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Repeatability coefficient estimates and optimum number of harvests in graft/rootstock combinations for 'tahiti' acid lime

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ABSTRACT. Combining longitudinal data and statistical models from perennial crops enabled us to estimate the optimum number of measures (harvests), implying accurate discrimination of superior genotypes in those crops. Herein, the goal of this study was to determine the optimum number of harvests based on yield traits and recommend a superior graft/rootstock combination (GRC) for *Citrus latifolia* Tanaka. Twenty-four GRCs of 'Tahiti' acid lime were evaluated from July 2017 to August 2018 for fruit yield per plant (FYP), number of fruits per plant (NFP), and longitudinal (LFD) and transversal fruit diameter (TFD). The experimental design was a randomized complete block with 4 replications. The experimental unit consisted of three individuals, totalling 244 individuals. The GRCs were composed of (i) two hybrids that were used as rootstock, citrumelo 'Swingle' (*Citrus paradisi* x *Poncirus trifoliata*) and cintrandarin 'Riverside' (*Citrus sunki* x *Poncirus trifoliata*); and (ii) 12 different *C. latifolia* genotypes that were used as grafts: Bello Fruit, Eledio, Iconha, Itarana, Santa Rosa, Bearss lime, CNPMF 01, CNPMF 02, CNPMF 2001, CNPMF 5059, BRS Passos, and Persian 58. Mixed models were employed to estimate the variance components. The optimum number of harvests was determined based on selective efficiency values above 0.9. The estimated repeatability coefficients presented values of 0.14 (LFD), 0.16 (TFD), 0.36 (FYP), and 0.38 (NFD). Based on the results, four harvests were able to choose genotypes based on FYP and NFP, whereas LFD and TFD were considered inefficient traits for recommending superior GRCs.

Keywords: *Citrus latifolia* Tanaka; mixed models; REML-BLUP; longitudinal data; perennial crop.

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Introduction

The socioeconomic importance of citriculture as an area of fruit growing stands out in a worldwide scenario (Sales et al., 2018). From the genus *Citrus*, the species *Citrus latifolia* (Tanaka), which is popularly known as the 'Tahiti' acid lime, has shown commercial potential in the increasing the Brazilian internal consumer market (Castricini, Silva, Silva, & Rodrigues, 2017). This fruit is prominent in the citrus market due to its availability throughout the year, and nearly 50 thousand hectares of the crop exist in Brazil (Morais et al., 2020).

The characteristics of the 'Tahiti' acid lime that grab attention from a commercial perspective are the fruit shape, fruit size, fruit shine, fruit flavour, nutritional value of the fruit, external fruit green coloration, and turgidity of the fruit (Bassan et al., 2015). However, a factor that can influence the quality of these characteristics is the graft/rootstock combination (GRC). It is worth mentioning that GRC also has a greater impact on giving greater vigour, productivity and longevity to the crop (Cerqueira et al., 2004; Soares et al., 2015). Due to the fact that in a breeding program of 'Tahiti' acid lime, much time is spent in experimental evaluation along with numerous harvests, the use of appropriate statistical methods to evaluate experiments is important in the decision making by breeders and allows the maximization of selection efficiency.

Another way to increase the chance of success in a breeding program is with the simultaneous selection index (SI). Thus, the SI is characterized as a linear function that combines different traits and assigns different weights according to the importance of a trait (Ramalho, Abreu, Santos, & Nunes, 2012). In this sense, the use of the SI allows various traits to be worked with to obtain genetic gains by combining multiple types of information contained in the experimental unit with the aim of selecting based on a complex of traits of economic importance (Cruz, Regazzi, & Carneiro, 2012).

The ability to predict genetic parameters, such as heritability and repeatability, is an important contribution of quantitative genetics to plant breeding (Resende, 2015). The estimation of repeatability coefficients provides an approximation of the maximum value that the heritability, in the broad sense, of a trait can reach (Lessa, Ledo, Amorim, & Silva, 2014). Alternative methods that consider these topics are the restricted maximum likelihood (REML), which estimates the variance components, and the best unbiased linear prediction (BLUP), which predicts the genetic values (Resende, 2015; Resende & Rosa-Perez, 2002).

Experimental analyses considering repeated measurements allow us to predict genetic values for each harvest individually and for all harvests simultaneously and to estimate the structure of variance among them. The repeatability coefficient (ρ) is defined as the correlation between repeated measurements of the same individual over time and space, as well as its associated coefficient of determination (R^2), which measures the accuracy in predicting the true value of an individual genotype (Cruz et al., 2012). Knowledge about trait repeatability is important in an experimental design. Understanding trait deviation over time or space to determine the number of measurements required for each individual allows genetic selection to be performed to obtain an appropriate level of accuracy to reduce labour time and budgets of the breeding program (Resende, 2007). Thus, studying ρ estimation allows the necessary number of measures to be obtained to estimate the individual's real genetic value, taking into account the permanent environmental, genetic and environmental effects and optimizing the evaluation time of the trait of interest in the field (Lessa et al., 2014).

Repeatability using the REML/BLUP methodology has been used in other fruit trees to determine the optimal number of measurements without compromising accuracy (Fonseca, Morais, Gonçalves, Aquino, & Rocha, 2018; Lessa et al., 2014; Negreiros, Andrade-Neto, Miqueloni, & Lessa, 2014). Sanchéz et al. (2017) evaluated that the number of measures to evaluate the productivity of *Annona muricata* L. could be reduced from sixteen to eight, maintaining a repeatability and accuracy coefficient above 80%. Herein, we aimed to determine the optimum number of harvests used in *C. latifolia* based on productive traits to recommend superior 'Tahiti' acid lime GRCs.

Material and methods

Experimental network

The experimental network was conducted at José Guarete Farm, which is owned by Bello Fruit Company, in São Mateus, Espírito Santo State, Brazil (18°48'21" S, 39°53'30" W), between July 2017 and August 2018. The climate of the region according to the Koppen classification system is tropical warm and humid (Aw), with rainy summers and dry winters (Alvares, Stape, Sentelhas, & Gonçalves, 2013). The average temperature during the experiment was 25°C, and the precipitation was 140 mm (weather information in Appendix S1).

Twenty-four GRCs of 'Tahiti' acid lime, which were arranged in a spacing of six metres between rows and three metres between plants, were used as the variation factors. The experimental design was a randomized complete block with 4 replications. The experimental unit consisted of three plants, totalling 244 individuals. The GRCs were composed of (i) two hybrids that were used as rootstock, citrumelo 'Swingle' (*Citrus paradisi* x *Poncirus trifoliata*) and cintrandarin 'Riverside' (*Citrus sunki* x *Poncirus trifoliata*); (ii) 12 different *C. latifolia* genotypes that were used as grafts: Bello Fruit, Eledio, Iconha, Itarana, Santa Rosa, Bearss lime, CNPMF 01, CNPMF 02, CNPMF 2001, CNPMF 5059, BRS Passos, and Persian 58.

Limes were harvested in July, November, and October 2017 and January, March, July, and October 2018 for a total of seven harvests. All mature fruits were harvested. Maturity is considered when the fruits present a minimum diameter of 47 mm, external rough texture and dark green to light colour (Morais et al., 2020). The fruit yield per plant (FYP in kg plant $^{-1}$) was taken by measuring the total weight using a digital scale, and the number of fruits per plant (NFP) was counted at each harvest. Ten fruits were randomly separated from each GRC in each harvest. Then, the longitudinal fruit diameter (LFD in mm) and transversal fruit diameter (TFD in mm) were measured using digital callipers.

Statistical analyses

The REML/BLUP procedure was adopted to estimate the variance components and to predict the genotypic values following the procedures in Patterson and Thompson (1971) and Henderson (1975). The statistical model was as follows:

$$y = Xm + Zg + Wp + Ti + \varepsilon$$

where: y is the data vector, m is the measuring-repetition combinations effect vector (assumed to be fixed), g is the vector of the genotypic effect (assumed to be random), p is the permanent environmental effect vector (assumed to be random), i is the vector of the genotype x measuring (G×M) interaction effects (assumed to be random), and ε is the vector of errors (random). The capital letters X, Z, W, and T represent the incidence matrices for those effects (Resende & Duarte, 2007).

The significance of the random effects was tested using the likelihood ratio test (LRT) (Rao, 1973), which was calculated with the following equation:

$$\lambda = 2\left[Log_e L_{p+1} - Log_e Log_p\right]$$

where: Log_e is the logarithm of the REML function and L_{p+1} and L_p are the likelihood peaks associated with the complete model and the reduced model, respectively. Thus, λ was compared with the probability density function (χ^2) for a given number of degrees of freedom and probability of error (Dobson & Barnett, 2018). The number of degrees of freedom was defined as the difference between the numbers of parameters between the evaluated models (one degree of freedom in this case).

The phenotypic individual variance ($\hat{\sigma}^2_{phen}$), average phenotypic variance ($\hat{\sigma}^2_{\overline{phen}}$), heritability in a broad sense ($\hat{h}^2_g$), repeatability (ρ), determination coefficient of permanent environmental effects (c^2_{perm}), determination coefficient of G×M effects (c^2_{gm}), phenotypic correlation throughout measurements (r_{gm}), average heritability of genotypes ($\hat{h}^2_{mg}$), and coefficient of experimental variation (CV_e) were obtained with the following expressions:

$$\hat{\sigma}^2_{phen} = \hat{\sigma}^2_g + \hat{\sigma}^2_{perm} + \hat{\sigma}^2_e + \hat{\sigma}^2_{gm},$$

$$\hat{\sigma}^2_{\overline{phen}} = \hat{\sigma}^2_g + \frac{\hat{\sigma}^2_{perm}}{r} + \frac{\hat{\sigma}^2_e}{r \, x \, m} + \frac{\hat{\sigma}^2_{gm}}{m},$$

$$\hat{h}^2_g = \frac{\hat{\sigma}^2_g}{\hat{\sigma}^2_{phen}},$$

$$\rho = \frac{\hat{\sigma}^2_g + \hat{\sigma}^2_{perm}}{\hat{\sigma}^2_{phen}},$$

$$c^2_{perm} = \frac{\hat{\sigma}^2_{perm}}{\hat{\sigma}^2_{phen}},$$

$$c^2_{gm} = \frac{\hat{\sigma}^2_{gm}}{\hat{\sigma}^2_{phen}},$$

$$r_{gm} = \frac{\hat{\sigma}^2_g}{\hat{\sigma}^2_g + \hat{\sigma}^2_{gm}},$$

$$\hat{h}^2_{mg} = \frac{\hat{\sigma}^2_g}{\hat{\sigma}^2_{\overline{phen}}}, \text{ and}$$

$$CV_e(\%) = \sqrt{\frac{\hat{\sigma}^2_e}{\mu}} \; x \; 100,$$

where: $\hat{\sigma}^2_g$ is the genotypic variance; $\hat{\sigma}^2_{perm}$ is the permanent environmental variance; $\hat{\sigma}^2_e$ is the residual variance; $\hat{\sigma}^2_{gm}$ is the G×M interaction variance; r is the number of repetitions; and m is the number of measures.

The determination for the permanent phenotypic effects ($r^2_{\hat{f}\hat{p}fp}$), mean selective accuracy ($r_{\hat{g}g}$), and selective efficiency (E), all based on m measurements, were given by the following equations:

$$r^2_{\hat{f}\hat{p}fp} = \frac{m\,\rho}{1 + (m-1)\rho}$$

$$r_{\hat{g}g} = \left(\frac{\hat{\sigma}_g^2}{\hat{\sigma}_g^2 + \frac{\hat{\sigma}_{perm}^2}{r} + \frac{\hat{\sigma}_e^2}{r\,x\,m} + \frac{\hat{\sigma}_{gm}^2}{m}} \right)^2$$

$$E = \left[\frac{m}{[1 + (m-1)\,\rho} \right]^{1/2}$$

The optimum number of GRCs for recommendation was estimated, though the accuracy values were superior to 0.9 (Resende, Silva, & Azevedo, 2014). The additive index (AI) (Resende, 2007), which was used to identify the superior GRC for use in the acid lime breeding program, was given by the following expression:

$$AI = \sum_{h=1}^{4} w_t \frac{vg}{\sigma_t}$$

where: w_t is the weight assigned for trait t, vg is the overall mean for trait t added to the predicted genetic value, and σ_t is the standard deviation for vg. For the additive index, the weights were set as equal to the genetic coefficient of variation (CV_g) using the following equation:

$$CV_g(\%) = \frac{100\,\hat{\sigma}_g^2}{\mu}$$

where the selection direction was "higher" for all traits. Two scenarios were explored: the first considered the seven harvests, and the second scenario took into consideration the number of optimum harvests obtained in this study. The predicted gain with the selection and the genotype ranking were obtained directly by the additive index output.

All analyses were carried out in the software Selegen-REML/BLUP (Resende, 2016).

Results and discussion

The traits FYP, NFP, and TFD were statistically significant for all effects (genotype, permanent environmental, and G×M) (Table 1), while the LFD trait indicated no significant difference for permanent environmental and G×M effects but only for the genetic effect. This implied differences between the values of the productive traits evaluated among the GRCs and that they were influenced throughout the crops. Similar studies by Shrestha, Dhakal, Gautum, Paudyal and Shrestha (2012) and Khankahdani, Rastegar, Golein, Golmohammadi and Jahromi (2017) also indicated the existence of genetic variability in the acid lime culture. Regarding the experimental quality, the FYP and NFP traits presented CV_e values of 50.38 and 48.83%, respectively, which were higher than those found for LFD and TFD (4.33 and 3.40%, respectively). The observed large difference evidenced the low precision of NFP and FYP traits and the strong influence suffered by the environment since these traits are quantitative traits (Viana & Resende, 2014).

Table 1. Likelihood ratio test (LRT) for the traits: fruit yield per plant (FYP), number of fruits per plant (NFP), longitudinal fruit diameter (LFD), and transversal fruit diameter (TFD) of the statistical analyses of 24 GRC of 'Tahiti' acid lime.

Effect	Traits			
	FYP	NFP	LFD	TFD
Genotype	58.95**	59.63**	20.12**	12.75**
Permanent environmental	5.5*	7.37**	0.36ns	5.11*
Genotype x Measurement	35.37**	34.89**	2.5ns	16.85**

ns, *, **, not significant, significance at 5 and 1% of probability by the LRT, respectively.

The statistical significance of the G × M interaction effect confirmed the existence of genotypes with different performances throughout harvests in terms of yield. This fact was expected since the recurrent significant interactions between genotypes and crops in the evaluation of perennial plants is commonly caused by the effect of the environment on the expression of traits (Resende, 2009). Heritability is estimative and allows for evaluating the proportion of the total variance that results from the genetic origin. The results of the analyses indicated that the $\hat{h}_{mg}^2$ of the traits ranged from 0.66 to 0.88 (Table 2), which were interpreted as elevated values, indicating strong genetic control of the traits. However, heritability estimates in young perennial plants are frequently biased by the G × M effect (Resende, Furlani-Júnior, Moraes, & Fazuoli, 2001). Those plants have lower competitive effects and consequently have lower estimates for the variance components (Araújo, Dias, Scarpinati, & Paula, 2015). Thus, the parameters obtained, among them ρ, which refers to the heritability limits, tended to be higher in the early stages but reached normality as the plants develop. In the experiment, the plants were approximately 36 months old, while a citrus orchard has (in the Southeastern region, Brazil) a life cycle of 25 years (Santana, Souza, Souza, & Fontes, 2006). Thus, the plants assessed in this study do not achieve commercial age, implying that high values of parameters were properly estimated. New experimental evaluations that account for more harvests should address the genotypes under analyses. They would allow a more precise parameter estimation for the 'Tahiti' acid lime crop.

Table 2. Estimates of variance components and genetic parameters for fruit yield per plant (FYP), number of fruits per plant (NFP), longitudinal fruit diameter (LFD), and transversal fruit diameter (TFD) of 24 GRC of 'Tahiti' acid lime.

Estimate [1]	Traits			
	FYP	NFP	LFD	TFD
$\hat{\sigma}_g^2$	317.42	2.56	0.95	0.55
$\hat{\sigma}_{perm}^2$	34.30	0.31	0.11	0.26
$\hat{\sigma}_e^2$	461.43	3.49	6.25	3.42
$\hat{\sigma}_{gm}^2$	142.64	1.08	0.42	0.68
$\hat{\sigma}_{phen}^2$	955.79	7.44	7.79	4.91
$\hat{\sigma}_{\overline{phen}}^2$	362.86	2.91	1.26	0.83
h_{mg}^2	0.87	0.88	0.75	0.66
ρ	0.36	0.38	0.14	0.16
c_{perm}^2	0.03	0.04	0.01	0.05
c_{gm}^2	0.15	0.14	0.054	0.14
r_{gm}	0.69	0.70	0.69	0.45
μ	42.63	3.83	57.72	54.23
CV_e (%)	50.38	48.83	4.33	3.40

[1] genotypic variance ($\hat{\sigma}_g^2$), permanent environmental variance ($\hat{\sigma}_{perm}^2$), temporary residual variance ($\hat{\sigma}_e^2$), genotype x measurement interaction variance ($\hat{\sigma}_{gm}^2$), individual phenotypic variance ($\hat{\sigma}_{phen}^2$), mean phenotypic variance ($\hat{\sigma}_{\overline{phen}}^2$), repeatability coefficient at parcel level (ρ), determination coefficient of permanent environmental effects (c_{perm}^2), determination coefficient of the effects of interaction genotype x measurement (c_{gm}^2), genotypic correlation through measurements (r_{gm}), heritability of genotype average (h_{mg}^2), overall mean (μ) and experimental coefficient of variation (CVe (%)).

The traits LFD and TFD presented ρ values of 0.14 and 0.16, respectively, while FYP and NFD presented higher values (0.36 and 0.38, respectively). These results were reasonable, considering a perennial culture and the complexity of the production traits, which are usually coordinated by many genes (Cruz et al., 2012, Laviola et al., 2013). There are no studies that have obtained ρ for the 'Tahiti' acid lime, which highlights the relevance of this study. However, in data from other citrus species, such as *Citrus aurantium*, the authors found similar values for total fruit number (0.262) and total fruit weight per plant (0.291) with variance analysis methodology (Negreiros, Saraiva, Oliveira, Álvares, & Roncatto, 2008). Pompeu Junior, Blumer and Resende (2013) used the mixed model methodology and found ρ values of 0.35 for 'Valencia' sweet orange (*Citrus sinensis*), which is like the values found in this study.

According to Resende (2015), ρ is classified as high when it has a value equal to or greater than 0.6, moderate when ρ is in the interval of 0.3-0.6, and low when it is equal to or less than 0.3. In the results of this study, the estimated repeatability was classified as moderate for NFP and FYP and low for TFD and LFD. Similar findings have been reported for other fruit crops, such as banana (Lessa et al., 2014), sweet orange (Negreiros et al., 2008), cashew (Maia et al., 2016), guava (Quintal, Viana, Campos, Vivas, & Amaral Junior, 2017), mangaba (Fonseca et al., 2018), grapes (Leão, Nunes, & Souza, 2018), and cupuassu (Alcoforado, Pedrozo, Mayer, & Lima-Primo, 2019).

The c_{perm}^2 estimates the proportion of individual phenotypic variations that directly results from measurements performed in an individual. Low values of 0.035, 0.041, 0.015, and 0.052 were observed for the FYP, NFP, LFD and TFD traits, respectively. The low values presented revealed that the permanent environmental variation from one harvest to another did not represent influences on the expression of the traits. Pompeu Junior et al. (2013) also found that low proportions of individual phenotypic variance were explained by the permanent environmental effects (0.004).

The determination coefficient of the G×M interaction (c_{gm}^2) showed similar values for FYP, NFP, and TFD (0.15, 0.14, and 0.14, respectively), whereas the LFD presented a lower value of c_{gm}^2 (0.054) when compared to the other three traits. These results showed that the FYP, NFP, and TFD traits collaborated more to express individual phenotypic variation than the LFD. Regarding magnitude, the FYP, NFP, and TFD values of c_{gm}^2 were considered high and the LFD values of c_{gm}^2were considered low (Resende, 2009), while Mariguele et al. (2011) studied models of longitudinal data in *Annona squamosa* and found results of similar magnitudes (0.099).

The r_{gm} values obtained were similar for the traits FYP, NFP, and LFD (0.69, 0.70, and 0.69, respectively), inasmuch as the trait LFD presented an inferior value (0.45). The magnitude of this correlation, which was moderate to high for the characteristics FYP, NFP and LFD, indicated that at an approximate 70% coincidence of the values repeating over the harvests. Conversely, the LFD trait did not demonstrate the same expression among harvests (Resende, 2007).

Our results stated that seven measurements for NFP and FYP were necessary to obtain determination higher than 0.8, which is considered good for selecting superior individuals in perennial cultures (Sanchéz et al., 2017) (Figure 1A). The LFD and TFD traits did not reach the desired minimum values even with the maximum number of estimated measurements (ten). The values of determination in the four harvests reached 0.7 for NFP and FYP, whereas the maximum number of harvests (ten) did not return appropriate values for genotype recommendations in LFD and TFD. When considering accuracy as a parameter for determining the optimal number of harvests, the result was different.

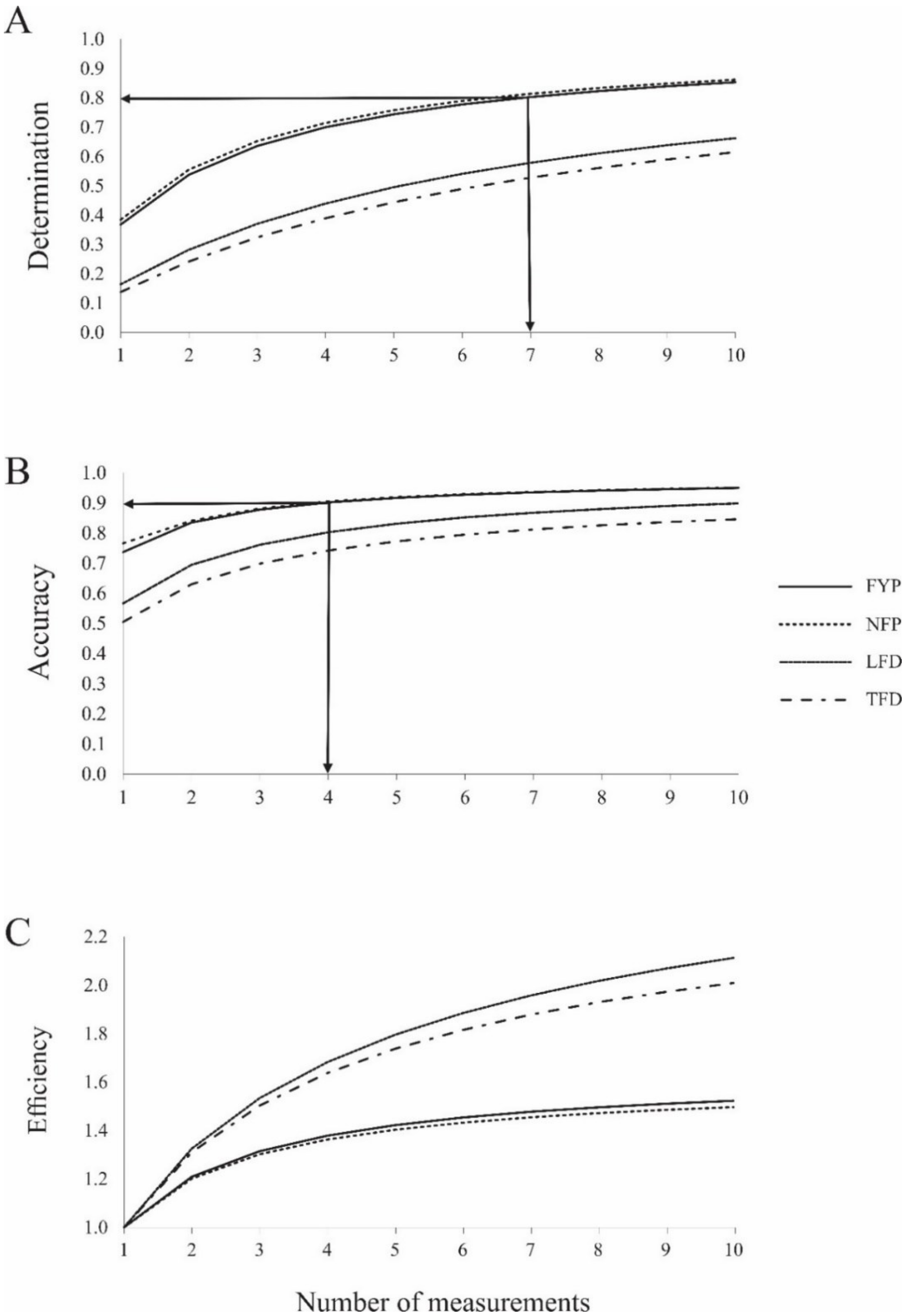

Figure 1. Phenotypic permanent effects determination (A), selection accuracy (B) and C) selective efficiency as a function of the number of measurements by fruit yield per plant (FYP), number of fruits per plant (NFP), longitudinal (LFD), and transversal fruit diameter (TFD) evaluated in 24 GRC of 'Tahiti' acid lime.

Taking this estimate into account, it was observed that the ideal number of harvests was four (Figure 1B). Resende and Rosa-Perez (2002) stated that a few measurements with accuracy values above 0.9 were sufficient to indicate superior genotypes. The selection efficiency based on the average of several measures in relation to a single measure was also inferred in this study (Figure 1C). A more imminent increment was observed by increasing the number of harvests for LFD and TFD traits, which reached efficiency values of higher than two with ten harvests. In contrast, the traits FYP and NFP were less responsive to the increase in the number of harvests, denoting higher precision.

Overall, the determination, accuracy, and selective efficiency increased as the number of measurements increased. For the FYP and NFP traits, with the evaluation of seven harvests, it was possible to reach a maximum determination coefficient of 0.8 with high precision and high selective efficiency. However, with four harvests evaluated, it may be appropriate to indicate superior genotypes for 'Tahiti' acid lime cultivation. Because the values did not reach at least 0.8 for determination and 0.9 for accuracy with the maximum yields estimated in this study, the LFD and TFD traits should not be considered in the selection of superior genotypes. In summary, four harvests were the optimum number selected without losing accuracy and achieved values higher than 0.9. For this reason, four harvests were considered in the second scenario of the SI. However, the plants analysed in this study were younger, at only 36 months of age. This fact implies reduced variation among the genotypes and, as a result, differentiation of them. Most likely, with more experimental evaluation, i.e. including more harvests, those traits tended to reach the reliability needed to recommend in this crop.

The additive selection index revealed no differences in the results of the GRC selection in the two scenarios considered (Table 3). The top GRCs selected for the seven harvests were the same as those selected for the four harvests, while the ranking presented slight differences. Thus, the results of the two scenarios showed certain similarities and precision. Overall, the worst GRC (CNPMF 2001 grafted onto the citrumelo ‘Swingle’) was the same under both conditions. The differences in ranking genotypes were probably due to G×M interaction, which had different genotype productions throughout the evaluations. In this case, the most productive genotype in one harvest was not necessarily the most productive in the other harvest. This may be due to the fact that they have multiple blooms throughout the year, have different fruit maturation mechanisms and are influenced by a large number of abiotic factors that can contribute to the increase in this G×M interaction (Iglesias et al., 2007).

The importance of doing more studies like this is emphasized, given the low amount of repeatability in the 'Tahiti' acid lime. In addition, the detection of superior genotypes is extremely important for breeding program that can be used as parents in the development of new cultivars.

Table 3. Additive index and selection gain for four productive traits of 24 GRC of 'Tahiti' acid lime.

Rank (°)#	Four harvests (measures)		Seven harvests (measures)	
	Genotype	Selection Gain (%)	Genotype	Selection Gain (%)
1	18	28.35	15	30.60
2	3	27.44	4	25.94
3	15	26.47	18	24.28
4	4	24.15	3	22.72
5	23	22.39	22	21.68
6	1	20.52	23	20.68
7	22	18.83	11	19.71
8	11	17.51	19	18.76
9	19	16.34	1	17.81
10	2	15.07	14	16.92
11	14	13.79	13	16.12
12	13	12.74	16	15.32
13	16	11.72	2	14.52
14	17	10.76	7	13.54
15	7	9.88	17	12.51
16	6	9.11	6	11.07
17	10	8.02	10	9.63
18	24	6.92	24	8.30
19	5	5.84	5	7.03
20	12	4.71	20	5.84
21	20	3.56	8	4.59
22	21	2.44	12	3.23
23	8	1.39	21	1.65
24	9	0	9	0

Genotypes numbers 1 to 12 refer to Bello Fruit, Éledio, Iconha, Itarana, Santa Rosa, Bearss Lime, CNPMF 01, CNPMF 02, CNPMF 2001, CNPMF 5059, BRS Passos and Persian 58 grafts grafted to the rootstock citrumelo ‘Swingle’, and of 13 to 24 the same grafts grafted in the citrandarin 'Riverside' rootstock, respectively.

Conclusion

In summary, four harvests were the recommended number for identifying superior acid lime ‘Tahiti’ GRCs based on FYP and NFP. On the other hand, the LFD and TFD traits demonstrated lower efficiency when recommending superior genotypes of acid lime 'Tahiti'. The best GRCs recommended based on this study for 4 harvests and for 7 harvests were Bearss lime grafted in citrandarin ‘Riverside’, Iconha grafted in citrumelo ‘Swingle’, Iconha grafted in citrandarin ‘Riverside’, and Itarana grafted in citrumelo ‘Swingle’.

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References

Alcoforado, A. T. W., Pedrozo, C. Â., Mayer, M. M., & Lima-Primo, H. E. (2019). Repeatability of morpho-agronomic characters of Theobroma grandiflorum fruits. *Revista Brasileira de Fruticultura*, *41*(2). DOI: 10.1590/0100-29452019142

Alvares, C. A., Stape, J. L., Sentelhas, P. C., & Gonçalves, J. L. M. (2013). Modeling monthly mean air temperature for Brazil. *Theoretical and Applied Climatology*, *113*(3-4), 407-427. DOI: 10.1007/s00704-012-0796-6

Araújo, M. J., Dias, D. C., Scarpinati, E. A., & Paula, R. C. (2015). Número de repetições, de plantas por parcela e de avaliações para testes clonais de eucalipto. *Pesquisa Agropecuária Brasileira*, *50*(10), 923-931. DOI: 10.1590/S0100-204X2015001000008

Bassan, M. M., Mourão Filho, F. A. A., Alves, R. F., Bezerra, D. F., Couto, H. T. Z., & Jacomino, A. P. (2015). Beneficiamento pós-colheita de lima ácida 'Tahiti' afeta sua qualidade e conservação. *Ciência Rural*, *46*(1). DOI: 10.1590/0103-8478cr20141492

Castricini, A., Silva, J. T. A. Silva, I. P. DA, & Rodrigues, M. G. V. (2017). Quality of ‘Tahiti’ acid lime fertilized with nitrogen and potassium in the semiarid region of Minas Gerais. *Revista Brasileira de Fruticultura*, *39*(2), 1-10. DOI: 10.1590/0100-29452017288

Cerqueira, E. C., Castro Neto, M. T., Peixoto, C. P., Filho, W. S. S., Ledo, C. A. S., & Oliveira, J. G. (2004). Resposta de porta-enxertos de citros ao défict hídrico. *Revista Brasileira de Fruticultura*, *26*(3), 515-519. DOI: 10.1590/S0100-29452004000300034

Cruz, C. D., Regazzi, A. J., & Carneiro, P. C. S. (2012). *Modelos biométricos aplicados ao melhoramento genético*. Viçosa, MG: UFV.

Dobson, A. J., & Barnett, A. G. (2018). *An introduction to generalized linear models* (3rd ed.). New York, NY: Chapman and Hall/CRC. DOI: 10.1201/9780367807849

Fonseca, C. E. L., Morais, F. M., Gonçalves, H. M., Aquino, F. G., & Rocha, F. S. (2018). Repeatability of fruit traits from two Hancornia speciosa populations from the core region of the Brazilian Cerrado. *Pesquisa Agropecuária Brasileira*, *53*(6), 710-716. DOI: 10.1590/s0100-204x2018000600007

Henderson, C. R. (1975). Best linear unbiased estimation and prediction under a selection model. *Biometrics*, *31*(2), 423-447. DOI: 10.2307/2529430

Iglesias, D. J., Cercós, M., Colmenero-Flores, J. M., Naranjo, M. A., Ríos, G., Carrera, E., ... Tadeo, F. R. (2007). Physiology of citrus fruiting. *Brazilian Journal of Plant Physiology*, *19*(4), 333-362. DOI: 10.1590/S1677-04202007000400006

Khankahdani, H. H., Rastegar, S., Golein, B., Golmohammadi, M., & Jahromi, A. A. (2017). Genetic diversity in Persian Lime (*Citrus latifolia* Tanaka) accessions using morphological and molecular markers. *The Journal 'Agriculture and Forestry'*, *63*(3), 221-231. DOI: 10.17707/AgricultForest.63.3.22

Laviola, B. G., Oliveira, A. M. C., Bhering, L. L., Alves, A. A., Rocha, R. B., Gomes, B. E. L., & Cruz, C. D. (2013). Estimates of repeatability coefficients and selection gains in Jatropha indicate that higher cumulative genetic gains can be obtained by relaxing the degree of certainty in predicting the best families. *Industrial Crops and Products*, *51*, 70-76. DOI: 10.1016/j.indcrop.2013.08.016

Leão, P. C. S., Nunes, B. T. G., & Souza, E. M. C. (2018). Repeatability coefficients and genetic gains in table grape progenies for the Brazilian semi-arid region. *Scientia Agricola*, *75*(5), 387-392. DOI: 10.1590/1678-992x-2017-0046

Lessa, L. S., Ledo, C. A. S., Amorim, E. P., & Silva, S. O. (2014). Estimativas de repetibilidade de híbridos diploides (AA) de bananeira. *Pesquisa Agropecuaria Brasileira*, *49*(2), 109-117. DOI: 10.1590/S0100-204X2014000200005

Maia, M. C. C., Almeida, A. S., Macedo, L. M., Resende, M. D. V., Lacerda, M. N., Vasconcelos, L. F. L., ... Silva, R. B. (2016). Heritability, repeatability and genetic gains in a improvement population of cajuizeiro. *Revista Árvore*, *40*(4), 715-722. DOI: 10.1590/0100-67622016000400015

Mariguele, K. H., Resende, M. D. V., Viana, J. M. S., Silva, F. F., Silva, P. S. L., & Knop, F. C. (2011). Métodos de análise de dados longitudinais para o melhoramento genético da pinha. *Pesquisa Agropecuária Brasileira*, *46*(12), 1657-1664. DOI: 10.1590/S0100-204X2011001200011

Morais, A. L., Zucoloto, M., Malikouski, R. G., Babosa, D. H. S. G., Passos, O. S., & Altoé, M. S. (2020). Vegetative development and production of 'Tahiti' acid lime clone selections grafted on different rootstocks. *Revista Brasileira de Fruticultura*, *42*(3). DOI: 10.1590/0100-29452020585

Negreiros, J. R. S., Andrade-Neto, R. C., Miqueloni, D. P., & Lessa, L. S. (2014). Estimativa de repetibilidade para caracteres de qualidade de frutos de laranjeira-doce. *Pesquisa Agropecuaria Brasileira*, *49*(1), 40-48. DOI: 10.1590/S0100-204X2014000100006

Negreiros, J. R. S., Saraiva, L. L., Oliveira, T. K., Álvares, V. S., & Roncatto, G. (2008). Estimativas de repetibilidade de caracteres de produção em laranjeiras-doces no Acre. *Pesquisa Agropecuária Brasileira*, *43*(12), 1763-1768. DOI: 10.1590/S0100-204X2008001200017

Patterson, H. D., & Thompson, R. (1971). Recovery of inter-block information when block sizes are unequal. *Biometrika*, *58*(3), 545-554. DOI: 10.1093/biomet/58.3.545

Pompeu Junior, J., Blumer, S., & Resende, M. D. V. (2013). Avaliação genética de seleções e híbridos de limões cravo, volkameriano e rugoso como porta-enxertos para laranjeiras Valência na presença da morte súbita dos citros. *Revista Brasileira de Fruticultura*, *35*(1), 199-209. DOI: 10.1590/S0100-29452013000100023

Quintal, S. S. R., Viana, A. P., Campos, B. M., Vivas, M., & Amaral Junior, A. T. (2017). Analysis of structures of covariance and repeatability in guava segreganting population. *Revista Caatinga*, *30*(4), 885-891. DOI: 10.1590/1983-21252017v30n408rc

Ramalho, M. A. P., Abreu, Â. F. B., Santos, J. B., & Nunes, J. A. R. (2012). *Aplicações da genética quantitativa no melhoramento de plantas autógamas*. Lavras, MG: UFLA.

Rao, C. R. (1973). *Linear statistical inference and its applications* (v. 2). New York, NY: Wiley.

Resende, M. D. V. (2007). *Matemática e estatística na análise de experimentos e no melhoramento genético*. Colombo, PR: Embrapa Florestas.

Resende, M. D. V. (2009). *Genética biométrica e estatística no melhoramento de plantas perenes*. Colombo, PR: Embrapa Florestas.

Resende, M. D. V. (2015). *Genética quantitativa e de populaçõe*. Viçosa, MG: UFV.

Resende, M. D. V. (2016). Software Selegen-REML/BLUP: a useful tool for plant breeding. *Crop Breeding and Applied Biotechnology*, *16*(4), 330-339. DOI: 10.1590/1984-70332016v16n4a49

Resende, M. D. V., & Duarte, J. B. (2007). Precisão e controle de qualidade em experimentos de avaliação de cultivares. *Pesquisa Agropecuária Tropical*, *37*(3), 182-194.

Resende; M.D.V, & Rosa-Perez, J. O. H. (2002). *Genética e melhoramento de ovinos*. Curitiba, PR: UFPR.

Resende, M. D. V., Silva, F. F., & Azevedo, C. F. (2014). *Estatística matemática, biométrica e computacional*. Viçosa, MG: UFV.

Resende, M. D. V., Furlani-Júnior, E., Moraes, M. L. T., & Fazuoli, L. C. (2001). Estimativas de parâmetros genéticos e predição de valores genotípicos no melhoramento do cafeeiro pelo procedimento REML/BLUP. *Bragantia*, *60*(3), 185-193. DOI: 10.1590/S0006-87052001000300005

Sales, G. N. B., Silva, L. A., Almeida, J. F., Nobre, R. G., Costa, F. B., Brito, M. E. B., ... Fernandes, P. D. (2018). Quality of fruits from grafted tahiti lime (*Citrus latifolia* Tan) irrigated with waters of different salinities. *Journal of Experimental Agriculture International*, *27*(2), 1-10. DOI: 10.9734/JEAI/2018/44302

Sanchéz, C. F. B., Alves, R. S., Garcia, A. P., Teodoro, P. E., Peixoto, L. A., Silva, L. A., ... Resende, M. D. V. (2017). Estimates of repeatability coefficients and the number of the optimum measure to select superior genotypes in Annona muricata L. *Genetics and Molecular Research*, *16*(3), 1-8. DOI: 10.4238/gmr16039753

Santana, M. B., Souza, L. S., Souza, L. D., & Fontes, L. E. F. (2006). Atributos físicos do solo e distribuição do sistema radicular de citros como indicadores de horizontes coesos em dois solos de tabuleiros costeiros do estado da Bahia. *Revista Brasileira de Ciência Do Solo*, *30*(1), 1-12. DOI: 10.1590/S0100-06832006000100001

Shrestha, R. L., Dhakal, D. D., Gautum, D. M., Paudyal, K. P., & Shrestha, S. (2012). Genetic diversity assessment of acid lime (*Citrus aurantifolia* Swingle Swingle) Landraces in Nepal, using SSR markers. *American Journal of Plant Sciences*, *3*(12), 1674-1681. DOI: 10.4236/ajps.2012.312204

Soares, L. A. A., Brito, M. E. B., Fernandes, P. D., Lima, G. S., Soares Filho, W. S., & Oliveira, E. S. (2015). Crescimento de combinações copa - Porta-enxerto de citros sob estresse hídrico em casa de vegetação. *Revista Brasileira de Engenharia Agricola e Ambiental*, *19*(3), 211-217. DOI: 10.1590/1807-1929/agriambi.v19n3p211-217

Viana, A. P., & Resende, M. D. V. (2014). *Genética quantitativa no melhoramento de fruteiras*. Rio de Janeiro, RJ: Interciência.