**The BRRI stability trials**

Bangladesh Rice Research Institute (BRRI) have conducted multi-location rice variety trials since 2001. These trials are called stability trials and comprise a fairly consistent set of varieties over the years (strong carry-over from year to year), with only very few varieties added each year and hardly any variety dropping out. The varieties included in the trials were developed by BRRI and represent the varieties that are grown in Bangladesh. Thus, these trials form an ideal basis for assessing long-term genetic trends / rates of genetic gain in the rice varieties developed by BRRI in their breeding programs.

There are two major growing seasons with different sets of varieties, that are tested in different trials:

(1) Boro rice, grown in the dry season, irrigated

(2) Aman rice, grown in the wet season, rainfed

For each season, trials were conducted at about 10 locations each year. Specifically, experiments are being conducted in the T. Aman and Boro seasons with BRRI released rice varieties at the locations listed in Table 1.

**Table 1**: List of trial locations in Boro and T. Aman seasons

|  |  |  |  |
| --- | --- | --- | --- |
| Boro | | T. Aman | |
| Location | Stability exp. started from | Location | Stability exp. started from |
| Rajshahi | 2001-2002 | Rajshahi | 2001 |
| Rangpur | 2001-2002 | Rangpur | 2001 |
| Comilla | 2001-2002 | Comilla | 2001 |
| Habiganj | 2001-2002 | Barisal | 2001 |
| Barisal | 2001-2002 | Satkhira | 2001 |
| Bhanga | 2001-2002 | Gazipur | 2001 |
| Satkhira | 2001-2002 | Sonagazi | 2001 |
| Gazipur | 2002-2003 | Kushtia | 2004 |
| Kushtia | 2004-2005 |  |  |
| Sonagazi | 2010-2011 |  |  |

Trial layouts were randomized complete block designs with three replications throughout. The effective plot size (harvest area) was 5-x-2 m2, discarding borders amounting to an area of about 2.72 m2 per plot. Recommended crop management practices were followed. Yield was assessed in tons/hectare (t ha-1).

In the T. Aman season, the number of varieties was 29 and 31 in the Boro season. As new varieties were added each year and old ones retained, the number of varieties tested increased over years. Varieties were grouped according to growth duration by the rice breeders (Table 2).

**Table 2:** Categories of 31 Boro and 29 Aman rice varieties based on growth duration

|  |  |  |
| --- | --- | --- |
| **Category** | **Definition of category** | |
| **Boro** | **T. Aman** |
| Long duration (days) | More than 150 | More than 145 |
| Medium duration (days) | - | 135 to 145 |
| Short duration (days) | Less than 150 | Less than 125 |
| Stress condition | Tolerance capacity against different stresses | Tolerance capacity against different stresses |
| Aromatic | - | Premium quality |

Source: Plant Breeders of BRRI and BRRI (2017).

**Analysis**

As there were no missing data and all trials had complete blocks, we computed genotype means per trial as the arithmetic mean across the three replicates and used the inverse of half the variance of a difference as a weight for the second stage of two-stage analysis (Möhring and Piepho 2009). The model fitted in the second stage was (Piepho et al. 2014)

, (1)

where *yijk* is the mean yield of the *i*th genotype in the *j*th location and *k*th year, *μ* is a fixed intercept,  is the fixed slope for genetic trend,  is the year of release for the *i*-th variety,  is the fixed slope for non-genetic trend,  is the calendar year, *Gi* is the random main effect of the *i*th genotype, *Lj* is the random main effect of the *j*th location, *Yk* is the random main effect of the *k*th year, (*LY*)*jk* is the *jk*th random location × year interaction effect, (*GL*)*ij* is the *ij*th random genotype × location interaction effect, (*GY*)*ik* is the *ik*th random genotype × year interaction effect,  is a *ijk*th random genotype × location × year interaction effect  is a *ijk*th error of a mean, assumed to have variance equal to half the variance of a difference of genotype means in the *jk*th trial. In order to assess the performance of the varieties in the system, we computed genotype means based on the last four years of data, taking *Gi* as fixed and dropping the two trend terms in (1).

**FA model**

For stability analysis based on the Finlay-Wilkinson (1963) regression, we use factor-analytic models. Since three-way data is available, in principle, such models could be used for the genotype-location effect, the genotype-year effect and the genotype-location-year effect (Piepho and van Eeuwijk, 2002). Here, we only consider the three-way effect because this has the largest number of levels. The model replaces the sum  with a multiplicative model of the form :

, (2)

where  is a slope for the *i*-th genotype,  is a random latent score for the *jk*-th environment (location-year combination) and is a residual three-way effect. The two random effects and  are assumed to be independent with variance 1 and , respectively. This model is essentially a mixed model version of Finlay-Wilkinson regression, extended to three-way data (Piepho 1998).

**Shukla’s stability Variance**

If the regression term is dropped, we obtain a stability variance (Shukla 1972; Piepho 1994) based on the three-way interaction :

, (3)

Where all effects are defined as in (2).

**“Random regression models“**

Five possible terms:







Test all combinations of those five terms and compare AIC.

**Results**

**Table 3**: Estimates of fixed effects (t ha-1) and variance components (t2 ha-2)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameters | Aman |  | Boro |  |
|  | Estimate | Standard error  (p-value, z-test) | Estimate | Standard error  (p-value, z-test) |
| Fixed effects (t ha-1) |  |  |  |  |
| Intercept | -38.0779 | 43.4912  (p = 0.4068) | -54.8098 | 48.9232 |
| Genetic trend | 0.002035 | 0.008477  (p= 0.8103) | 0.01159 | 0.003392 (p=0.006) |
| Non-genetic trend | 0.01890 | 0.02005  (p= 0.3458) | 0.01853 | 0.02418  (p= 0.4434) |
| Variance components (t2 ha-2) |  |  |  |  |
| G | 0.2854 | 0.08219 | 0.06516 | 0.02070 |
| L | 0.2143 | 0.1292 | 0.4987 | 0.2573 |
| Y | 0.03846 | 0.04364 | 0.08861 | 0.06509 |
| Y×L | 0.5085 | 0.07692 | 0.6097 | 0.08350 |
| L×G | 0.05174 | 0.009452 | 0.06489 | 0.009552 |
| Y×G | 0.02175 | 0.005724 | 0.006617 | 0.003874 |
| Y×L×G | 0.2745 | 0.01076 | 0.2728 | 0.009817 |
| Error  (mean across trials) | 0.0625 |  | 0.0673 |  |

**Table 4**: Genotype means based on the last four years (2012-2015) of trials.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Aman |  |  | Boro |  |
| Variety name | Estimate | Standard error | Variety name | Estimate | Standard error |
| BR10 | 4.9029 | 0.3225 | BR1 | 5.5362 | 0.2858 |
| BR11 | 4.7236 | 0.3225 | BR12 | 5.0995 | 0.2858 |
| BR22 | 4.3674 | 0.3225 | BR14 | 5.7745 | 0.2858 |
| BR23 | 4.2809 | 0.3225 | BR15 | 5.7379 | 0.2858 |
| BR25 | 4.0976 | 0.3225 | BR16 | 5.7559 | 0.2858 |
| BR3 | 4.0388 | 0.3225 | BR17 | 5.0492 | 0.2858 |
| BR4 | 4.3565 | 0.3225 | BR18 | 5.2571 | 0.2858 |
| BR5 | 3.0579 | 0.3225 | BR19 | 5.2568 | 0.2858 |
| BRRI dhan30 | 4.4158 | 0.3225 | BR2 | 5.3294 | 0.2858 |
| BRRI dhan31 | 4.3897 | 0.3225 | BR3 | 5.6219 | 0.2858 |
| BRRI dhan32 | 4.4203 | 0.3225 | BR6 | 5.4676 | 0.2858 |
| BRRI dhan33 | 3.7573 | 0.3225 | BR7 | 5.3543 | 0.2858 |
| BRRI dhan34 | 2.9757 | 0.3225 | BR8 | 5.5970 | 0.2858 |
| BRRI dhan37 | 3.0357 | 0.3225 | BR9 | 5.8665 | 0.2858 |
| BRRI dhan38 | 3.1848 | 0.3225 | BRRI dhan28 | 5.7149 | 0.2859 |
| BRRI dhan39 | 4.2642 | 0.3225 | BRRI dhan29 | 6.2862 | 0.2858 |
| BRRI dhan40 | 4.5123 | 0.3225 | BRRI dhan35 | 5.5064 | 0.2858 |
| BRRI dhan41 | 4.2366 | 0.3225 | BRRI dhan36 | 5.4291 | 0.2858 |
| BRRI dhan44 | 4.6852 | 0.3226 | BRRI dhan45 | 5.4718 | 0.2858 |
| BRRI dhan46 | 4.4196 | 0.3225 | BRRI dhan47 | 5.7425 | 0.2858 |
| BRRI dhan49 | 4.7048 | 0.3225 | BRRI dhan50 | 5.4017 | 0.2858 |
| BRRI dhan51 | 4.5731 | 0.3225 | BRRI dhan55 | 5.8846 | 0.2927 |
| BRRI dhan52 | 4.7214 | 0.3225 | BRRI dhan58 | 6.1745 | 0.2927 |
| BRRI dhan53 | 4.3120 | 0.3218 | BRRI dhan59 | 5.7501 | 0.3004 |
| BRRI dhan54 | 4.5857 | 0.3232 | BRRI dhan60 | 6.0674 | 0.3019 |
| BRRI dhan56 | 3.8118 | 0.3232 | BRRI dhan61 | 5.9237 | 0.3019 |
| BRRI dhan57 | 3.1446 | 0.3218 | BRRI dhan63 | 5.6487 | 0.3295 |
| BRRI dhan62 | 3.1236 | 0.3479 | BRRI dhan64 | 5.4665 | 0.3004 |
| BRRI dhan66 | 4.1362 | 0.3895 | BRRI dhan67 | 5.5807 | 0.3351 |
|  |  |  | BRRI dhan68 | 5.8949 | 0.3351 |
|  |  |  | BRRI dhan69 | 6.2633 | 0.3351 |
|  |  |  |  |  |  |
| Mean SED | 0.2147 |  |  | 0.1904 |  |

We also compared the genetic trends for the five groups of varieties (Table 2), adding group-specific intercepts and slopes, and found non-significant differences in genetic trend for Aman (F= 1.06, p = 0.3743) or Boro (F= 0.17, p= 0.8454). The corresponding trend estimates are shown in Table 5.



**Figure 1.** Adjusted genotype means per environment…



**Figure 2.** Adjusted genotype means per environment…



**Figure 3.** Adjusted genotype means per environment…



**Figure 4.** Adjusted genotype means per environment…

**Table 5**: Estimates of fixed effects (t ha-1) in model with group-specific trends

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameters | Aman |  | Boro |  |
|  | Estimate | Standard error  (p-value, z-test) | Estimate | Standard error  (p-value, z-test) |
| Fixed effects (t ha-1) |  |  |  |  |
| Intercept |  |  |  |  |
| Aromatic | -45.1082 | 57.2609 | - | - |
| Long | -15.2264 | 55.7423 | -55.9052 | 49.2750 |
| Medium | -70.8412 | 47.0906 | - | - |
| Short | -35.6331 | 59.6999 | -52.9244 | 50.5350 |
| Stress | 40.8033 | 70.7175 | -65.3275 | 51.2546 |
| Genetic trend |  |  |  |  |
| Aromatic | 0.005165  (n=4) | 0.02044  (p=0.8005) | - | - |
| Long | -0.00925  (n=4) | 0.01945  (p=0.6344) | 0.01224  (n=17) | 0.004500 (p=0.0065) |
| Medium | 0.01866  (n=8) | 0.01237  (p=0.1315) | - | - |
| Short | 0.000810  (n=6) | 0.02221  (p=0.9709) | 0.01068  (n=6) | 0.007192 (p=0.1375) |
| Stress | -0.03720  (n=10) | 0.02917  (p=0.2021) | 0.01686  (n=8) | 0.008417  (p=0.0452) |
| Non-genetic trend | 0.01887 | 0.02004  (p= 0.3464) | 0.01846 | 0.02418  (p=0.4451) |

Table 6 shows the stability variance estimates for the varieties.

**Table 6**: Stability variance estimates for the three-way interaction genotype-by-location-by-year. The smaller the variance, the more stable the variety.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Aman |  |  | Boro |  |
| Variety name | Estimate | Standard error | Variety name | Estimate | Standard error |
| BR10 | 0.3722 | 0.0617 | BR1 | 0.2697 | 0.0432 |
| BR11 | 0.4088 | 0.0675 | BR12 | 0.2119 | 0.0351 |
| BR22 | 0.2892 | 0.0493 | BR14 | 0.176 | 0.0311 |
| BR23 | 0.2107 | 0.039 | BR15 | 0.3035 | 0.0468 |
| BR25 | 0.2471 | 0.0439 | BR16 | 0.2807 | 0.0446 |
| BR3 | 0.3701 | 0.0611 | BR17 | 0.3543 | 0.0543 |
| BR4 | 0.1754 | 0.0342 | BR18 | 0.2401 | 0.0385 |
| BR5 | 0.2756 | 0.0479 | BR19 | 0.329 | 0.05 |
| BRRI dhan30 | 0.2042 | 0.0369 | BR2 | 0.2593 | 0.0419 |
| BRRI dhan31 | 0.2292 | 0.0423 | BR3 | 0.2342 | 0.0383 |
| BRRI dhan32 | 0.3163 | 0.0544 | BR6 | 0.3637 | 0.0552 |
| BRRI dhan33 | 0.4119 | 0.0674 | BR7 | 0.2836 | 0.0446 |
| BRRI dhan34 | 0.2056 | 0.039 | BR8 | 0.4881 | 0.0713 |
| BRRI dhan37 | 0.1864 | 0.0364 | BR9 | 0.1876 | 0.0323 |
| BRRI dhan38 | 0.1101 | 0.0243 | BRRI dhan28 | 0.2616 | 0.0414 |
| BRRI dhan39 | 0.4597 | 0.0735 | BRRI dhan29 | 0.2926 | 0.0461 |
| BRRI dhan40 | 0.2126 | 0.0412 | BRRI dhan35 | 0.2218 | 0.0362 |
| BRRI dhan41 | 0.3328 | 0.0592 | BRRI dhan36 | 0.2704 | 0.043 |
| BRRI dhan44 | 0.131 | 0.0337 | BRRI dhan45 | 0.2513 | 0.0488 |
| BRRI dhan46 | 0.2405 | 0.0557 | BRRI dhan47 | 0.3386 | 0.0735 |
| BRRI dhan49 | 0.1369 | 0.0451 | BRRI dhan50 | 0.1501 | 0.0409 |
| BRRI dhan51 | 0.0865 | 0.0389 | BRRI dhan55 | 0.4341 | 0.1275 |
| BRRI dhan52 | 0.1147 | 0.0474 | BRRI dhan58 | 0.3453 | 0.1062 |
| BRRI dhan53 | 0.2416 | 0.0857 | BRRI dhan59 | 0.3348 | 0.1176 |
| BRRI dhan54 | 0.3365 | 0.1217 | BRRI dhan60 | 0.2832 | 0.1108 |
| BRRI dhan56 | 0.4046 | 0.1357 | BRRI dhan61 | 0.0878 | 0.0472 |
| BRRI dhan57 | 0.7264 | 0.2218 | BRRI dhan63 | 0.0782 | 0.1202 |
| BRRI dhan62 | 1.3604 | 0.5987 | BRRI dhan64 | 0.1904 | 0.1059 |
| BRRI dhan66 | 0.4207 | 0.3067 | BRRI dhan67 | 0.2895 | 0.2312 |
|  |  |  | BRRI dhan68 | 0.0957 | 0.1483 |
|  |  |  | BRRI dhan69 | 0.1598 | 0.1684 |



**Figure 5.** Shukla’s stability variances per genotype



**Figure 6.** Shukla’s stability variances per genotype

**Table 7**: Wald-Test for fixed effects (trends) obtained by the model used to estimate the stability variances

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Aman |  |  | Boro |  |
|  | Df | Wald F | p-Value | Df | Wald F | p-Value |
| Intercept | 1 | 369.3806 | <0.0001 | 1 | 480.3118 | <0.0001 |
| Genetic trend (r\_i) | 1 | 0.113 | 0.7367 | 1 | 11.9697 | 0.0005 |
| Non-genetic trend (tj) | 1 | 0.8179 | 0.3658 | 1 | 0.5271 | 0.4678 |

**Table 8**: Wald-Test for fixed effects (trends) obtained by the factor-analytic model

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | Aman |  |  | Boro |  |
|  | Df | Wald F | p-Value | Df | Wald F | p-Value |
| Intercept | 1 | 335.9557 | <0.0001 | 1 | 471.9626 | <0.0001 |
| Genetic trend (r\_i) | 1 | 0.236 | 0.6271 | 1 | 10.9298 | 0.0009 |
| Non-genetic trend (tj) | 1 | 3.1586 | 0.0755 | 1 | 2.5365 | 0.1112 |

**Table 9**: Estimates for FA-model for aman.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variety name | Variance | | Lambda | | |
| Estimate | Standard error | Estimate | Standard error | Standardized |
| BR10 | 0.2572 | 0.0466 | 1.1690 | 0.0897 | 1.4674 |
| BR11 | 0.2752 | 0.0495 | 1.1910 | 0.0919 | 1.4949 |
| BR22 | 0.2853 | 0.0483 | 0.9312 | 0.0810 | 1.1689 |
| BR23 | 0.2072 | 0.0385 | 0.8664 | 0.0714 | 1.0875 |
| BR25 | 0.2496 | 0.0434 | 0.7442 | 0.0713 | 0.9341 |
| BR3 | 0.3795 | 0.0617 | 0.8230 | 0.0849 | 1.0330 |
| BR4 | 0.1762 | 0.0343 | 0.9402 | 0.0731 | 1.1801 |
| BR5 | 0.2307 | 0.0398 | 0.5244 | 0.0657 | 0.6582 |
| BRRI dhan30 | 0.1910 | 0.0347 | 0.9240 | 0.0741 | 1.1598 |
| BRRI dhan31 | 0.2073 | 0.0393 | 0.9937 | 0.0770 | 1.2473 |
| BRRI dhan32 | 0.3217 | 0.0544 | 0.8690 | 0.0817 | 1.0907 |
| BRRI dhan33 | 0.4328 | 0.0688 | 0.7148 | 0.0870 | 0.8972 |
| BRRI dhan34 | 0.1843 | 0.0339 | 0.5410 | 0.0613 | 0.6790 |
| BRRI dhan37 | 0.1458 | 0.0293 | 0.5593 | 0.0577 | 0.7020 |
| BRRI dhan38 | 0.0950 | 0.0209 | 0.5986 | 0.0535 | 0.7514 |
| BRRI dhan39 | 0.4836 | 0.0757 | 0.7847 | 0.0913 | 0.9849 |
| BRRI dhan40 | 0.2182 | 0.0414 | 0.8431 | 0.0739 | 1.0583 |
| BRRI dhan41 | 0.3405 | 0.0592 | 0.7925 | 0.0840 | 0.9948 |
| BRRI dhan44 | 0.1231 | 0.0322 | 0.9022 | 0.0743 | 1.1325 |
| BRRI dhan46 | 0.2495 | 0.0566 | 0.8196 | 0.0949 | 1.0288 |
| BRRI dhan49 | 0.1254 | 0.0420 | 0.9538 | 0.0926 | 1.1972 |
| BRRI dhan51 | 0.0766 | 0.0372 | 0.9833 | 0.0954 | 1.2343 |
| BRRI dhan52 | 0.0748 | 0.0364 | 1.0118 | 0.0966 | 1.2700 |
| BRRI dhan53 | 0.2743 | 0.0923 | 0.8234 | 0.1444 | 1.0335 |
| BRRI dhan54 | 0.3245 | 0.1174 | 1.0629 | 0.1567 | 1.3342 |
| BRRI dhan56 | 0.4237 | 0.1372 | 0.7005 | 0.1691 | 0.8793 |
| BRRI dhan57 | 0.7333 | 0.2166 | 0.4757 | 0.2024 | 0.5972 |
| BRRI dhan62 | 0.7320 | 0.3431 | -0.1737 | 0.3009 | -0.2181 |
| BRRI dhan66 | 0.4454 | 0.3096 | 0.7341 | 0.3247 | 0.9215 |

**Table 9**: Estimates for FA-model for boro.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Variety name | Variance | | Lambda | | |
| Estimate | Standard error | Estimate | Standard error | Standardized |
| BR1 | 0.2739 | 0.0433 | 0.6819 | 0.0664 | 0.8385 |
| BR12 | 0.2172 | 0.0355 | 0.7306 | 0.0626 | 0.8983 |
| BR14 | 0.1803 | 0.0315 | 0.7678 | 0.0613 | 0.9441 |
| BR15 | 0.2813 | 0.0451 | 0.9177 | 0.0730 | 1.1284 |
| BR16 | 0.2458 | 0.0409 | 0.9419 | 0.0719 | 1.1581 |
| BR17 | 0.3516 | 0.0540 | 0.7986 | 0.0758 | 0.9819 |
| BR18 | 0.2313 | 0.0376 | 0.8345 | 0.0675 | 1.0261 |
| BR19 | 0.3284 | 0.0501 | 0.8328 | 0.0742 | 1.0240 |
| BR2 | 0.2600 | 0.0420 | 0.7861 | 0.0678 | 0.9665 |
| BR3 | 0.2157 | 0.0363 | 0.8729 | 0.0675 | 1.0733 |
| BR6 | 0.3509 | 0.0532 | 0.635 | 0.0699 | 0.7808 |
| BR7 | 0.2798 | 0.0441 | 0.7854 | 0.0697 | 0.9657 |
| BR8 | 0.4750 | 0.0692 | 0.6812 | 0.0795 | 0.8376 |
| BR9 | 0.1712 | 0.0306 | 0.8569 | 0.0631 | 1.0536 |
| BRRI dhan28 | 0.2535 | 0.0397 | 0.6507 | 0.0634 | 0.8001 |
| BRRI dhan29 | 0.2473 | 0.0411 | 0.9999 | 0.0741 | 1.2295 |
| BRRI dhan35 | 0.2214 | 0.0361 | 0.7981 | 0.066 | 0.9813 |
| BRRI dhan36 | 0.2731 | 0.0427 | 0.6530 | 0.0656 | 0.8030 |
| BRRI dhan45 | 0.2570 | 0.0495 | 0.7669 | 0.077 | 0.9430 |
| BRRI dhan47 | 0.3478 | 0.0746 | 0.7051 | 0.0925 | 0.8670 |
| BRRI dhan50 | 0.1485 | 0.0399 | 0.7184 | 0.0752 | 0.8833 |
| BRRI dhan55 | 0.4357 | 0.1269 | 0.7305 | 0.1506 | 0.8982 |
| BRRI dhan58 | 0.3360 | 0.1043 | 0.9058 | 0.1372 | 1.1138 |
| BRRI dhan59 | 0.3021 | 0.1094 | 0.8403 | 0.146 | 1.0333 |
| BRRI dhan60 | 0.2819 | 0.1099 | 0.8360 | 0.1429 | 1.0279 |
| BRRI dhan61 | 0.0815 | 0.0452 | 0.8207 | 0.101 | 1.0092 |
| BRRI dhan63 | 0 | NA | 1.1818 | 0.1735 | 1.4531 |
| BRRI dhan64 | 0.2078 | 0.1095 | 0.7135 | 0.1701 | 0.8773 |
| BRRI dhan67 | 0 | NA | 1.4807 | 0.2381 | 1.8207 |
| BRRI dhan68 | 0.0021 | 0.0974 | 0.4602 | 0.1707 | 0.5659 |
| BRRI dhan69 | 0.1749 | 0.1723 | 0.8269 | 0.2378 | 1.0168 |

**“Random Regression Models”**

**Table 10.** AIC and parameter estimates for all possible combinations of linear random regression coefficients… for aman.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | **Converged** | **AIC** |
|  | -0.00139 |  |  | -0.01658 | TRUE | 1952.44065 |
|  | -0.00126 |  | -0.00303 | -0.01436 | TRUE | 1952.57165 |
| 0.00068 | -0.00124 |  | -0.00342 | -0.01457 | TRUE | 1954.12397 |
| 0.00030 | -0.00139 |  |  | -0.01681 | TRUE | 1954.34640 |
|  | -0.00140 | 0.00004 |  | -0.01662 | TRUE | 1954.44030 |
|  | -0.00105 | -0.00060 | -0.00318 | -0.01366 | TRUE | 1954.48726 |
|  |  | -0.00309 | -0.00448 | -0.01148 | TRUE | 1954.60121 |
|  |  | -0.00359 | -0.00546 |  | TRUE | 1955.41375 |
|  | -0.00138 |  | -0.00444 |  | TRUE | 1955.56039 |
| 0.00077 |  | -0.00305 | -0.00487 | -0.01179 | TRUE | 1956.02560 |
| 0.00068 | -0.00103 | -0.00061 | -0.00357 | -0.01387 | TRUE | 1956.03712 |
|  | -0.00069 | -0.00200 | -0.00466 |  | TRUE | 1956.33496 |
| 0.00030 | -0.00141 | 0.00006 |  | -0.01688 | TRUE | 1956.34526 |
| 0.00067 |  | -0.00356 | -0.00584 |  | TRUE | 1956.98509 |
| 0.00057 | -0.00136 |  | -0.00480 |  | TRUE | 1957.25111 |
|  |  | -0.00314 |  | -0.01527 | TRUE | 1957.32915 |
|  | -0.00160 |  |  |  | TRUE | 1957.56567 |
| 0.00059 | -0.00067 | -0.00203 | -0.00504 |  | TRUE | 1958.00043 |
|  | -0.00111 | -0.00147 |  |  | TRUE | 1958.73850 |
| 0.00021 |  | -0.00313 |  | -0.01545 | TRUE | 1959.28441 |
| -0.00002 | -0.00160 |  |  |  | TRUE | 1959.56527 |
|  |  | -0.00387 |  |  | TRUE | 1960.56219 |
| -0.00002 | -0.00111 | -0.00147 |  |  | TRUE | 1960.73797 |
| -0.00008 |  | -0.00387 |  |  | TRUE | 1962.55533 |
|  |  |  | -0.00461 | -0.01753 | TRUE | 1966.84877 |
| 0.00090 |  |  | -0.00511 | -0.01783 | TRUE | 1968.05705 |
|  |  |  |  | -0.02135 | TRUE | 1969.60401 |
| 0.00031 |  |  |  | -0.02160 | TRUE | 1971.50477 |
|  |  |  | -0.00636 |  | TRUE | 1972.06346 |
| 0.00075 |  |  | -0.00683 |  | TRUE | 1973.51749 |
|  |  |  |  |  | TRUE | 1978.95203 |
| -0.00012 |  |  |  |  | TRUE | 1980.93605 |

**Table 10.** AIC and parameter estimates for all possible combinations of linear random regression coefficients… for boro.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | **Converged** | **AIC** |
|  | - |  | - |  | FALSE | - |
|  | -0.00056 | -0.00407 |  | 0.00873 | TRUE | 2786.98422 |
|  | -0.00054 | -0.00381 |  |  | TRUE | 2787.03736 |
|  |  | -0.00481 |  |  | TRUE | 2787.37187 |
|  |  | -0.00511 |  | 0.00840 | TRUE | 2787.48067 |
| 0.00103 | -0.00055 | -0.00377 |  |  | TRUE | 2788.04628 |
| 0.00101 | -0.00058 | -0.00402 |  | 0.00857 | TRUE | 2788.06725 |
| 0.00098 |  | -0.00480 |  |  | TRUE | 2788.48474 |
| 0.00095 |  | -0.00509 |  | 0.00822 | TRUE | 2788.67180 |
|  |  | -0.00511 | -0.00157 | 0.00942 | TRUE | 2788.79696 |
|  | -0.00063 | -0.00368 | 0.00086 |  | TRUE | 2788.88689 |
|  | -0.00059 | -0.00403 | 0.00021 | 0.00861 | TRUE | 2788.97576 |
|  |  | -0.00479 | -0.001 |  | TRUE | 2789.07839 |
| 0.00127 |  | -0.00507 | -0.00216 | 0.00957 | TRUE | 2789.44779 |
| 0.00121 |  | -0.00475 | -0.00155 |  | TRUE | 2789.80365 |
| 0.00108 | -0.00052 | -0.00410 | -0.00049 | 0.00884 | TRUE | 2790.02624 |
| 0.00100 | -0.00057 | -0.00374 | 0.00022 |  | TRUE | 2790.03725 |
|  | -0.00177 |  |  |  | TRUE | 2794.80996 |
| 0.00114 | -0.00176 |  |  |  | TRUE | 2795.56991 |
|  | -0.00184 |  |  | 0.00644 | TRUE | 2795.61299 |
| 0.00114 | -0.00184 |  |  | 0.00635 | TRUE | 2796.40654 |
|  | -0.00196 |  | 0.00200 | 0.00544 | TRUE | 2796.82246 |
| 0.00090 | -0.00188 |  | 0.00178 |  | TRUE | 2796.96232 |
| 0.00095 | -0.00192 |  | 0.00138 | 0.00568 | TRUE | 2798.06074 |
|  |  |  |  |  | TRUE | 2835.38489 |
| 0.00105 |  |  |  |  | TRUE | 2836.31596 |
|  |  |  | -0.00147 |  | TRUE | 2836.87209 |
| 0.00139 |  |  | -0.00231 |  | TRUE | 2837.14858 |
|  |  |  |  | 0.00088 | TRUE | 2837.36269 |
| 0.00105 |  |  |  | 0.00072 | TRUE | 2838.30097 |
|  |  |  | -0.00161 | 0.00183 | TRUE | 2838.78232 |
| 0.00141 |  |  | -0.00248 | 0.00212 | TRUE | 2839.02712 |

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