THE MODIFIED ARCSINE-LOGARITHM METHODOLOGY FOR ANALYZING SOIL TEST–RELATIVE YIELD RELATIONSHIPS

Adrián A. CORRENDO[1]*, Flavio H. GUTIÉRREZ-BOEM[2], Fernando SALVAGIOTTI[3] & Fernando O. GARCÍA[1]

[1] IPNI Latin America Southern Cone, [2] College of Agriculture, University of Buenos Aires, [3]INTA. *Corresponding author: acorrendo@ipni.net

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INTRODUCTION

Which is the critical value -or range- of a soil fertility variable for a specific crop response level?

We aim to discuss the arcsine-logarithm calibration curve (ALCC), as an alternative method for answering this usual question when developing models for diagnosing crop fertilization. It has two main differences as compared with usual methodologies: i) transformation of both variables; and ii) estimation of a confidence interval (CI) of the critical soil test value (CSTV).

The original method (Dyson & Conyers, 2013) often produces too wide $CI_{95\%}$ and authors suggests to reduce the confidence level to get narrower estimates. Still this method can be further adjusted and improved in order to avoid reducing the confidence level.

METHODOLOGY

The performance of the modified-ALCC was compared vs.: i) the original-ALCC, and ii) a traditional method. For this purpose a non-linear regression (Mistcherlich) of RY (dependent) on STV (independent) was also fitted. The comparisons were based on: i) the CSTV, ii) the CI, and iii) the fulfillment of normality and homoscedasticity assumptions.

Data from 103 phosphorus (P) fertilization experiments in wheat (*Triticum aestivum* L.), between 1997 and 2014 in Argentina, were used. As a minimum criteria, experiments consisted in: a Check (non-fertilized) and a P fertilized treatment, and data of pre-plant soil-test Bray-1 P value (STV) at soil surface (0-20 cm). Relative yield (RY) was calculated relative to the maximum yield attained in each experiment.

PROCEDURES OF THE MODIFIED-ALCC

1 - Transform both variables (**Fig. 1**): *Natural logarithm* for STV = ln(Bray-1 P), hereinafter Y; *Arcsine of square root* of RY = ASIN[√(RY/100)], hereinafter X.

2 - Centre X values with respect to a RY goal (e.g. 90%).

3 - Estimate the correlation coefficient (r_{xy}).

4 - Calculate the average mean of X and Y to get the centroid coordinates ($\bar{X}$,$\bar{Y}$) of the data ellipse, where all possible regressions pass through.

5 - Fit a common least squares (LS) linear regression $\hat{Y}_i = \hat{\alpha}_{LS} + \hat{\beta}_{LS} * X_i$ (**Fig. 2B**-blue-)

6 - Rotate the LS to a standardized major axis (SMA) regression (**Fig. 2B**-red-): divide $\hat{\beta}_{LS}$ by r_{xy}, then use $\bar{X}$ and $\bar{Y}$ to obtain the intercept ($\hat{\alpha}_{SMA}$).

7 - Back-transform the $\hat{\alpha}_{SMA}$ and its standard error (SE$\hat{\alpha}$) to obtain the CSTV and its CI.

8 - Back-transform the SMA line to the original units to get the ALCC curve (**Fig. 3**)

*Procedures of the original-ALCC are described in:
Dyson and Conyers (2013). *Crop & Pasture Science 64, 435-441*. http://dx.doi.org/10.1071/CP13009

RESULTS

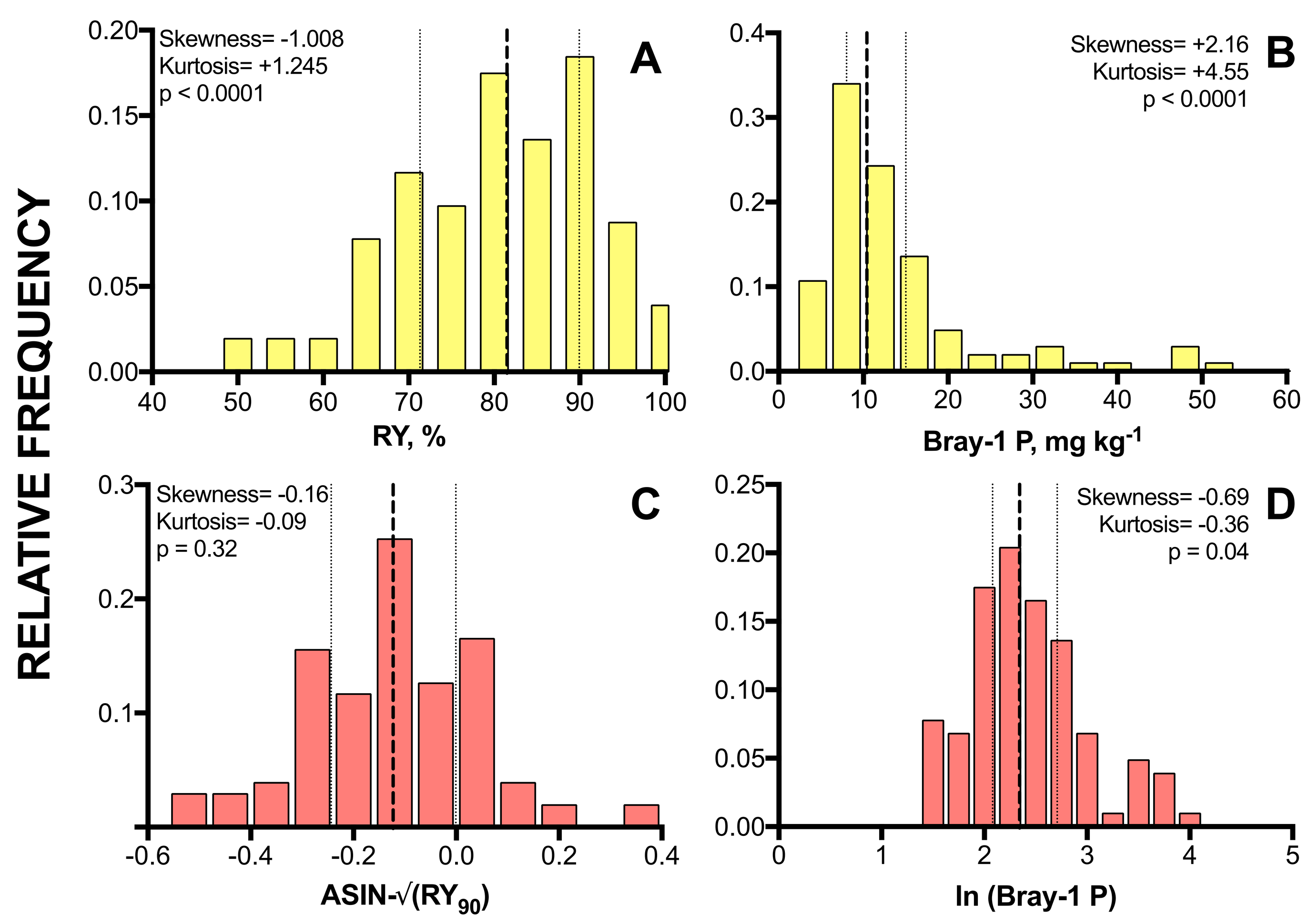

Figure 1. Empirical distribution of variables before (A and B) and after transformations (C and D). The Skewness and Kurtosis values indicate the level of asymmetry and bias. Vertical dotted lines indicate percentiles 25, 50 (median) and 75 of distribution. Significance of D´Agostino-Pearson normality test is indicated with the p-values.

- Transformations improved the distribution of both variables (**Fig. 1**).
- The modified-ALCC resulted in the same equation as the original-ALCC, but it comes from a smaller data ellipse (**Fig. 2**).
- For this dataset, the modified-ALCC showed a 57% smaller SE$\hat{\alpha}$ as compared with the original-ALCC approach (**Fig. 2**).

ACKNOWLEDGEMENTS

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RESULTS (continued)

- For 90% of RY, the estimate of CSTV was lower (17.2 mg kg^{-1}) with the ALCC compared to the LS method (23.8 mg kg^{-1}) (**Fig. 3**)
- The $CI_{95\%}$ for the modified-ALCC (15.2 to 19.6 mg kg^{-1}) was 30% more accurate than the original-ALLC (14.1 to 20.2 mg kg^{-1}) and 67% more accurate than the best fitted LS regression (18.5 to 31.7 mg kg^{-1}).

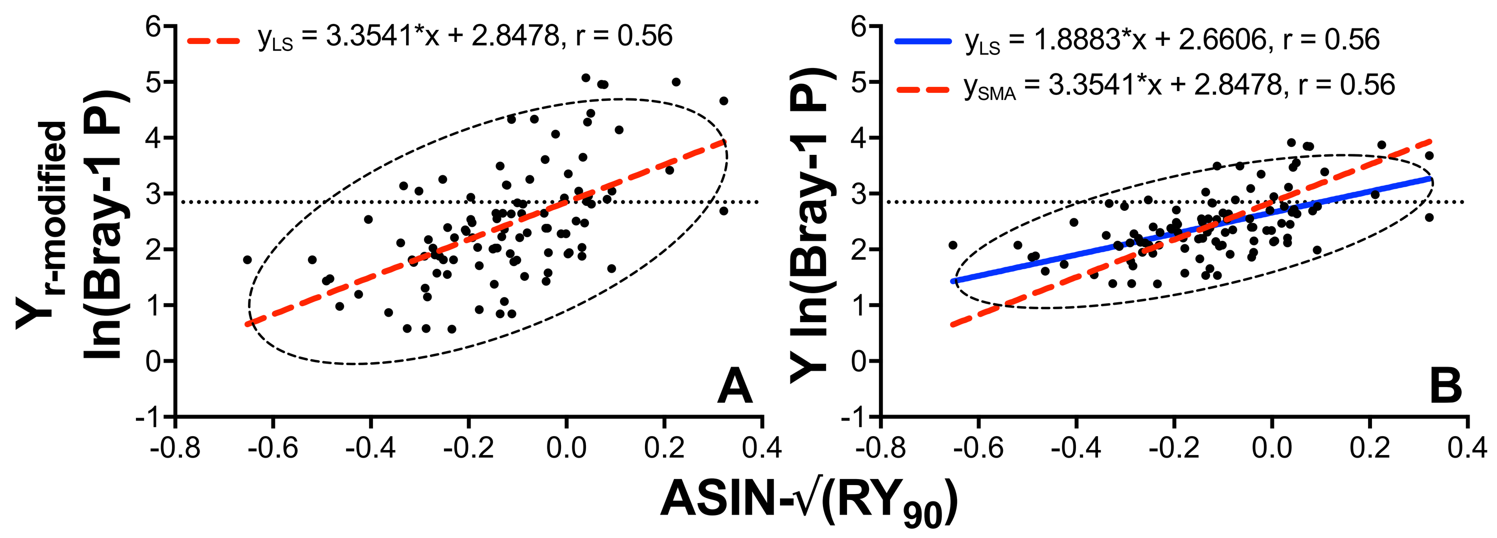

Figure 2. Linear relationships between Bray-1 P (mg kg^{-1}, 0-20cm) and wheat relative yield (RY, %) both as transformed variables. (A) LS regression of $Y_{r\text{-}modified}$ values used by the original-ALCC method. (B) bivariate SMA regression used by the modified-ALCC method. The intercept of dotted lines represents the natural logarithm of the CSTV. In A, $\hat{\alpha}_{LS}$= 2.8478± 0.1045(SE$\hat{\alpha}$). In B, $\hat{\alpha}_{SMA}$= 2.8478± 0.0666. Data ellipses are drawn with dashed black lines.

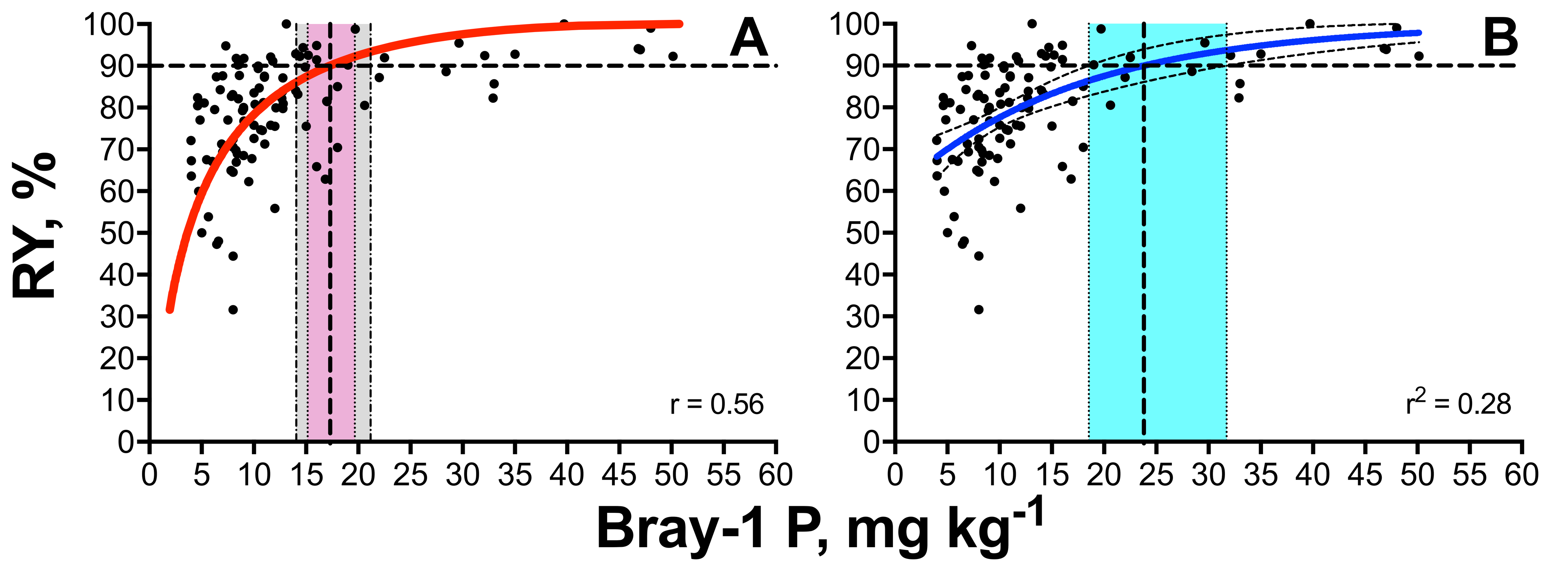

Figure 3. Relationship between wheat relative yield (RY) and soil Bray-1 P (mg kg^{-1}) using two different approaches: (A) ALCC (original and modified), (B) non-linear LS regression. Vertical strips represent the CI for 95% confidence level: grey (original-ALCC), pink (modified-ALCC) and light blue (LS regression).

- The best fitted LS regression model (non-linear) did not fulfill the assumptions of normality and homoscedasticity, while the modified-ALLC did it (**Fig. 4**).

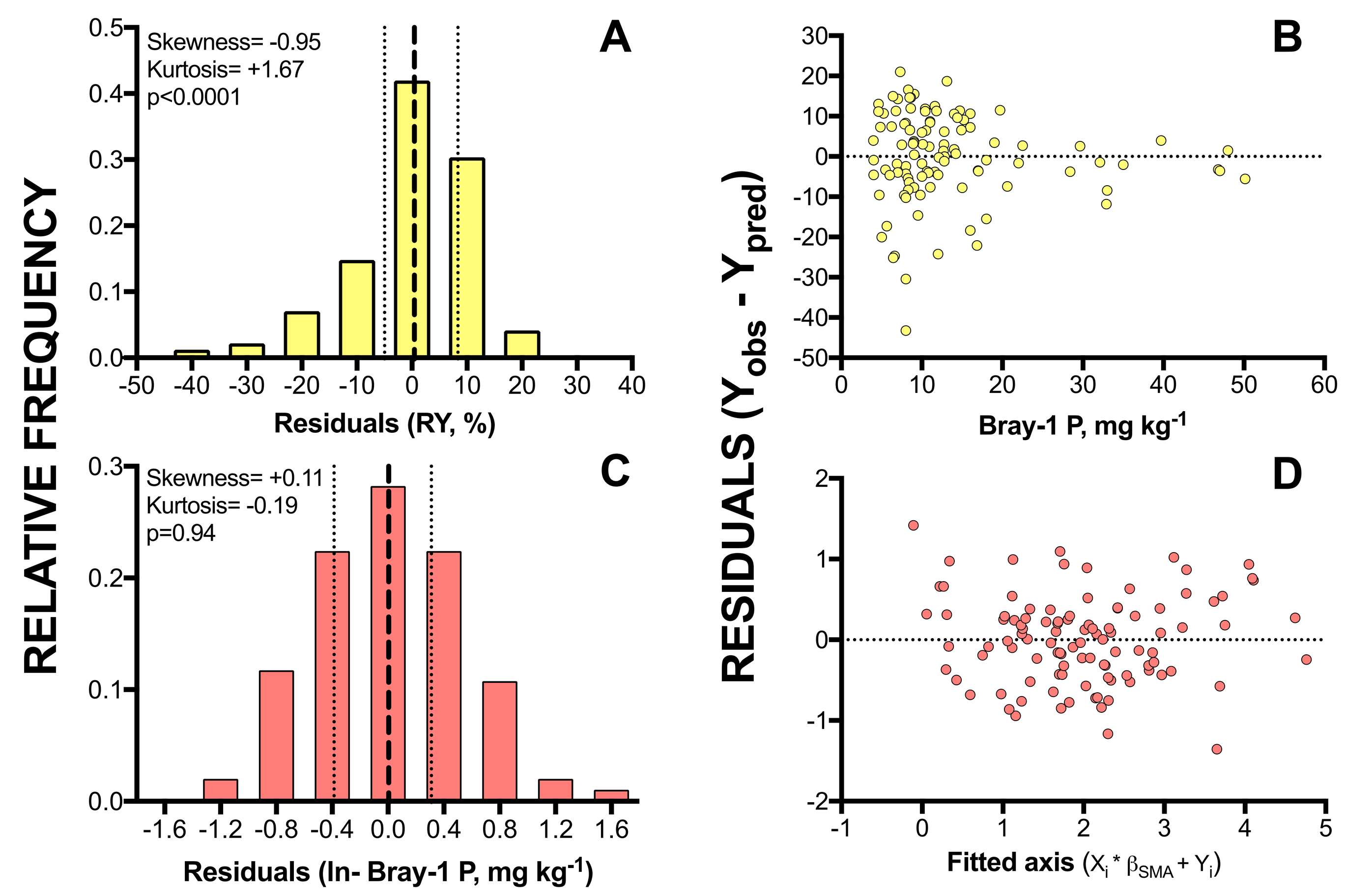

Figure 4. Residual distribution for testing normality and homogeneity for the best fitted non-linear LS regression (traditional method) and for the SMA regression of transformed variables used by the modified-ALCC. The Skewness and Kurtosis values indicate the level of asymmetry and bias. Vertical dotted lines indicate percentiles 25, 50 (median) and 75 of distribution. Significance of D´Agostino-Pearson normality test is indicated with the p-values. Homogeneity of variances was tested visually.

CONCLUSIONS

- A predictive model such as LS regression may have risks of misuse since the explanatory variable is not fixed and usually shows problems with normality and homoscedasticity assumptions.
- The ALCC is based on a bivariate relationship between transformed variables and may represent a reliable and even more accurate approach.
- This modified-ALCC approach avoids the error overestimation of the CSTV. Consequently, for any given level of confidence (e.g. 95%), the CI of the modified-ALCC is always more accurate than the original-ALCC.