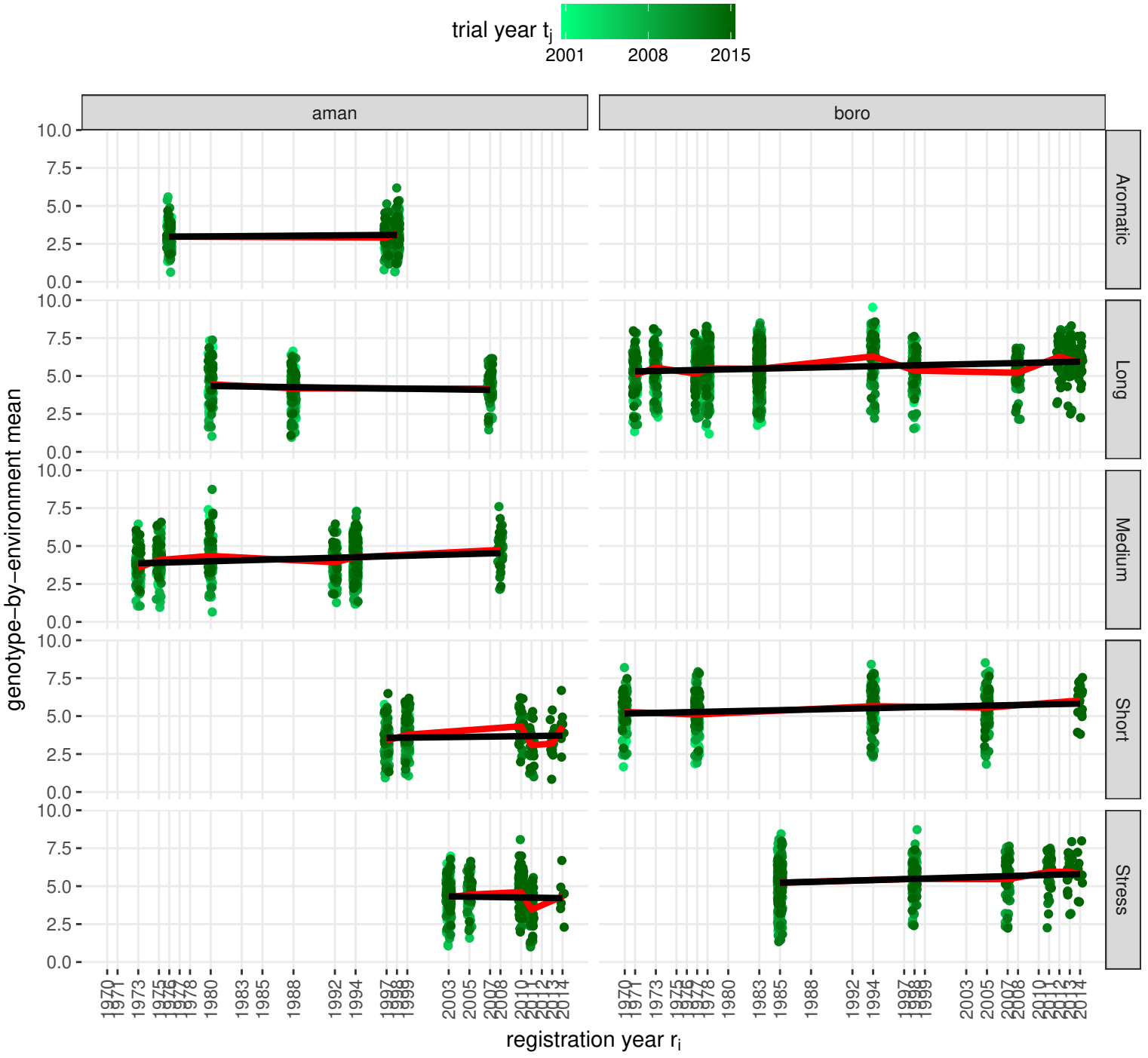
**AMAN** dataset: Number of observations for genotype-group combinations

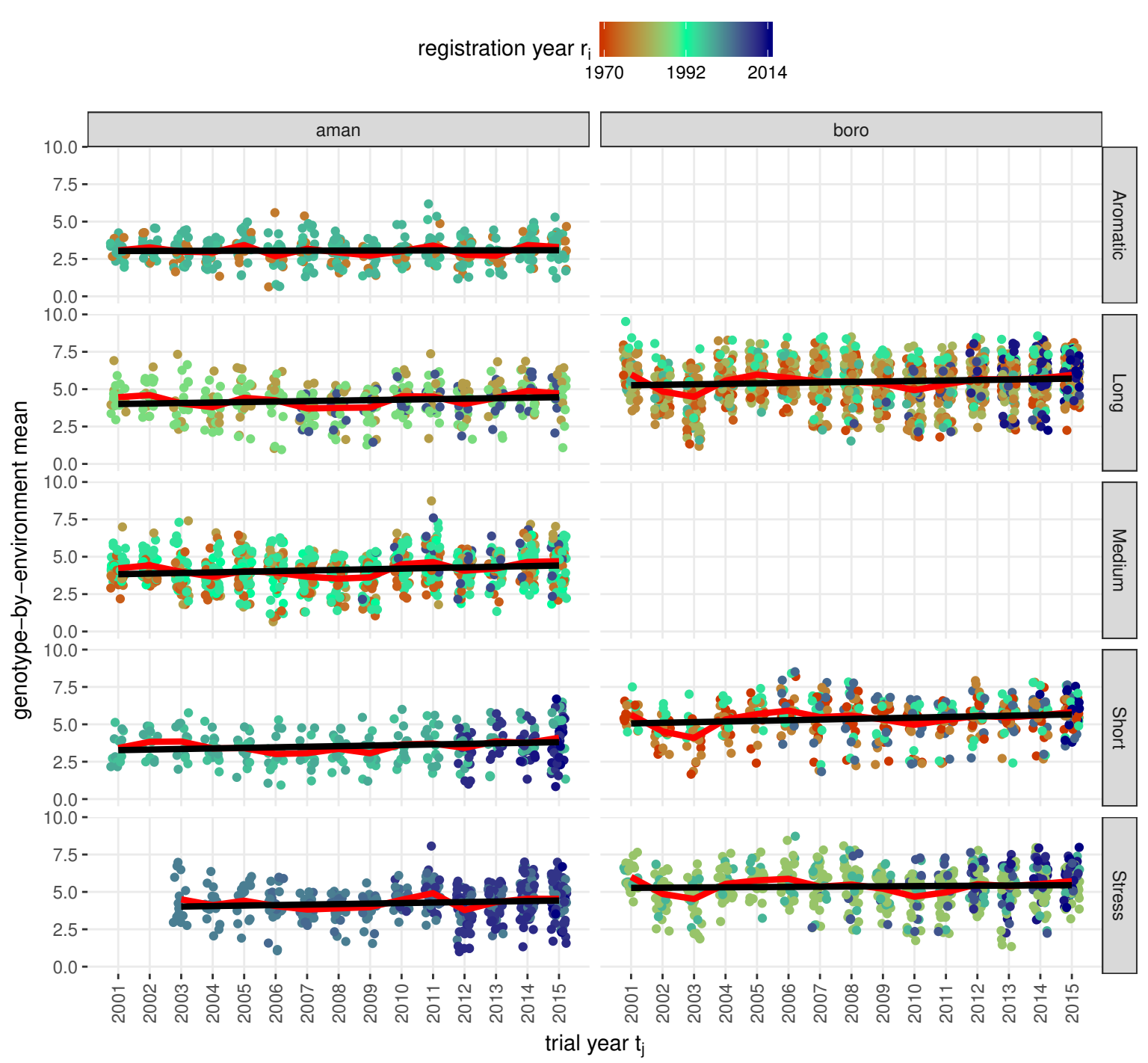
| | Aromatic | Long | Medium | Short | Stress |
|---|---|---|---|---|---|
| BR10 | 0 | 348 | 0 | 0 | 0 |
| BR11 | 0 | 0 | 348 | 0 | 0 |
| BR22 | 0 | 348 | 0 | 0 | 0 |
| BR23 | 0 | 348 | 0 | 0 | 0 |
| BR25 | 0 | 0 | 348 | 0 | 0 |
| BR3 | 0 | 0 | 348 | 0 | 0 |
| BR4 | 0 | 0 | 348 | 0 | 0 |
| BR5 | 348 | 0 | 0 | 0 | 0 |
| BRRI dhan30 | 0 | 0 | 348 | 0 | 0 |
| BRRI dhan31 | 0 | 0 | 348 | 0 | 0 |
| BRRI dhan32 | 0 | 0 | 348 | 0 | 0 |
| BRRI dhan33 | 0 | 0 | 0 | 347 | 0 |
| BRRI dhan34 | 348 | 0 | 0 | 0 | 0 |
| BRRI dhan37 | 348 | 0 | 0 | 0 | 0 |
| BRRI dhan38 | 348 | 0 | 0 | 0 | 0 |
| BRRI dhan39 | 0 | 0 | 0 | 348 | 0 |
| BRRI dhan40 | 0 | 0 | 0 | 0 | 306 |
| BRRI dhan41 | 0 | 0 | 0 | 0 | 306 |
| BRRI dhan44 | 0 | 0 | 0 | 0 | 236 |
| BRRI dhan46 | 0 | 206 | 0 | 0 | 0 |
| BRRI dhan49 | 0 | 0 | 147 | 0 | 0 |
| BRRI dhan51 | 0 | 0 | 0 | 0 | 120 |
| BRRI dhan52 | 0 | 0 | 0 | 0 | 120 |
| BRRI dhan53 | 0 | 0 | 0 | 90 | 90 |
| BRRI dhan54 | 0 | 0 | 0 | 0 | 90 |
| BRRI dhan56 | 0 | 0 | 0 | 0 | 90 |
| BRRI dhan57 | 0 | 0 | 0 | 90 | 90 |
| BRRI dhan62 | 0 | 0 | 0 | 45 | 0 |
| BRRI dhan66 | 0 | 0 | 0 | 21 | 21 |

**BORO** dataset: Number of observations for genotype-group combinations

| | Long | Short | Stress |
|---|---|---|---|
| BR1 | 0 | 411 | 0 |
| BR12 | 411 | 0 | 0 |
| BR14 | 411 | 0 | 0 |
| BR15 | 411 | 0 | 0 |
| BR16 | 411 | 0 | 0 |
| BR17 | 0 | 0 | 411 |
| BR18 | 0 | 0 | 411 |
| BR19 | 0 | 0 | 411 |
| BR2 | 411 | 0 | 0 |
| BR3 | 411 | 0 | 0 |
| BR6 | 0 | 411 | 0 |
| BR7 | 411 | 0 | 0 |
| BR8 | 411 | 0 | 0 |
| BR9 | 411 | 0 | 0 |
| BRRI dhan28 | 0 | 411 | 0 |
| BRRI dhan29 | 411 | 0 | 0 |
| BRRI dhan35 | 411 | 0 | 0 |
| BRRI dhan36 | 0 | 0 | 411 |
| BRRI dhan45 | 0 | 285 | 0 |
| BRRI dhan47 | 0 | 0 | 210 |
| BRRI dhan50 | 189 | 0 | 0 |
| BRRI dhan55 | 0 | 0 | 114 |
| BRRI dhan58 | 111 | 0 | 0 |
| BRRI dhan59 | 87 | 0 | 0 |
| BRRI dhan60 | 81 | 0 | 0 |
| BRRI dhan61 | 0 | 0 | 81 |
| BRRI dhan63 | 0 | 33 | 0 |
| BRRI dhan64 | 60 | 0 | 0 |
| BRRI dhan67 | 0 | 0 | 30 |
| BRRI dhan68 | 0 | 30 | 0 |
| BRRI dhan69 | 30 | 0 | 0 |

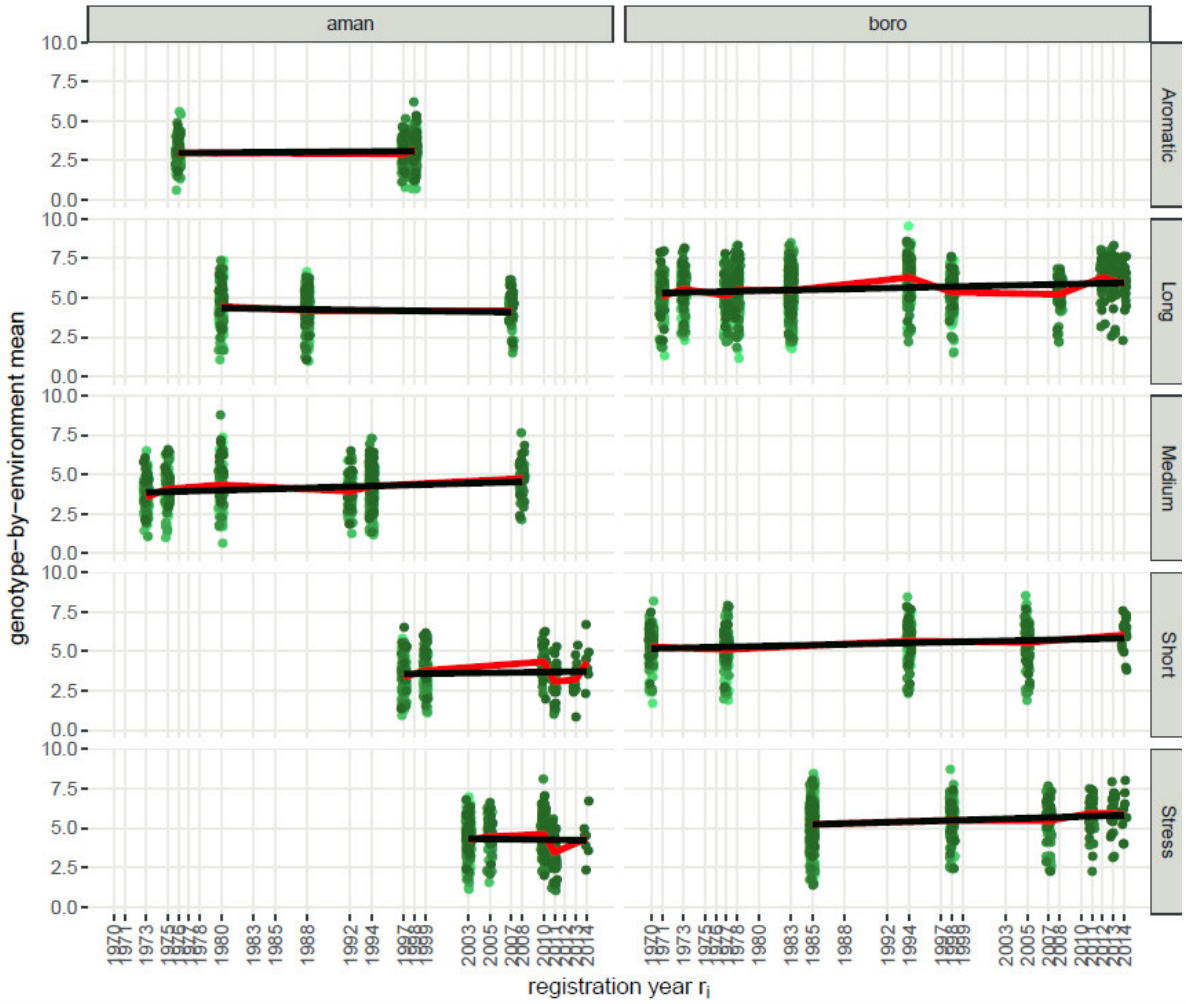



Genotype−by−environment means.
Red line: arithmetic mean per year. Black line: linear Regression y = a + bx.
Note that the black line does neither equal the genetic (r.i) nor the agronomic (t.k) trend




Genotype−by−environment means.
Red line: arithmetic mean per year. Black line: linear Regression y = a + bx.
Note that the black line does neither equal the genetic (r.i) nor the agronomic (t.k) trend

```
> withGroup <- lmer(formula = G.ari.mean ~ r.i:Group + t.k +
+                             (1|G) + (1|L) + (1|Y) + (1|Y:L) + (1|L:G) + (1|Y:G),
+                   data    = dat)
> # Type III Analysis of Variance Table with Satterthwaite's method
> anova(withGroup)
Type III Analysis of Variance Table with Satterthwaite's method
          Sum Sq Mean Sq NumDF  DenDF F value   Pr(>F)
t.k       0.3046 0.30457     1 14.004  0.9209 0.353518
r.i:Group 8.1678 1.63356     5 24.471  4.9392 0.002901 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> # Fixed effects. t-tests use Satterthwaite's method
> coef(summary(withGroup))
                       Estimate   Std. Error       df    t value  Pr(>|t|)
(Intercept)       -46.223782767 44.004077466 19.28084 -1.0504432 0.3065031
t.k                 0.019273273  0.020084049 14.00357  0.9596309 0.3535180
r.i:GroupAromatic   0.005322837  0.009027666 20.15078  0.5896139 0.5620030
r.i:GroupLong       0.005919468  0.009034842 20.15436  0.6551822 0.5197593
r.i:GroupMedium     0.005883291  0.009043624 20.15470  0.6505458 0.5226874
r.i:GroupShort      0.005681231  0.008962133 20.17469  0.6339151 0.5332584
r.i:GroupStress     0.005733012  0.008960372 20.15913  0.6398185 0.5294956
```




# Implementation of genetic gain assessment using the BRRI data

# Overview

**Two datasets**

- Aman & Boro

→ Get mean yield for each genotype at each environment

**Genetic gain assessment**

1. Incorporating regression terms in basic MET mixed model
    - Genetic trend: $\beta r_i$
        - Per group
    - Agronomic trend: $\gamma t_k$

# Data

**Two datasets**

- Aman & Boro

# Data

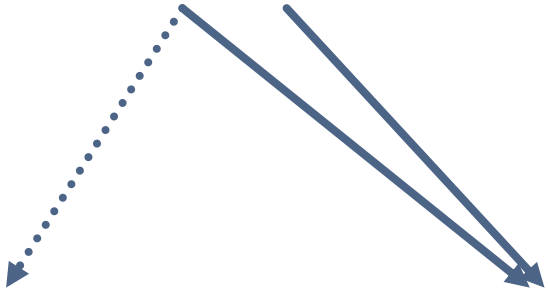
**Original**

| SL | Year | Location | Year of release | Rep | Variety | Group | Yield |
|---|---|---|---|---|---|---|---|
| 1 | 2001 | Barisal | 1980 | 1 | BR10 | Long | 3.5 |
| 2 | 2001 | Comilla | 1980 | 1 | BR10 | Long | 5.01104651 |
| 3 | 2001 | Gazipur | 1980 | 1 | BR10 | Long | 4.28023256 |
| 4 | 2001 | Rajshahi | 1980 | 1 | BR10 | Long | 4.48 |

# Data

**Original**

| SL | Year | Location | Year of release | Rep | Variety | Group | Yield |
|---|---|---|---|---|---|---|---|
| 1 | 2001 | Barisal | 1980 | 1 | BR10 | Long | 3.5 |
| 2 | 2001 | Comilla | 1980 | 1 | BR10 | Long | 5.01104651 |
| 3 | 2001 | Gazipur | 1980 | 1 | BR10 | Long | 4.28023256 |
| 4 | 2001 | Rajshahi | 1980 | 1 | BR10 | Long | 4.48 |



**Formatted**

| | Y | t.k | r.i | L | Env | G | Rep | Group | Yield |
|---|---|---|---|---|---|---|---|---|---|
| 1: | 2001 | 2001 | 1980 | Barisal | 2001-Barisal | BR10 | 1 | Long | 3.500000 |
| 2: | 2001 | 2001 | 1980 | Comilla | 2001-Comilla | BR10 | 1 | Long | 5.011047 |
| 3: | 2001 | 2001 | 1980 | Gazipur | 2001-Gazipur | BR10 | 1 | Long | 4.280233 |
| 4: | 2001 | 2001 | 1980 | Rajshahi | 2001-Rajshahi | BR10 | 1 | Long | 4.480000 |
| 5: | 2001 | 2001 | 1980 | Rangpur | 2001-Rangpur | BR10 | 1 | Long | 3.176419 |
| --- | | | | | | | | | |
| 7631: | 2015 | 2015 | 2014 | Comilla | 2015-Comilla | BRRI dhan66 | 3 | Stress | 5.219160 |
| 7632: | 2015 | 2015 | 2014 | Gazipur | 2015-Gazipur | BRRI dhan66 | 3 | Stress | 1.988598 |
| 7633: | 2015 | 2015 | 2014 | Rajshahi | 2015-Rajshahi | BRRI dhan66 | 3 | Stress | 4.926488 |
| 7634: | 2015 | 2015 | 2014 | Rangpur | 2015-Rangpur | BRRI dhan66 | 3 | Stress | 2.200000 |
| 7635: | 2015 | 2015 | 2014 | Satkhira | 2015-Satkhira | BRRI dhan66 | 3 | Stress | 3.820000 |

Numeric

New columns

# Data

**Table:** Number of unique entries per column

| Aman | | Boro | |
|---|---|---|---|
| | number | | number |
| Y | 15 | Y | 15 |
| t.k | 15 | t.k | 15 |
| r.i | 18 | r.i | 16 |
| L | 9 | L | 10 |
| Env | 116 | Env | 137 |
| G | 29 | G | 31 |
| Rep | 3 | Rep | 3 |
| Group | 5 | Group | 3 |

# Data

**Table:** Number of unique entries per column

| Aman | | Boro | |
|---|---|---|---|
| | number | | number |
| Y | 15 | Y | 15 |
| t.k | 15 | t.k | 15 |
| r.i | 18 | r.i | 16 |
| L | 9 | L | 10 |
| Env | 116 | Env | 137 |
| G | 29 | G | 31 |
| Rep | 3 | Rep | 3 |
| Group | 5 | Group | 3 |

**Basic model for long-term MET data**

$$y_{ijk} = \mu + G_i + L_j + Y_k + (LY)_{jk} + (GL)_{ij} + (GY)_{ik} + (GLY)_{ijk} \quad (1)$$

$y_{ijk}$ = mean yield of the $i$-th genotype in the $j$-th location and $k$-th year

$\mu$ = overall mean

**Two datasets**

- Aman & Boro

→ Get mean yield for each genotype at each environment

# GxE means

# GxE means

**Goal:** Obtain yield per genotype and environment averaged over replicates

## Option 1: Arithmetic means

```
dat[, ari.mean  := mean(Yield), by=c("Env","G")]
```

# GxE means

**Goal:** Obtain yield per genotype and environment averaged over replicates

## Option 1: Arithmetic means

```
dat[, ari.mean  := mean(Yield), by=c("Env","G")]
```

## Option 2: Adjusted means

For each environment separately:

1. Fit simple linear model: $y_{ij} = \mu + g_i + rep_j + e_{ij}$
2. Calculate adj. means per genotype
3. Calculate Smith's weights (Smith et al., 2001)

```
mod <- lm(formula = Yield ~ G + Rep,
          data    = subset(dat, Env==dat$Env[sel.env]))
adj.mean <- emmeans(mod, "G")
weight   <- diag(solve(vcov(adj.mean)))
```

# GxE means

## Aman

| | Y | L | Env | t.k | r.i | Group | G | G.ari.mean | G.adj.mean | w.G |
|---|---|---|---|---|---|---|---|---|---|---|
| 1: | 2001 | Barisal | 2001-Barisal | 2001 | 1980 | Long | BR10 | 3.873333 | 3.873333 | 58.926346 |
| 2: | 2001 | Barisal | 2001-Barisal | 2001 | 1980 | Medium | BR11 | 3.743333 | 3.743333 | 58.926346 |
| 3: | 2001 | Barisal | 2001-Barisal | 2001 | 1988 | Long | BR22 | 4.236667 | 4.236667 | 58.926346 |
| 4: | 2001 | Barisal | 2001-Barisal | 2001 | 1988 | Long | BR23 | 4.710000 | 4.710000 | 58.926346 |
| 5: | 2001 | Barisal | 2001-Barisal | 2001 | 1992 | Medium | BR25 | 4.086667 | 4.086667 | 58.926346 |
| --- | | | | | | | | | | |
| 2542: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2011 | Short | BRRI dhan57 | 2.372395 | 2.372395 | 15.605064 |
| 2543: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2011 | Stress | BRRI dhan57 | 2.372395 | 2.372395 | 15.605064 |
| 2544: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2013 | Short | BRRI dhan62 | 2.784334 | 2.784334 | 7.802532 |
| 2545: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2014 | Short | BRRI dhan66 | 3.523763 | 3.523763 | 15.605064 |
| 2546: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2014 | Stress | BRRI dhan66 | 3.523763 | 3.523763 | 15.605064 |

## Boro

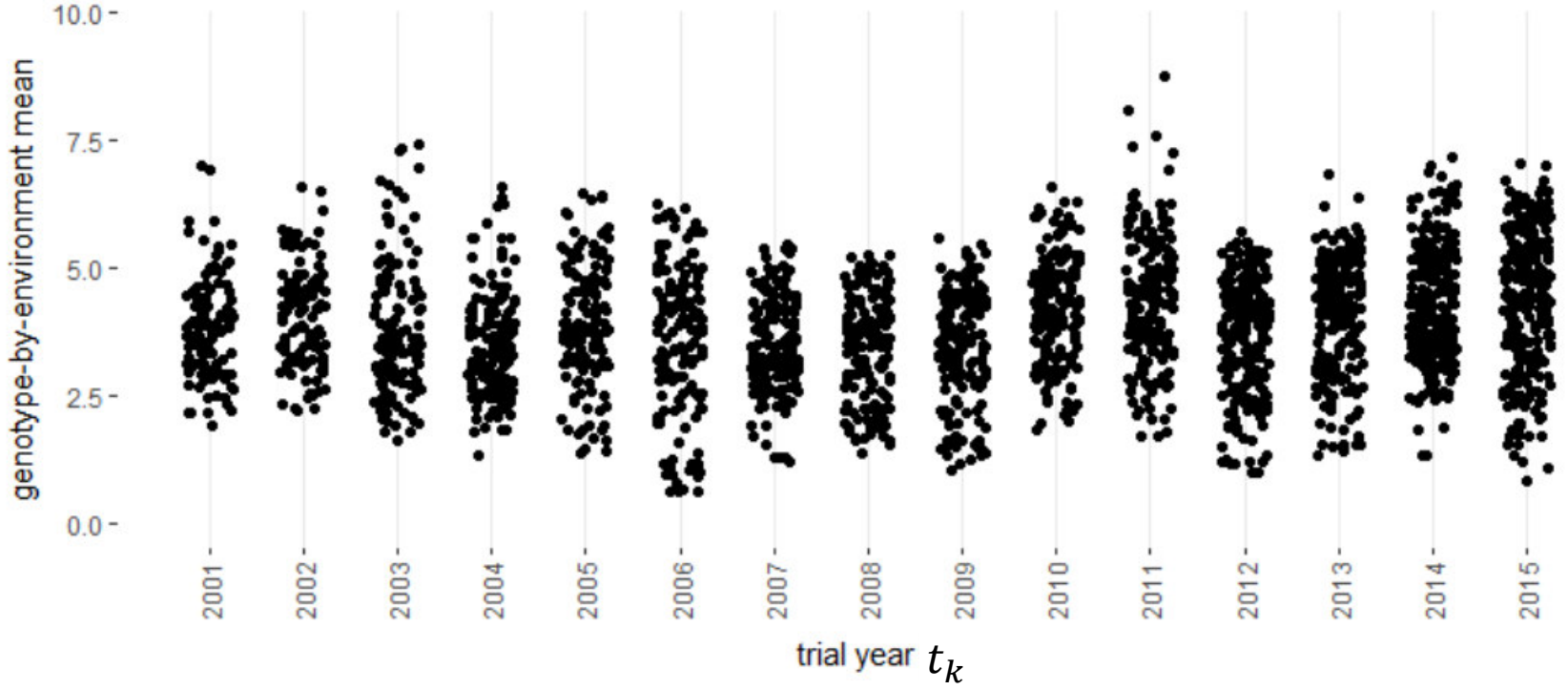
| | Y | L | Env | t.k | r.i | Group | G | G.ari.mean | G.adj.mean | w.G |
|---|---|---|---|---|---|---|---|---|---|---|
| 1: | 2001-2002 | Barisal | 2001-2002-Barisal | 2001 | 1970 | Short | BR1 | 6.556667 | 6.556667 | 16.369190 |
| 2: | 2001-2002 | Barisal | 2001-2002-Barisal | 2001 | 1983 | Long | BR12 | 7.556667 | 7.556667 | 16.369190 |
| 3: | 2001-2002 | Barisal | 2001-2002-Barisal | 2001 | 1983 | Long | BR14 | 6.390000 | 6.390000 | 16.369190 |
| 4: | 2001-2002 | Barisal | 2001-2002-Barisal | 2001 | 1983 | Long | BR15 | 6.820000 | 6.820000 | 16.369190 |
| 5: | 2001-2002 | Barisal | 2001-2002-Barisal | 2001 | 1983 | Long | BR16 | 7.073333 | 7.073333 | 16.369190 |
| --- | | | | | | | | | | |
| 2909: | 2015-2016 | Sonagazi | 2015-2016-Sonagazi | 2015 | 2014 | Short | BRRI dhan63 | 3.930000 | 3.930000 | 4.818834 |
| 2910: | 2015-2016 | Sonagazi | 2015-2016-Sonagazi | 2015 | 2014 | Long | BRRI dhan64 | 6.000000 | 6.000000 | 4.818834 |
| 2911: | 2015-2016 | Sonagazi | 2015-2016-Sonagazi | 2015 | 2014 | Stress | BRRI dhan67 | 3.956667 | 3.956667 | 4.818834 |
| 2912: | 2015-2016 | Sonagazi | 2015-2016-Sonagazi | 2015 | 2014 | Short | BRRI dhan68 | 6.056667 | 6.056667 | 4.818834 |
| 2913: | 2015-2016 | Sonagazi | 2015-2016-Sonagazi | 2015 | 2014 | Long | BRRI dhan69 | 5.140000 | 5.140000 | 4.818834 |

Option 1

Option 2

# GxE means

| | Y | L | Env | t.k | r.i | Group | G | G.ari.mean | G.adj.mean | w.G |
|---|---|---|---|---|---|---|---|---|---|---|
| 1: | 2001 | Barisal | 2001-Barisal | 2001 | 1980 | Long | BR10 | 3.873333 | 3.873333 | 58.926346 |
| 2: | 2001 | Barisal | 2001-Barisal | 2001 | 1980 | Medium | BR11 | 3.743333 | 3.743333 | 58.926346 |
| 3: | 2001 | Barisal | 2001-Barisal | 2001 | 1988 | Long | BR22 | 4.236667 | 4.236667 | 58.926346 |
| 4: | 2001 | Barisal | 2001-Barisal | 2001 | 1988 | Long | BR23 | 4.710000 | 4.710000 | 58.926346 |
| 5: | 2001 | Barisal | 2001-Barisal | 2001 | 1992 | Medium | BR25 | 4.086667 | 4.086667 | 58.926346 |
| --- | | | | | | | | | | |
| 2542: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2011 | Short | BRRI dhan57 | 2.372395 | 2.372395 | 15.605064 |
| 2543: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2011 | Stress | BRRI dhan57 | 2.372395 | 2.372395 | 15.605064 |
| 2544: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2013 | Short | BRRI dhan62 | 2.784334 | 2.784334 | 7.802532 |
| 2545: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2014 | Short | BRRI dhan66 | 3.523763 | 3.523763 | 15.605064 |
| 2546: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2014 | Stress | BRRI dhan66 | 3.523763 | 3.523763 | 15.605064 |




Genotype-by-environment means from aman dataset.

# GxE means

| | Y | L | Env | t.k | r.i | Group | G | G.ari.mean | G.adj.mean | w.G |
|---|---|---|---|---|---|---|---|---|---|---|
| 1: | 2001 | Barisal | 2001-Barisal | 2001 | 1980 | Long | BR10 | 3.873333 | 3.873333 | 58.926346 |
| 2: | 2001 | Barisal | 2001-Barisal | 2001 | 1980 | Medium | BR11 | 3.743333 | 3.743333 | 58.926346 |
| 3: | 2001 | Barisal | 2001-Barisal | 2001 | 1988 | Long | BR22 | 4.236667 | 4.236667 | 58.926346 |
| 4: | 2001 | Barisal | 2001-Barisal | 2001 | 1988 | Long | BR23 | 4.710000 | 4.710000 | 58.926346 |
| 5: | 2001 | Barisal | 2001-Barisal | 2001 | 1992 | Medium | BR25 | 4.086667 | 4.086667 | 58.926346 |
| --- | | | | | | | | | | |
| 2542: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2011 | Short | BRRI dhan57 | 2.372395 | 2.372395 | 15.605064 |
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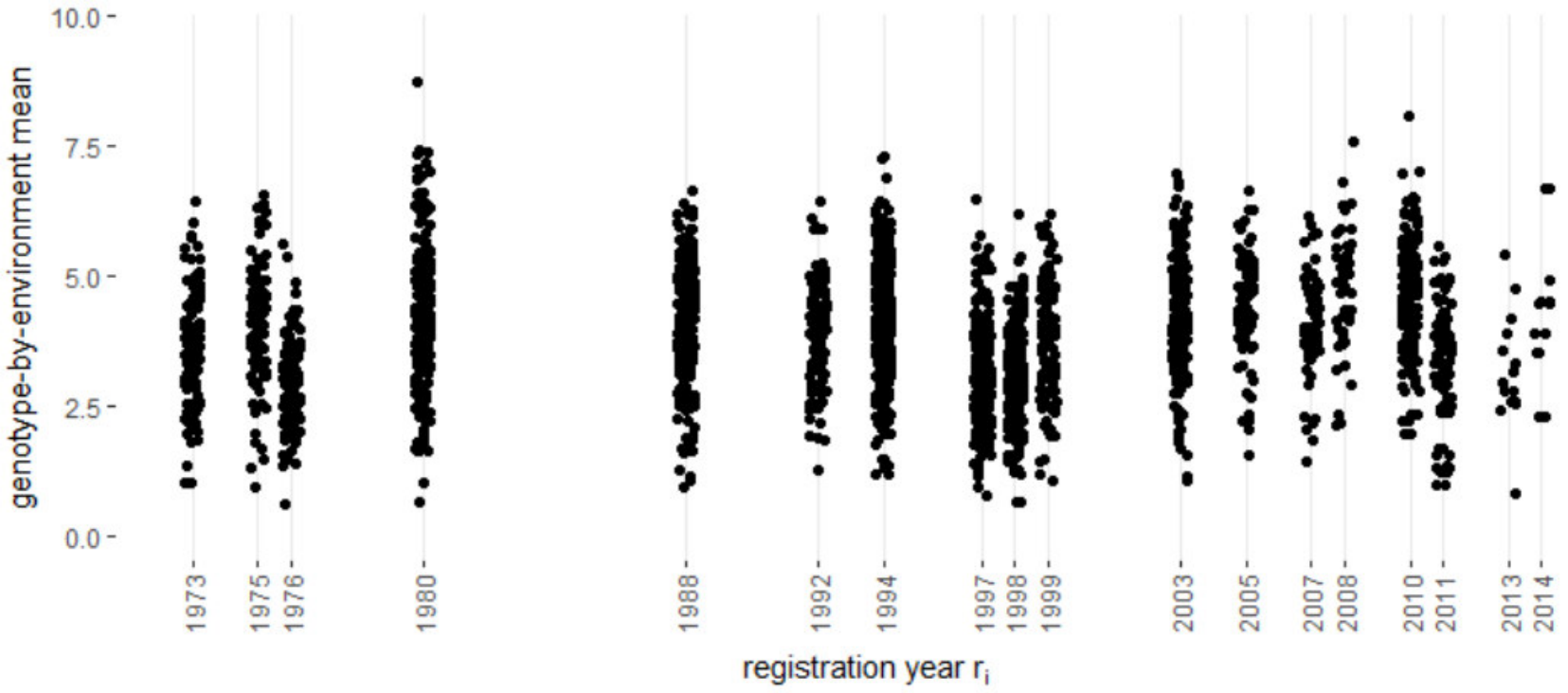
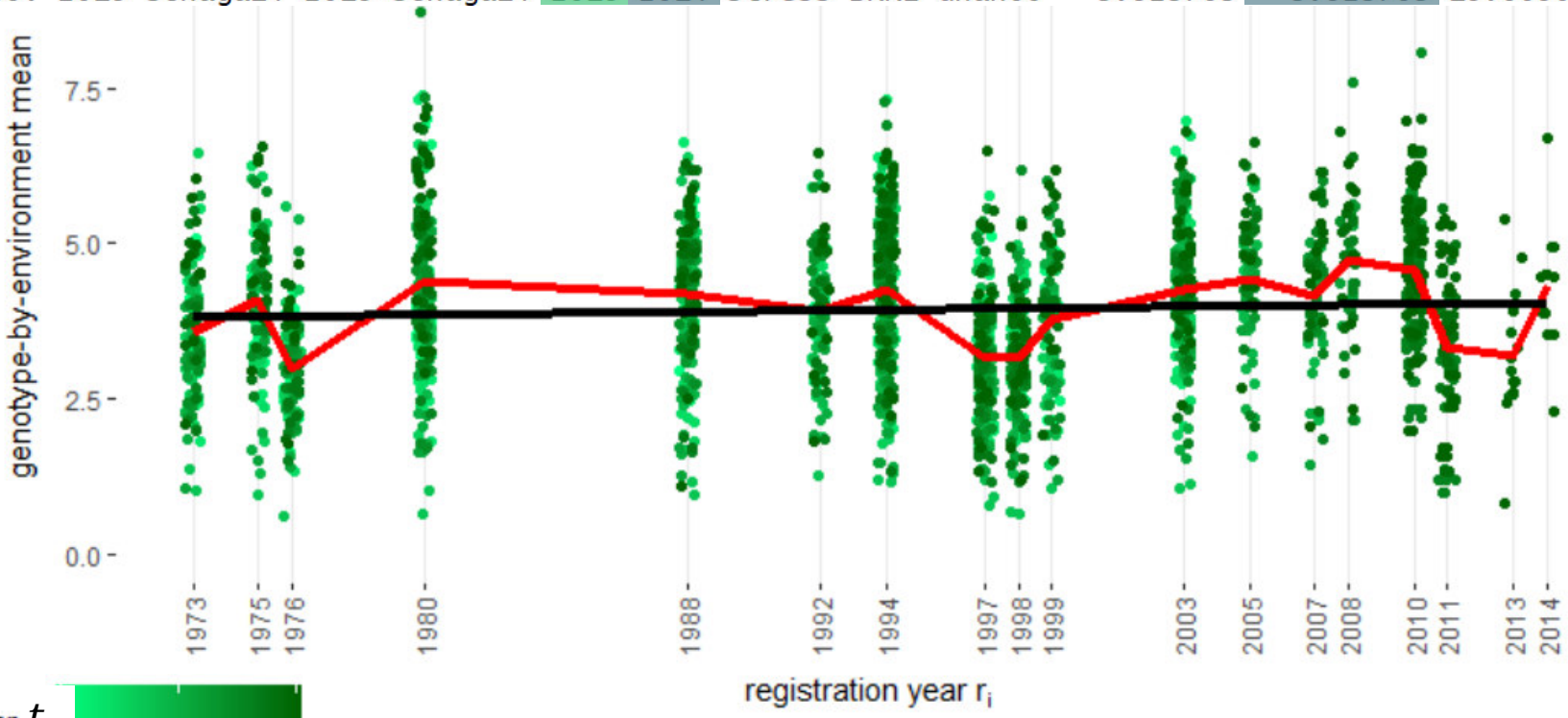
| 2544: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2013 | Short | BRRI dhan62 | 2.784334 | 2.784334 | 7.802532 |
| 2545: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2014 | Short | BRRI dhan66 | 3.523763 | 3.523763 | 15.605064 |
| 2546: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2014 | Stress | BRRI dhan66 | 3.523763 | 3.523763 | 15.605064 |



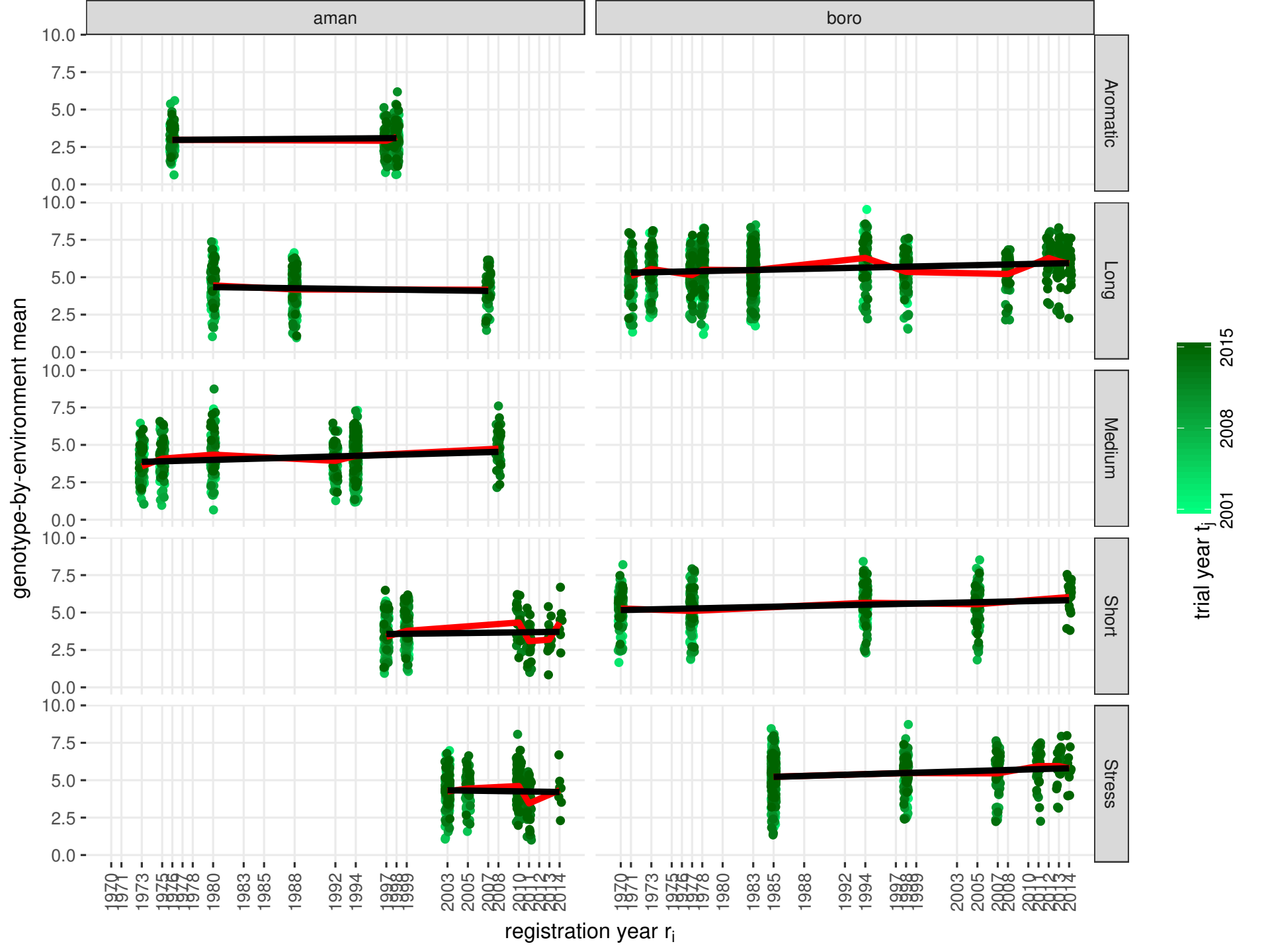

Genotype-by-environment means from aman dataset.

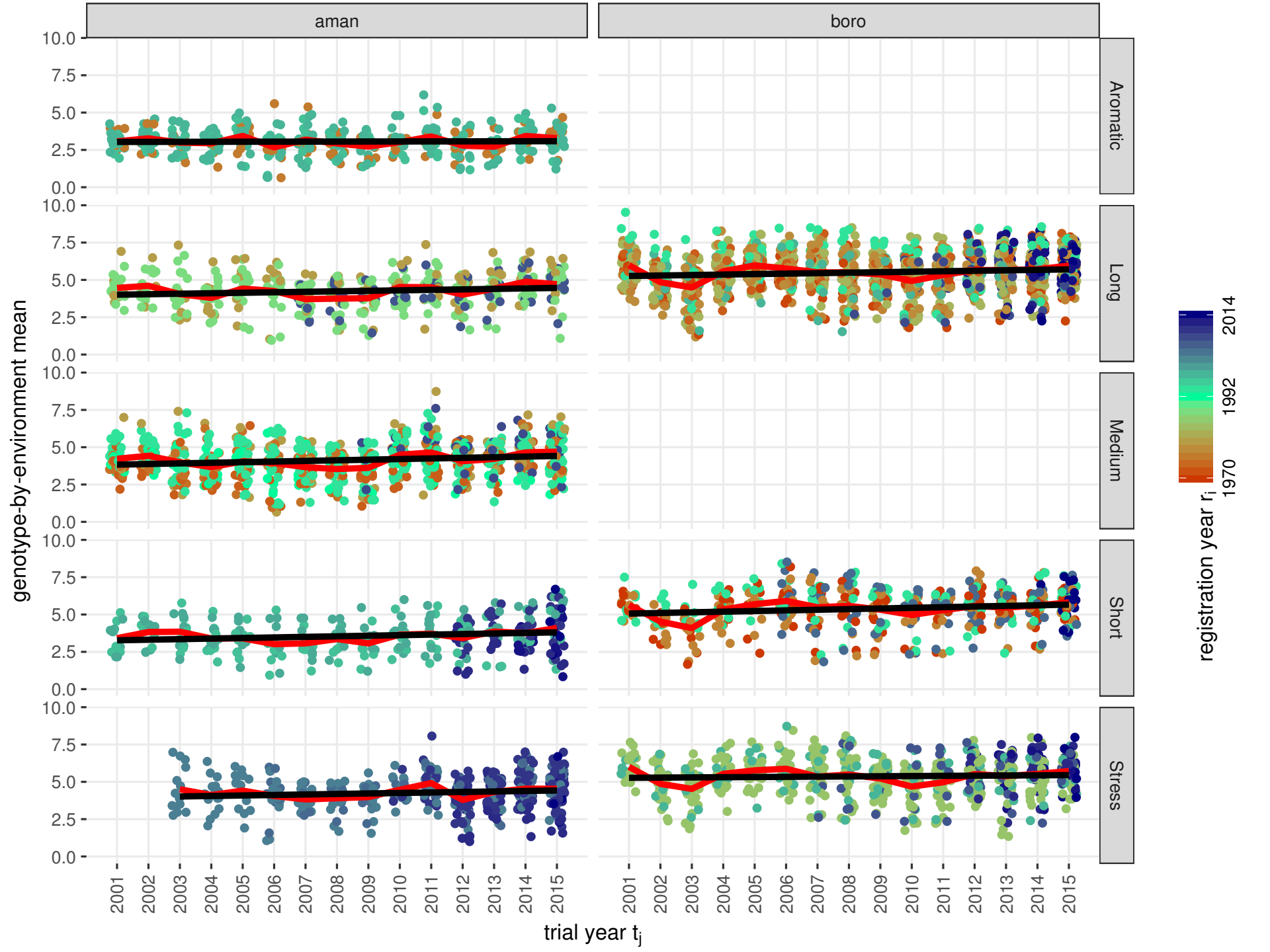
# GxE means

| | Y | L | Env | t.k | r.i | Group | G | G.ari.mean | G.adj.mean | w.G |
|---|---|---|---|---|---|---|---|---|---|---|
| 1: | 2001 | Barisal | 2001-Barisal | 2001 | 1980 | Long | BR10 | 3.873333 | 3.873333 | 58.926346 |
| 2: | 2001 | Barisal | 2001-Barisal | 2001 | 1980 | Medium | BR11 | 3.743333 | 3.743333 | 58.926346 |
| 3: | 2001 | Barisal | 2001-Barisal | 2001 | 1988 | Long | BR22 | 4.236667 | 4.236667 | 58.926346 |
| 4: | 2001 | Barisal | 2001-Barisal | 2001 | 1988 | Long | BR23 | 4.710000 | 4.710000 | 58.926346 |
| 5: | 2001 | Barisal | 2001-Barisal | 2001 | 1992 | Medium | BR25 | 4.086667 | 4.086667 | 58.926346 |
| --- | | | | | | | | | | |
| 2542: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2011 | Short | BRRI dhan57 | 2.372395 | 2.372395 | 15.605064 |
| 2543: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2011 | Stress | BRRI dhan57 | 2.372395 | 2.372395 | 15.605064 |
| 2544: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2013 | Short | BRRI dhan62 | 2.784334 | 2.784334 | 7.802532 |
| 2545: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2014 | Short | BRRI dhan66 | 3.523763 | 3.523763 | 15.605064 |
| 2546: | 2015 | Sonagazi | 2015-Sonagazi | 2015 | 2014 | Stress | BRRI dhan66 | 3.523763 | 3.523763 | 15.605064 |




Genotype-by-environment means from aman dataset.
Red line: arithmetic mean per year. Black line: linear Regression y = a + bx.


aman
boro
Aromatic
Long
Medium
Short
Stress
genotype-by-environment mean
registration year $r_i$
trial year $t_j$
2001
2008
2015


aman
boro
Aromatic
Long
Medium
Short
Stress
genotype-by-environment mean
trial year $t_j$
registration year $r_i$
1970
1992
2014
0.0
2.5
5.0
7.5
10.0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

# Genetic gain assessment

1. Incorporating regression terms in basic MET mixed model

# Genetic gain assessment

Genetic trend: $\beta r_i$
Agronomic trend: $\gamma t_k$

```
lmer(formula = G.ari.mean ~ r.i      + t.k +
                (1|G) + (1|L) + (1|Y) + (1|Y:L) + (1|L:G) + (1|Y:G),
     data    = dat)
```

**Basic model for long-term MET data**

$$y_{ijk} = \mu + G_i + L_j + Y_k + (LY)_{jk} + (GL)_{ij} + (GY)_{ik} + (GLY)_{ijk} \quad (1)$$

$y_{ijk}$ = mean yield of the *i*-th genotype in the *j*-th location and *k*-th year
$\mu$ = overall mean
$G_i$ = main effect of the *i*-th genotype
$L_j$ = main effect of the *j*-th location
$Y_k$ = main effect of the *k*-th year
$(LY)_{jk}$ = *jk*-th location × year interaction
$(GL)_{ij}$ = *ij*-th genotype × location interaction
$(GY)_{ik}$ = *ik*-th genotype × year interaction
$(GLY)_{ijk}$ = residual comprising both genotype × location × year interaction as well as the error of a mean

**2. Incorporating regression terms**

**Genetic trend**

$$G_i = \beta r_i + H_i \quad (2)$$

$\beta$ = fixed regression coefficient for genetic trend
$r_i$ = year of first trial for *i*-th variety
$H_i \sim N(0, \sigma_H^2)$

**Non-genetic trend**

$$Y_k = \gamma t_k + Z_k \quad (3)$$

$\gamma$ = fixed regression coefficient for agronomic trend
$t_k$ = calendar year
$Z_k \sim N(0, \sigma_Z^2)$

# Genetic gain assessment

Genetic trend per group: $\beta r_{il}$
Agronomic trend: $\gamma t_k$

```
lmer(formula = G.ari.mean ~ r.i:Group + t.k +
       (1|G) + (1|L) + (1|Y) + (1|Y:L) + (1|L:G) + (1|Y:G),
     data    = dat)
```

**Basic model for long-term MET data**

$$y_{ijk} = \mu + G_i + L_j + Y_k + (LY)_{jk} + (GL)_{ij} + (GY)_{ik} + (GLY)_{ijk} \quad (1)$$

$y_{ijk}$ = mean yield of the *i*-th genotype in the *j*-th location and *k*-th year
$\mu$ = overall mean
$G_i$ = main effect of the *i*-th genotype
$L_j$ = main effect of the *j*-th location
$Y_k$ = main effect of the *k*-th year
$(LY)_{jk}$ = *jk*-th location × year interaction
$(GL)_{ij}$ = *ij*-th genotype × location interaction
$(GY)_{ik}$ = *ik*-th genotype × year interaction
$(GLY)_{ijk}$ = residual comprising both genotype × location × year interaction as well as the error of a mean

**2. Incorporating regression terms**

**Genetic trend**

$$G_i = \beta r_i + H_i \quad (2)$$

$\beta$ = fixed regression coefficient for genetic trend
$r_i$ = year of first trial for *i*-th variety
$H_i \sim N(0, \sigma_H^2)$

**Non-genetic trend**

$$Y_k = \gamma t_k + Z_k \quad (3)$$

$\gamma$ = fixed regression coefficient for agronomic trend
$t_k$ = calendar year
$Z_k \sim N(0, \sigma_Z^2)$

# Summary: Genetic gain assessment

| Dataset | Group | Genetic Trend | Agronomic Trend |
|---|---|---|---|
| **aman** | Aromatic | 0.0053 (p=0.562) | |
| | Long | 0.0059 (p=0.520) | |
| | Medium | 0.0059 (p=0.523) | 0.0192 (p=0.353) |
| | Short | 0.0057 (p=0.527) | |
| | Stress | 0.0057 (p=0.529) | |
| **boro** | Long | 0.0124 (p<0.001) | |
| | Short | 0.0123 (p<0.001) | 0.0189 (p=0.779) |
| | Stress | 0.0123 (p<0.001) | |