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CROP PRODUCTION

Conilon coffee outturn index: a precise alternative for estimating grain yield

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ABSTRACT. Coffee outturn can be defined as the ratio between the harvested coffee and its respective processed grains. This character is greatly influenced by genotypic and environmental effects, and in breeding programs your analysis is costly and time-consuming. In this sense, the use of an outturn index to estimate coffee yield on experimental plots is a desirable measure aiming at reducing resources and time in postharvest evaluations. Thus, the present study aimed to evaluate the accuracy of the use of an outturn index equal to 4.0, in the estimation of Conilon coffee grains production. This index indicates that four kilograms of harvested fruit would be needed to obtain one kilogram of processed grains. Based on the average of 157 genotypes conducted in three trials and four harvests, we evaluated the relationship between harvested fruits and processed grains (FcBe), the observed (OGY), and the estimated grain yield per plant (EGY) based on FcBe equal to 4.0 (an outturn index). Descriptive statistics, adequation test for EGY, and the coincidence of occurrence of genotypes observations relating to the top 20% of all observations of OGY and EGY. In the estimation of grain yield in Conilon, the use of FcBe equal to 4.0 showed high precision in the average of the analyzed trials. However, further studies should be conducted to elucidate the effects of climate variables on the yield of Conilon coffee, especially in atypical crop years. Thus, the use of an outturn index becomes interesting in cases where the number of genotypes to be evaluated is very large and a screening of the promising ones is desirable.

Keywords: *Coffea canephora*; biometry; desirable measure.

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Introduction

Coffee outturn can be defined as the ratio between the harvested coffee and its respective processed grains. This character has a direct influence on the economy of coffee activity. The operation costs with inputs, harvesting, transporting, drying, storage, processing, among others, influence directly on the fruits production. However, the revenue comes from the sale of grain corresponds to just a percentage of fruits (Medina Filho & Bordignon, 2008; Silva, Moreli, & Verdin Filho, 2015; Ferrão, Fonseca, Ferrão, & De Muner, 2019a).

The coffee outturn is influenced by the effect of genotypes, leafiness of plants, fruit ripening stage at harvest time, thickness of the epicarp, mesocarp volume, occurrence of mocha type seeds and shell, seed density and especially the presence of withered fruits; as well as environmental factors such as amount and distribution of rainfall, nutrient balance and attack of pests, diseases, and nematodes (Mônaco, 1960; Medina Filho & Bordignon, 2003; Ronchi & DaMatta, 2019).

Vacarelli, Medina Filho, and Fazuoli (2003) studied 138 *Coffea* genotypes kept in a live collection at the Alcides Carvalho Coffee Center of the *Instituto Agronômico de Campinas* (IAC) of São Paulo State and demonstrated that outturn vary among species and between interspecific hybrids. Rena and Maestri (1985) reported that leaf retention in *C. arabica* plants increased the grain outturn by 20%.

Regarding the fruit ripening at the beginning of the harvest, unripe and immature fruits results in lower outturn than the end when concentrated cherry fruit, raisin, and drier ones. The thickness of the peel and the mucilage content of the fruits are also traits of genetic origin. Thus, the relationship between fruit harvested and processed grains will be greater the thickness of the epicarp and endocarp volume increases (Mônaco,

1960) resulting in low outturn. Thus, genotypes of Conilon present higher outturn than Arabica coffee due to presenting thinner peel and less mucilage content (Vacarelli et al., 2003).

Gaspari-Pezzopane at al. (2005) pointed out that the outturn of fruits containing moca seeds is lower than that fruits that have both flat grains. Concha seeds are small brittle and dense and thus contribute to low outturn. Mônaco (1960) studying *C. arabica* cv. 'Mundo Novo' observed that outturn decreases linearly with the increasing percentage of withered fruits.

Prolonged water stress interferes with the physiological processes of the coffee plant limiting its growth and development. Thus, under water stress can occur leaf and fruit fall, poor fruit granulation, reducing coffee outturn (Rena & Maestri, 1985).

Well-nourished coffee plants are more vigorous and better balanced with regard to their energy balance. They are also able to better withstand the environmental adversities, contributing to satisfactory grain yield, either in Arabic or Conilon. Healthy plants are indispensable for high outturn, as proper nutrition can be impaired by the high incidence of pests and diseases. A severe occurrence of coffee rust often leads to high defoliation. Coffee leaf miner attacks reduce the photosynthetically active leaf area; and nematodes and cicadas contribute to coffee tree die-back, following the death of their roots (Matiello, Santiago, Almeida, & Garcia, 2016). Thus, different biotic and abiotic factors interfere in coffee production.

Ferrão et al. (2019b), discussing seed size and outturn in Conilon coffee, stated that they are quantitative characters and therefore controlled by several genes. However, it appears that the character has been little studied scientifically; Indexes of the relationship between fruit harvested and processed grains have been suggested for the estimation of the production in both commercial coffee species.

For coffee breeding programs, outturn analysis is expensive and time-consuming. For example, in a trial with 40 genotypes growing at two sites with four replicates and four harvests, 1,280 measurements of the relationship between harvested fruit and processed grain would be required. In addition, the coffee crop is concentrated and special care should be directed to each fruit sample for proper drying and processing, avoiding mixtures.

In this sense, the use of an outturn index for correcting coffee production on experimental plots would be desirable as time, labor and financial resources could be reduced with postharvest evaluations. Thus, the present study aimed at evaluating the accuracy of an outturn index which is based on the relationship between harvested fruit and processed grains equal to 4.0, in the estimation of the grain yield of Conilon coffee.

Material and methods

Genetic material and experimental development

It was analyzed in three experimental trials 157 genotypes (40 in trials I and II, and 117 in trial III). *C. canephora* var. *conilon*, belonging to the Conilon coffee breeding program of the *Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural* (Incaper) in the state of, Brazil. The tests were installed in representative regions of Conilon coffee production in the Espírito Santo State, Brazil (Table 1 and 2) under natural rainfall. Management practices, fertilization, cultivation, harvest and pruning were performed according to the technical recommendations of the crop (Ferrão et al., 2019a).

Table 1. List of locations, spacing, planting and harvesting times, number of harvests, and number of genotypes of each experimental trial.

Trial	Location	Spacing	Planting year	Harvesting times	Number of harvests	Number of genotypes
I	Sooretama	3x1.5m	1993	1998 a 2001	4	40
II	Marilândia	3x1.5m	1993	1998 a 2001	4	40
III	Sooretama	3x1.0m	2005	2008 a 2011	4	117

Table 2. Locations with geographical coordinates and edaphoclimatic characteristics showing annual averages (Ferrão et al., 2019a).

Location	GC		A	SC	Fertility	Topography	Rainfall (mm)	T°C	RU[1] (%)
Sooretama	Lat. Long.	15° 47' S 43° 18' O	40	LVAd[2] (80% sand)	Low	Flat land	1.200	24	80
Marilândia	Lat. Long.	19° 24' S 40° 31' O	70	LVA[3]	Low	Hillside land	1.130	24	74

[1]RU, relative air humidity. [2]LVAd, Sandy Dystrophic Red-Yellow Latosol. [3]LVA, Red-Yellow Latosol, SC: Soil classification, GC: Geographical coordinates, A: Altitude (m) T°C: Temperature

The experimental design was a randomized block design with four replicates and two plants per plot in trials I and II, and two replications with five plants per plot in trial III. The variables analyzed for each genotype in the average of replicates were:

The ratio between harvested fruits and processed grains (FcBe)

determined by calculating the relationship between a rate of 2 kg sample of harvested fruits on experimental plots and the grains resulting from their drying and processing.

Observed grain yield (OGY, kg plant^{-1})

$OGY = (PF/FcBe)$,

where: PF is the fruit yield in (kg plant^{-1}) and FcBe is the genotype outturn as the relationship between harvested fruits and their respective benefited grains;

Estimated grain yield (EGY, kg plant^{-1})

$EGY = (PF/4.0)$,

where: PF is fruit yield in (kg plant^{-1}) and 4.0 is an outturn index for FcBe. This index indicates that four kilograms of harvested fruit would be needed to obtain one kilogram of processed grains. In Incaper since the beginning of the Conilon breeding program, it has been observed that the average for FcBe is close to 4.0 (Ferrão et al., 2019a).

All experimental procedures were conducted by Incaper's Conilon coffee breeding program, which very kindly provided the experimental data for this research.

Statistical analysis

a) Descriptive statistics

Aiming at detecting and describing patterns of interest genotype's performance for FcBe, for each test and harvest the following statistics were calculated: mean, standard error of the mean, median, mode, coefficient of variation, kurtosis and the minimum and maximum values.

b) Comparison between observed (OGY) and estimated (EGY) grain yield

A 1:1-line plot was used to verify the accuracy and error inherent in the EGY based on FcBe = 4.0. Thus, for each trial and harvest, a simple linear regression model was adjusted, relating the values of OGY and EGY:

$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$,

where:
Y_i is the EGY of the ith genotype;
β_0 is the linear coefficient;
β_1 is the angular coefficient;
X_i is the OGY of the ith genotype;
ε_i is the random error associated with each observation. The model parameters were estimated by the ordinary least squares method and then the model determination coefficient (r^2) was calculated as:

$r^2 = SSReg/SYY$,

where:
SSreg and SSY are the sum of squares due to regression and total sum of squares, respectively.

The existence of a linear association between the OGY and EGY data regarding its magnitude and meaning was investigated using Pearson's correlation coefficient, in this case, estimated as the square root of r^2.

The verification of the agreement between EGY and OGY was carried out by performing Willmott's index of agreement (*d*), which values can range from 0 (no agreement) to 1 (perfect agreement). This methodology has been widely used in several areas of agronomy (Fialho, Dalvi, Corrêa, Kuhlcamp, & Effgen, 2011; Erlacher, Oliveira, Fialho, Silva, & Carvalho, 2016). The index d is calculated as follows:

$\hat{d} = 1 - \left[\frac{\sum_{i=0}^{n}(EGY_i - OGY_i)^2}{\sum_{i=1}^{n}(|EGY_i - \overline{OGY}| + |OGY_i - \overline{OGY}|)^2}\right]$,

where:
EGY_i is the estimated grain yield of the ith genotype;
OGY_i is the observated grain yield of the ith genotype, and;
$\overline{OGY}$ is the overall mean of the observed grain yield.

The error inherent in the EGY estimator was evaluated as the mean relative error (MRE%), the mean value of the differences (absolute values) between values of EGY and OGY, expressed as a percentage of OGY.

A scatter plot with the OGY in the abscissa and EGY in the ordinate containing a 1:1 equivalence line was used to show de results. Between data sets formed by the EGY and OGY, it was also calculated the coincidence of the occurrence of Conilon genotypes on observations relating to the top 20% of all observations.

Results and discussion

Descriptive statistics

For FcBe the coefficient of variation (CV), considering the tests I, II and III, varied from 4.97 to 19.75% (Table 3). These values are within the range considered acceptable for perennial crops (Ferrão et al., 2008).

The minimum value found for the FcBe was 3.07 at the trial II in the 2000 harvest and a maximum of 10.53 at the trial III in the 2008 harvest (Table 3). This variation was somewhat expected as 157 non-irrigated genotypes were analyzed in a total of 12 environments, a combination of crops and locations. Thus, the variability found to FcBe, most likely was due to the effect of genotype and seasonality.

Overall, the mean, median, and mode values were similar and the kurtosis values positive for all trials (Table 3). This indicates high concentration and homogeneous values of FcBe near the mean (Spiegelhalter, 2019).

The mean of FcBe considering all trials was 4.11 ± 0.09 (Table 3). The small standard error detected denotes good accuracy of the mean estimate and reinforces the hypothesis that there is a tendency to FcBe keep their values around 4.0. These results are in accordance with Matiello (1998).

The estimator of grain yield based on FcBe = 4,0

The suitability of mathematical estimators that simulate biological observations is possible by combining a set of appropriate statistics regarding the purpose for which the estimator was designed. The Figure 1, 2 and 3 shows – for trials I, II and III, respectively – the scatter plots containing linear regression equation, coefficient of determination, 1:1 equivalence line, Pearson correlation (r), Willmott's d statistic, and mean relative error expressed as a percentage of data observed for the variables OGY and EGY.

For most trials and harvests the r-value with magnitudes close to the unit indicated a strong and linear association between OGY and EGY. However, in the 1999 harvest of trial II, the value of r was 0.79, which although smaller, can also be considered as high magnitude (Figure 1, 2 and 3). Thus, the detected r values denote high accuracy for the EGY estimator. Although r is a good indicator of linear association, it cannot detect the deviations of the data set from the 1:1 equivalence line (Lin, 1989).

Table 3. Descriptive statistics for the ratio between harvested fruits and beneficiated grains observed in 40 genotypes of Conilon coffee in the trials I and II; e 117 genotypes in the trial III.

Trial	Harvest	n[a]	GY[b]	FcBe						
				Mean	Md[d]	Mo[e]	CV (%)[f]	k[g]	Min.[h]	Max.[i]
I	1998	40	57.63 ± 2.82	4.15 ± 0.05	4.16	4.48	8.00	0.48	3.42	5.08
	1999		45.45 ± 2.73	3.96 ± 0.05	3.96	4.01	8.20	1.05	3.40	4.60
	2000		71.34 ± 3.04	3.85 ± 0.04	3.82	3.78	6.46	0.83	3.18	4.45
	2001		54.63 ± 3.16	3.76 ± 0.03	3.78	3.70	4.97	0.89	3.28	4.18
II	1998	40	55.67 ± 2.25	3.87 ± 0.06	3.84	3.93	9.12	1.47	3.35	4.93
	1999		54.38 ± 1.93	4.39 ± 0.14	4.17	-	19.75	2.72	3.39	7.10
	2000		36.42 ± 2.49	3.60 ± 0.04	3.60	-	7.04	0.18	3.07	4.19
	2001		36.28 ± 1.90	4.64 ± 0.09	4.59	4.95	11.75	0.07	3.80	5.98
III	2008	117	93.51 ± 1.82	4.25 ± 0.06	4.19	4.24	15.80	66.41	3.36	10.53
	2009		42.87 ± 1.78	4.21 ± 0.07	4.10	-	17.13	30.35	3.37	9.13
	2010		106.78 ± 2.66	4.55 ± 0.07	4.35	-	15.65	24.03	3.66	9.75
	2011		61.16 ± 2.46	4.14 ± 0.03	4.14	-	7.09	0.79	3.41	5.08
	A[j]	12		4.11 ± 0.09	4.15	-	7.73	0.76	3.60	4.64

[a]*n*, sample size, [b]*GY*, grain yield (bags per hectare) and standard error of the mean, [c]Mean, the mean and standard error for FcBe ratio, [d]Md, median value, [e]Mo, mode value, [f]CV (%), coefficient of variation in percentage, [g]k, kurtosis value, [h]Min, minimum values, [i]Max, maximum values, [j]A, statistics considering all trials and harvests.

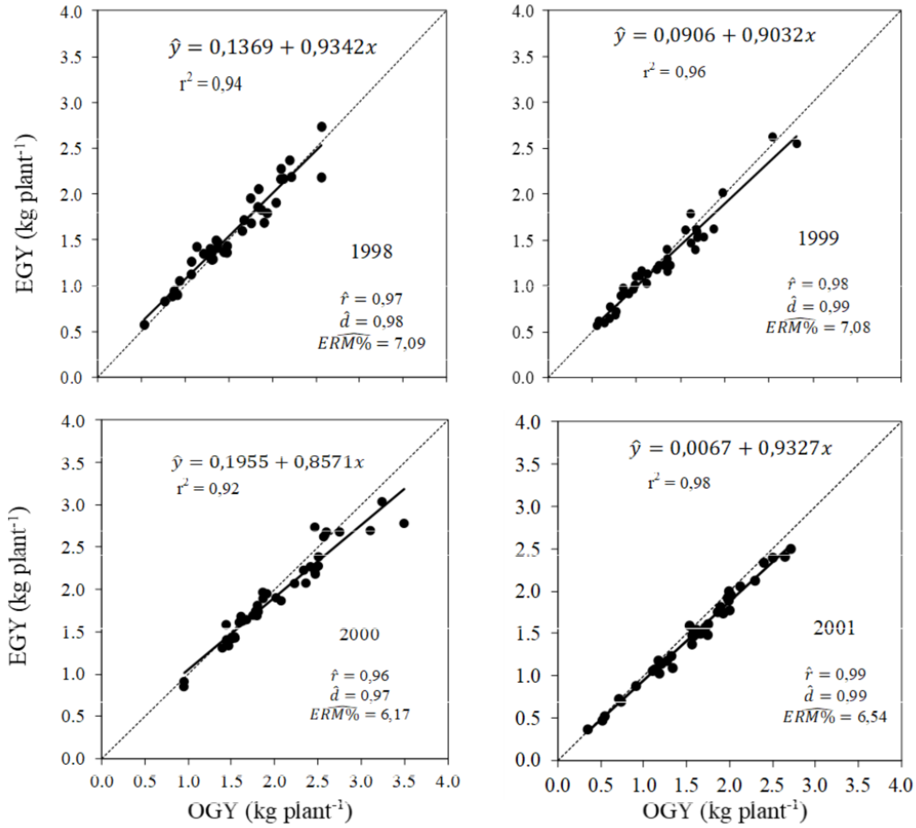

Figure 1. Relationship between observed (OGY) and estimated (EGY) grain yield considering FcBe outturn index equal to 4.0, and statistical indexes ‘r’, ‘d’ and ERM% in the 1998, 1999, 2000 and 2001 harvests for 40 Conilon coffee genotypes at the trial I. The dashed line in the diagonal represents the 1:1 equivalence line.

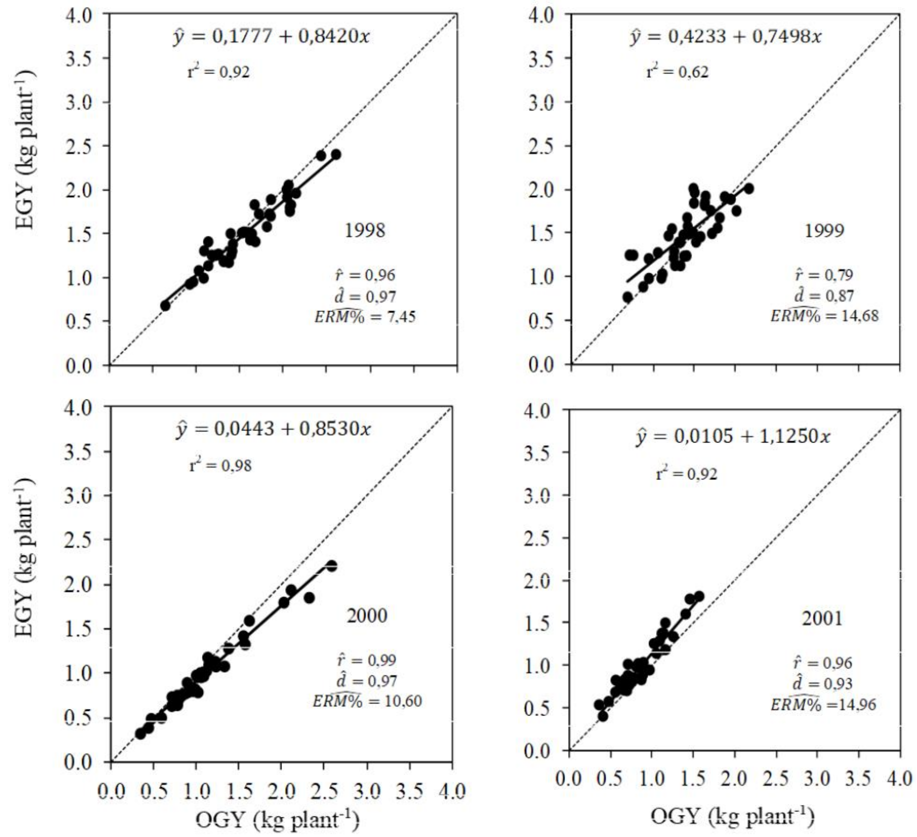

Figure 2. Relationship between observed (OGY) and estimated (EGY) grain yield considering FcBe outturn index equal to 4.0, and statistical indexes ‘r’, ‘d’ and ERM% in the 1998, 1999, 2000 and 2001 harvests for 40 Conilon coffee genotypes at the trial II. The dashed line in the diagonal represents the 1:1 equivalence line.

The Willmott's agreement index (d) measures how close to the 1:1 equivalence line the estimated data is, or, in other words, indicates the degree of approximation of the estimated values to those observed (Erlacher at al., 2016). Estimates of *d* greater than 0.90 were found for most trials and harvests, except for trial II in the 1999 harvest (0.87). The values of *d* indicate that the EGY based on FcBe = 4.0 was close OGY.

The mean relative error in the average of the four harvests was 6.72, 11.92 and 9.08% for trials I, II and III, respectively (Figure 1, 2 and 3). These values can be considered as small magnitude. This result was expected due to a large number of variables involved in the FcBe ratio and the year-to-year variations.

For the three trials, the coincidence of the occurrence of conilon genotypes in the observations above 20% of the total observations of OGY and EGY is shown in Table 4. The maximum and minimum limits found for the coincidence, considering all the tests and harvests ranged from 38 to 100%.

It is important to note that the minimum coincidence was observed at the trial II in the 1999 harvest, confirming that found by previous statistics (Table 3 and Figure 2). According to *Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural* (Incaper, 2020), the average annual rainfall for the year 1999 in Marilandia was 833 mm, 297 mm below the average of the historical series of the locality. By contrast, the maximum coincidence was observed at trial II in the 2000 harvest. In this year the average rainfall was 1360 mm, 230 mm above the average of the historical series of the locality (Incaper, 2020). Our results indicated that further studies should be conducted to elucidate the effects of climate variables on the yield of Conilon coffee, especially in atypical years for the crop.

For coincidence measured in biennia, discordant values were detected (Table 4). Thus, it is more reliable to use the coincidence estimates taken all accumulated harvests that generally showed magnitudes above 74% (Table 4). For example, among the 23 higher genotypes of trial III, 17 were coincident in the OGY and EGY datasets (Table 4).

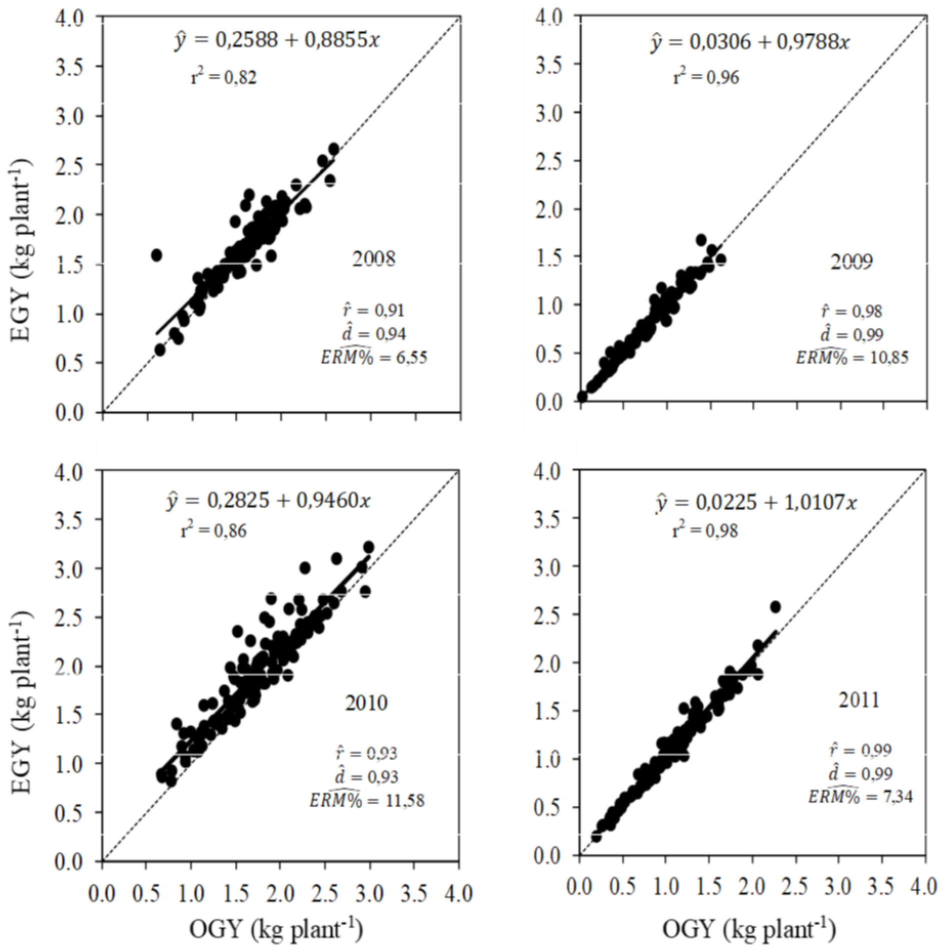

Figure 3. Relationship between observed (OGY) and estimated (EGY) grain yield considering FcBe outturn index equal to 4.0, and statistical indexes ‘r’, ‘d’ and ERM% in the 1998, 1999, 2000 and 2001 harvests for 117 Conilon coffee genotypes at the trial III. The dashed line in the diagonal represents the 1:1 equivalence line.

Table 4. Coefficient of coincidence (CC%) for 20% of the total of the higher observations, obtained by comparing the observed grain yield (OGY) and estimated grain yield (EGY) by outturn index [a] in different trials, harvests, biennia and genotypes of Conilon coffee.

Trial	NG[b]	Harvest	CC%
		1998	88
		1999	75
		2000	88
I	8	2001	88
		B1[c]	75
		B2[d]	88
		TSA[e]	75 (6)
		1998	63
		1999	38
		2000	100
II	8	2001	88
		B1[c]	50
		B2[d]	75
		TSA[e]	88 (7)
		2008	74
		2009	87
		2010	83
III	23	2011	91
		B1[c]	83
		B2[d]	78
		TSA[e]	74 (17)

[a]Outturn index, ration between harvested fruits and beficiated grains of 4:1, [b]NG, number of genotypes related to 20% of the total number of observations for each trial, [c]B1, corresponds to the sum of the first two harvests, [d]B2, corresponds to the sum of the last two harvests, [e]TSA, all harvests accumulated. Note : parenthetical values refer to the number of genotypes coinciding between EGY and OGY considering a sample of 20% of all observations superior in both datasets.

Implications for Conilon coffee breeding programs

In the environmental conditions in which the experiments were carried out and the germplasm investigated, we observed that the high precision associated with the low relative mean error for the EGY, and the coincidences between Conilon genotypes on observations of OGY and EGY, indicate that the yield index FcBe = 4.0 fits the studies of grain yield estimation of these coffee trees. The results are in agreement with those mentioned Matiello (1998).

Due to the large variability found in *Coffea* germplasm (Medina-Filho et al., 2008), in particular cases, the use of an outturn index may under- or overestimate the yield of genotypes that have sharp deviation relation to this index.

In competition trials where interest is the ‘ranking’ of genotypes, it is important to use measures of individual outturn (FcBe) in each genetic material. Thus the estimates of grain yield based on FcBe = 4.0 may be useful in future studies.

The most productive genotypes showed an average of FcBe around 4.0. Thus, the use of this outturn index is interesting in cases where the number of genotypes to be evaluated is high and a ‘screening’ of the promising ones is desirable. Using this index would reduce time, labor and financial resources in postharvest evaluations of experimental trials.

When making a decision in favor of using the outturn index FcBe = 4.0, it is important to consider the percentages of withered fruits and moca grains in genotypes, since actual outturn is strongly dependent on the values of these traits (Medina Filho, Bordignon, 2008). Such conduct would reduce possible misconceptions regarding the behavior of coffee genotypes for the character in question.

Conclusion

The use of outturn index (ratio between harvested fruits and processed grains) equal to 4.0, in the estimation of yield in Conilon coffee trees, showed high precision in the average of the analyzed trials.

Further studies should be conducted to elucidate the effects of climate variables on the yield of Conilon coffee, especially in atypical cropping seasons.

The use of an outturn index becomes interesting in cases where the number of genotypes to be evaluated is very large and a screening of the promising ones is desirable.

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