Quantifying and mitigating shading effects in winter barley trials

Joint work with Adrian Roberts and Tess Vernon

Acknowledgements: AHDB (Cereals and Oilseeds) & BSPB.

Overview

- Introduction
- Shading models
- Results
- Mitigation options
- Conclusions

Winter barley shading

- Breeders' concerns over possible impact on varietal decisions
  - **"Do taller varieties stunt the yields of neighbouring shorter varieties?"**
  - initially posed in terms of **2-row vs. 6-row**

- BioSS asked to investigate
  - **magnitude** of any shading effect
  - possible **mitigations**

UK testing system

National List (NL)

- 2 years of testing for Value for Cultivation and Use
- Trials across the UK
- Successful candidates go onto the National List (marketable)

Recommended List (RL)

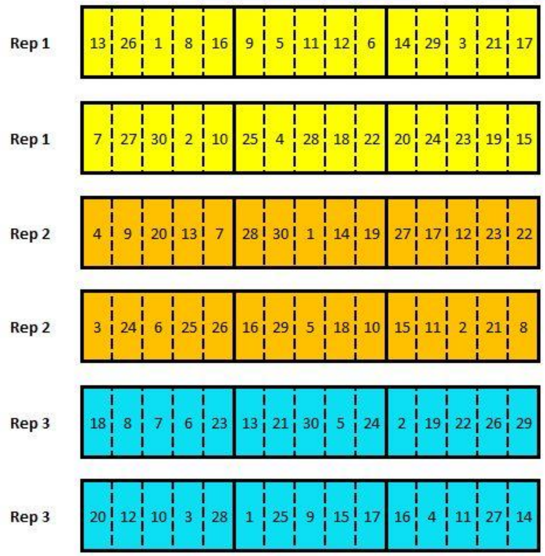
- Further post-registration testing for recommendation

- Yield, agronomic and disease data collected.
- **Primary** determinant of value is **yield**.

Trial design

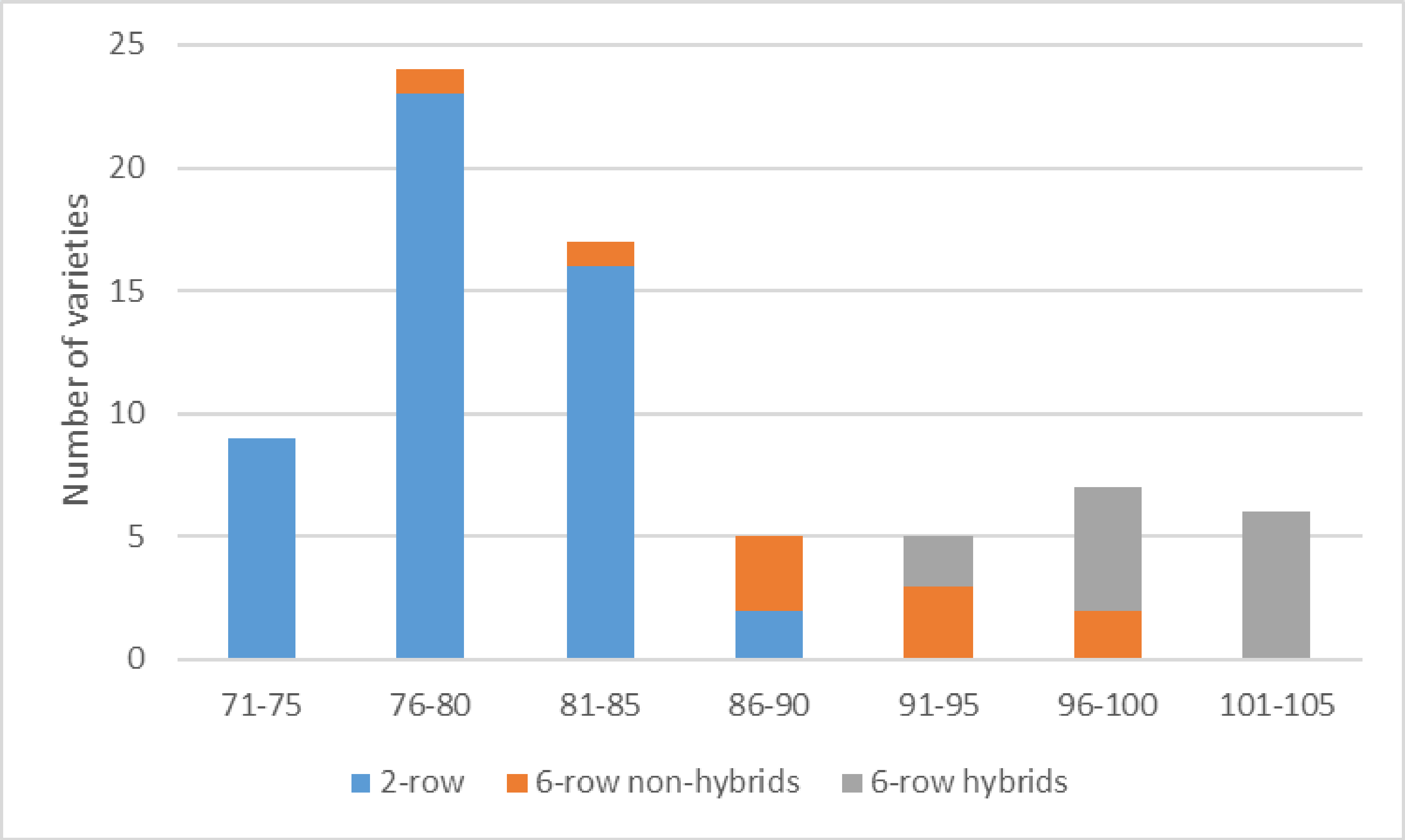
- Alpha-lattice designs
- Individual plots – approx. 9.5m x 2m
- Assortment of possible layouts – **plots border on long side**

e.g.

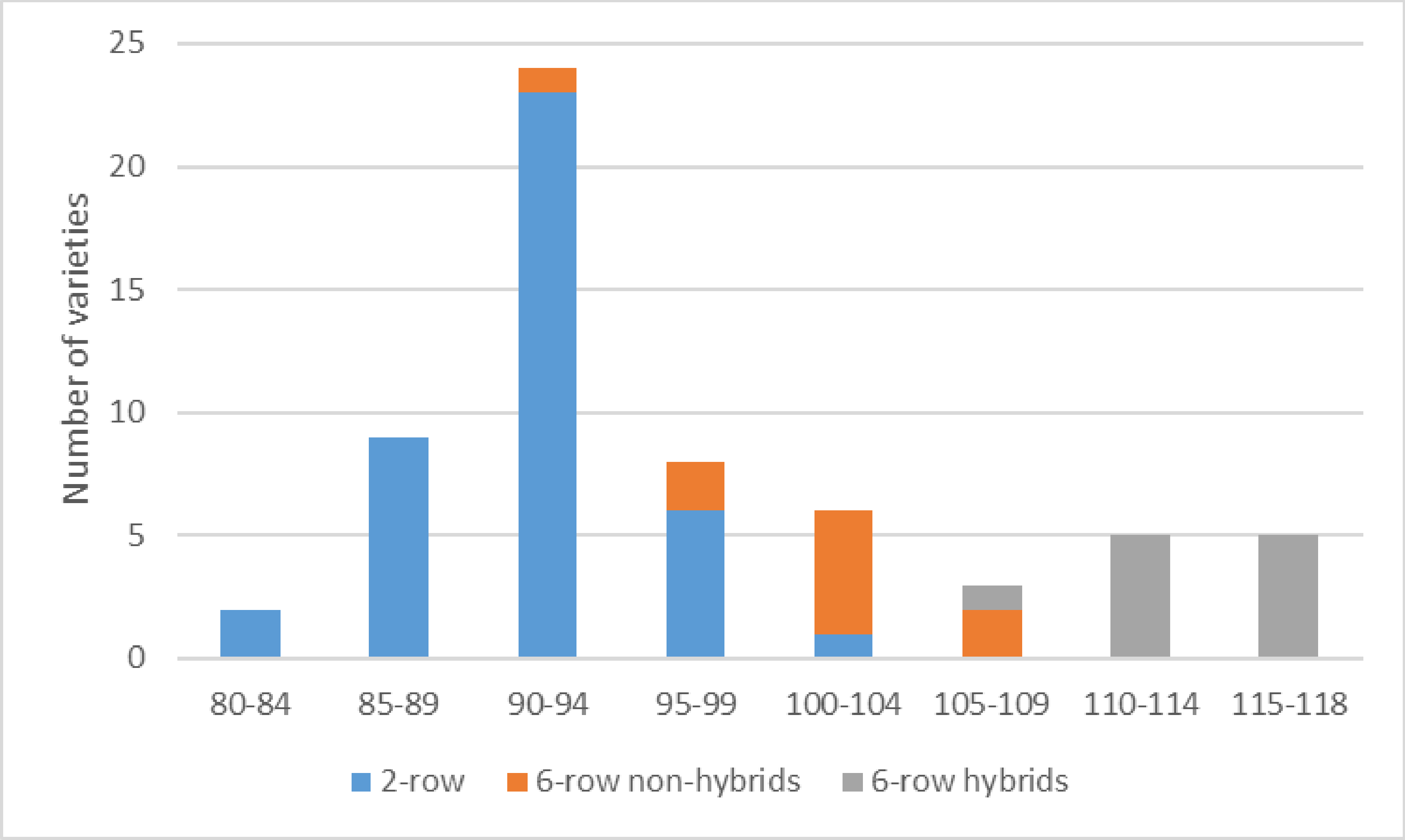


Unlike what a farmer does!

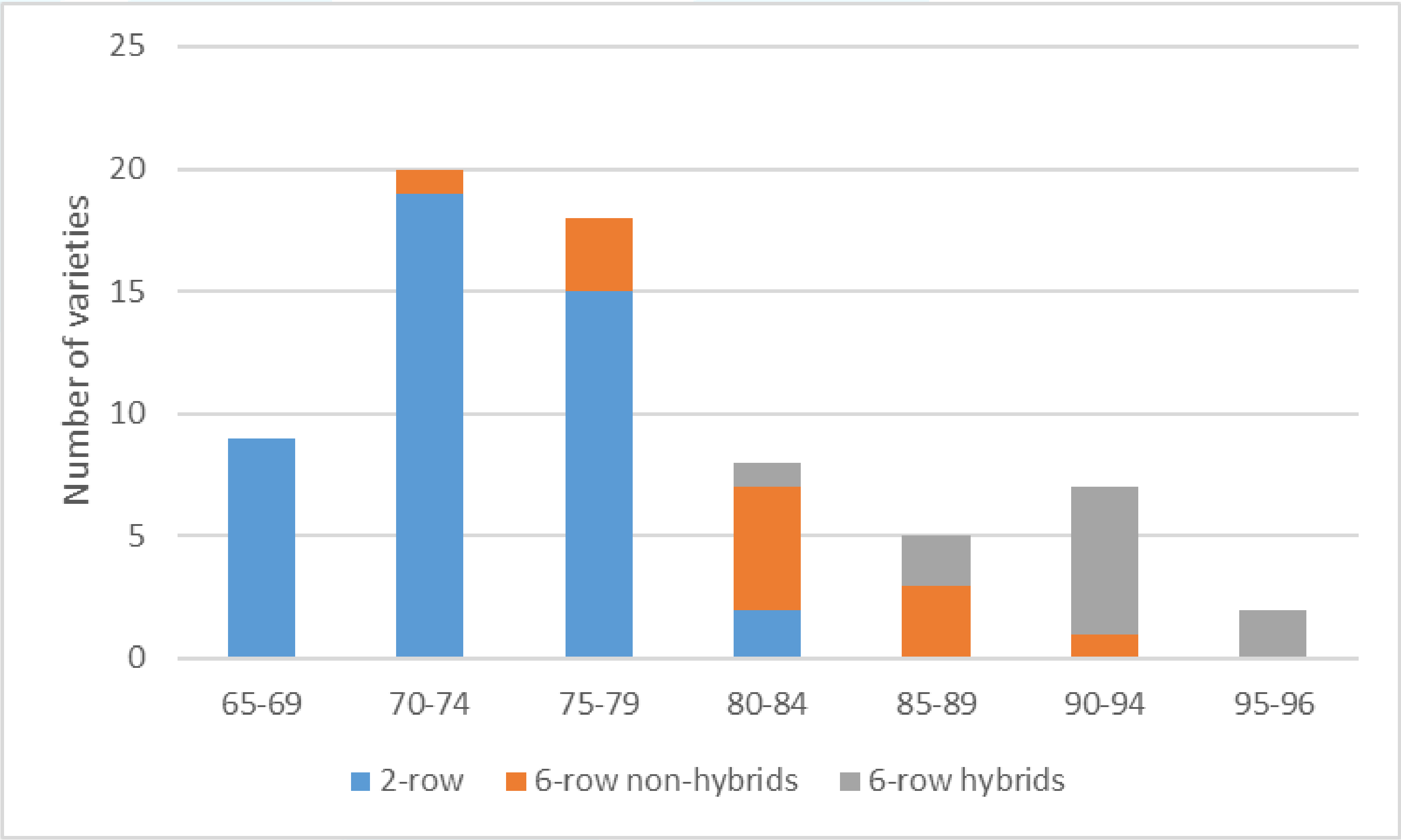
Over-trials varietal straw length means (cms) in 2018 Treated NL trials



Over-trials varietal straw length means (cms) in 2019 Treated NL trials



Over-trials varietal straw length means (cms) in 2020 Treated NL trials



Historic interference/competition model

<u>Simple model (1990s):</u> α_i = shading effect of variety i.

Plot yield = Grand mean + Replicate effect + Variety effect + Interference effects on plot + random error

Plot 1 Vty 9	Plot 2 Vty 3	Plot 3 Vty 66	Plot 4 Vty 39	Plot 5 Vty 10	…

$+\alpha_9$ $-\alpha_3$	$-\alpha_9$ $+2*\alpha_3$ $-\alpha_{66}$	$-\alpha_3$ $+2*\alpha_{66}$ $-\alpha_{39}$	$-\alpha_{66}$ $+2*\alpha_{39}$ $-\alpha_{10}$	etc

Historic interference/competition model

$$Y_{ij} = \mu + \beta_{[j]} + v_i + \sum_{k=1}^{v} \alpha_k Z_k + e_{ij}$$

for i=1,….v varieties, and j=1….n plots.

v_i is the effect of variety I in a pure stand (neighboured by itself).

$\beta_{[j]}$ is the block effect for the block containing plot j.

α_k is the interference effect associated with variety k.

Z_k is the dummy covariate for variety k with corresponding plot elements of 2, 1, -1 or 0 depending on circumstances.

N.B. Variety-specific shading effects here are *fixed* effects.

Shading – dataset coding

Plot	Variety	x[1]	x[2]	x[3]	x[4]	x[5]	x[6]	x[7]
:	:	-1	:	:	:	:	:	
10	1	2	-1	0	0	0	0	0
11	2	-1	2	-1	0	0	0	0
12	3	0	-1	2	-1	0	0	0
13	4	0	0	-1	2	-1	0	0
14	5	0	0	0	-1	2	-1	0
15	6	0	0	0	0	-1	2	-1
16	7	0	0	0	0	0	-1	2
:	:	:	:	:	:	:	:	-1

Individual variety-specific shading effect covariates

Historic interference/competition model

- Variety-specific shading effects here were *fixed* effects.
- Hence 2 d.f. used for each variety – direct & shading effects
- Hence impossible to fit model to 2-rep trials!
- **Varietal estimates of shading can be very variable with large s.e.**
- **Asking a lot of the data!**

New shading models

Model 0 – No shading (baseline)

Model 1 - Variety-specific (random)

Model 2 – Height differences

Model 3 – Row-type

Model 4 – Hybrid status

Model 5 – Row-type and hybrid status

Random variety-specific shading

Plot	Variety	x[1]	x[2]	x[3]	x[4]	x[5]	x[6]	x[7]
:	:	-1	:	:	:	:	:	
10	1	2	-1	0	0	0	0	0
11	2	-1	2	-1	0	0	0	0
12	3	0	-1	2	-1	0	0	0
13	4	0	0	-1	2	-1	0	0
14	5	0	0	0	-1	2	-1	0
15	6	0	0	0	0	-1	2	-1
16	7	0	0	0	0	0	-1	2
:	:	:	:	:	:	:	:	-1

Create matrix of x[1…v] covariates & fit matrix as random term

Potential shrinkage in shading effects. Better residual d.f. position.

Shading covariates for height & row-type etc.

Plot	Variety	str_length	2-row	hybrid	ht diff	Row diff	Hybrid Diff
:	:	:	:	:	:	:	:
10	1	80	1	0	:	:	:
11	2	111	0	1	41	-1	2
12	3	101	0	0	-5	0	-1
13	4	96	0	0	2	-1	0
14	5	89	1	0	-11	1	0
15	6	93	1	0	-2	0	0
16	7	99	1	0	:	:	:
:	:	:	:	:	:	:	:

e.g. Plot 11 Straw length diff: 2(111)-80-101 = (111-80) + (111-101)=41

Hybrid diff: 2(1) - 0 - 0 = 2

Model fit comparisons (1)

Models differing in random effects only

No shading vs. *random* variety-specific shading effects

Models differing in fixed effects only (some nested)

Comparison of any pair of models except *random* variety-specific shading effects

Models differing in both fixed and random effects

All comparisons with variety-specific shading (random) model

Model fit comparisons (2)

<u>**Comparison of models differing in fixed effects**</u>

Problematic with REML-based AIC and BIC

Residual likelihoods are not comparable

Verbyla (2019): Full likelihood can be decomposed into two parts:

- Marginal likelihood (residual likelihood)
- Conditional likelihood (fixed effects estimation based on this)

Model fit comparisons (3)

Comparison of models differing in fixed effects

Evaluate FULL likelihood at REML estimates

Use full-likelihood based AIC or BIC for model comparisons

Consequently

Information criteria account for both:

- Fixed effects parameters
- Variance parameters

Full likelihood AIC & SEDs in 2019

No shading and variety-specific shading models

BioSS

	Increase in AIC	Shading model		Av SED	Av SED	Range for shading
Trial	Vty model	Shading VC	Residual VC	None	Vty	Effect as % of vty mean
1	17.4	0.0111	0.2270	0.499	0.573	1.14%
2	30.5	0.0273	0.1750	0.510	0.670	2.47%
3	19.3	0.0032	0.0957	0.273	0.315	0.72%
4	31.8	0.0213	0.0623	0.277	0.403	3.66%
5	39.3	0.0275	0.1280	0.373	0.544	3.88%
6	28.8	0.0326	0.1710	0.482	0.645	3.81%
7	28.5	0.0352	0.1020	0.334	0.480	4.50%
8	26.8	0.0039	0.0768	0.268	0.327	0.84%
9	-5.6	0.0579	0.0760	0.346	0.465	9.46%

Baseline vs. random variety-specific shading effects

Generally

Inclusion of random variety-specific shading:

- Shading variance component >0

  but

- SEDs for variety comparisons increase
- Reflected generally in increase in AIC
  Exception for largest single shading variance component.

Changes in full likelihood AIC from baseline model in 2019 trials

BioSS

Trial	Model 2 Straw length	Model 3 Row-type	Model 4 Hybrid status	Model 5 Row-type + hybrid status
1	-47.2	-21.9	-25.1	-27.9
2	1.2	1.2	1.0	3.8
3	-11.8	-6.1	-8.5	-7.4
4	-48.4	-35.1	-20.1	-34.0
5	-30.9	-20.2	-22.5	-23.8
6	-15.9	-11.4	-12.2	-12.7
7	-58.3	-44.1	-60.3	-65.5
8	-15.0	-18.7	-8.8	-16.7
9	-71.9	-46.1	-48.6	-56.5

Alternative height difference model

Plot 12: 101 cm **Plot 13: 96 cm** **Plot 14: 89 cm**

Current height difference covariate for plot 13:

(96 – 101) + (96 – 89) = -5 +7 = 2

Alternative height difference covariate:

Min[(96 – 101), 0] + Min[(96 – 89),0] = -5 +0 = -5

Analysis shows poorer fit than current height difference approach.

Over-trials impact assessment

BioSS

For each shading model

Matrix of varieties-by-trials means from individual trials' analyses

FIXED : Variety
RANDOM : Trial + Trial.Variety

Obtain over-trials variety means.

Calculate variety deviations from baseline model as % of baseline.

Deviations from baseline as percentage of no shading means in 2019 (over-trials)

BioSS

Statistic	Variety-specific%	Straw length%	Row%	Hybrid%	Row + hybrid %
Maximum	1.84	3.98	2.18	2.01	2.50
Minimum	-2.78	-5.42	-3.42	-4.59	-4.71
Median	0.21	0.88	1.32	0.82	1.27
Lower quartile	-0.63	-1.36	-2.76	0.44	-1.32
Upper quartile	0.94	1.59	1.52	1.10	1.57

- Positive medians – Most varieties are 2-row, shorter and hence adjusted upwards.
- Range narrower for row-type model as height within row-type ignored.

Ways to mitigate?

Potentially one (or more) of:

- Trial protocol amendments
- Statistical analysis
- Statistical design

Mitigation by Trial protocol

Possible options

- Larger plots – harvesting central rows
- Border row plots

Outcome

Potential to remove / reduce the problem at source

Trial much larger – Very expensive!

Mitigation by statistical analysis?

- **Improvement over doing nothing BUT**
- **Adjustments dependent on choice of model fitted**
- **Imprecision in adjustments**
- **Estimating even a 1% shading effect precisely is important.**

- Any adjustment would currently need to be done at the individual trial level.
- **Questionable whether interference effects can be estimated sufficiently well for this.**
- Maybe including more advanced spatial modelling would improve precision but sufficiently? (Stringer *et al.*)

Mitigation by statistical analysis?

Some other considerations

- Using row-type as a proxy for height has consequences.
- Potential danger of adjusting for height differences if short height and low yield have a common driver within a trial.
- Shading effects on height itself!
- **Mitigation by analysis NEVER previously adopted in U.K. for these reasons.**

Mitigation by statistical design?

ONLY REDUCES impact of shading.

1. Genetically determined sections within each replicate

2. Neighbour restricted designs (David et *al.*)

Mitigation by statistical design

Genetically determined sections designs

- Group 1: 2-row varieties. Group 2: 6-row non-hybrid varieties.
  Group 3: 6-row hybrid varieties.
- Insert buffers between group sections.

REP 1		GROUP 1		GROUP 2	GROUP 3
REP 2	GROUP 3		GROUP 1		GROUP 2
REP 3	GROUP 2	GROUP 3		GROUP 1	

Aims to reduce worst case shading effects.

Bias vs. precision trade-off.

Group allocation policy clear.

Possible at <u>all</u> stages of testing – **No advance height info needed!**

Mitigation by statistical design

Neighbour restricted alpha-lattice designs

- **Assign varieties to 3 interference groups on the basis of height.**
- Group 1 (shortest) varieties will not be next to Group 3 (tallest) varieties.
- **Only prevents the most extreme scenarios.**

- Applied within alpha design framework.
- v varieties; s small blocks / rep; k plots per small block.
- Group 2 must contain **at least** $2s$ varieties.

Mitigation by statistical design

Neighbour restricted alpha-lattice designs

BioSS

- Consider 3-rep trial. 20 varieties. Small blocks of 5 plots.
- Varieties assigned to one of three groups on height. Constraints on numbers per group
- Short [S] – 6 varieties
  Medium [M] – 8 varieties
  Tall [T] – 6 varieties

Block	I	II	III	IV
Rep 1	TTMSM	MSSMT	TMSSM	TMSMT
Rep 2	MSSMT	TMSSM	TMSMT	TTMSM
Rep 3	TMSMT	TMSMT	MSSMT	TMSSM

No tall variety next to a short variety (including at block boundaries)

Two approaches - slightly different bias vs. precision trade-offs.

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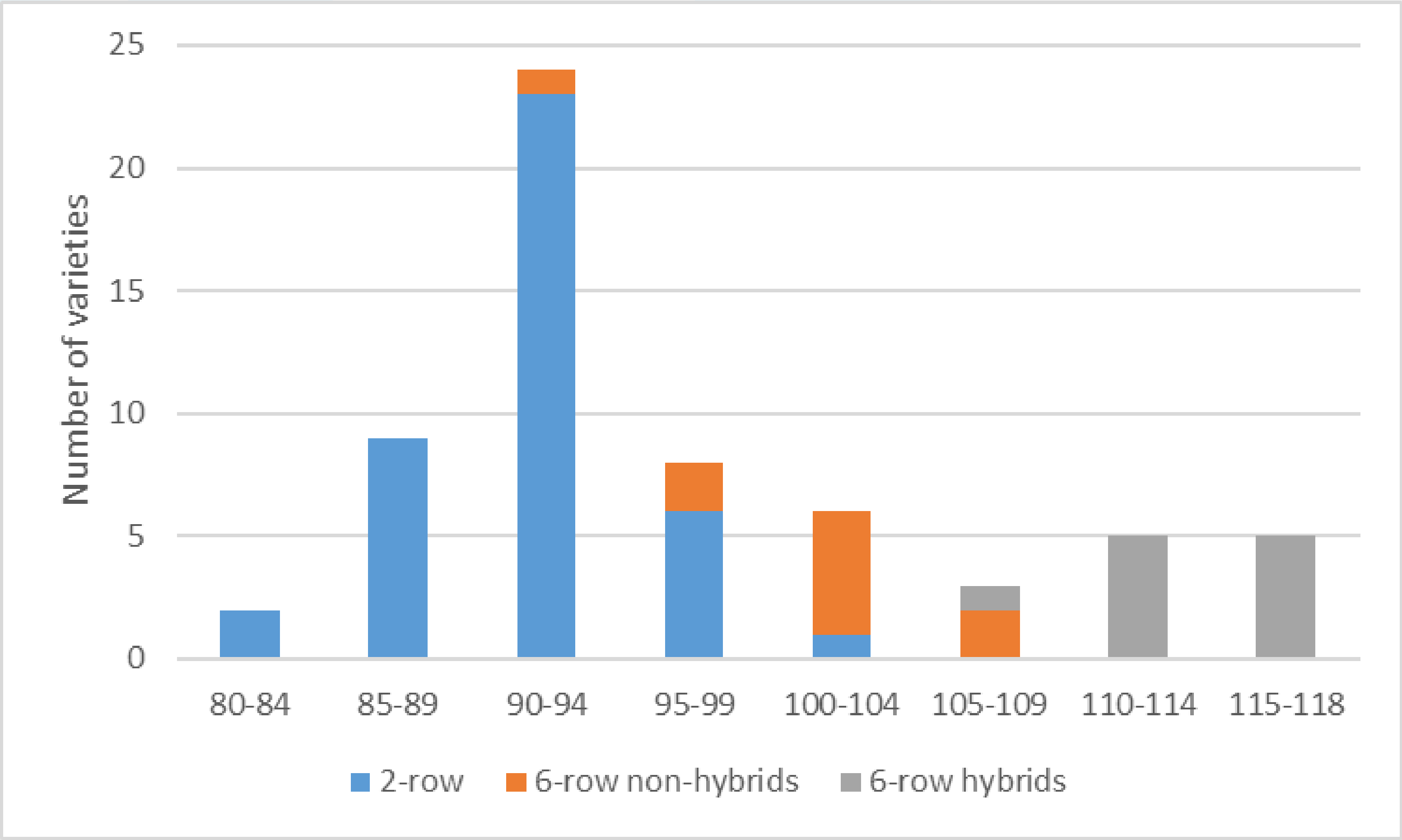

Example - Designs for height competition

Genetically determined sections in each replicate

- 2019 WB 62 varieties.
  Height range (excluding possible fillers): 80-118cm.

  2-row : 80-100 cm
  6-row non-hybrids: 90-107 cm   6-row hybrids: 106-118cm

Worst case scenario: 20 cm

Example - Designs for height competition

Neighbour restricted designs

- 2019 WB 62 (+3 fillers) varieties. Sown as 13 blocks of 5. Height range (excluding fillers): 80-118cm.

One possible allocation (Others are available!)

Group 1:	25 varieties (+fillers)	80 – 91 cm
Group 2:	26 (s=13; 2s=26) varieties	92 – 106 cm
Group 3:	11 varieties	107 – 118 cm

Chosen to minimise the worst case scenario.

- No group 1 variety is next to a group 3 variety
  Maximum possible height differences:
  Grp 1 vs. 2 – 26cm & Grp 2 vs. 3 – 26 cm

Worst case scenario: 26 cm

Conclusions

- Sizeable shading effects identified.
- Most appropriate shading model unclear at present.
- Shading effect estimation improvements may be possible.
- Mitigation needed.
- Currently in discussion with stakeholders on mitigation by statistical design options.

References

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