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Field heterogeneity of soil texture controls leaf water potential spatial distribution predicted from UAS-based vegetation indices in non-irrigated vineyards

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Supplementary tables

Table S1 – List of vegetation indices (VIs), spectral bands and structural features used in this study to predict Ψ_{leaf}.

Vegetation index (VI), band or structural feature	**Full name**	**Formula**
Red	Red band	-
Green	Green band	-
Blue	Blue band	-
RedEdge	Red-edge band	-
NIR	Near infrared band	-
ARI	Anthocyanin Reflectance Index	1/green – 1/rededge
CI	Chlorophyll Index	(nir/red)-1
CIVE	Color Index of Vegetation Extraction	0.441*red – 0.811*green + 0.385*blue + 18.78745
CLGreen	Chlorophyll index green	(nir/green)-1
CLRedEdge	Chlorophyll index rededge	(nir/rededge)-1
DVI	Difference Vegetation Index	nir-red
EVI	Enhanced Vegetation Index	(2.5*(nir-red))/(nir+6*red-7.5*blue+1)
EVI2	Enhanced Vegetation Index 2	(2.5*(nir-red))/(nir+2.5*red+1)
ExG	Excess Green Vegetation Index	2*green-red-blue
ExGR	-	ExG-ExR
ExR	Excess Red Vegetation Index	(1.4*red-green)/ (red+green+blue)
GCC	Green chromatic coordinates	Green/(red+green+blue)
GNDVI	Green Normalized Difference Vegetation Index	(nir-green)/(nir+green)
GRVI	Green-Red Vegetation Index	(red-green)/(red+green)
Green NDVI	Green Normalized Difference Vegetation Index	(green-nir)/(green+nir)
Green Percentage	Green Percentage	Green/(green+red+blue)
Green/red	Green/red	Green/red
MCARI	Modified Chlorophyll Absorption Ratio Index	((rededge-red)-0.2*(rededge-green))*(rededge/rd)
MCARIone	-	1.2*(2.5*(nir-red)-1.3*(nir-green))
MCARItwo	-	$\frac{1.5*(2.5(\text{nir-red})-1.3(\text{nir-green}))}{\sqrt{(2*\text{nir}+1)^2-(6*\text{nir}-5*\sqrt{\text{red}}-0.5)}}$
MSAVI	Modified Soil Adjusted Vegetation Index	$0.5*(2*\text{nir}+1-\sqrt{(2*\text{nir}+1)^2-8(\text{nir-red})})$

MSR	Modified Simple Ratio	$\frac{\frac{nir}{red}-1}{\sqrt{\frac{nir}{red}-1}}$
MTVIone	Modified Triangular Vegetation Index one	1.2*(1.2*(nir-green)-2.5*(red-green))
MTVItwo	Modified Triangular Vegetation Index two	$\frac{1.2*(1.2*(nir-green)-2.5*(red-green))}{\sqrt{(2*nir+1)^2-(6*nir-5*\sqrt{red}-0.5)}}$
NDRE	Normalized Difference Red Edge	(nir-rededge)/(nir+rededge)
NDVI	Normalized Difference Vegetation Index	(nir-red)/(nir+red)
NGRDI	Normalized Green-Red Difference Index	(green-red)/(green+red)
Nir/green	Nir/green	Nir/green
OSAVI	Optimized Soil-Adjusted Vegetation Index	(1.16/(nir-red))*nir+red+0.16
RDVI	Renormalized Difference Vegetation Index	$\frac{nir-red}{\sqrt{nir+red}}$
Red/green	Red/greed	Red/green
SRI	Simple ratio index	Nir/red
SAVI	Soil-Adjusted Vegetation Index	((nir-red)/(nir+red+0.5))*1.5
SIPI	Structure Insensitive Pigment Index	(nir-blue)/(nir+red)
TCARI	Transformed Chlorophyll Absorption Reflectance Index	3*((rededge-red)-0.2*(rededge-green)*(rededge/green))
TCARI/OSAVI	-	TCARI/OSAVI
VARI	Visible Atmospherically Resistant Index	(green-red)/(green+red-blue)
CWSIa	Crop water stress index a	$\frac{CST-T_{wet}}{T_{dry}-T_{wet}}$.
CWSIb	Crop water stress index b	$\frac{CST-CST_{max}}{CST_{max}-CST_{max}}$
dT	Difference of temperature	CST – air temperature
CST	Canopy surface temperature	-
CH	Canopy height	-
LAI	Leaf area index	-

Table S2 – Variance Inflation Factor (VIF) to assess the collinearity between the predictor variables in the model 1 Ψ_{leaf_pred} = -1.55 + 0.27*CLRedEdge -0.49*CWSIb + 8.40*Blue + 0.27*CH (multispectral, thermal and LiDAR data).

Predictor variable	CH	CLRedEdge	CWSIb	Blue
VIF	1.67	1.78	1.17	1.30

Table S3 – Variance Inflation Factor (VIF) to assess the collinearity between the predictor variables in the model 2 Ψ_{leaf_pred} = -0.77 + 0.81*CLRedEdge + 6.78*Blue + 0.38*CH + 1.49*RedEdge +0.02*ARI -3.32*GNDVI (multispectral and LiDAR data).

Predictor variable	CH	RedEdge	ARI	Blue	CLRedEdge	GNDVI
VIF	1.73	2.86	3.63	3.75	4.49	4.08

Table S4 – Variance Inflation Factor (VIF) to assess the collinearity between the predictor variables in the model 3 Ψ_{leaf_pred} = -0.94 – 0.28*CWSIb + 0.38*CH - 0.01*CST (thermal and LiDAR data).

Predictor variable	CH	CWSIb	CST
VIF	1.41	2.21	2.43

Supplementary figures

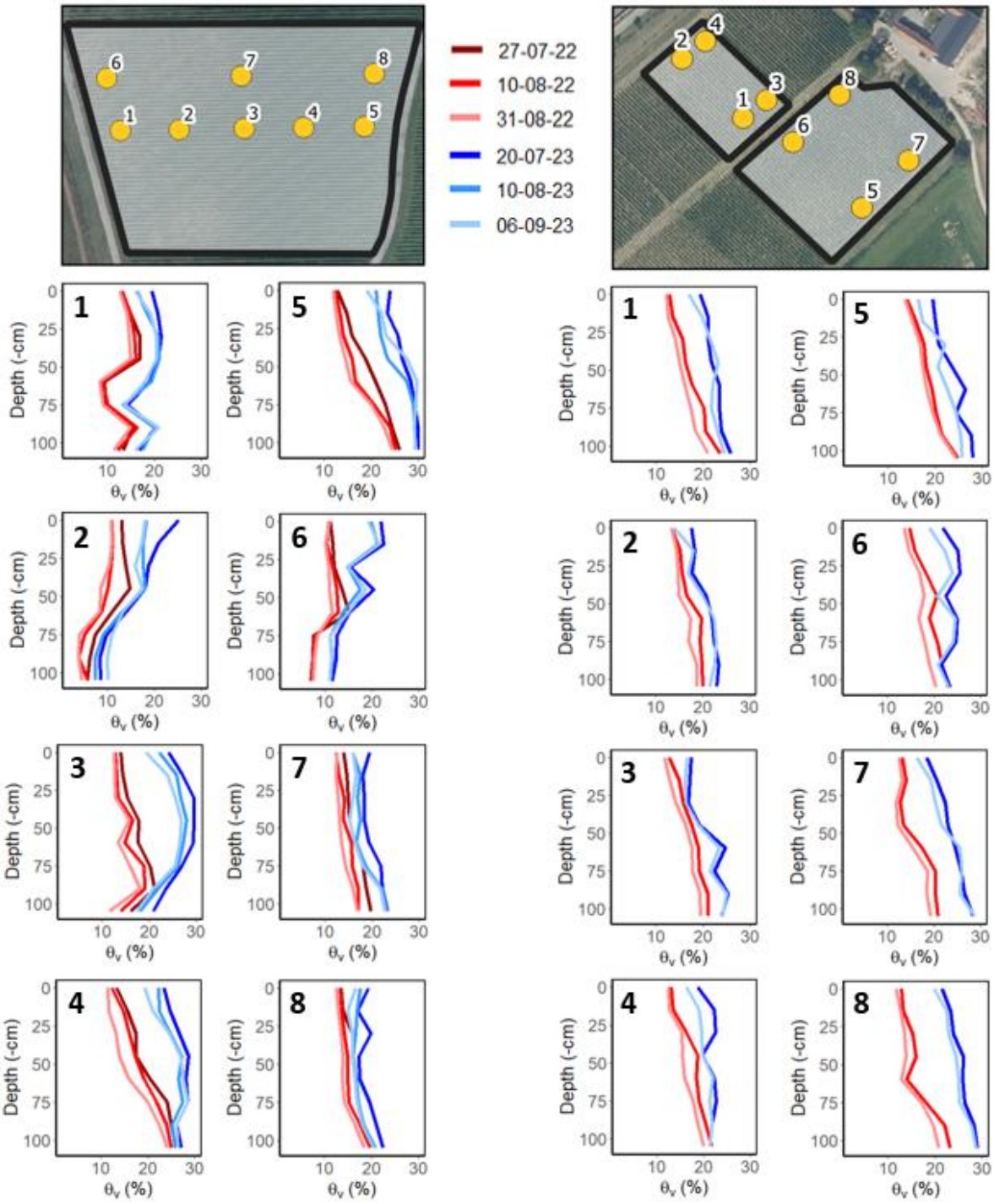
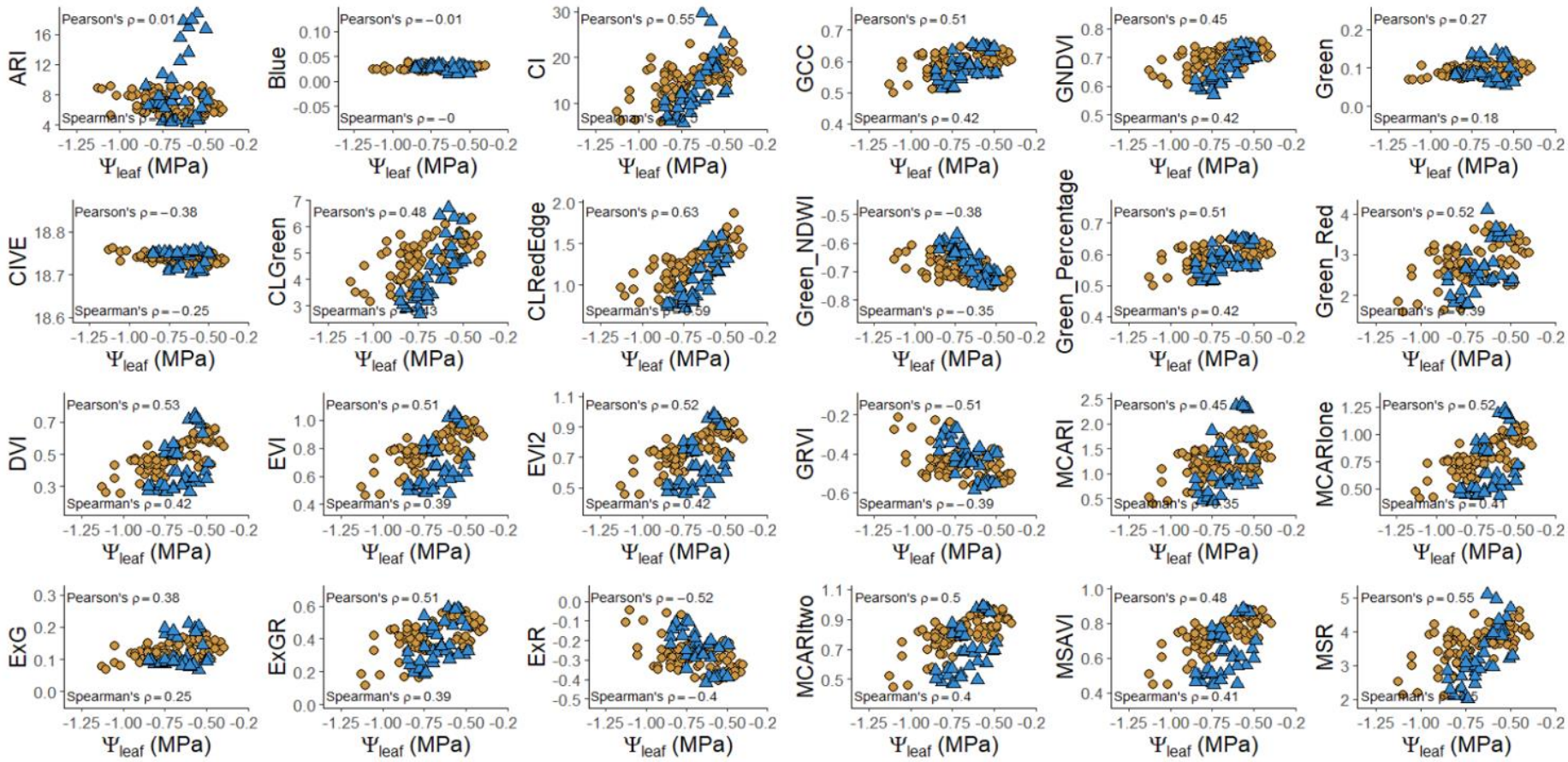


Figure S1 - Evolution of soil water content (θ_v) profile down to 105 cm depth, measured just before each UAS flight at different locations (yellow points) in both vineyards.


ARI
Pearson's ρ = 0.01
Spearman's ρ = −0.01
Blue
Pearson's ρ = −0.01
Spearman's ρ = −0
CI
Pearson's ρ = 0.55
Spearman's ρ = 0.5
GCC
Pearson's ρ = 0.51
Spearman's ρ = 0.42
GNDVI
Pearson's ρ = 0.45
Spearman's ρ = 0.42
Green
Pearson's ρ = 0.27
Spearman's ρ = 0.18
CIVE
Pearson's ρ = −0.38
Spearman's ρ = −0.25
CLGreen
Pearson's ρ = 0.48
Spearman's ρ = 0.43
CLRedEdge
Pearson's ρ = 0.63
Spearman's ρ = 0.59
Green_NDWI
Pearson's ρ = −0.38
Spearman's ρ = −0.35
Green_Percentage
Pearson's ρ = 0.51
Spearman's ρ = 0.42
Green_Red
Pearson's ρ = 0.52
Spearman's ρ = 0.39
DVI
Pearson's ρ = 0.53
Spearman's ρ = 0.42
EVI
Pearson's ρ = 0.51
Spearman's ρ = 0.39
EVI2
Pearson's ρ = 0.52
Spearman's ρ = 0.42
GRVI
Pearson's ρ = −0.51
Spearman's ρ = −0.39
MCARI
Pearson's ρ = 0.45
Spearman's ρ = 0.35
MCARIone
Pearson's ρ = 0.52
Spearman's ρ = 0.41
ExG
Pearson's ρ = 0.38
Spearman's ρ = 0.25
ExGR
Pearson's ρ = 0.51
Spearman's ρ = 0.39
ExR
Pearson's ρ = −0.52
Spearman's ρ = −0.4
MCARItwo
Pearson's ρ = 0.5
Spearman's ρ = 0.4
MSAVI
Pearson's ρ = 0.48
Spearman's ρ = 0.41
MSR
Pearson's ρ = 0.55
Spearman's ρ = 0.5
Ψleaf (MPa)

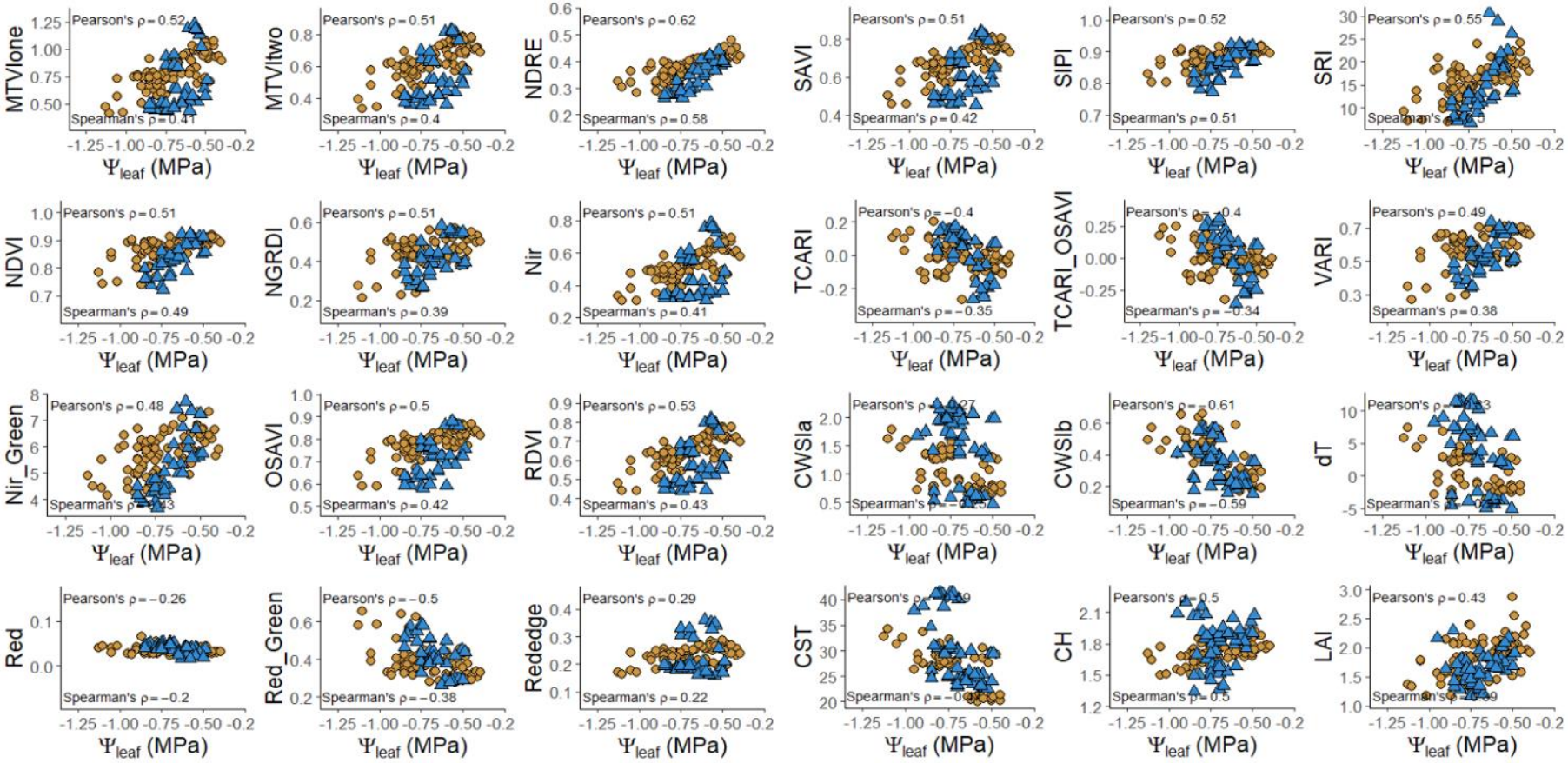


Figure S2 – Univariable relation between measured Ψ_{leaf} and the different VIs. The Pearson's and Spearman's coefficients (ρ), on all points together, are shown in the plots. Brown circles correspond to data from *Château de Bousval* vineyard; blue triangles correspond to data from *Domaine W* vineyard.

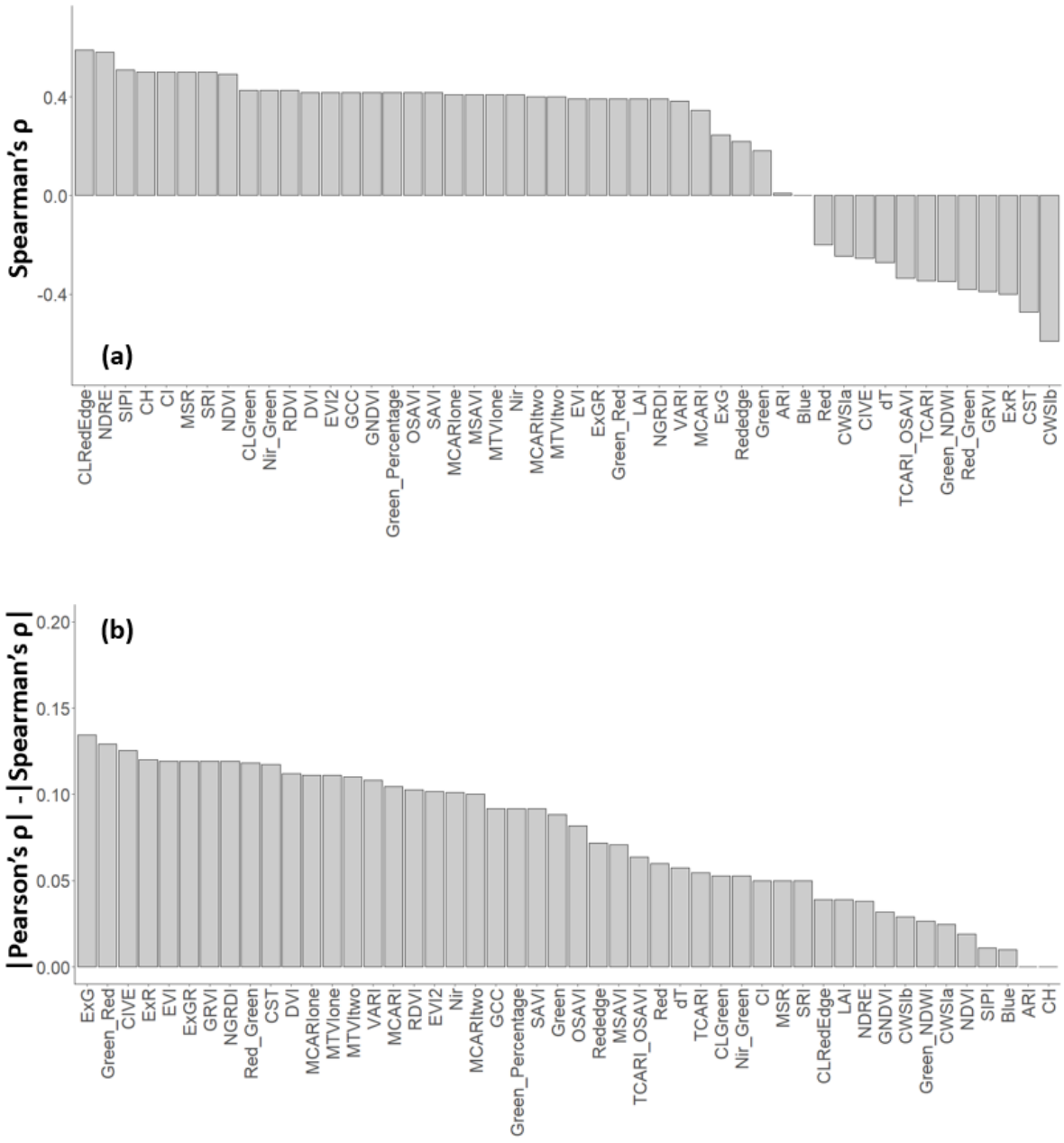


Figure S3 – (a) Spearman's coefficient (Spearman's ρ) quantifying the non-linear correlation between measured Ψ_{leaf} and each vegetation index (VI), by taking all the measurements in both vineyards and at all dates. **(b)** Difference between the absolute values of Pearson's ρ and Spearman's ρ.

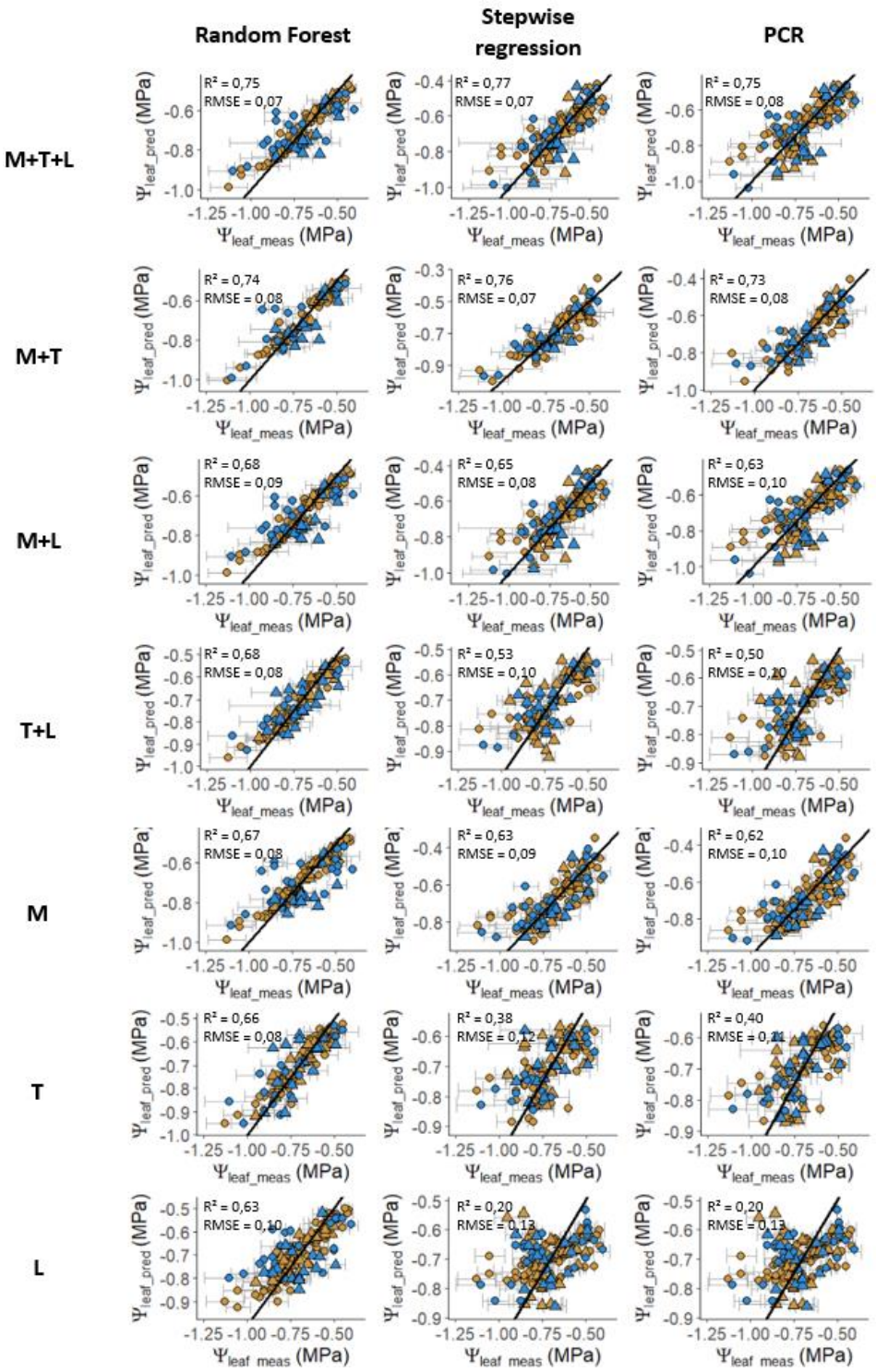


Figure S4 – Relation between leaf water potential measured (Ψ_{leaf_meas} – x-axis) and predicted (Ψ_{leaf_pred} – y-axis) with random forest model (left column), stepwise regression model (middle column) and principal component regression model (PCR – right column), for the different UAS data combinations of multispectral (M), thermal (T) and LiDAR (L) data. Blue and brown points are respectively data from *Château de Bousval* and *Domaine W* vineyards. Circles and triangles are respectively data used for the calibration and validation of the models. Horizontal grey lines are the standard deviation of measured Ψ_{leaf}. The black lines are the 1:1 line. R^2 and RMSE are calculated taking account to all points.

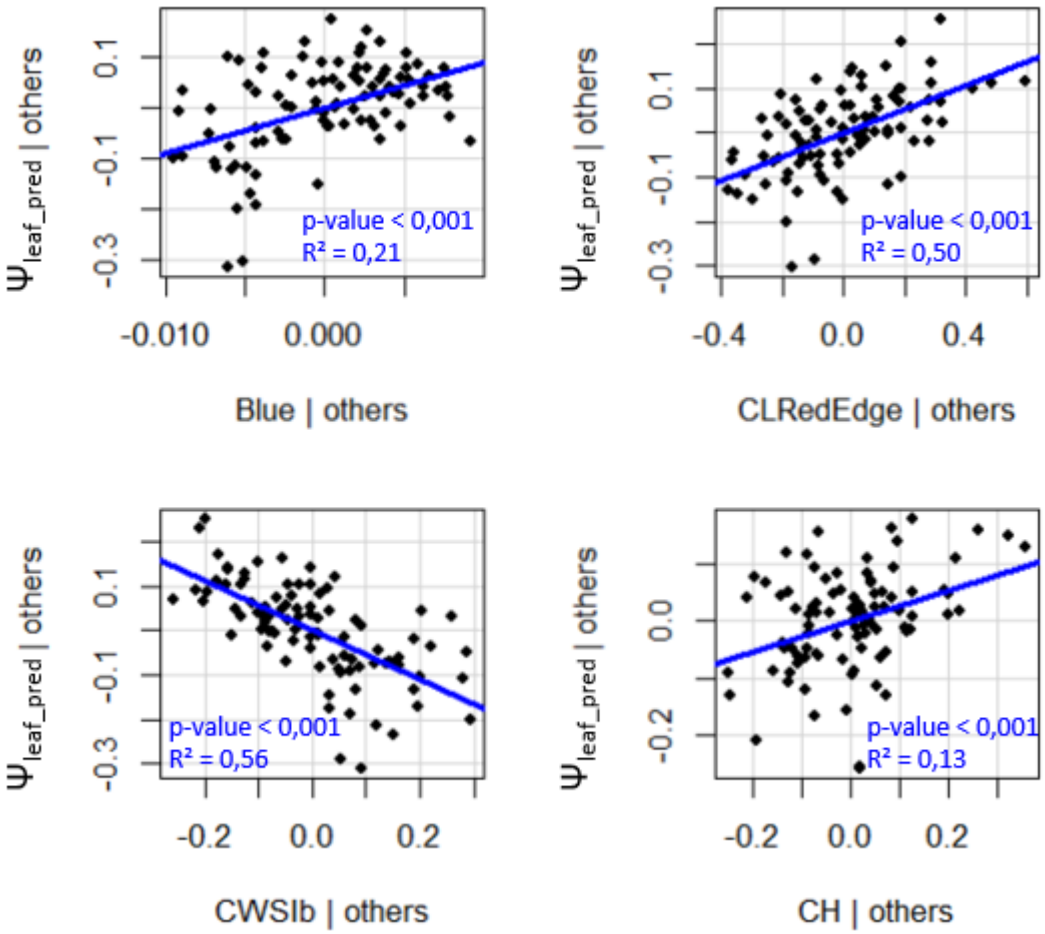


Figure S5 – Partial regression plots of each predictor variable on the prediction of Ψ_{leaf}, for the model 1 Ψ_{leaf_pred} = -1.55 + 0.27*CLRedEdge -0.49*CWSIb + 8.40*Blue + 0.27*CH (multispectral, thermal and LiDAR data). The p-value < 0.001 signifies that the slope of the linear regression (blue line) is significantly different from 0.

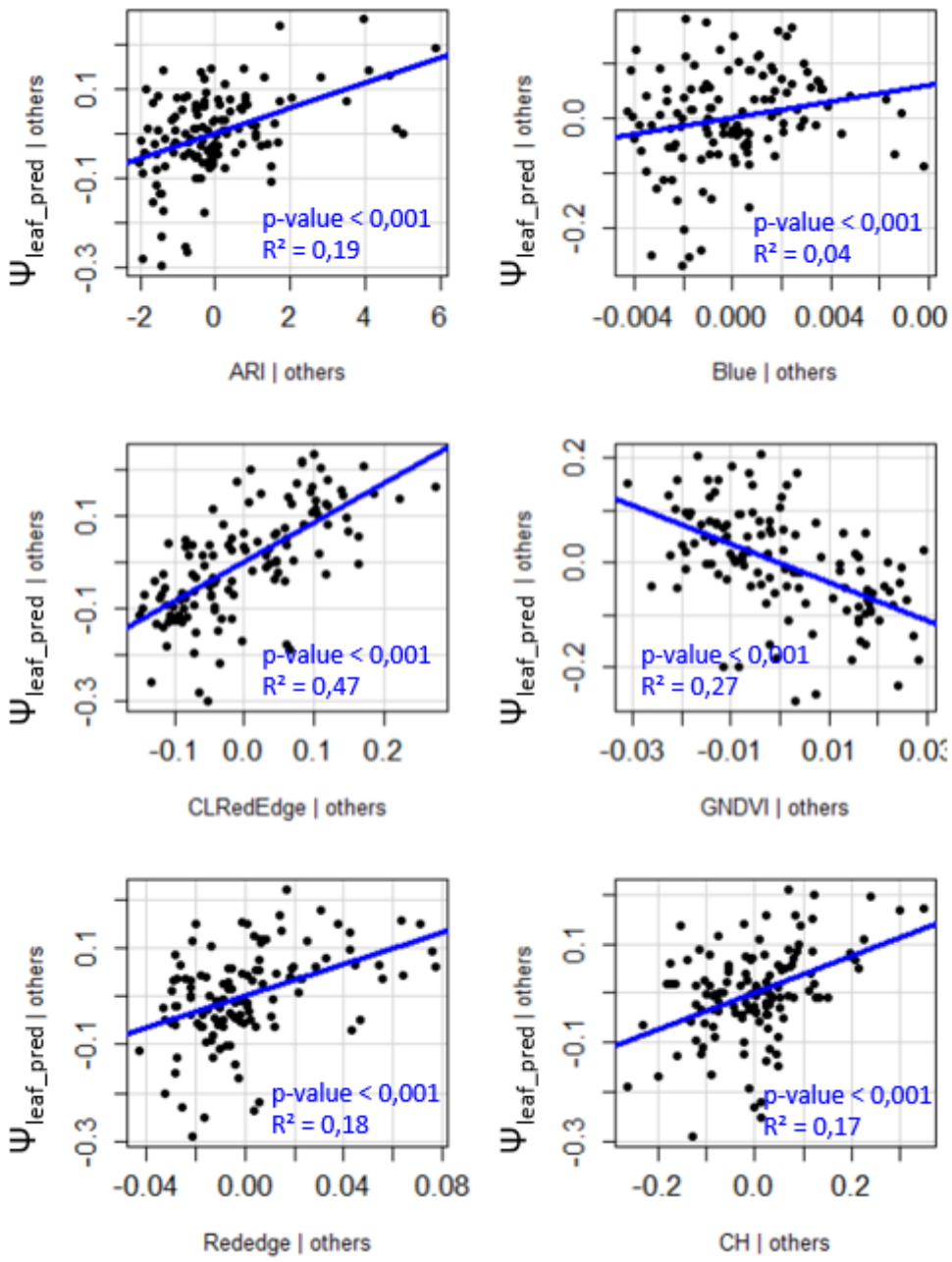


Figure S6 – Partial regression plots of each predictor variable on the prediction of Ψ_{leaf}, for the model 2 Ψ_{leaf_pred} = -0.77 + 0.81*CLRedEdge + 6.78*Blue + 0.38*CH + 1.49*RedEdge +0.02*ARI - 3.32*GNDVI (multispectral and LiDAR data). The p-value < 0.001 signifies that the slope of the linear regression (blue line) is significantly different from 0.

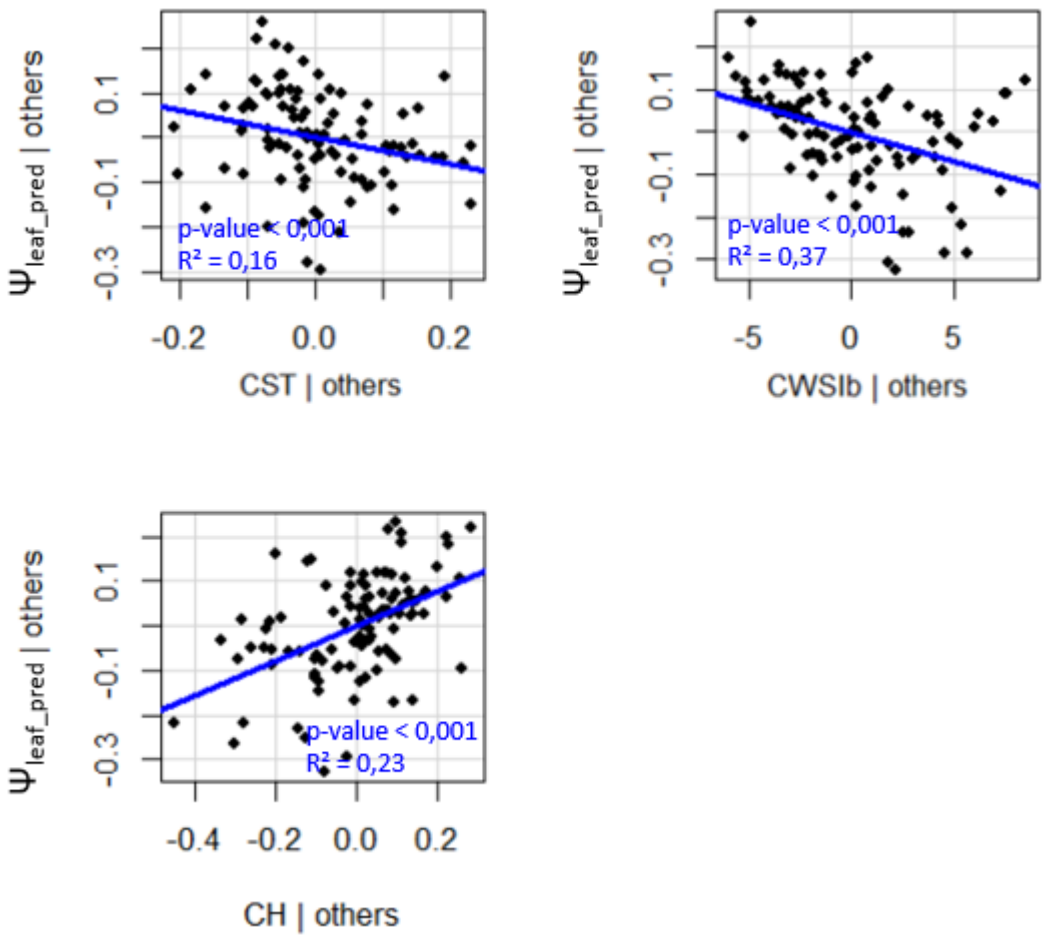


Figure S7 – Partial regression plots of each predictor variable on the prediction of Ψ_{leaf}, for the model 3 Ψ_{leaf_pred} = -0.94 – 0.28*CWSIb + 0.38*CH - 0.01*CST (thermal and LiDAR data). The p-value < 0.001 signifies that the slope of the linear regression (blue line) is significantly different from 0.

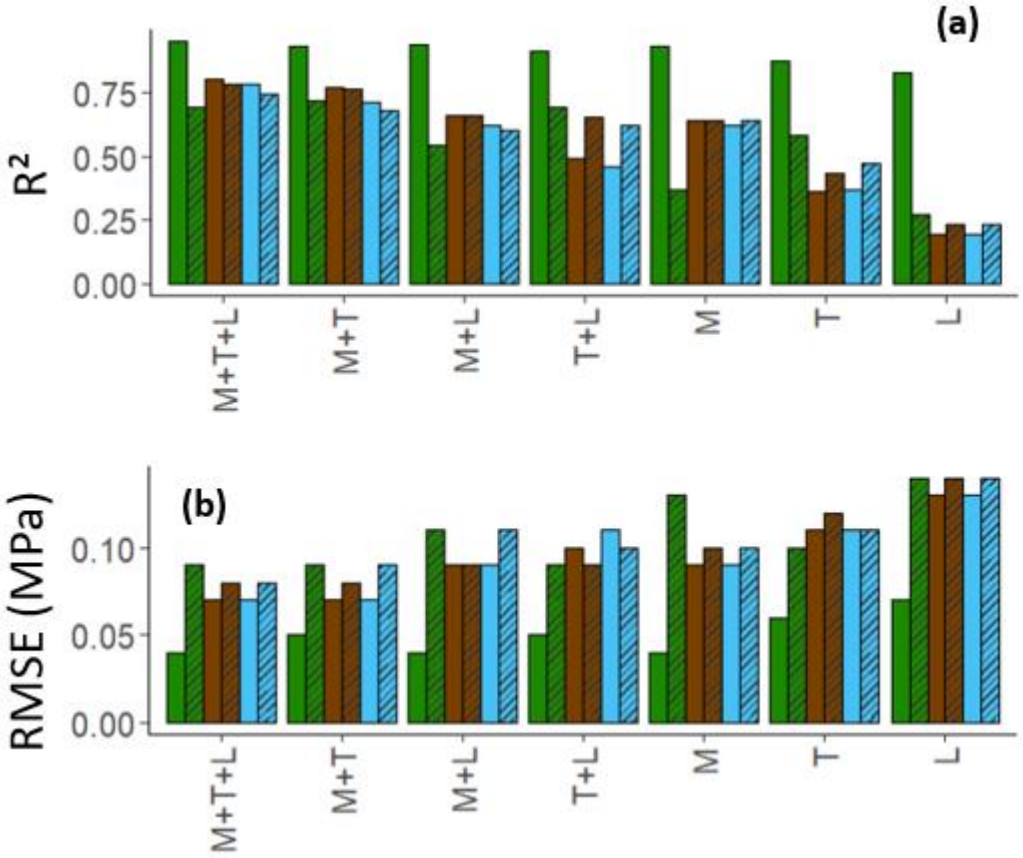


Figure S8 - **(a)** R^2 and **(b)** RMSE obtained by comparing measured Ψ_{leaf} (Ψ_{leaf_meas}) and predicted Ψ_{leaf} (Ψ_{leaf_pred}) with different multiple linear regression models, for the different data combinations. The green bars correspond to the random forest model, the brown bars to the stepwise regression model, and the blue bars to the principal component regression model. The full bars correspond to the calibration dataset (70 % of the data), while the hatched bars correspond to the validation dataset (30 % of the data).