Contrasted reaction norms of wheat yield in pure vs mixed stands explained by tillering plasticities and shade avoidance

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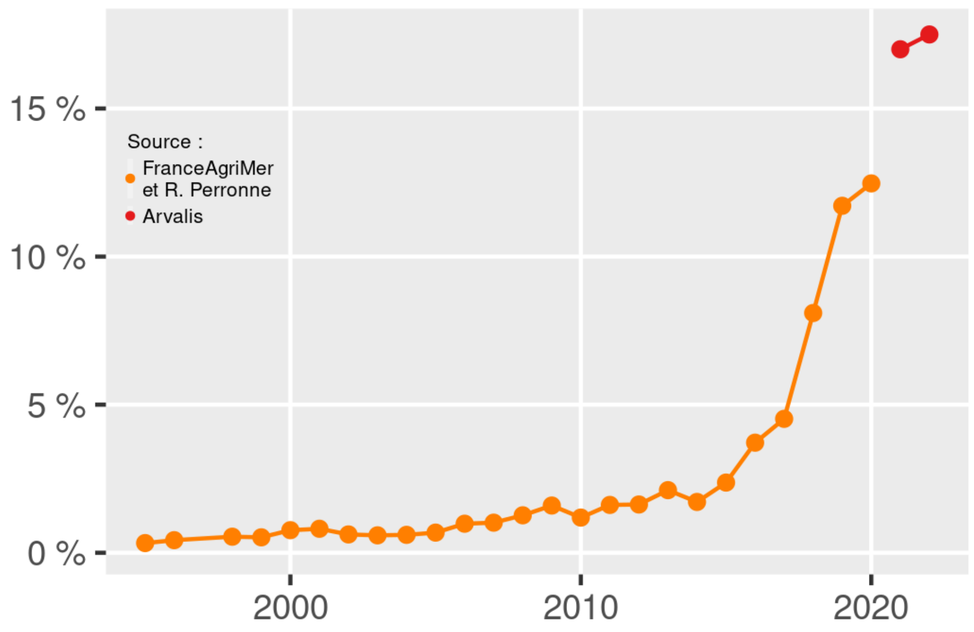
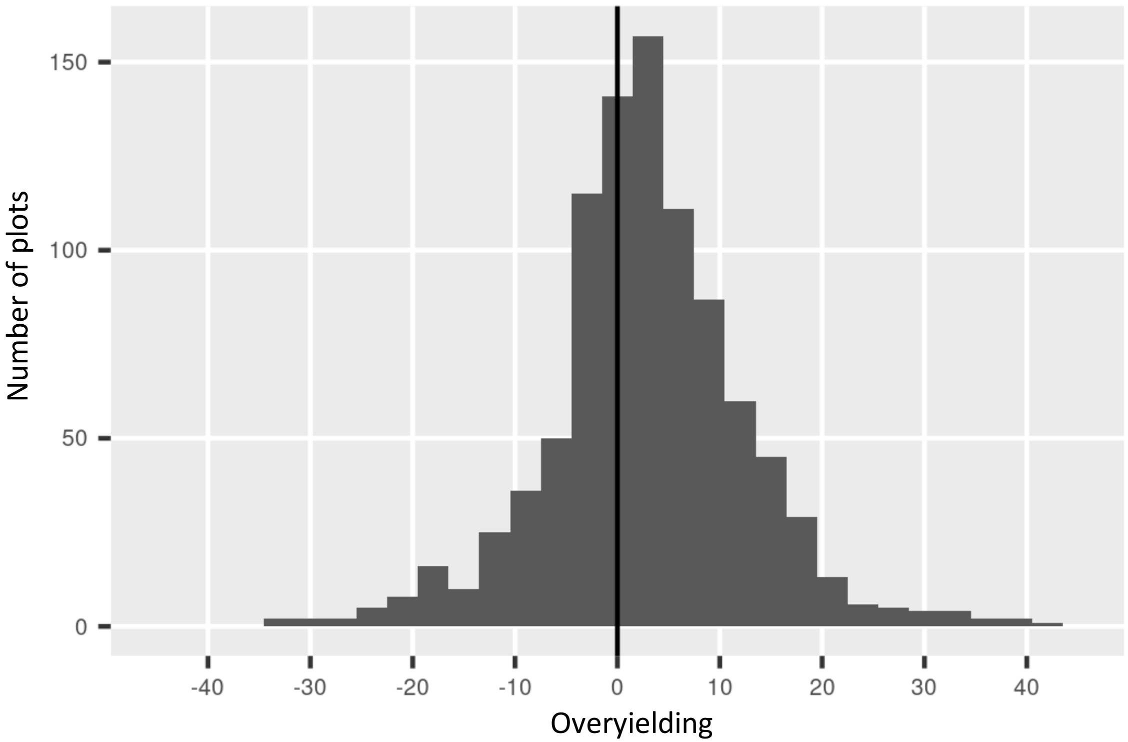
Wheat cultivar mixtures

- Agroecological transition → crop diversification
- Wheat cultivar mixtures at plot scale → increasing use in France but few assembly rules
- Highly variable distribution of overyielding in mixture as performance strongly impacted by plant-plant interactions misunderstood in such heterogeneous canopies
- Plant-plant interactions shaped by phenotypic plasticity

Wheat cultivated area in mixtures in France

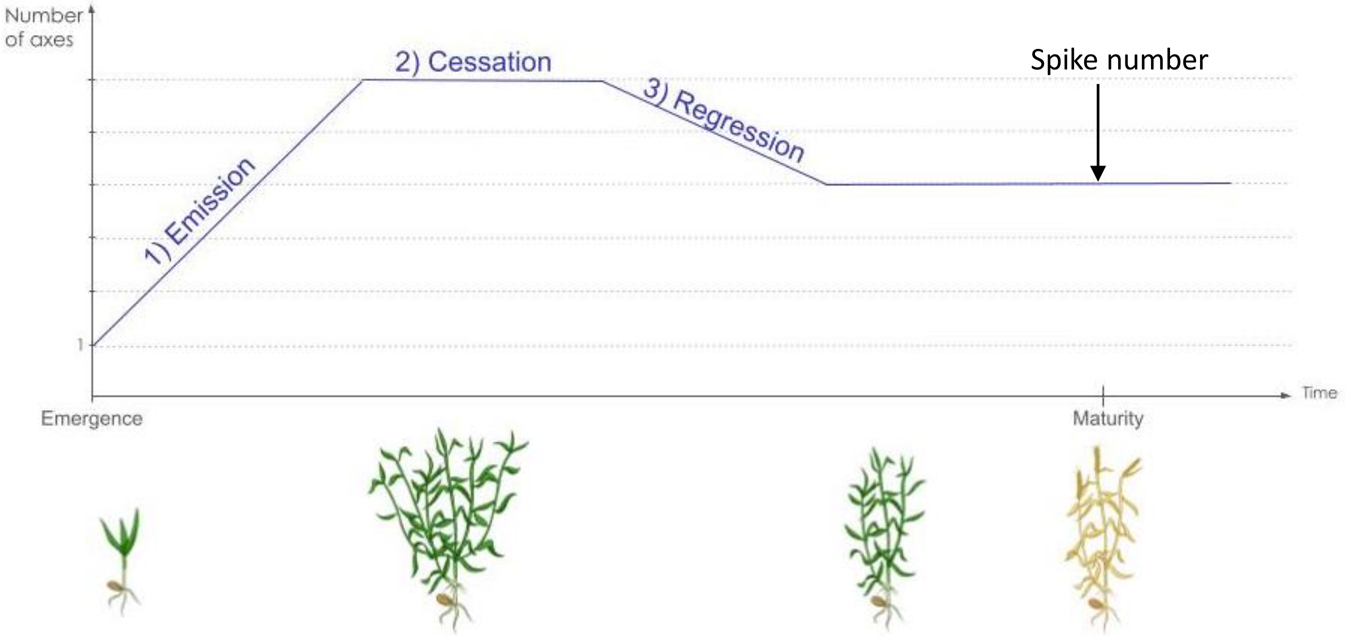


Distribution overyieldings from meta-analysis Borg et al. (2019)



Importance of tillering plasticity in wheat cultivar mixtures

- Cultivation in mixtures → change in plant's environment and modification of some signals triggering plasticity
- Still competition for light under conventional conditions (non-limiting for nitrogen and water) that can induce plastic responses in wheat canopies, what are these responses in heterogeneous canopies like mixtures ?
- Focus on tillering (=branching) plasticity → major yield component and most plastic trait in response to competition for light
- Design of an original field experiment with dynamic phenotyping of tillering at plant scale



Tillering = branching

One tiller = 1 ramification

The Perfomix experiment

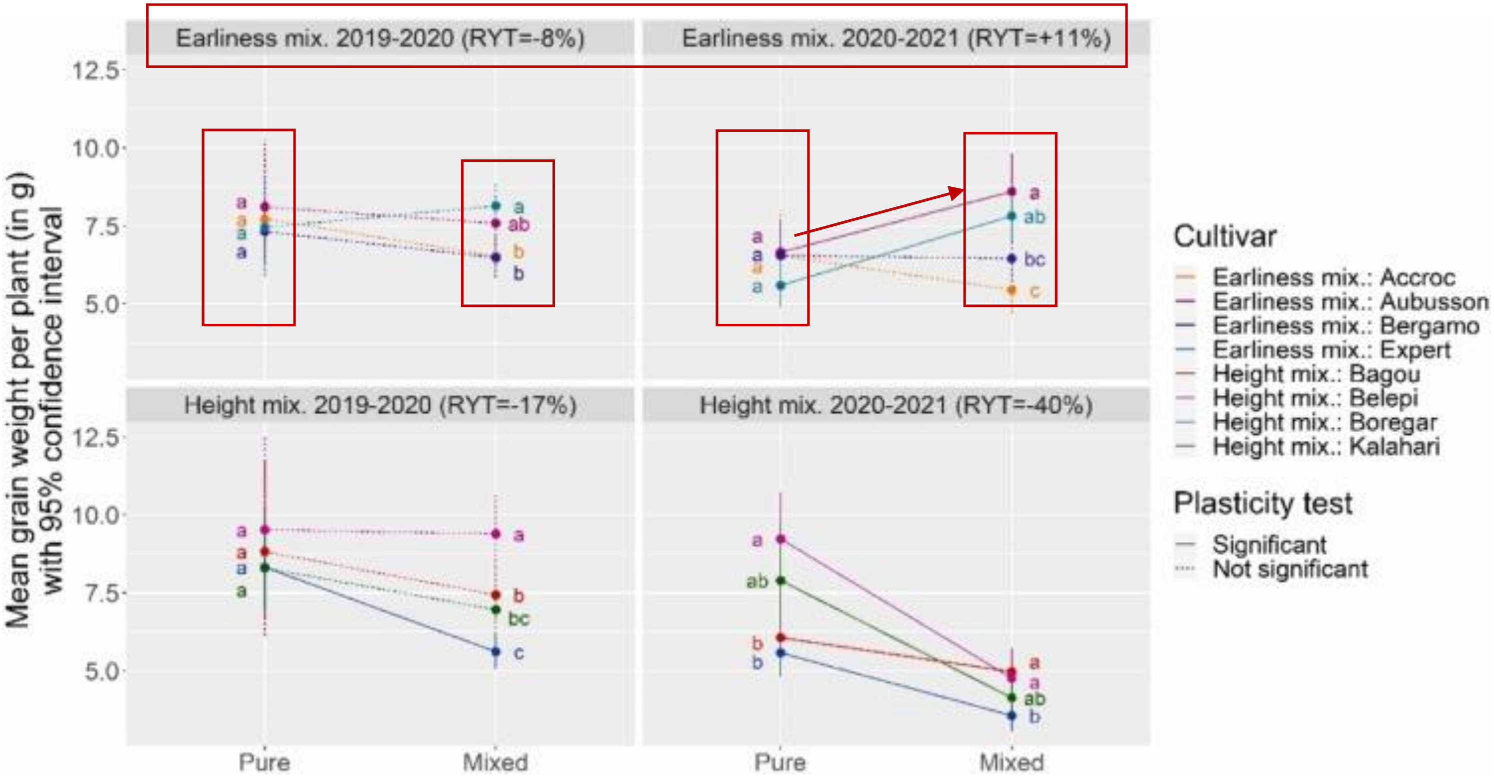
- Field experiment of small plots (1.5-2m^2) at Le Moulon, Gif-sur-Yvette (France) in pure stands and mixtures for two years (2019-2020, 2020-2021)
- Eight wheat cultivars for 2 quaternary mixtures with earliness or height heterogeneity, replicated twice
- Precision sowing according to predefined spatial distributions for the identification of each plant's cultivar in mixture
- Phenotyping at plant scale
  - Once a month during growth
    - In mixtures → height and number of tillers non destructively for all plants (266 per mixture)
    - In pure stands → height, number of tillers and biomass for a sample of 20 plants
  - At harvest → height, biomass, number of tillers, spike number, grain weight, grain number

Mixture	Cultivar	Heading DOY	Final height (cm)
Earliness	Accroc	128.4	87.02
	Aubusson	129.9	87.03
	Bergamo	145.3	92.17
	Expert	144.1	90.93
Height	Bagou	136.7	82.97
	Belepi	138.1	100.93
	Boregar	140.7	84.08
	Kalahari	141.9	115.19

C	Ber	Aub	Acc	Ber	Exp	Acc	Aub	Exp	Aub	Ber	Ber	Exp	22
D	Exp	Exp	Acc	Aub	Aub	Exp	Ber	Acc	Exp	Aub	Acc	Exp	21
E	Acc	Aub	Exp	Exp	Ber	Acc	Aub	Aub	Ber	Aub	Exp	Ber	20
F	Exp	Acc	Ber	Aub	Aub	Exp	Acc	Ber	Exp	Acc	Aub	Acc	19
G	Acc	Acc	Aub	Exp	Acc	Ber	Exp	Aub	Acc	Exp	Ber	Exp	18
H	Exp	Ber	Ber	Aub	Aub	Acc	Exp	Ber	Acc	Exp	Acc	Aub	17
A	Aub	Acc	Exp	Acc	Ber	Exp	Aub	Acc	Aub	Acc	Ber	Exp	16
B	Ber	Acc	Acc	Exp	Ber	Acc	Aub	Exp	Ber	Acc	Aub	Ber	15
C	Aub	Exp	Ber	Aub	Aub	Ber	Ber	Aub	Aub	Ber	Aub	Exp	14
D	Ber	Aub	Exp	Acc	Exp	Aub	Ber	Ber	Exp	Exp	Acc	Ber	13
E	Acc	Acc	Exp	Acc	Ber	Acc	Acc	Aub	Aub	Acc	Aub	Exp	12
F	Exp	Aub	Ber	Aub	Aub	Exp	Ber	Acc	Exp	Exp	Acc	Ber	11
G	Ber	Acc	Acc	Acc	Exp	Acc	Aub	Acc	Ber	Aub	Ber	Exp	10
H	Exp	Acc	Ber	Aub	Ber	Exp	Ber	Ber	Aub	Aub	Acc	Ber	9
A	Aub	Exp	Exp	Acc	Acc	Exp	Aub	Exp	Acc	Ber	Aub	Exp	8
B	Ber	Ber	Aub	Ber	Aub	Ber	Acc	Acc	Exp	Aub	Acc	Ber	7
C	Acc	Acc	Exp	Acc	Acc	Exp	Ber	Exp	Ber	Ber	Acc	Aub	6
D	Ber	Exp	Ber	Aub	Exp	Aub	Aub	Acc	Aub	Ber	Ber	Exp	5
E	Aub	Acc	Aub	Aub	Ber	Acc	Ber	Acc	Exp	Acc	Aub	Exp	4
F	Acc	Ber	Exp	Acc	Exp	Aub	Acc	Ber	Exp	Aub	Ber	Exp	3
G	Exp	Aub	Aub	Acc	Aub	Ber	Exp	Aub	Acc	Exp	Acc	Ber	2
H	Acc	Exp	Ber	Aub	Exp	Aub	Acc	Ber	Aub	Ber	Ber	Exp	1
	1	2	3	4	5	6	7	8	9	10	11	12	

Yield plasticity and cultivar dominance in mixtures

- Reaction norms of grain weight per plant and cultivar dominance in mixture



- Mixture performance
  - Overyielding in 2020 for earliness mix.

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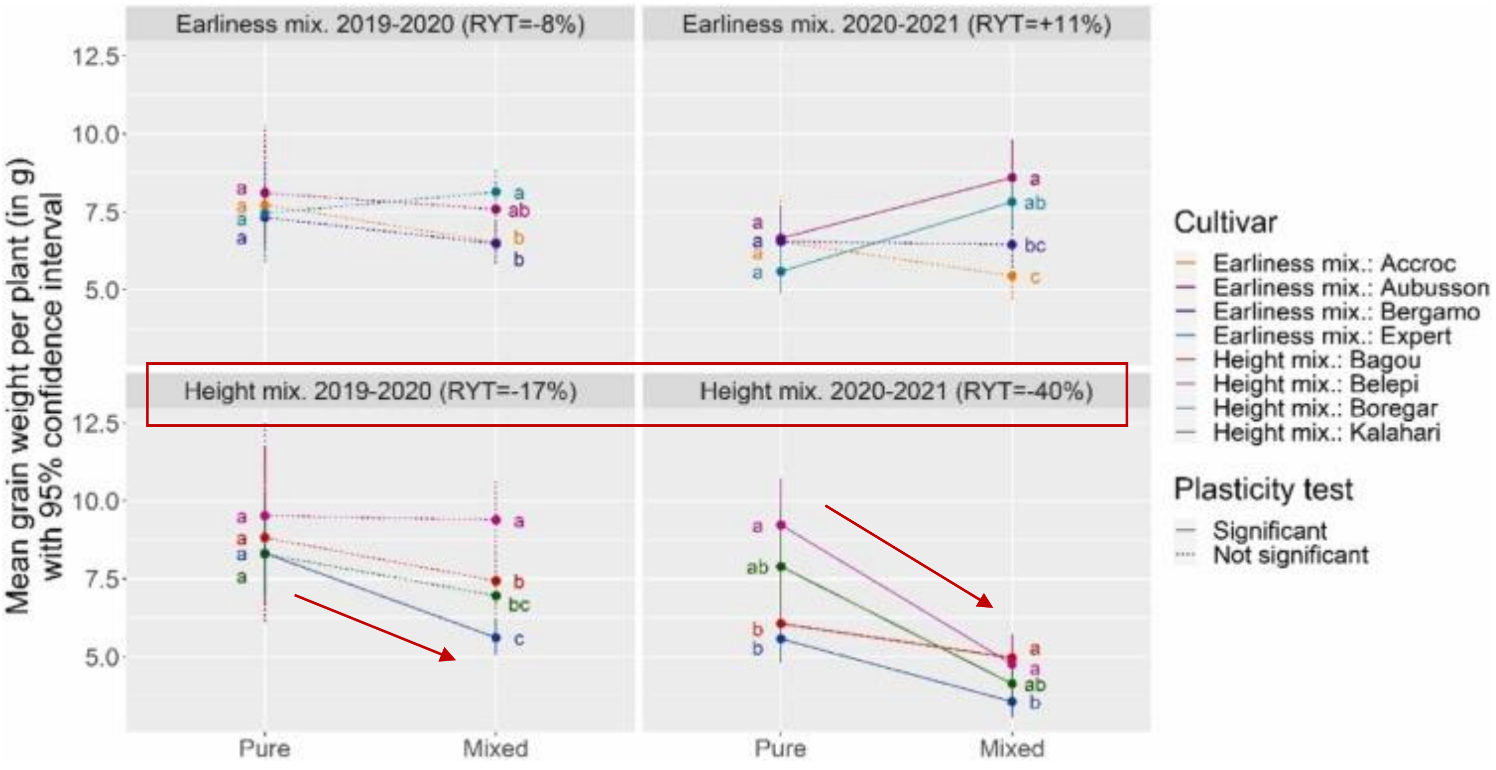

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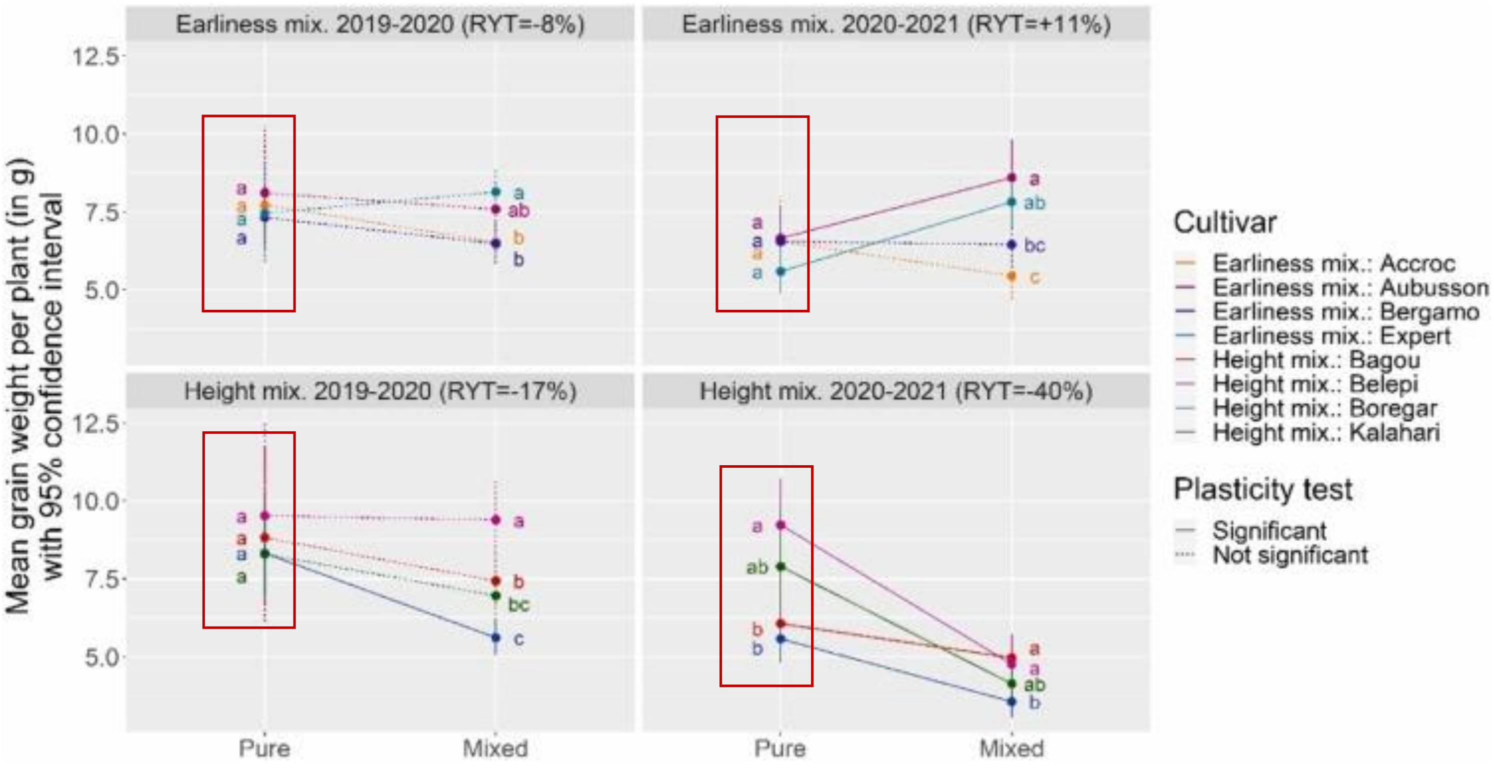

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  - Similar performance in pure

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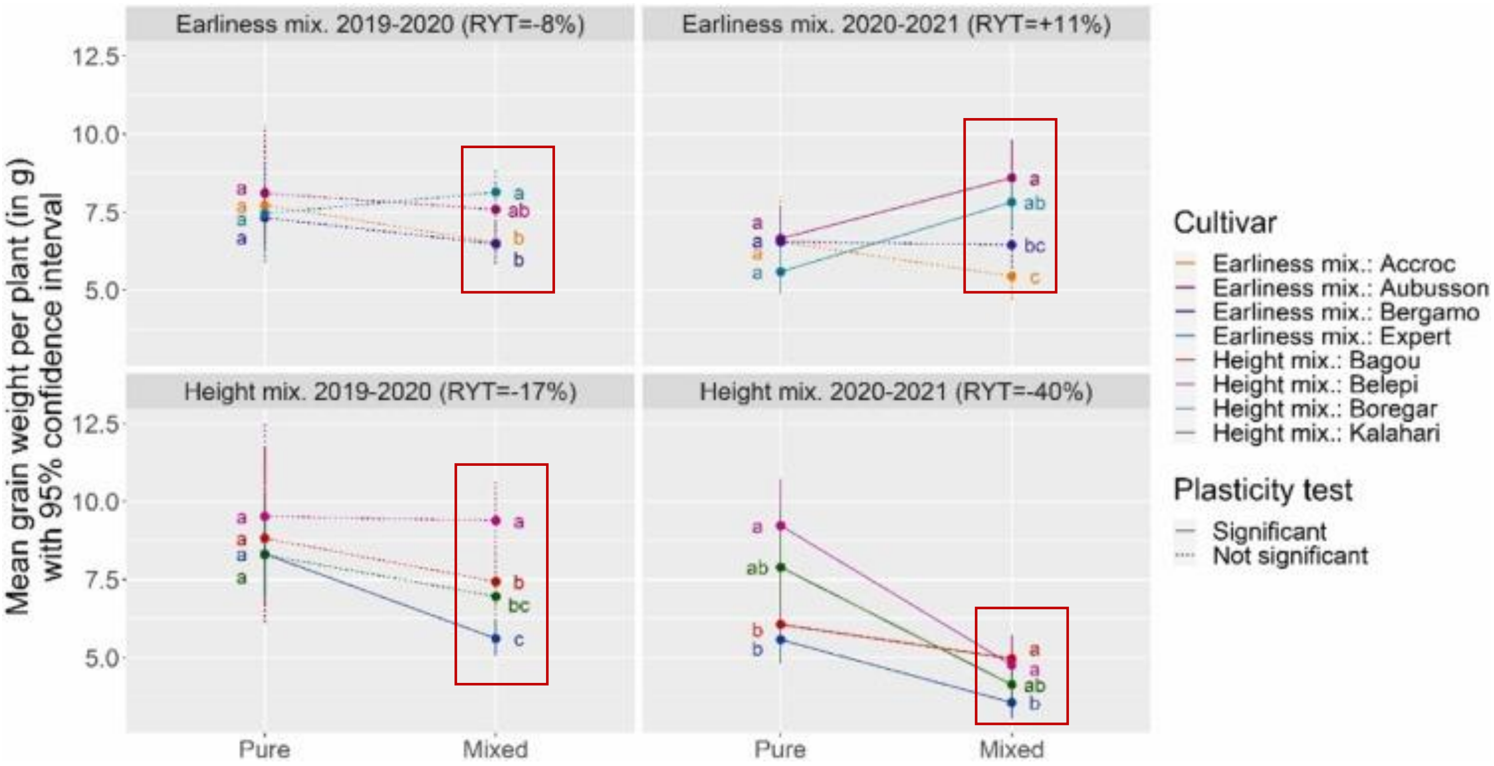

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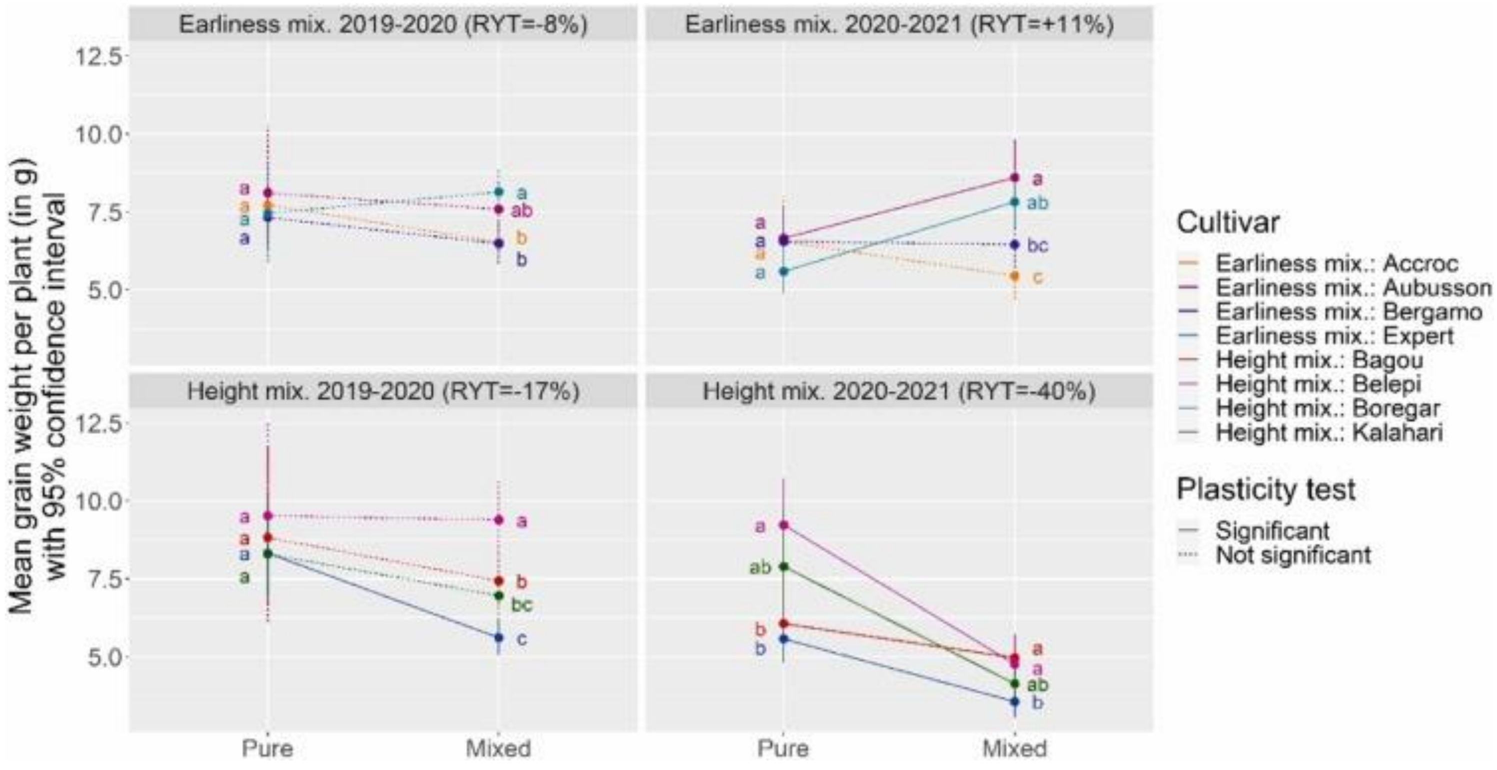

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  - Similar performance in pure
  - Rankings in mixture
    - Earliness mix. → Aubusson (early) and Expert
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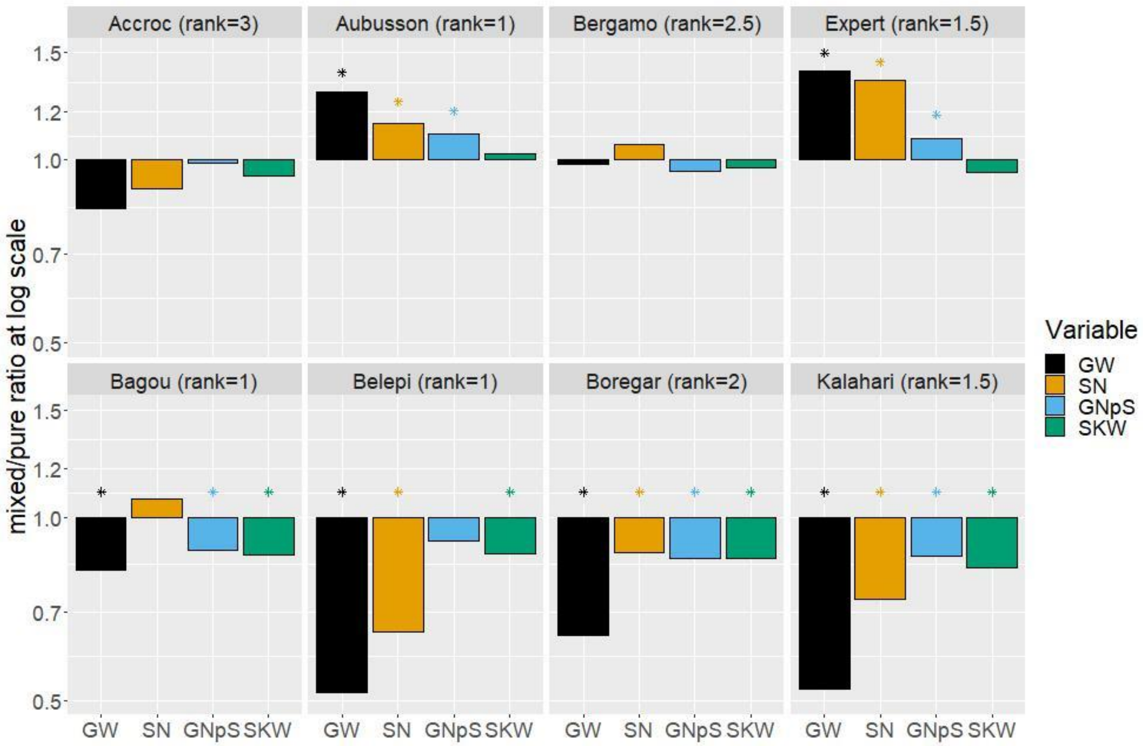
- Dominance in mixture not necessarily due to earliness or height at maturity
- Strong year effect but similar dominance rankings

Decomposition of yield plasticity

- Yield per plant, i.e grain weight (GW) can be decomposed into spike number/plant (SN), grain number per spike (GNpS) and single kernel weight (KW) → so we propose a way to decompose its plasticity
- $GW = SN \times GNpS \times SKW \Leftrightarrow \log\left(\frac{GW_{mix}}{GW_{pure}}\right) = \log\left(\frac{SN_{mix}}{SN_{pure}}\right) + \log\left(\frac{GNpS_{mix}}{GNpS_{pure}}\right) + log(\frac{SKW_{mix}}{SKW_{pure}})$, where ratios are plasticity indicators



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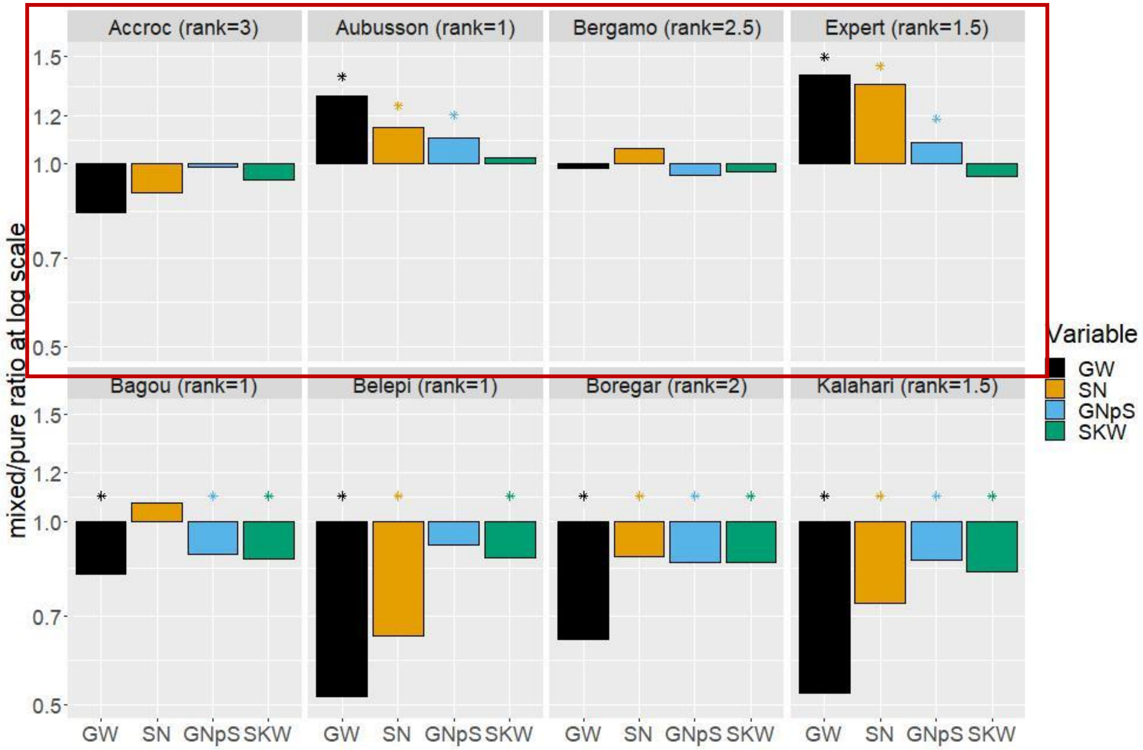

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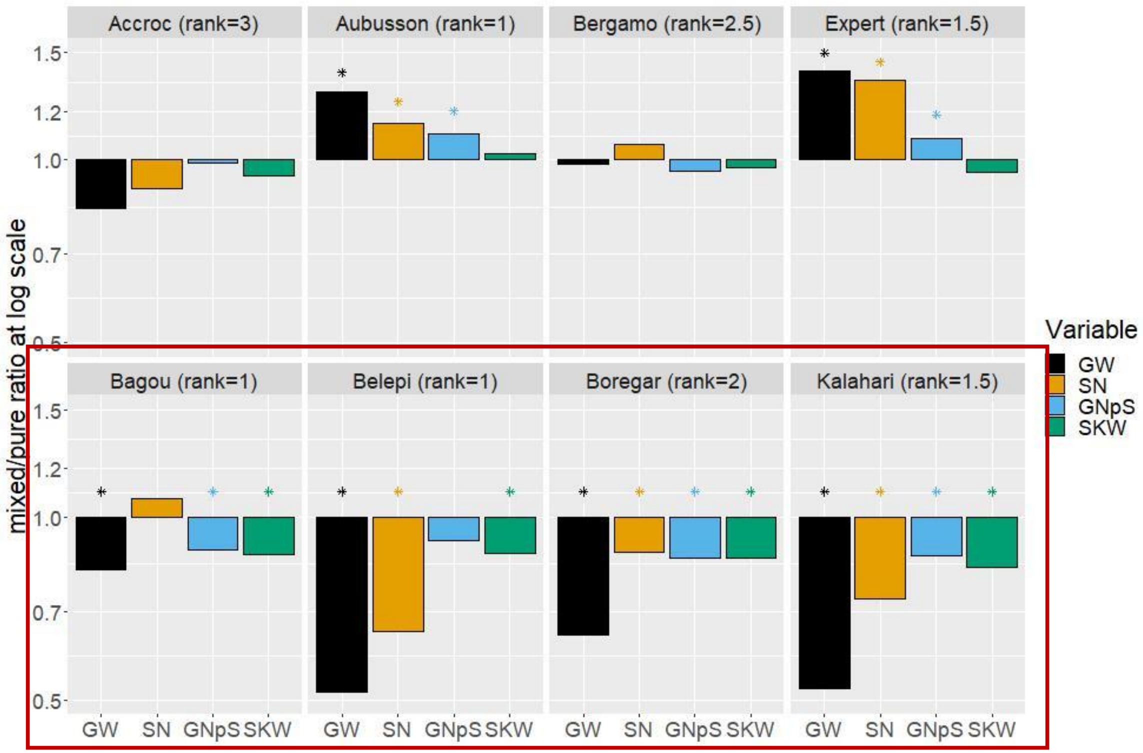

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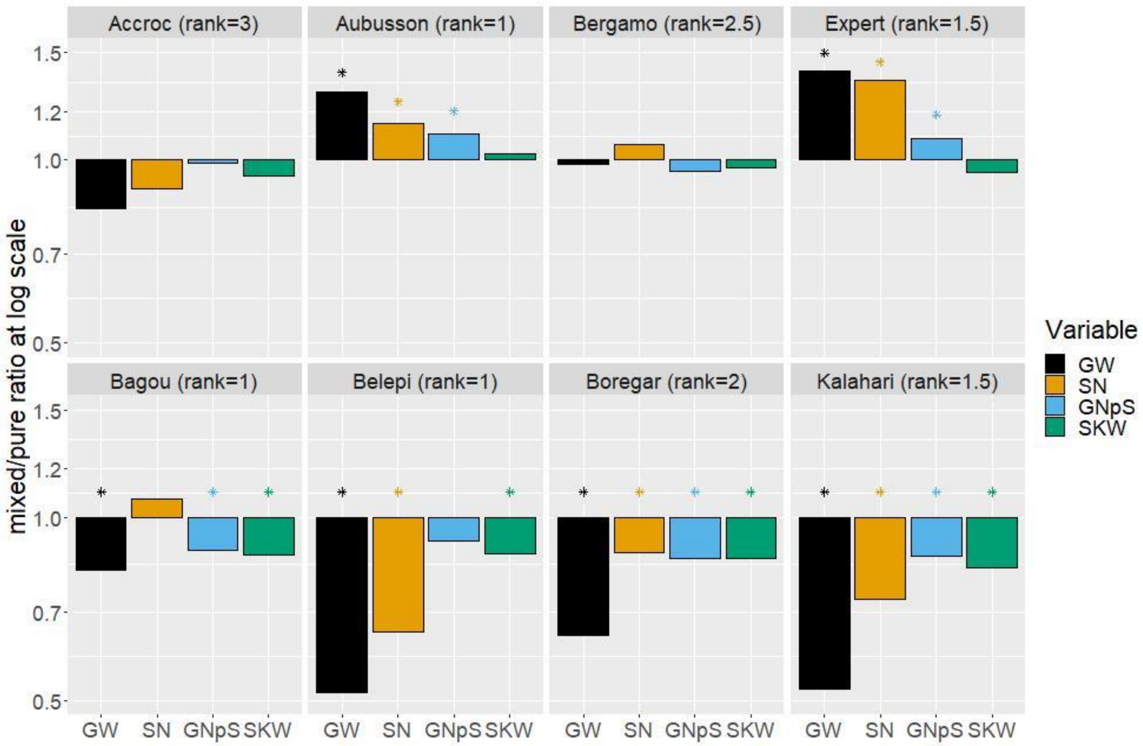
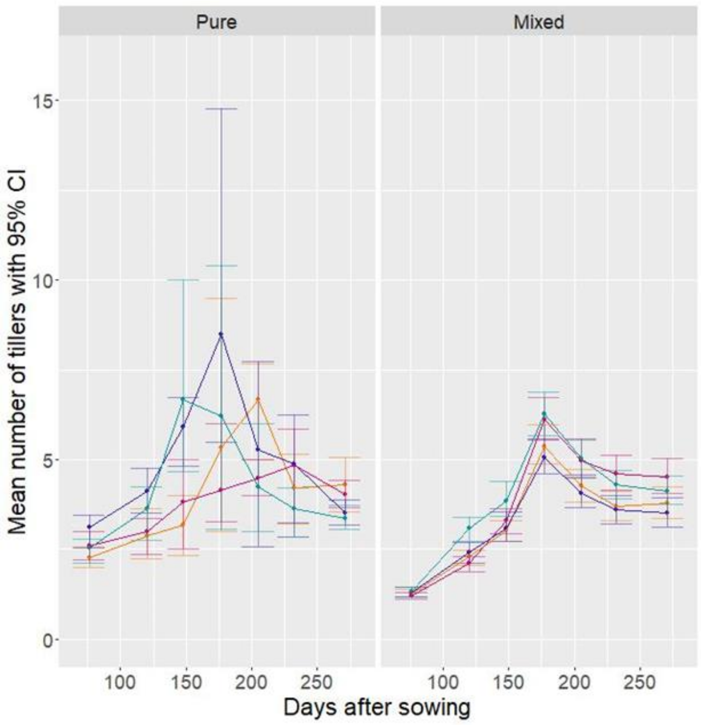
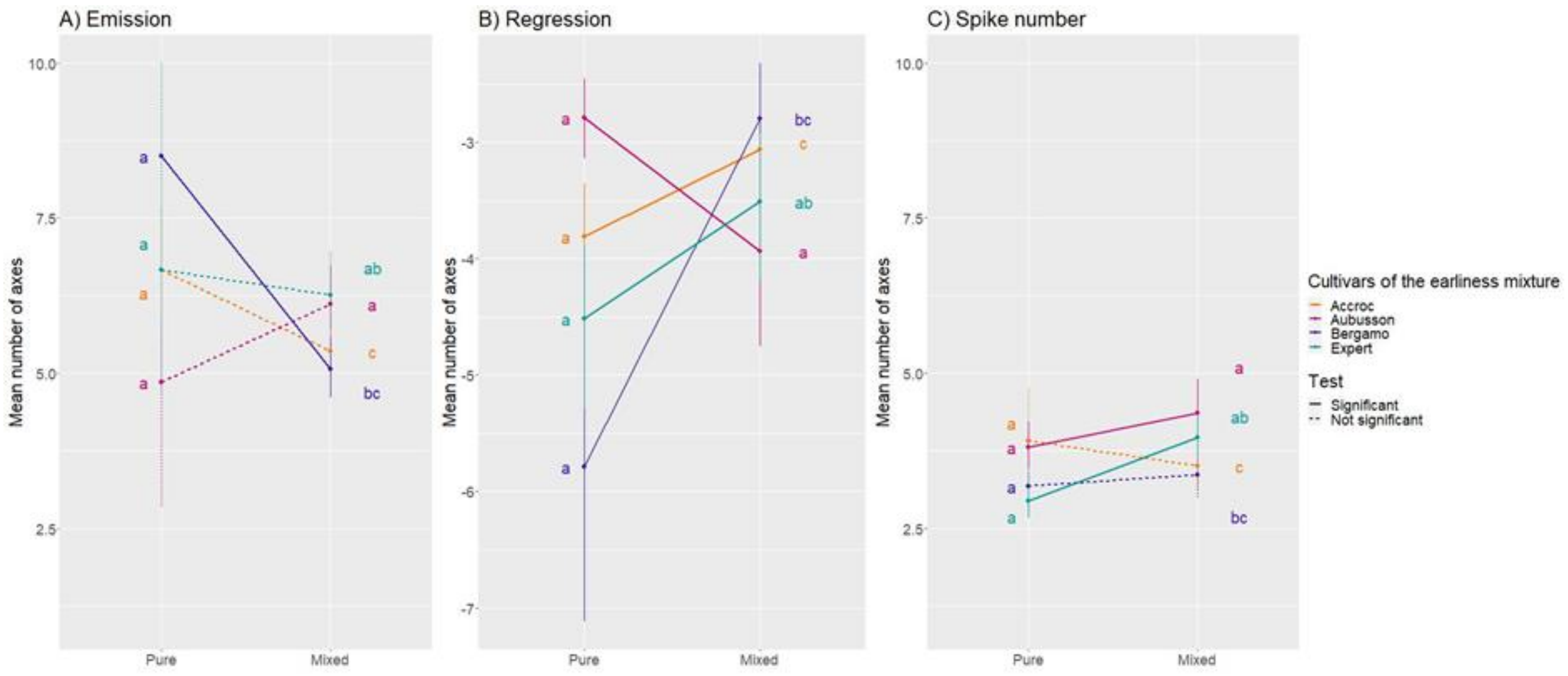


- Ratio above 1 → higher mean in mixture
- Earliness mix. → positive mixture effect on SN and GNpS
- Height mix. → negative mixture effect on all components
- SN is the major contributor (highest absolute value) in most cases
- Variations in GW are mostly due to variations in SN

Decomposition of tillering dynamics

- Plasticity in spike number is directly related to tillering plasticity with two aspects: cessation and regression, so SN can be decomposed as the maximum tiller number (MTN) minus the number of regressed tillers (NRT)
- $SN = MTN + (-NRT) \Leftrightarrow SN_{mix} - SN_{pur}$ = $(MTN_{mix}$ - $MTN_{pur})$ + -$(NRT_{mix}$ - $NRT_{pur})$, where differences are plasticity indicators





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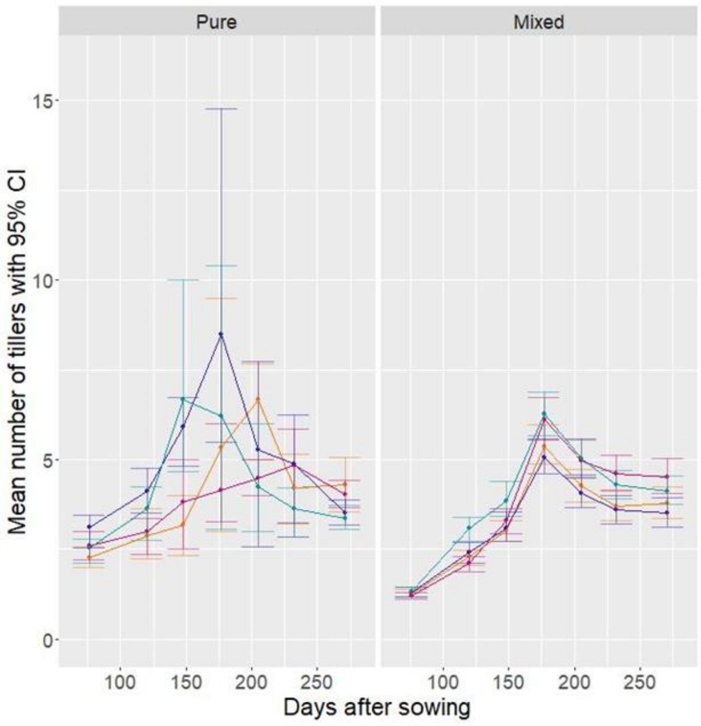

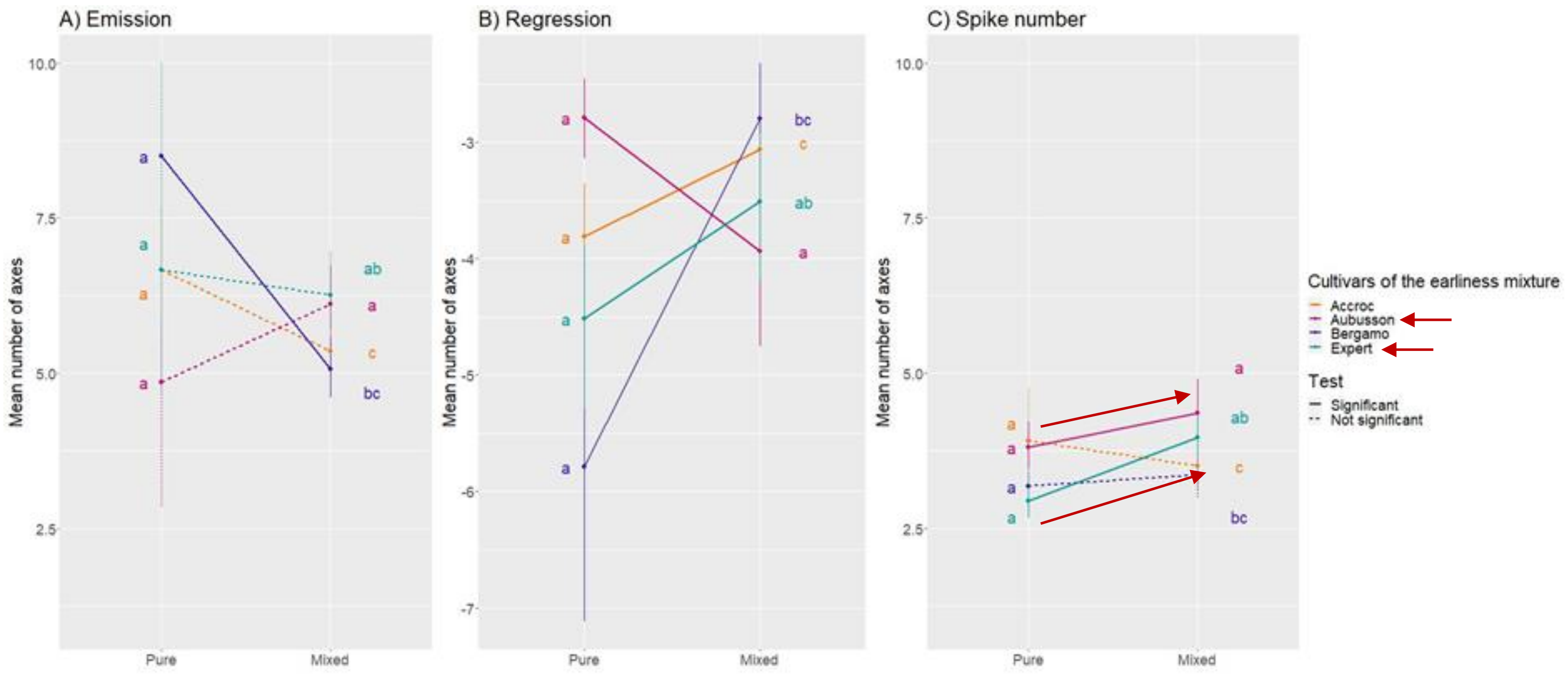

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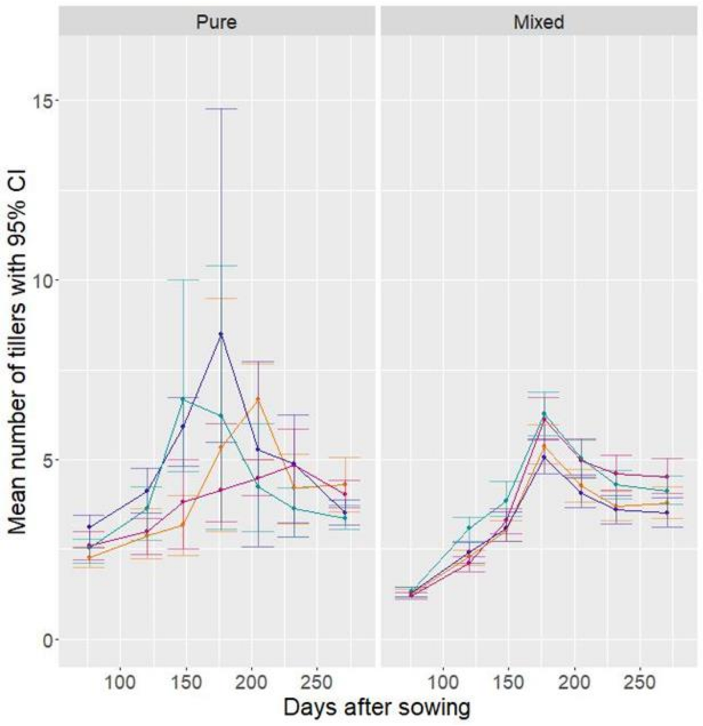

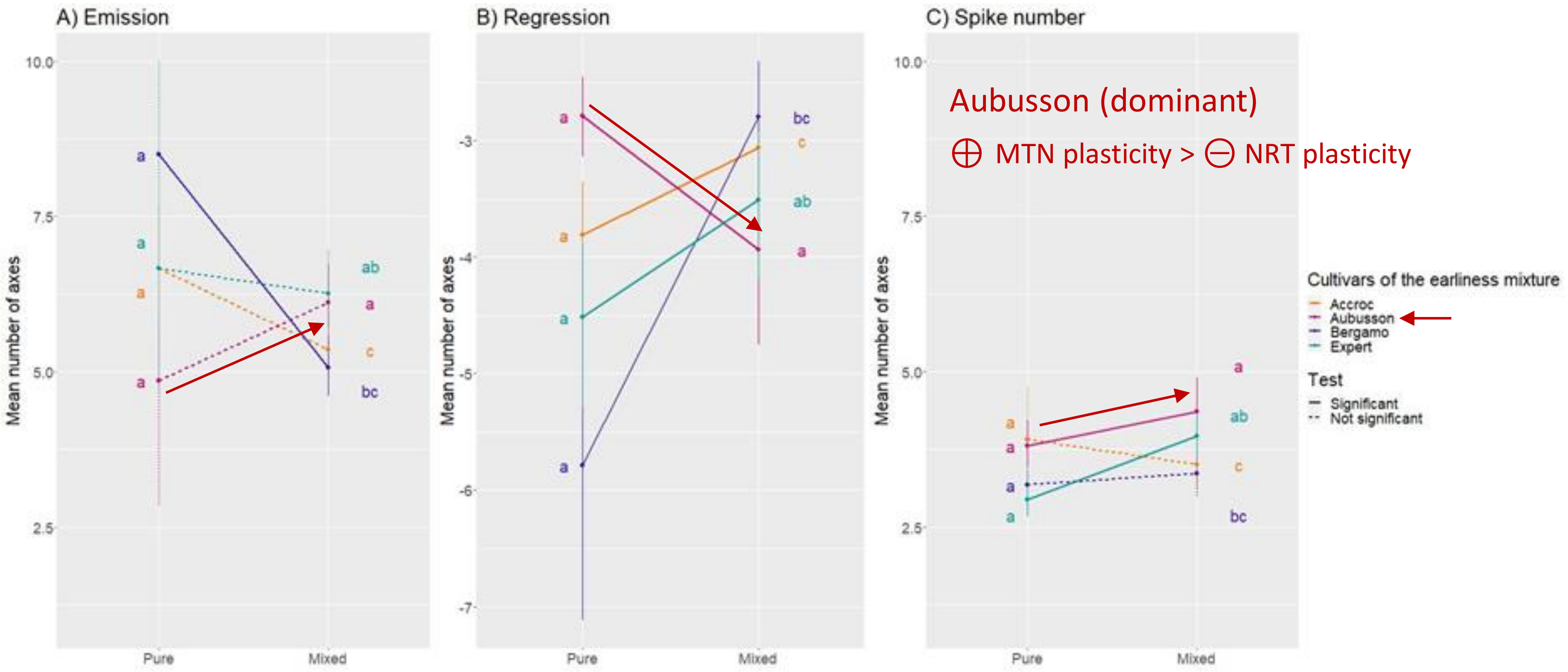

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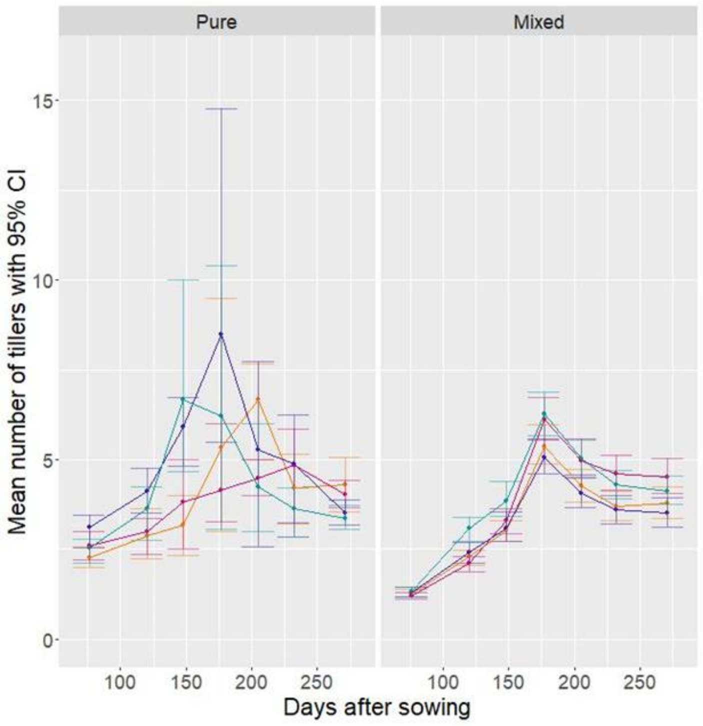

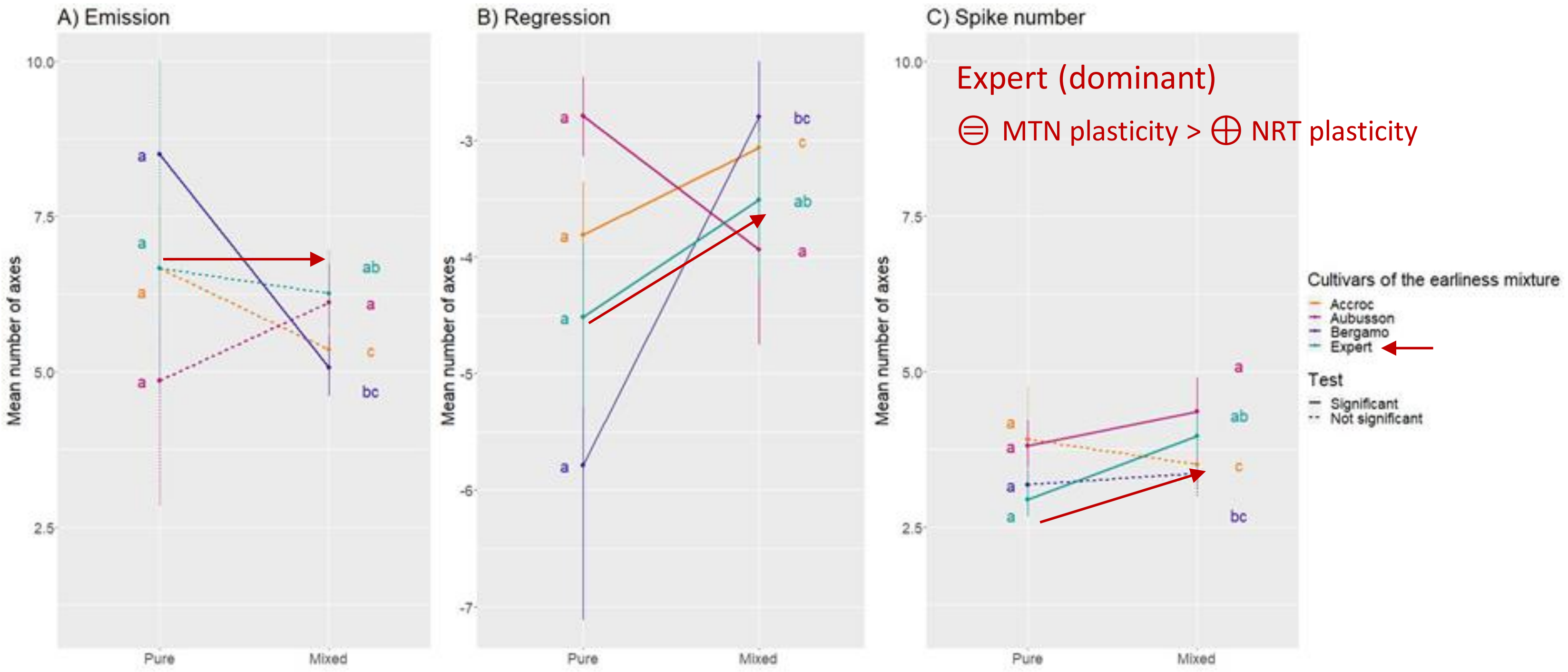

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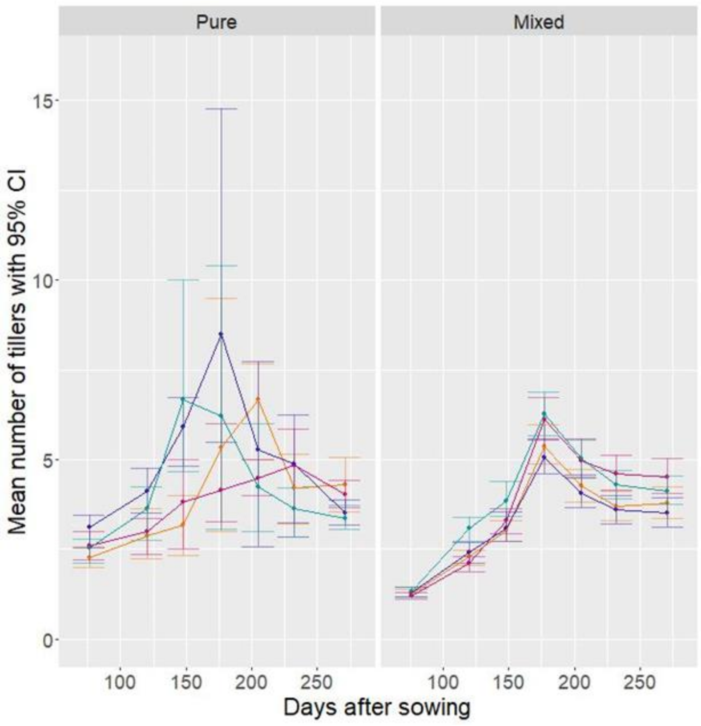
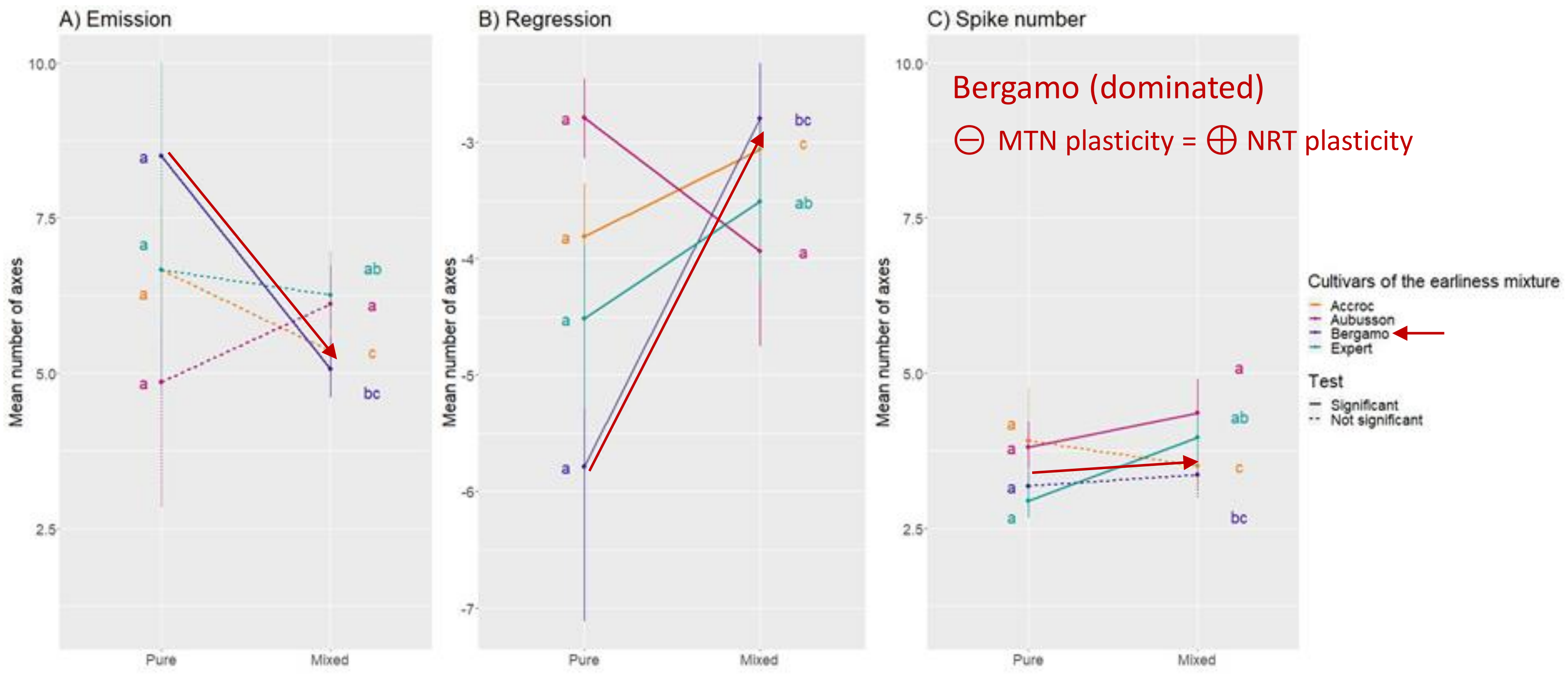
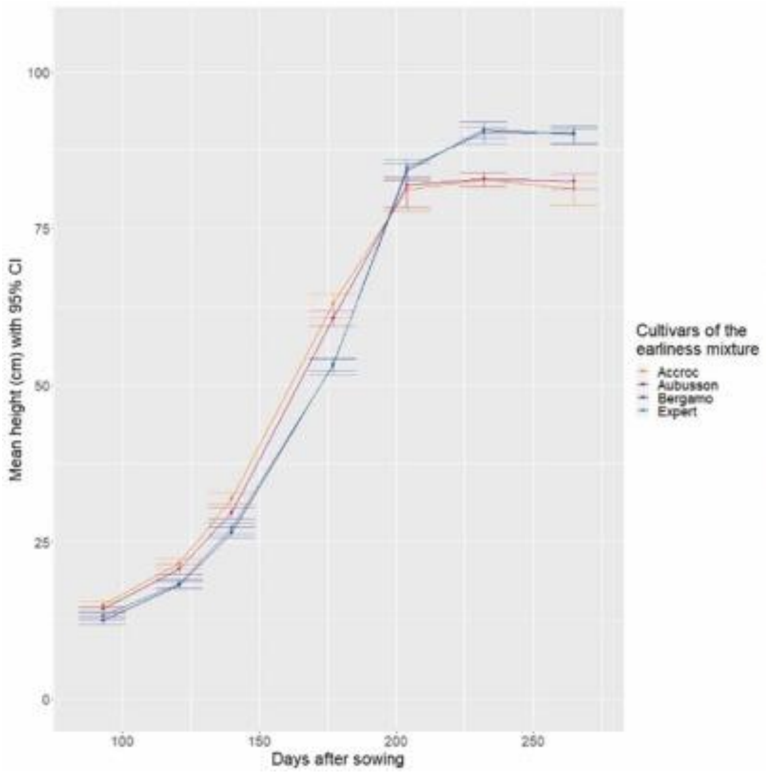
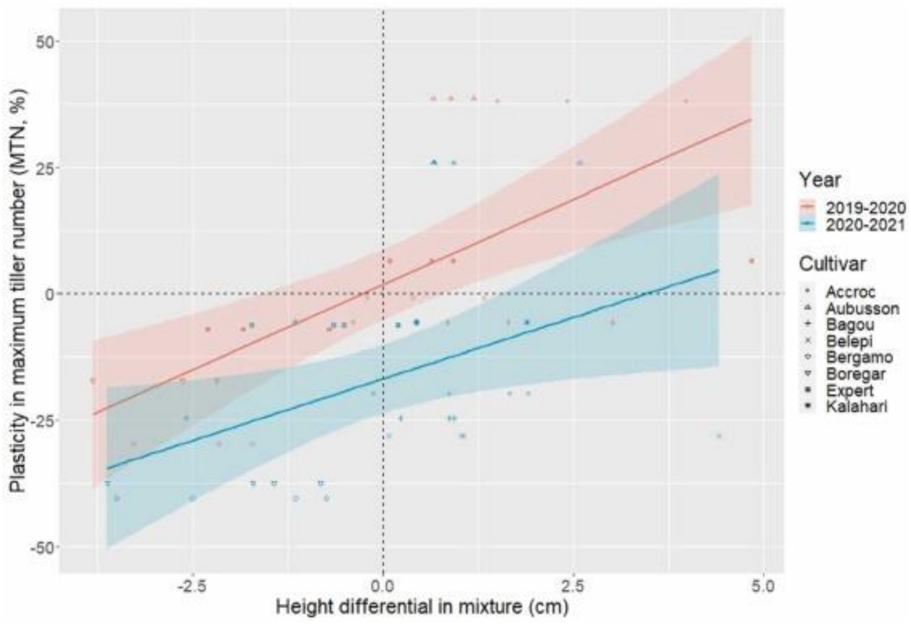




Decomposition of yield plasticity

- Plasticity in tiller emission, i.e. in maximum tiller number (MTN) is correlated to height difference between cultivars in mixture during the period of emission





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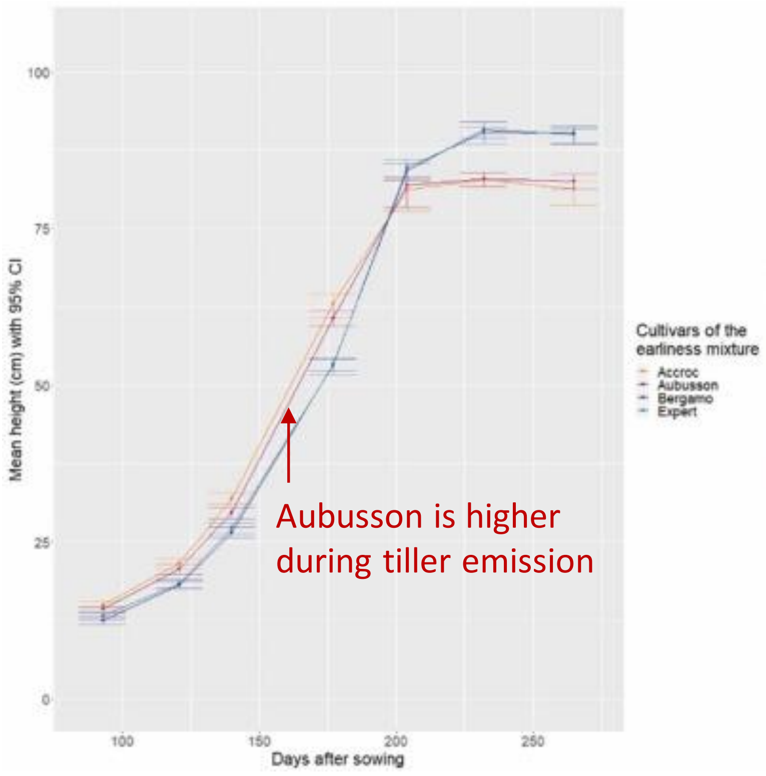

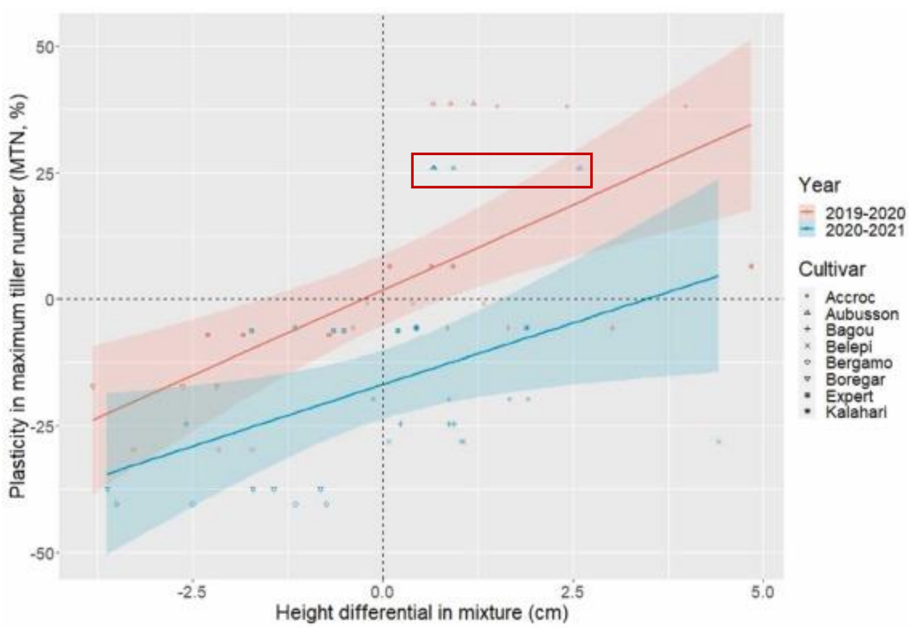

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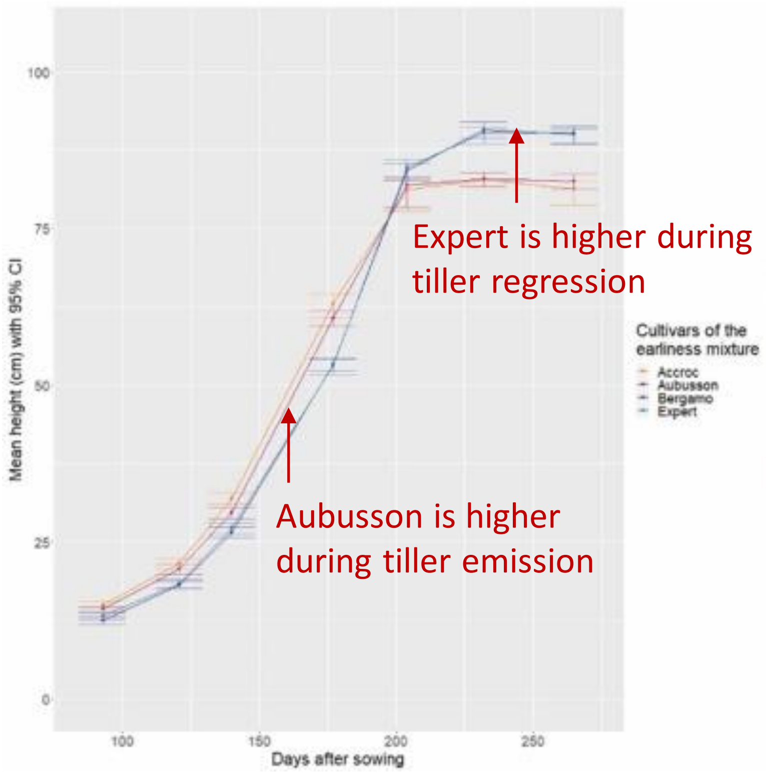
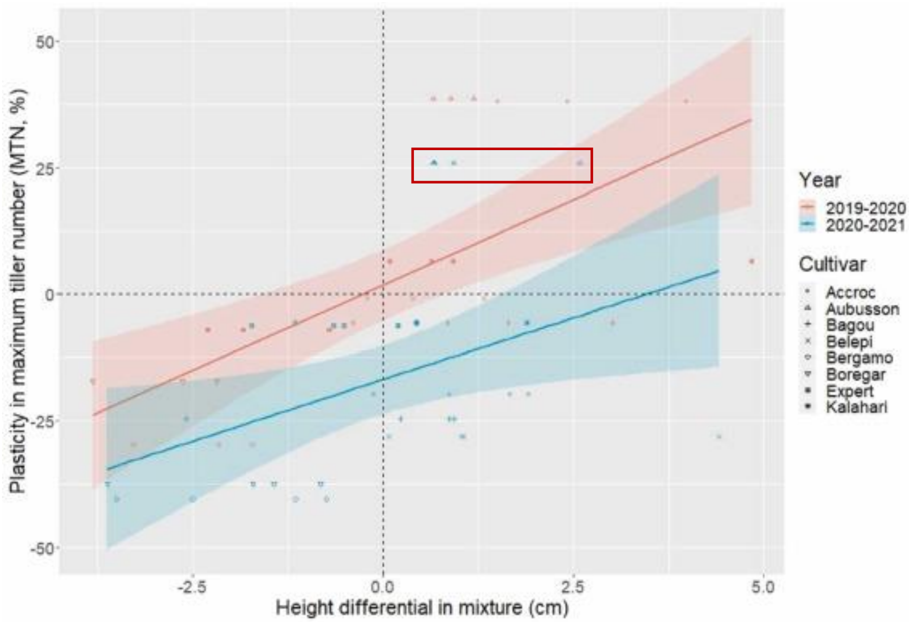
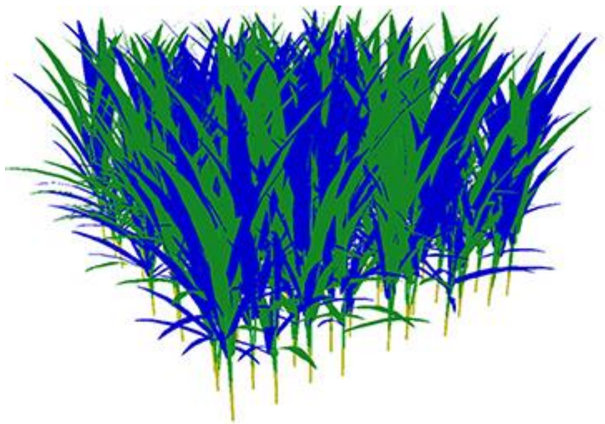


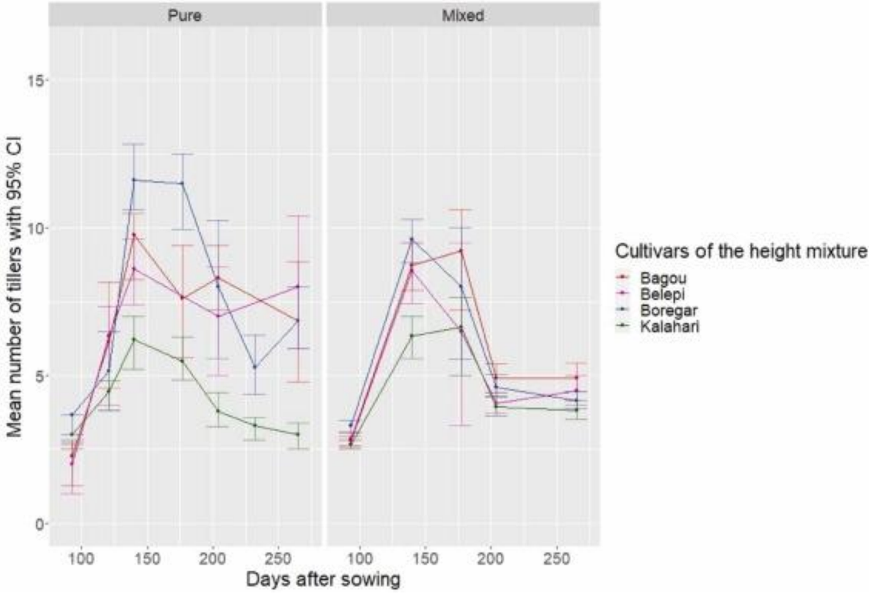


- Tiller emission
  - Earlier cultivars are higher
  - Significant effect of height differential on MTN plasticity
- Tiller regression
  - Later cultivars are taller
  - Significant effect of height differential on NRT plasticity only in 2020
  - But also significant effect of MTN plasticity on NRT plasticity (stronger emission → stronger regression)

Conclusion and perspectives

- Yield variation in mixtures mainly explained by spike number plasticity as the result of plastic tillering dynamics for cessation and regression, often compensating each other → outputs depends on compensation level
- Tillering plasticity is explained by height differentials between cultivars in mixtures as a shade avoidance response
- Dominant cultivars are not necessarily the earliest or tallest ones → the ones expressing positive plastic overcompensation either for cessation or regression of tillers
- What about (de-)canalization, i.e differences in variance between pure and mixed stands? Tillering dynamics notably seem to converge in mixtures
- First acquisition of dynamic plant scale data in wheat cultivar mixtures in field conditions → major interest for the calibration/validation of Functional-Structural Plant Models (FSPMs)





Thank you for your attention !

For more information meije.gawinowski@inrae.fr

Published results in (Gawinowski et al., 2024) Gawinowski, M., Enjalbert, J., Cournède, P.-H., Flutre, T., 2024. Contrasted reaction norms of wheat yield in pure vs mixed stands explained by tillering plasticities and shade avoidance. Field Crops Res. 310, 109368. https://doi.org/10.1016/j.fcr.2024.109368