also greater in aerial parts than in roots.

Under water stress conditions, the availability of potassium (K) from the soil to plants is reduced, which limits its uptake by roots and ultimately affects its translocation between roots and shoots[3], which could explain the low concentration in roots and stem under water stress. The effect is probably the opposite under WWHS conditions as observed in all three organs.

Stomatal opening is partly regulated by calcium concentration in leaves, which is controlled by abscisic acid. This would probably explain why calcium to increase in leaves grown under water stress (WS.OT; WS.HS)[4 ; 5]

Conclusion

We observed more severe deterioration in Stocata genotype than in Wendy under combined conditions. This does not seem to be due to morphological characteristics (leaf surface, root architecture, etc.) but rather to functional differences, especially with regard to water uptake. Regarding the mineral nutrition of the plants under the different stresses, the preliminary results are in line with the results found in other species. This certainly suggests the crucial role of K and Ca availability in the soil in the resistance of soybean to future climatic conditions.

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