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# Field trials of cultivar mixtures in wheat and barley – a broader perspective

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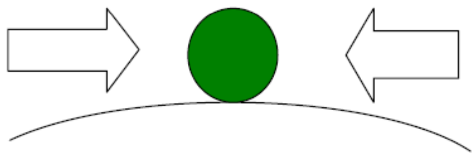
# Early research in variety mixtures

*It has been experimentally proved, that if a plot of ground be sown with one species of grass, and a similar plot be sown with several distinct genera of grasses, a greater number of plants and a greater weight of dry herbage can be raised in the latter than in the former case. The same has been found to hold good when one variety and several mixed varieties of wheat have been sown on equal spaces of ground*

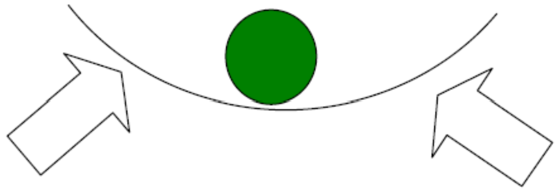
C. R. Darwin, 1859

# Two approaches to agriculture

**Control model**



**Adaptation model**



Monoculture

Composite-crosses

Multilines

Variety mixtures

# Potential benefits of growing variety mixtures

Diversity in
- resist.genes
- physiology
- morphology
- phenology

Lower yield loss due to disease infection

Better overall utilization of resources

Higher and more stable yields across environments

Lower loss of resources to competitive structures

Lower loss of important resources to weedy plants

**Compensation**

**Complementarity**

# ’The situation’

- Only scattered large-scale cultivation of variety mixtures

- Continuous research
  - Potential benefits of variety mixtures
    - Disease resistance
    - Competition (crop-crop and crop-weed )
  - Prediction of beneficial variety mixtures

- Reported results highly variable
  - Variety mixtures not always an advantage
  - Many sources of variation
  - The effects of environmental variation on mixing effect remain unknown to a significant extent!
  - Basic interactions are unclear

# Two studies addressing this situation

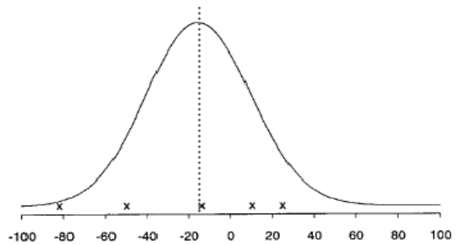
- Meta-analysis
- Multi-environment field study

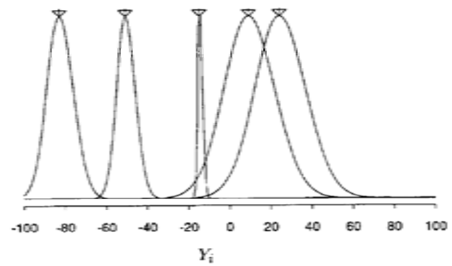
# Meta-analysis - Aims

- Provide overview of existing findings within a scientific area
- Expose tendencies across studies
- Model and quantify the variation in the set of studies
- Identify and quantify factors that affect study outcomes

# Meta-analysis - Approach

- Several study outcomes are combined into a single model




- Weighting of effects according to their precision

- Sources of random variation and systematic differences investigated

$$\theta_i = \theta + \beta_1 X_{i1} + \ldots + \beta_p X_{ip} + \varepsilon_i , \qquad \varepsilon_i \ \ iid \sim \mathrm{N}(0, v_i^2 + \tau^2)$$

# Meta-analysis of variety mixtures

## Research questions

- Significant effects of growing variety mixtures overall?
- Can mixing effect be explained by specific factors?
- What are the most important traits for mixing success?
- Are environmental conditions as important as varietal traits?
- Do mixtures provide more stable grain yields than pure varieties?

# Meta-analysis – Identification of suited published papers

**Wide Boolean search** → ~10,000

Filtering by subject category ↓

~3,500

Studying titles and abstracts ↓

213

Detailed reading ↓

28

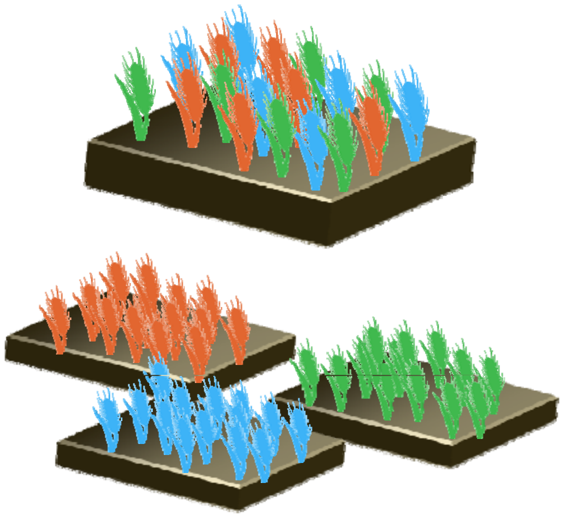
# Meta-analysis - Identified results per crop type

| Crop type | Studies | Trials | Mixtures | Effects | Countries |
|---|---|---|---|---|---|
| Winter wheat | 12 | 54 | 118 | 238 | Australia, Hungary, India, Nepal, Pakistan, USA |
| Spring wheat | 5 | 28 | 22 | 87 | Canada, England, USA |
| Winter barley | 4 | 16 | 34 | 118 | Germany, USA |
| Spring barley | 5 | 16 | 72 | 132 | Canada, Germany, Northern Ireland, Wales |
| Total | 26 | 114 | 246 | 575 | |

# Meta-analysis - Quantifying effects of mixing

- Mixed plot and pure stand grain yields
- Relative mixing effect

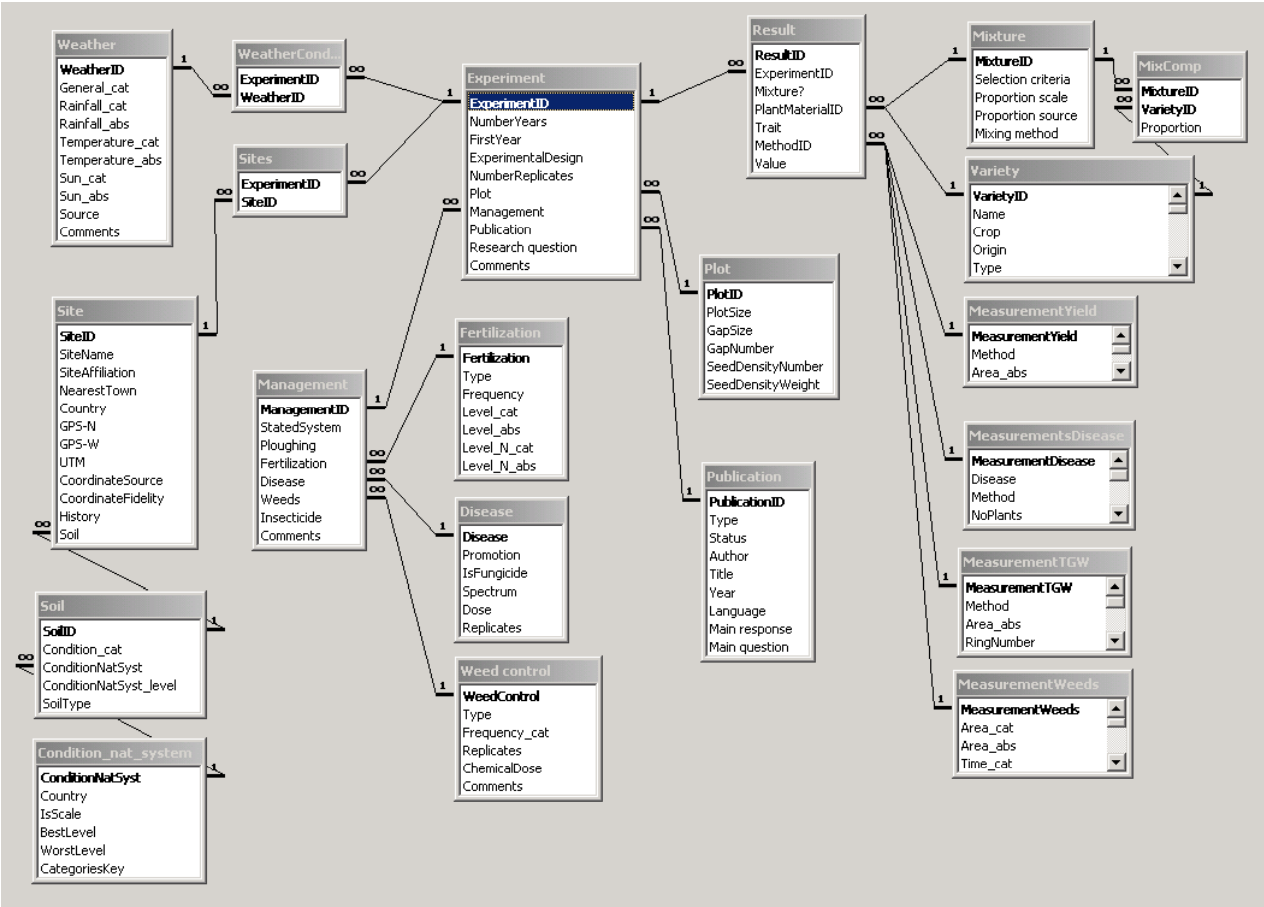
$$e_{rel} = \frac{\mu_{mix} - \sum_{i=1}^{k} p_i \cdot \mu_i}{\sum_{i=1}^{k} p_i \cdot \mu_i}$$



# Meta-analysis - Overall meta-estimates

- Relative mixing effect ranged from -30 % to +100 %
- The overall meta-estimate was 3.5 % ($p < 0.001$)
- Mixing effect differed significantly between crop types
- Winter wheat: 5.7 % ($p < 0.001$)
- Spring barley: 5.1 % ($p < 0.001$)
- Spring wheat: 1.0 % (insignificant)
- Winter barley: 0.4 % (insignificant)

# Meta-analysis - Supplementary information



# Meta-analysis - Supplementary information

- Crop type
- Component number and proportions
- Purpose of mixing
  - Diversity in disease resistance of components
  - Diversity in weed suppression characteristics
- Seeding rate
- Field site geography
- Component yield diversity
- Publication year

# Meta-analysis - Supplementary information

| Covariate | Studies | Trials | Effects |
|---|---|---|---|
| Effective no. components | 26 | 114 | 575 |
| Disease resistance diversity | 26 | 114 | 575 |
| Weed suppression diversity | 26 | 114 | 575 |
| Component yield diversity | 23 | 109 | 514 |
| Publication year | 26 | 114 | 575 |
| Seeding rate | 15 | 67 | 341 |
| Latitude | 21 | 109 | 500 |
| Altitude | 13 | 80 | 358 |

# Meta-analysis – Meta-regression against covariates

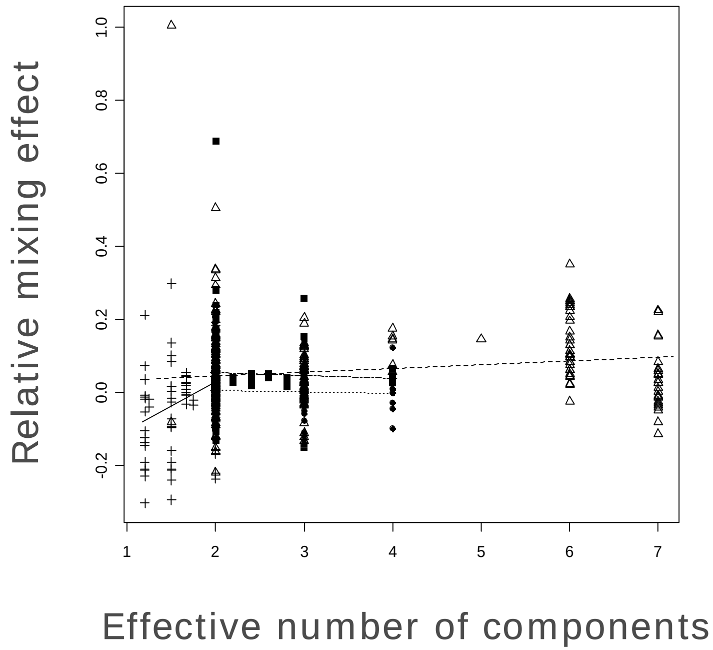
$$\hat{\theta}_i = \theta + \beta_{1,c(i)} + \beta_{2,c(i)} X_i + u_i + \varepsilon_i$$

↓

$$\hat{\theta}_i = \theta + \beta_{1,c(i)} + \beta_2 X_i + u_i + \varepsilon_i$$

↓

$$\hat{\theta}_i = \theta + \beta_{1,c(i)} + u_i + \varepsilon_i$$



# Meta-regression of mixing effect against covariates

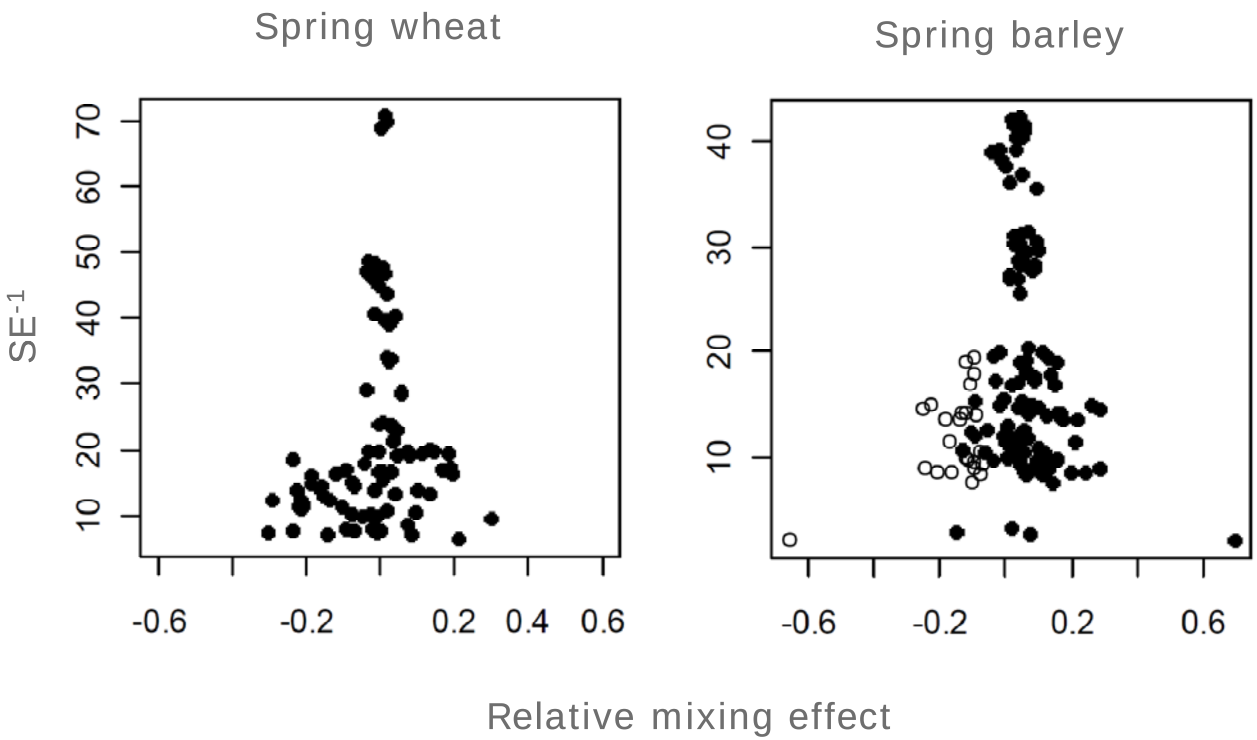
| Covariate | Effect (% per unit) |
|---|---|
| ***Component yield diversity*** | 43 |
| Disease resistance diversity | 1.1 |
| Weed suppression diversity | -0.0 |
| ***Effective no. of components*** | 1.0 |
| Winter wheat | 1.0 |
| Spring wheat | 13 |
| Winter barley | -0.4 |
| Spring barley | -0.8 |
| Seeding rate ($m^{-2}$) | 0.0 (-0.0018) |
| ***Latitude*** ($10^3$ km) | -0.1 |
| Winter wheat | -2.3 |
| Spring wheat | 6.9 |
| Winter barley | 1.5 |
| Spring barley | 0.0 |
| Altitude (m) | 0.0 |

# Meta-analysis – a combined meta-regression model

| Covariate | | Effect (% per unit) |
|---|---|---|
| Overall | (WW) | -17 |
| | (SW) | -27 |
| | (WB) | -12 |
| | (SB) | -5 |
| CYD | | 22 |
| DRD | | 3.6 |
| Latitude ($10^3$ km) | | 1.8 |
| ECN | (WW) | 2.2 |
| | (SW) | 9.0 |
| | (WB) | -0.7 |
| | (SB) | - 1.7 |
| WSD | (WW) | 5.3 |
| | (SW) | 3.1 |
| | (WB) | 5.8 |
| | (SB) | 0.9 |

# Meta-analysis - testing for publication bias

***Are certain types of results less published?***



# Meta-analysis – Main points

- A low proportion of published studies on variety mixtures reported information required for meta-analysis
- Supplementary information was sparse
- Variety mixtures of winter wheat and spring barley showed overall in 5 % higher grain yields
- Component yield diversity was the covariate with highest influence on mixing effect
- Mixing effect was also influenced by the effective number of components, latitude, and component diversity in both disease resistance and traits related to weed suppression
- A significant publication bias was indicated among published spring barley

# Multi-environment field study

**Aim**

- Investigate why some mixtures perform better and more stable than others

- Test if specific varietal and environmental characteristics can explain mixing effect

# Multi-environment field study

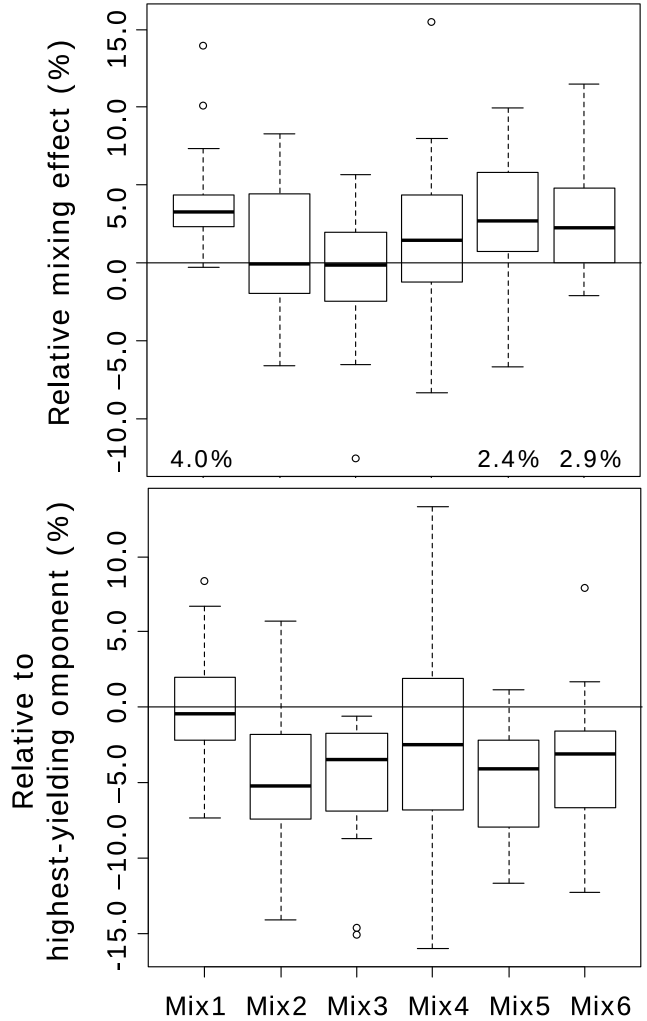
**Set-up**

- 17 trial environments
  - 4 years
  - 4 sites (experimental stations in Denmark)
  - 3 management systems (conventional, ‘organic’, low-input)
- Six mixtures and 14 component varieties of spring barley
- Part of a large sample of spring barley varieties (35-132)
- Observations of a wide range of crop characteristics
- Background varietal information from national test trials

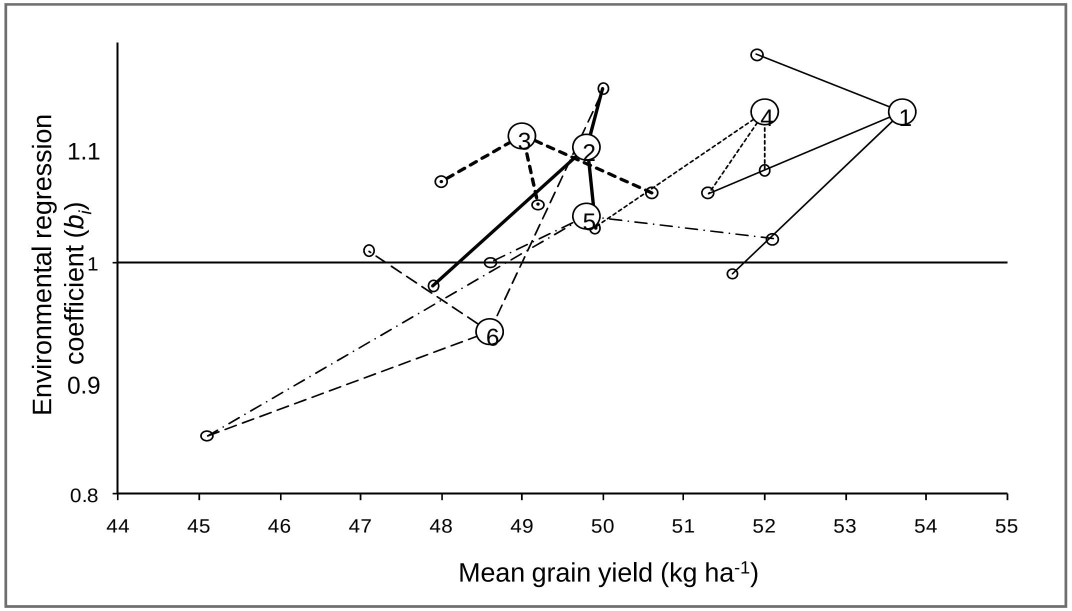
Østergård *et al. (2008)*

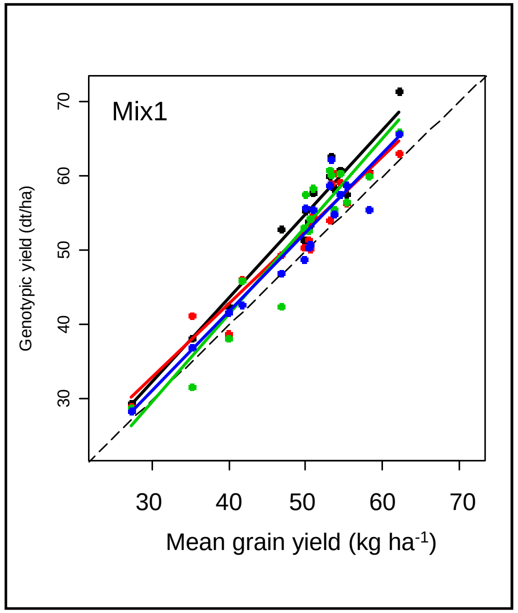
# Varieties and mixing effects

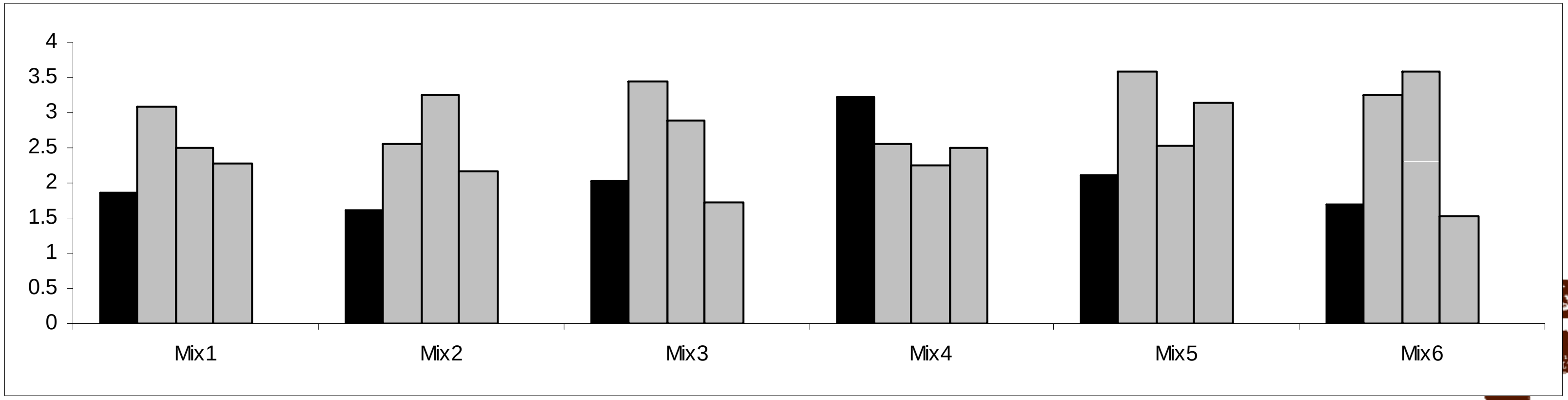
| Variety | Mixture |
|---|---|
| Alabama | 3 |
| Brazil | 2,4 |
| Cicero | 2,6 |
| Culma | 2 |
| Danuta | 4 |
| Fabel | 5,6 |
| Harriot | 5 |
| Landora | 1 |
| Neruda | 3 |
| Orthega | 1,4 |
| Otira | 1 |
| Prestige | 3 |
| Punto | 6 |
| Sebastian | 5 |



# Stability


Environmental regression coefficient ($b_i$)
1.1
1
0.9
0.8
44
45
46
47
48
49
50
51
52
53
54
55
Mean grain yield (kg ha-1)
1
2
3
4
5
6


Mix1
Genotypic yield (dt/ha)
30
40
50
60
70
Mean grain yield (kg ha-1)


4
3.5
3
2.5
2
1.5
1
0.5
0
Mix1
Mix2
Mix3
Mix4
Mix5
Mix6

# Variety characteristics

| Background | Observed |
|---|---|
| Grain yield potential | Grain yield |
| | |
| Mildew resistance | Mildew severity |
| Leaf rust resistance | Leaf rust severity |
| Net blotch resistance | Net blotch severity |
| Scald resistance | Scald severity |
| | |
| Straw length potential | Straw length (maturity) |
| Weed suppressiveness | Weed infestation (tall) |
| | Weed infestation (creeping) |

→ **Mixture characteristics (std.dev.)**

# Regression against relative mixing effect

## Mixed model

$$e_{rel(ij)} = \mu + \beta \cdot X(\text{MixtureCharacteristic}_{ij}) + C(\text{Mixture}_i) + D(\text{Environment}_j) + \varepsilon_{ij}$$

| Characteristic | β (%) | R2 (%) |
|---|---|---|
| Grain Yield Potential | 3.223 * | 7.6 |
| Straw length x Tall Annual Weeds(env) | 0.036 * | 3.8 |

# Multi-environment field study – Main points

- Some mixtures are consistently better in outyielding the highest yielding component variety
- The likelihood of outyielding is higher when component varieties give more similar yields
- Inferred stability of mixtures depend on the perspective
- Mixtures were more responsive to environmental productivity and more resilient than their component varieties
- Average mixing effect higher when component varieties differ more in response to environmental productivity (compensation)
- Complementarity more important when components yield more similarly
- Mixing effect is poorly described by single varietal characteristics

# Conclusions and Perspectives

- A significant effect of growing variety mixtures overall – compared to the average of component varieties
- Mixtures of high-yielding components outyield their components more often
- Mixing effect is influenced by a vast range of factors that each contribute only vaguely to mixing success
- Research is needed on types of diversity suited for specific growing conditions
- It may be fruitful to consider more general responses
- Mixtures often more responsive to environmental productivity
- Mixtures often more resilient
- If stability is a selling argument, clarify what this is

# Questions?