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ROLE OF PHENOTYPIC PLASTICITY IN THE EXPRESSION OF HYBRID LARCH HETEROSIS

A CASE STUDY USING RANDOM REGRESSION MODELING

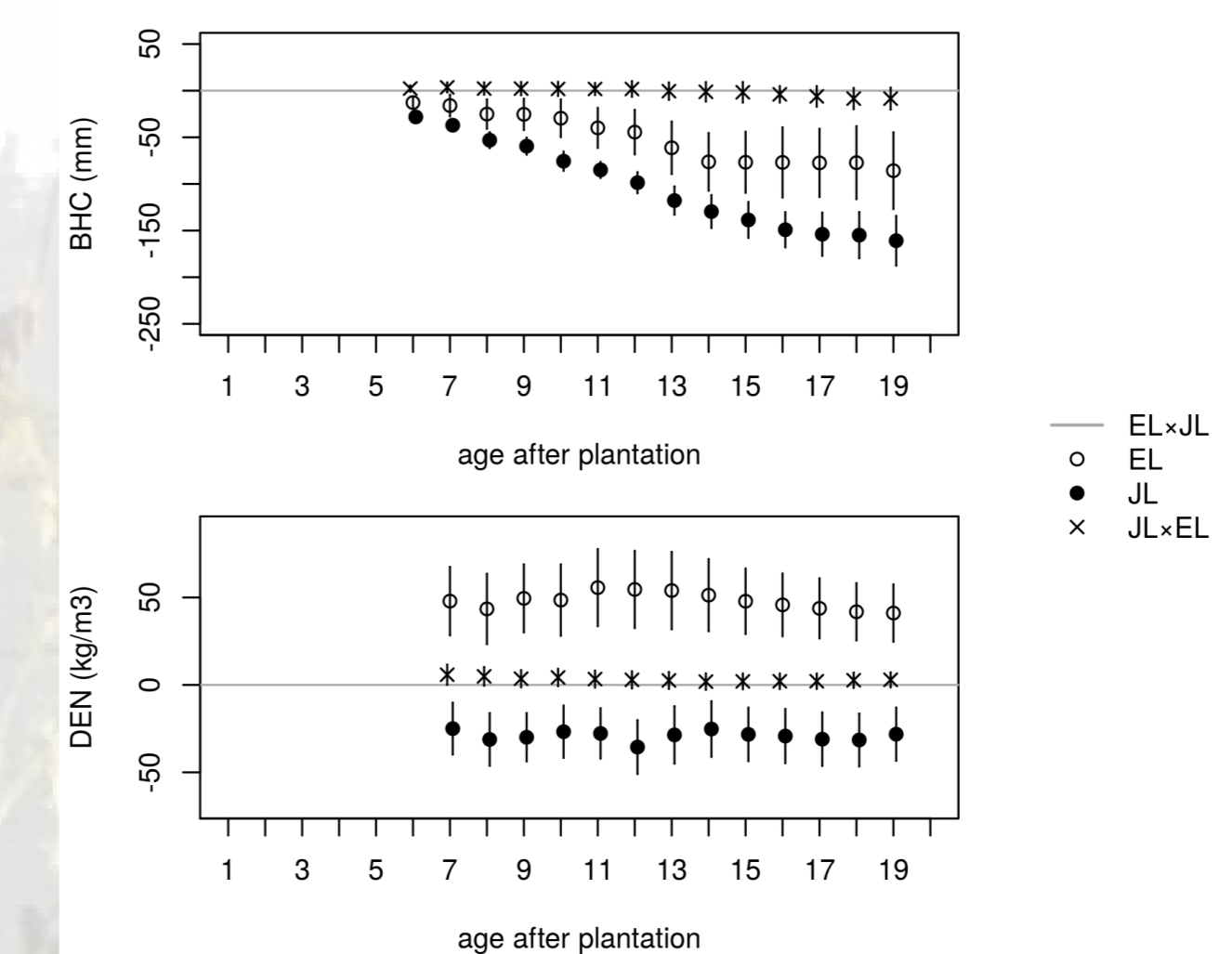
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Introduction

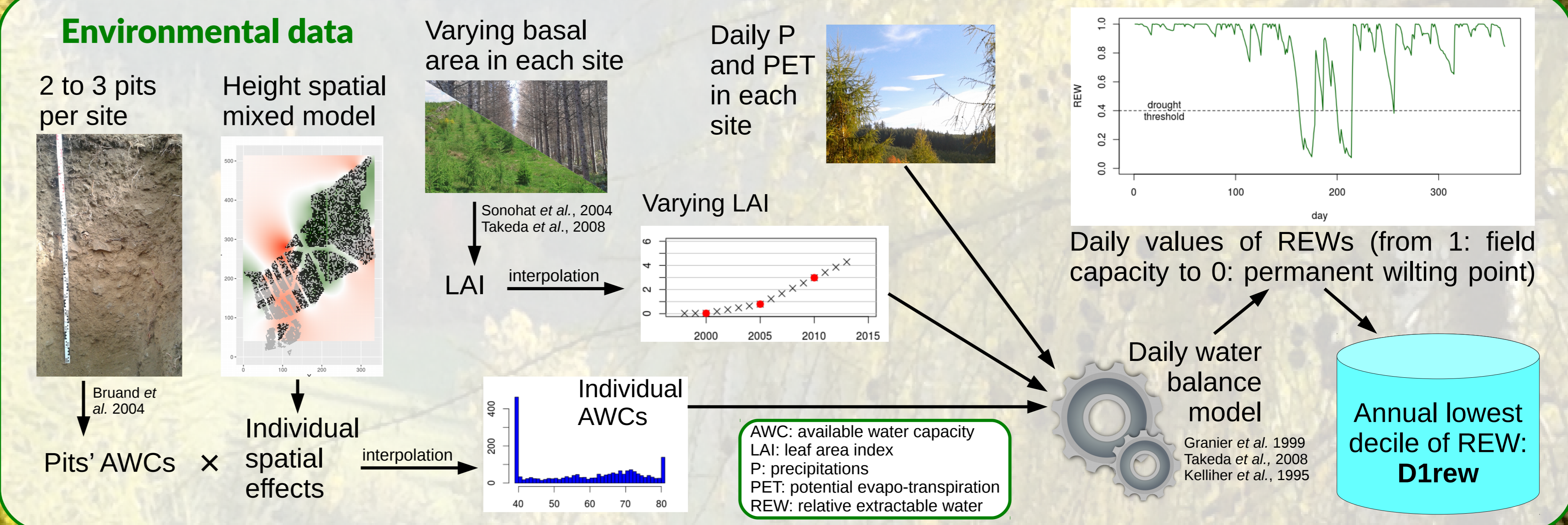
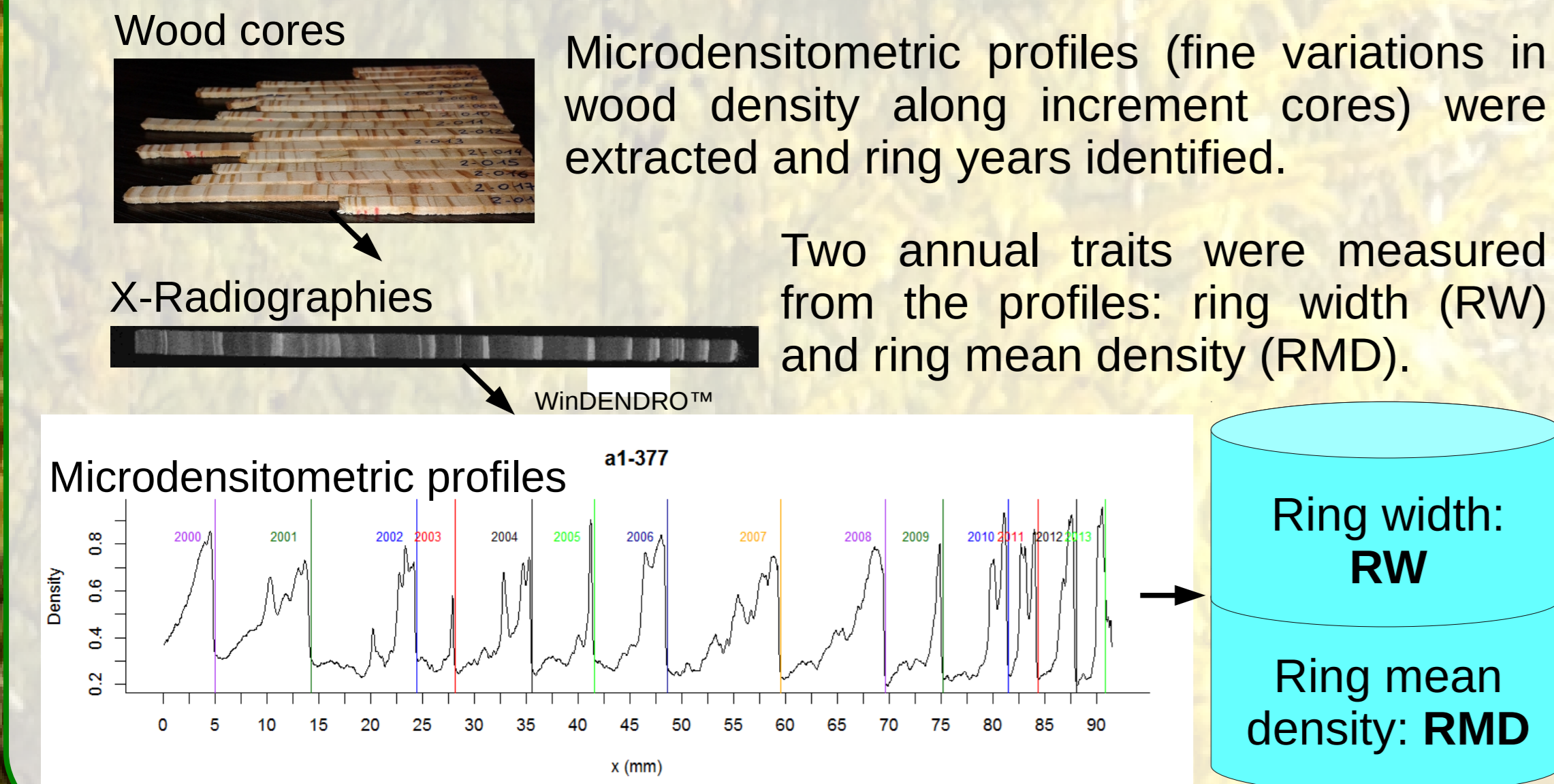
- Hybrid larch (HL) between *Larix decidua* and *Larix kaempferi* shows heterosis on growth traits (Pâques 1989; Baltunis *et al.* 1998; Pâques 2013; Greenwood *et al.* 2015)
- Water availability is known to induce plastic responses in tree ring formation (Sánchez-Vargas *et al.* 2007; Fallour-Rubio *et al.* 2009; Martinez-Meier *et al.* 2009; Bryukhanova and Fonti 2013).
- Question 1:** What role does tree ring formation phenotypic plasticity in response to water availability play in the expression of hybrid larch heterosis ?
- Question 2:** How do the quantitative genetic parameters of tree ring formation change along a water availability gradient ?

Based on the same dataset, we showed heterosis of breast height circumference (BHC). Hybrid wood density (DEN) was intermediate (Marchal *et al.*, *in prep.*)



	European larch (EL)									Japanese larch (JL)									
	104	106	108	109	116	214	221	222	242	284	3179	3180	3183	3190	3193	3194	3200	3203	3217
EL	37	40	13	21	43	10	5	30	42	40	38	38	43	42	25	34	38	40	10
JL	29	37	41	20	48	1	14	37	46	30	28	41	36	25	40	10	10	10	10

Phenotypic data
The phenotypic data were collected in a diallel trial between 9 European larches (EL) and 9 Japanese larches (JL).
The trial was set up in 3 ecologically contrasted sites in France: Saint-Apollinaire (SA) and Saint-Saud (SS) in 1997 and Peyrat-le-Château (PC) in 2004.
Annual tree rings constitute a unique record of the trees plastic responses to past climatic events. We collected a total of 5508 radial increment cores from this trial.



Statistical modeling
Legendre polynomial random regressions were used to model the reaction norms of phenotypic traits y (RW, RMD) along the environmental gradient x (D1rew).
This approach is commonly used in animal breeding for longitudinal traits such as lactation curves (Schaeffer 2004; Druet *et al.* 2005). Applied to the study of phenotypic plasticity, it allows the estimation of shape parameters that can describe variance components of complex reaction norms (Murren *et al.* 2014).

$$(1) y_{ijkn;x} = \sum_{m=0}^{M_1} s_{im} L_m(x') + \sum_{m=0}^{M_2} a_{jm} L_m(x') + \sum_{m=0}^{M_3} e_{km} L_m(x') + \epsilon_{ijkn;x}$$

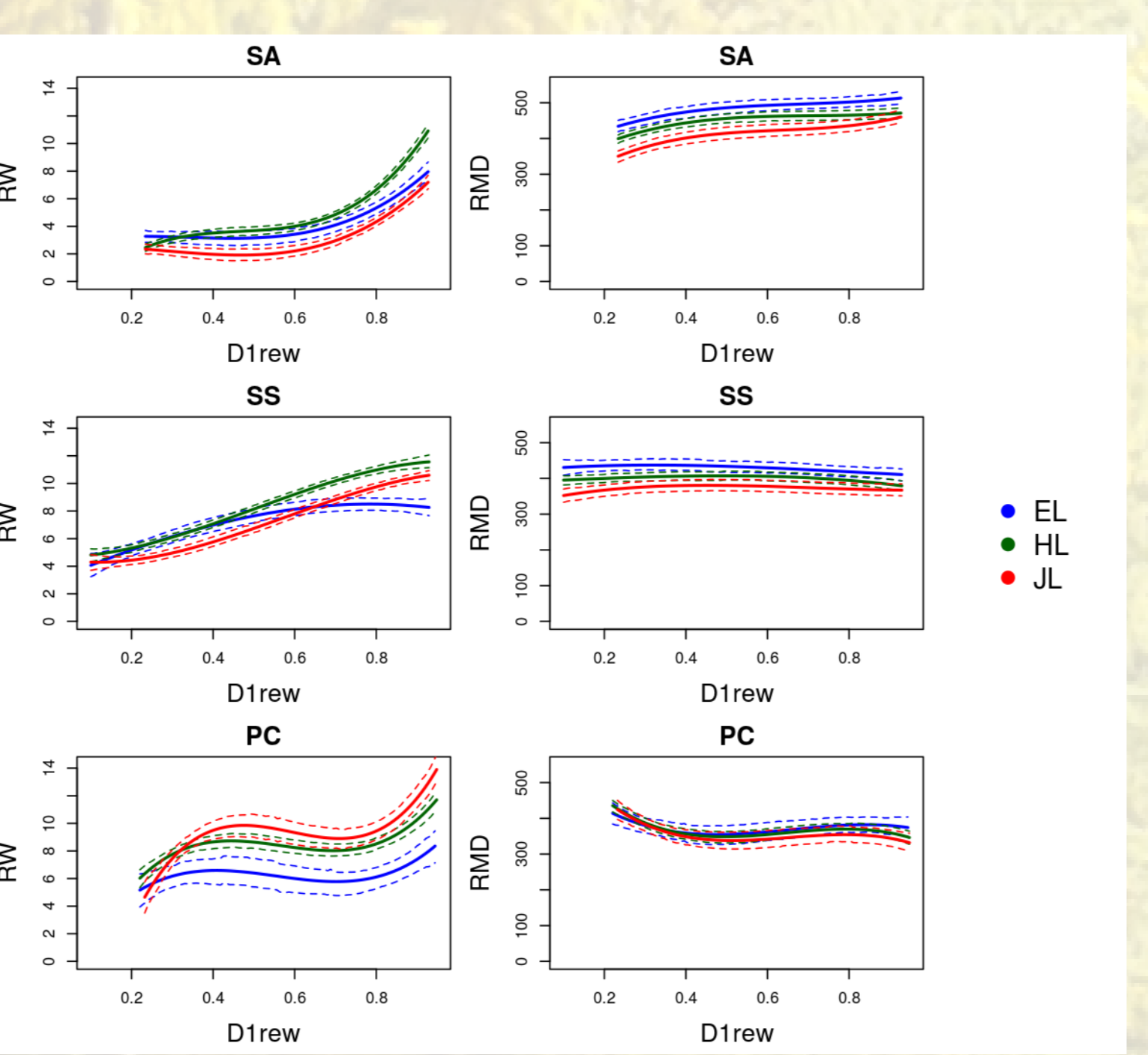
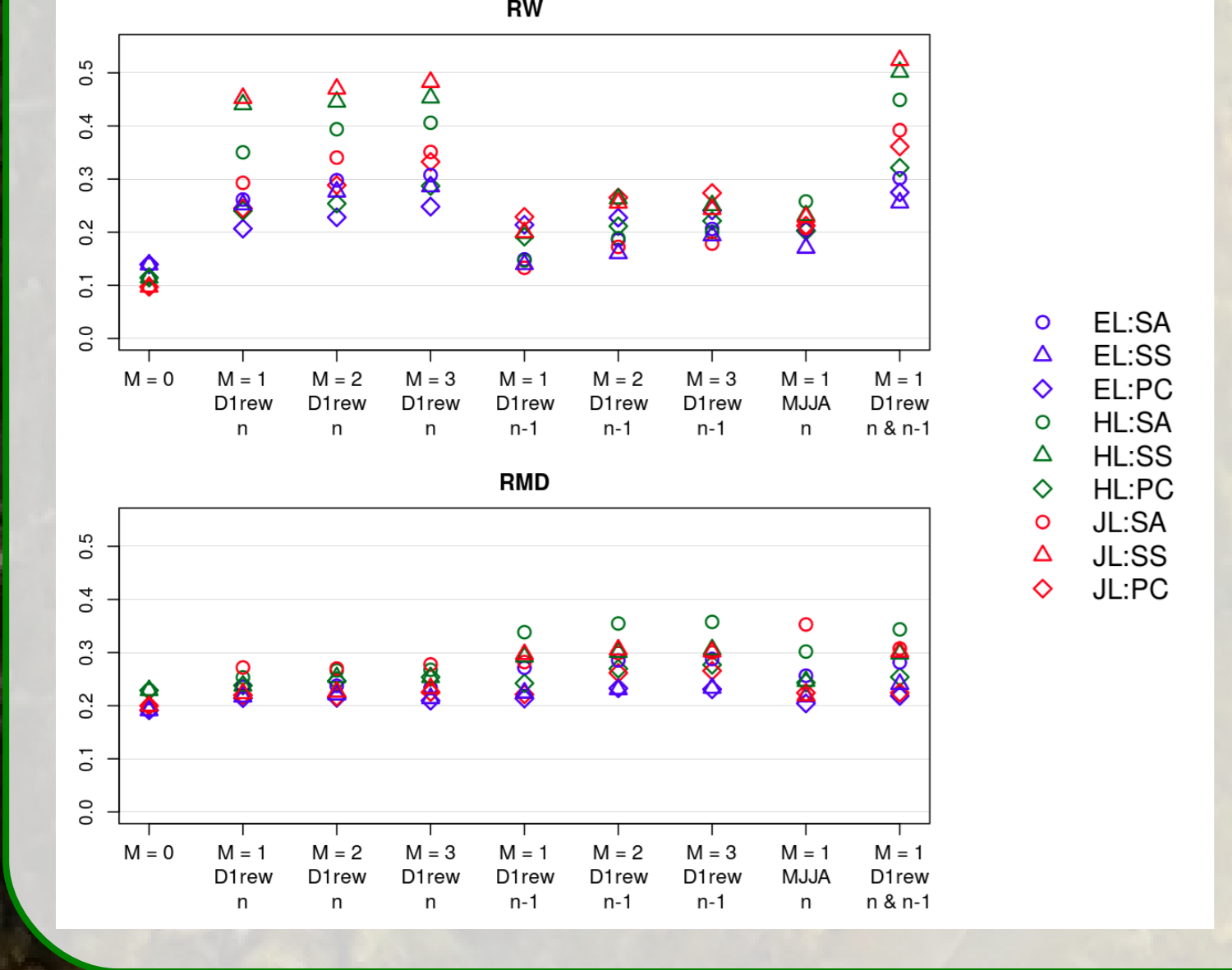
For pure species EL and JL:

$$(2) \begin{pmatrix} a_0 \\ a_1 \\ \vdots \\ a_{M_k} \end{pmatrix} \sim N(0, (\Sigma_A \otimes A)) \text{ with } \Sigma_A = \begin{pmatrix} \sigma_{A0}^2 & C_{A0:1} & \dots & C_{A0:M_k} \\ C_{A0:1} & \sigma_{A1}^2 & \dots & C_{A1:M_k} \\ \vdots & \vdots & \ddots & \vdots \\ C_{A0:M_k} & C_{A1:M_k} & \dots & \sigma_{AM_k}^2 \end{pmatrix}$$
For hybrids HL (Stuber and Cockerham, 1966):

$$(2') \begin{pmatrix} a_0 \\ a_1 \\ \vdots \\ a_{M_k} \end{pmatrix} = \begin{pmatrix} h_{EL0} \\ h_{EL1} \\ \vdots \\ h_{ELM_k} \end{pmatrix} + \begin{pmatrix} h_{JL0} \\ h_{JL1} \\ \vdots \\ h_{JLM_k} \end{pmatrix} \text{ with } \begin{pmatrix} h_{EL0} \\ h_{EL1} \\ \vdots \\ h_{ELM_k} \end{pmatrix} \sim N(0, (\Sigma_{HE} \otimes 0.5A))$$

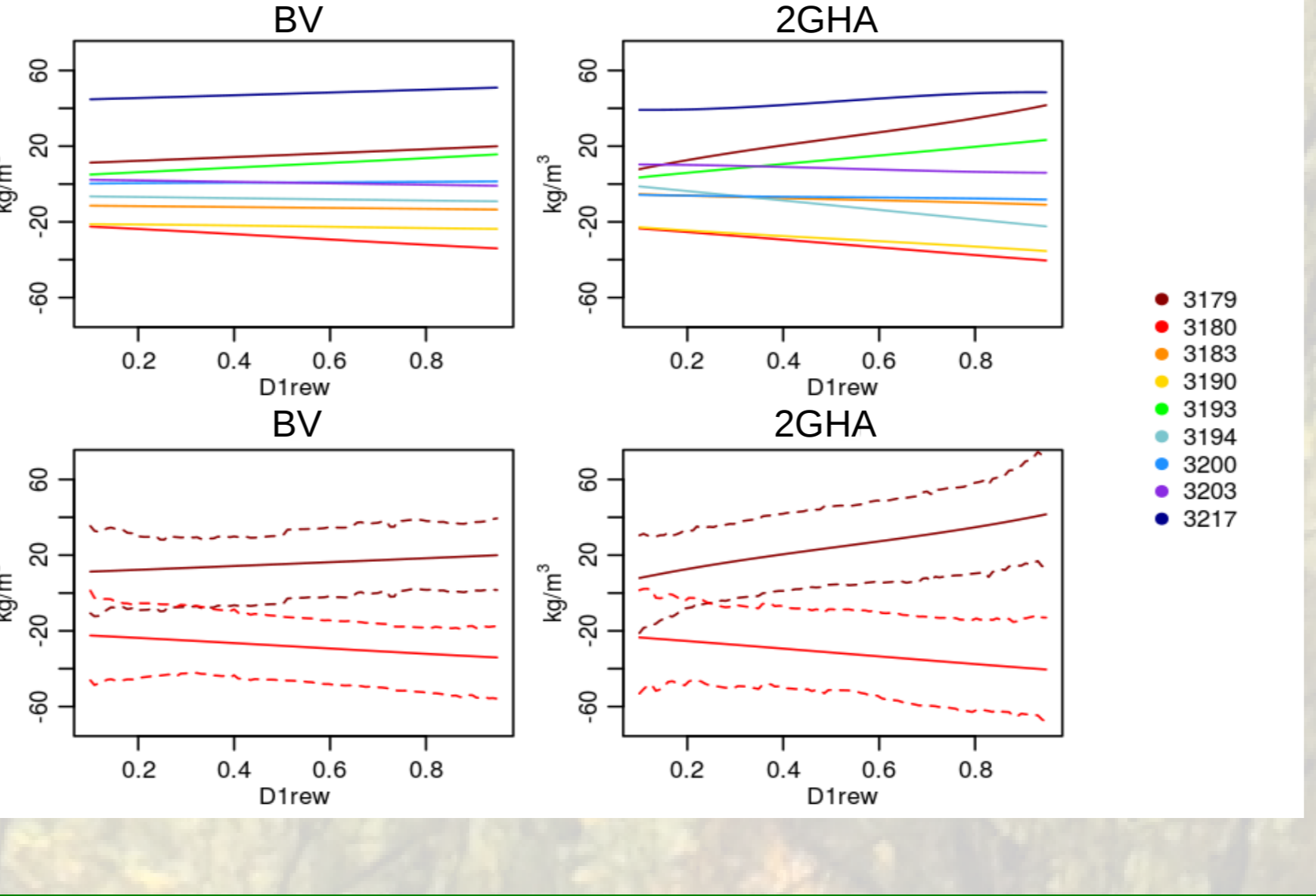
$$(3) \begin{pmatrix} e_0 \\ e_1 \\ \vdots \\ e_{M_k} \end{pmatrix} \sim N(0, (\Sigma_E \otimes I)) \text{ and } (4) \epsilon_{ijkn;x} \sim N(0, \sigma_e^2)$$

Results and discussion
Below: Coefficients of determination (R^2) for several model configurations.
• The 1st order (intercept + slope) model performs very well for RW. Higher orders increase only a little the R^2 .
• The 0th order (intercept only) model performs well for RMD. Higher orders (even 1st) increase only a little the R^2 .
• The water availability index D1rew explains much more variance for RW than the simpler index: sum of precipitations from May to August (MJJA).
• Year n explains more variance for RW than year $n-1$. The opposite is found for RMD.



Above: Average order 3 reaction norms of RW and RMD along D1rew, for all 3 taxa in all 3 sites.
• RW is the most plastic trait. RW increases with higher D1rew (wet years).
• For RW, in SA and in SS, the expression of heterosis is stronger with high D1rew (wet years). For dry years, there is no expression of heterosis.
• JL outperforms HL in PC for RW.
• RMD shows almost no plasticity in response to D1rew. Moreover, the ranking of taxa mean RMDs is well preserved in SA and in SS.

Right: RMD on the JL side is the most heritable trait of the study, with very low h^2 though. This h^2 increases slightly with D1rew.
Below: The additive performances of the 9 JL parents for RMD in pure species breeding (BV) and in hybridization (2GHA).
• Genotype #3217 shows a high performance, almost independent of D1rew.
• The contrast in performances between #3179 and #3180 more than doubles with increasing D1rew. Unfavorable conditions (drought: low D1rew) seem to inhibit the expression of the genetic contrasts.



Conclusion
• Hybrid larch heterosis for RW is overall expressed in favorable (wet) weather conditions, except in 1 site.
• Increasing water availability allows the expression of contrasted genetic performances for RMD, thus increasing the heritability for this trait.
• Although we did not capture complex shape variance parameters in this study, this is a powerful method that can be applied to any study of reaction norms across a well covered environmental gradient.

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