Estimation of factors related to the fertilization of banana plants selected in a fractional factorial scheme[1]

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ABSTRACT

The objective of this study was to (i) use a combination of a definitive screening design (DSD) and a complete 3^3 factorial design to estimate the effects of four fertilizer supplements (factors) screened in the 1st planting cycle of Prata Gorutuba banana trees and (ii) determine whether combinations of these four factors can be identified for a future test. A DSD was combined with a complete 3^3 factorial scheme composed of three factors with three levels (application doses) each and three extra repetitions of the central level (commercial dose), totaling 30 experimental plots (27 + 3). The experimental area was divided into six blocks in a randomized block design (RBD) with 5 experimental plots each. The four selected factors included three soil conditioning products and a biostimulant based on seaweed extract. Experimental efficiency was maintained by performing a single trial with only 35.71% of the number of total plots used in the previous screening experiment. The results corroborated the main hypothesis of the study, i.e., that the most important factors previously screened in a previous trial could be maintained with three dose levels without altering the cultivation performance.

Keywords: combined designs; 'Prata Anã' banana; selection of factors.

INTRODUCTION

Alternative agricultural experimental designs that can meet the needs of any type of experiment have been discussed since before the 1950s, as proposed by Plackett & Burman (1946). The screening design strategy was developed to solve specific problems, with the aim of avoiding analysis patterns in any experimental situation (Mead *et al.,* 2012).

In general, most factors are expected to be unimportant, and few are relevant to agricultural research. In this case, according to Ribeiro *et al.* (2019), repetition of the levels of irrelevant factors simply confirms the identification of the important factors. Definitive screening designs (DSDs) make it possible to identify factors with greater potential effects by performing an initial screening followed by a field test investigating these same factors under the same experimental conditions (Goos & Gilmour, 2017).

DSDs are a new class of designs recently introduced by Jones & Nachtsheim (2011), aimed at screening quantitative factors with three levels in the presence of second-order (quadratic) effects. This class of screening designs can provide unbiased estimates of main effects to any quadratic effect, as well as interactions between two factors.

DSDs are often applied in identifying the most relevant factors in the early stages of an experimentation process,

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which typically involves a large number of factors (Ribeiro *et al.*, 2019). Therefore, when experimentation is costly, time-consuming, or challenging, smaller designs end up being preferred (Yang *et al.*, 2014).

In agronomic experimental situations where multiple factors need to be considered and there are significant financial constraints for research, it is also necessary to exclude factors that will not have a relevant effect in the design (Yang *et al.*, 2014), aiming to achieve greater efficiency in the experimental evaluation time.

Brazilian banana farming is considered an essential branch of national agriculture; due to the high domestic consumption of the fruit and the large production volume, banana is the most consumed fruit in the country (Santana Júnior *et al.*, 2020), and it is second in production according to IBGE data for the 2019/2020 harvest, with 6.86 million tons produced (IBGE, 2020).

Given the importance of banana farming in the national agricultural context and the ongoing search for new fertilizers that can increase productivity and improve the quality of harvested bunches, an experiment was conducted in a randomized block design (RBD) with four factors — three soil conditioners and a biostimulant based on seaweed extract — in a fractional factorial scheme with the banana cultivar Prata Gorutuba (*Musa* AAB 'Prata Anã' clone: Gorutuba).

The above confirmatory field experiment was based on the main hypothesis of this study, i.e., the most important factors screened in a previous assay can be maintained at low (half), central (commercial dose) and high (double) levels without crop performance losses. Thus, the objective of this experiment was to (i) estimate the effects of the main products (factors) by combining a DSD and a complete 3^3 factorial scheme for four factors screened as fertilization supplements for Prata Gorutuba banana plants in the 1st planting cycle and (ii) determine whether combinations of these four factors can be selected for a future test in the same region, during the same cycle, with the same cultivar and with values maintained at the central level.

MATERIALS AND METHODS

The experiment was conducted in a commercial banana farm with an 80 ha irrigated crop area located in the municipality of Paraopeba, central region of the state of Minas Gerais (19°16`01.1" S, 44°26`02.6" W, 761 m altitude). The regional climate is the Aw type according to the Köppen classification and is tropical with a dry season, an average annual rainfall of 1244 mm and a critical period of water deficiency extending from May to September. The average annual temperature in the region is 21.8 °C, with a variation of + 5.2 °C throughout the year.

The experimental area was located in a central pivot area of approximately 22.3 ha. The soil is classified as Red Latosol (Embrapa, 2013), and the area was previously cultivated with corn and/or beans and remained fallow for two years.

The soil chemical characteristics before the implementation of the banana plantation in December 2017 are presented in Table 1.

The macronutrient levels were as follows: P: low; K: high; S: low; Ca: adequate; and Mg: low. The base saturation (V%) was below the ideal value (V% = 70) for the crop; therefore, the soil was adjusted with limestone to increase this index and the soil basic Mg content (Ribeiro *et al.*, 1999).

Seedlings were planted on December 27, 2017, in furrows (0.40 x 0.40 x 0.40 m) with double row spacing, and distances of 2.7 m between rows, 3.3 m between double rows and 2.0 m between plants were established, totaling a planting density of 1666 plants/ha. The fertilization scheme

Table 1: Analysis of the initial fertility of the 0-20 cm layer of soil collected in a Cerrado area in the central region of Minas Gerais - Brazil, located in the experimental and commercial cultivation area of the ´Prata Anã` banana clone Gorutuba

pH		P resin	K	SS	Ca	Mg	Al	H+ Al
(water)	($CaCl_2$)	mg/dm³			cmolc/dm³			
6.00	5.30	22.00	128.7	7.90	4.20	0.70	0.0	2.80
S	**m**	**Relationships**			**Total CEC**	**SB**	**OM**	**OC**
%		**Ca/K**	**Mg/K**	**Ca/Mg**	**cmolc/dm³**		**g/dm³**	
65.13	0.00	12.72	2.12	6.00	8.03	5.23	22.00	13.00

Total CEC: total cation exchange capacity; OM: organic matter; OC: organic carbon; V: base saturation; m: saturation by aluminum.

was as follows: 200 grams of simple superphosphate, 200 grams of Yoorin and 1 kg of chicken manure per seedling or meter of planting furrow. The experiment was installed in the experimental area on May 19, 2018, and conducted until the end of the 1st crop cycle, which coincided with the date of the last (third) harvest on March 8, 2019.

During six months (0 until 180 days after transplanting), irrigation was provided by a center pivot with a two-day watering shift. This way, every two days, the plants were irrigated, meaning the watering shift had 48-hour interval. Subsequently, a microsprinkler was used for 1 h 30 min with a two-day watering cycle until the end of the 1st cycle and throughout all other banana-growing cycles.

The design consisted of a combination of a DSD proposed by Jones & Nachtseim (2011) for the three-level biostimulant factor and a complete 3^3 factorial scheme (27 plots) for the three remaining factors. The complete factorial consisted of three factors at three levels (application doses) each and three extra replicates of the central level (commercial dose) for all factors, totaling 30 experimental plots (27 + 3).

The experimental area was divided into six randomized blocks in an RBD; each block was assigned a DSD, in which each treatment contained the central points of both the complete factorial design and the DSD and a combination of noncentral points for both types of factors (Ribeiro *et al.*, 2019).

From the initial design with 30 plots (five per block), one plot in each block was reserved for the central point, or commercial dose, of the four factors (four zeros, with a zero coded for each factor). The other 24 plots (four per block) represented a combination of the other two doses or noncentral points from the DSD and complete factorial (3^3) design. These points were allocated randomly by exchange algorithms used to concatenate the levels of the factors (R Core Team, 2018).

Each experimental plot consisted of three Prata Gorutuba banana plants (*Musa* AAB 'Prata Anã' clone: Gorutuba), totaling N = 90 plants (sampling units) within the 30 plots. This experiment consisted of four factors representing fertilizer supplements that had been previously screened as the most efficient for application in banana plantations in the state of Minas Gerais.

The fertilizer products selected as factors were divided into a biostimulant (foliar or topdressing application) and soil conditioners (topdressing application). All factors had three levels, which were the application doses, coded as follows: standard or commercial dose (100% or 0); double the standard dose (200% or +1); and half the standard dose (50% or -1).

The biostimulant was the algal extract-based biostimulant Acadian (5.3% K_2O; Acadian Seaplants Limited – ASL), coded as ACA. The three soil conditioners used as sources of Ca and Mg were the following: lime from marine oyster shells (49% CaO, 0.05% MgO; CYSY®; 180 g/pit/year); Celtonite (zeolite enriched with NPK; ZEOCEL Portugal Ltda.; 200 g/pit/year); and ALGUE® (32% Ca; *Lithothamnium calcareum* (powder); CERES TECNOLOGIA LTDA; 180 g/pit/year), coded as LS, CT and LT, respectively. A Figure 1 presents the layout of the experiment and Figure 2 shows the banana plants used in the experiment.

The soil conditioner doses were converted to 1/3 of the commercial value because each plant received a blend of LS:CT:LT (m:m:m). This modification was performed because overfertilization of Ca in the conditioners could cause a nutritional imbalance in banana plants. The biostimulant (ACA) was applied separately at the commercial dose.

Plant parameters were evaluated as follows for 5 seasons, separated by 21-day intervals: 1st season (May 21, 2018) - plant height (PH, measured from the central plant of the plot), pseudostem diameter (SD, measured from the central plant of the plot), and number of expanded leaves (NL, counted from the three plants of the plot); 2nd season (June 11, 2018) - PH, SD, NL and number of tillers (NT, counted from the three plants of the plot); 3rd season (July 2, 2018), 4th season (July 23, 2018) and 5th season (August 13, 2018) - all variables.

A tape measure was used to measure PH in meters, considering the height of the plant from the ground to the leaf rosette. A graduated tape measure was used to measure the circumference of the pseudostem in meters at the base of the plant next to the soil, which was converted to SD by the formula $D = C/\pi$ (Barbosa *et al.*, 2013). Of the three plants in each experimental plot, the central plant was considered the useful area, and the plants on the edges were considered a border.

Production and cycle duration were evaluated from the beginning of the reproductive phase of the banana tree (flowering) and ended at the time of fruit harvest in stage I (physiologically mature fruit, but with a completely green peel) according to the scale of bark coloration (Cordeiro, 2000).

Block	LS	CT	LT	ACA	Plots
1	0	-1	0	-1	1
1	0	0	0	0	2
1	0	1	0	1	3
1	0	1	0	-1	4
1	0	-1	0	1	5
2	0	0	0	0	6
2	1	-1	0	0	7
2	-1	-1	0	0	8
2	1	1	0	0	9
2	-1	1	0	0	10
3	-1	0	0	1	11
3	0	0	0	0	12
3	-1	0	0	-1	13
3	1	0	0	-1	14
3	1	0	0	1	15
4	1	0	1	0	16
4	-1	0	1	0	17
4	-1	0	-1	0	18
4	0	0	0	0	19
4	1	0	-1	0	20
5	0	0	1	1	21
5	0	0	1	-1	22
5	0	0	0	0	23
5	0	0	-1	1	24
5	0	0	-1	-1	25
6	0	0	0	0	26
6	0	1	1	0	27
6	0	-1	1	0	28
6	0	1	-1	0	29
6	0	-1	-1	0	30

Annual doses g/pit	LS	CT	LT	
Dose (-)	90	100	90	0,25%
Dose (0)	180	200	180	0,50%
Dose (+)	360	400	360	1,00%

Figure 1: Layout of the experiment. with the ´Prata Anã` banana clone Gorutuba. LS = lime from marine oyster shells; CT = Celtonite; LT = Lithothamnium; ACA = Acadian.

Figure 2: Banana plants of the Prata Anã variety, Gorutuba clone, used in the experiment.

Fruit harvesting began approximately 13.6 months after transplanting (1st harvest); the second harvest (2nd harvest) took place 14.0 months after transplanting; and the last assessed harvest was done at 14.5 months after transplanting (3rd harvest).

During the three harvest periods, bunches were collected from the useful plants in each plot, and the following parameters were determined with a scale or by numerical counting: the weight of the bunch including stems (WBIS), in kg; the weight of the bunch without stems (WBWS), in kg; the number of fruits per bunch (NFB); the number of fruits per clusters (NFC); the number of clusters per bunch (NCB); the average bunch weight (ABW), in kg; and productivity (PROD), in Mg ha^{-1}, from the product of the WBWS of the useful plant and the planting density (1666 plants/ha). A digital electronic scale of the brand Baisec was used to obtain the parameters above.

The duration of the crop cycle was determined based on the harvest date of the useful plant bunch of each treatment (plot). The day of inflorescence emission was also determined to calculate the length of the reproductive cycle of each treatment and to verify the production uniformity (Barbosa *et al.*, 2013). O day of inflorescence emission was determined by the missile tip stage of the banana plant (when the inflorescence is pointing above the new leaves and the bunch begins to emerge). Thus, the following variables were obtained (in days): vegetative cycle (CV), reproductive cycle (RC) and total cycle (ToC).

Samples of four fruits from the central part of the 2nd stem, from the base to the apex of the bunch, were selected for each treatment for physical/chemical analysis and the determination of the following variables: mean fruit length (MFL), in mm; mean fruit diameter (MFD), in mm; fruit pulp firmness (FPF), in N; mature fruit weight (MFW) in kg; % weight reduction (WR), in %; mean pH of the fruit (pH); total soluble solids (TSS), in °Brix; total titratable acidity as malic acid (TTA), in % or g/100 g; and the ratio TSS/TTA (RATIO) (Barbosa *et al.*, 2013).

The pH was measured using a Marconi pH meter (PA200), with readings taken after the mixture of 1 g of pulp with 20 mL of water. The titratable acidity (%) was estimated by weighing 1 g of pulp, which, after being mixed with 20 mL of water, was titrated with 0.1 N NaOH, using 0.1% phenolphthalein as an indicator. The results were expressed in grams of malic acid per 100 g of pulp. The soluble solids content was determined with a benchtop refractometer, Milwaukee brand, and the results were expressed in degrees ºBrix (AOAC, 2007). Firmness was assessed in the middle third of the fruits using a portable digital penetrometer from the brand Homis.

All statistical analyses were performed using R software (R Core Team, 2018). All variables were subjected to analysis of variance (ANOVA) with the appropriate assumptions, and when necessary, the Box–Cox transformation was performed to determine the best distribution of the data. NT was subjected to log transformation. The other variables were not transformed.

In the generalized linear mixed models, the sources of variation (SVs) included all first-order and quadratic effects of all 14 factors and the main pairs of interactions of the four factors in the complete factorial. For the counting variables, the generalized linear mixed model glmerMod was used with the plants as a random effect, adopting the lme4 library of R version 3.5.1 (R Core Team, 2018). Before defining the *glmer* model, a normal approximation was used to reduce the terms of the model.

After the ANOVA, the best factors were subjected to a t test to determine the direction of the causal effect of that factor or SV on a given variable, i.e., whether it increases (+ sign) or decreases (- sign) the variable in question. For this study, an exchange algorithm was implemented to combine the DSD (fractional factorial design) with the complete factorial (3^3) design.

RESULTS AND DISCUSSION

All plant parameters showed significance at 1% or 5% in the F test (Table 2).

The effect of season was significant for all variables throughout the experimental period (α = 1%). However, there were no interactions between season and other factors. CT was irrelevant for all plant parameters. PH and SD were the most affected by the three other factors (Table 2).

All the plant parameters were significant according to the t test (Table 3). The intercept values in each linear model represented the overall mean of each variable plus the effect of the sum of the factors ($\sum_i^k \tau i = 0$). The t test-estimated effects of the factors or their combinations on each variable that was significant according to the F test (Table 2) represented a gain or reduction in the response variable. That is, a linearly increasing or linearly decreasing effect, depending on the sign (+ or -), occurred with increasing dose (Table 3).

Table 2: F values, including their significance at 1% (**) and 5% (*), for plant parameters and each factor in the experiment with the ´Prata Anã` banana clone Gorutuba

SV	PH	SD	NL	logNT
Season	56.216**	42.704**	73.418**	62.111**
WC	3.494	3.493	0.920	11.401**
CT	0.961	0.039	0.009	0.023
LT	14.573**	13.615**	6.599*	2.274
ACA	12.427**	4.557*	0.180	0.319
LS:CT	0.712	1.275	2.761	1.238
LS:LT	17.176**	11.364**	1.678	0.258
LS:ACA	0.129	0.000	1.225	4.991*
CT:LT	0.577	0.072	1.219	0.559
CT:ACA	0.059	0.426	0.000	1.170
LT:ACA	8.844**	10.698**	4.157*	2.825
Season:LS	0.034	0.099	0.321	0.364
Season:CT	0.086	0.043	0.205	0.401
Season:LT	0.029	0.080	0.763	0.110
Season:ACA	0.135	0.060	0.941	0.173
Season:LS:CT	0.065	0.054	0.738	0.206
Season:LS:LT	0.120	0.058	0.137	0.317
Season:LS:ACA	0.070	0.023	0.696	0.241
Season:CT:LT	0.045	0.051	0.287	1.241
Season:CT:ACA	0.014	0.058	0.321	0.328
Season:LT:ACA	0.080	0.069	0.548	1.253

SV: source of variation; PH: plant height (m); SD: pseudostem diameter (m); NL: number of leaves; logNT: log of the number of tillers.

For PH, an increase of 0.051 m (p value: 0.028) was obtained when applying the highest dose of LS compared to the commercial dose, with a standard error of ± 0.023 m. An increase in vegetative growth was also obtained when applying LS combined with LT, with a value of 0.197 m (p value: 2.30e-06) and a standard error of 0.04 m (Table 3).

In addition, there was a negative effect on PH growth when LT and ACA were applied separately or in combination. All estimates were between 10 and 15 cm of growth suppression (Table 3).

Regarding SD, an increase of 0.006 m (p value: 0.027) was estimated when applying the highest dose of LS compared to the commercial dose, with a standard error of ± 0.003 m; when LS and LT were applied together, an increase of 0.02 m was obtained (p value: 9.07e-05), with a standard error of ± 0.005 m. In addition, there was a negative effect on the radial growth of plants when LT and ACA were applied separately or in combination. All estimates were within 1-2 cm of SD restriction (Table 3).

Vegetative growth in banana plants in both the vertical and radial directions was strongly influenced by LS and its combination with LT (Table 3). Both products can be classified as calcitic limestone because they are rich in calcium and have low contents of magnesium (MgO < 5.0%) and other nutrients (Lobo *et al.*, 2019; Negreiros *et al.*, 2019).

The growth of "Prata Gorutuba" plants in terms of both PH and SD may be attributed to the positive effects of limestone and calcareous algae on vegetative development. These effects include enhanced availability of soil calcium (Ca) and magnesium (Mg), decreased levels of exchangeable aluminum (Al), and an elevation in soil pH (Diniz *et al.*, 2020; Melo *et al.*, 2019).

The increase in total bases with increased Ca and Mg also favors plant growth, according to Mantovani *et al.* (2017). However, mineral nutrition strongly affects plant conditions; an excess of a certain nutrient, such as Ca, can

Table 3: Summary of the model estimates and t test results for plant parameters, considering only the factors selected after the reduction of the linear model and including the significance at 0.1% (***), 1% (**) and 5% (*), for the experiment with the ´Prata Anã` banana clone Gorutuba

		PH		
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	0.870	0.046	18.922	< 2.00e-16***
Season 2	0.117	0.046	2.553	0.012*
Season 3	0.354	0.046	7.702	2.56e-12***
Season 4	0.522	0.046	11.365	< 2.00e-16***
Season 5	0.712	0.046	15.491	< 2.00e-16***
WC	0.051	0.023	2.227	0.028*
LT	-0.105	0.023	-4.547	1,20e-05***
ACA	-0.097	0.023	-4.199	4,83e-05***
LS:LT	0.197	0.040	4.937	2,30e-06***
LT:ACA	-0.141	0.040	-3.542	5.45e-04***
		SD		
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	0.131	0.006	22.707	< 2.00e-16***
Season 2	0.018	0.006	3.128	0.002**
Season 3	0.034	0.006	5.846	3.61e-08***
Season 4	0.066	0.006	11.431	< 2.00e-16***
Season 5	0.076	0.006	13.154	< 2.00e-16***
WC	0.006	0.003	2.238	0.027*
LT	-0.013	0.003	-4.417	2.03e-05***
ACA	-0.007	0.003	-2.556	0.012*
LS:LT	0.020	0.005	4.036	9.07e-05***
LT: ACA	-0.020	0.005	-3.916	1.42e-04***
		NL		
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	7.515	0.193	38.968	< 2.00e-16***
Season 2	2.267	0.193	11.754	< 2.00e-16***
Season 3	1.467	0.193	7.605	4.10e-12***
Season 4	3.366	0.193	17.454	< 2.00e-16***
Season 5	1.123	0.193	5.821	3.96e-08 ***
LT	-0.267	0.096	-2.772	0.006**
ACA	-0.044	0.096	-0.458	0.648
		NL		
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
LT:ACA	-0.368	0.167	-2.200	0.029*
		logNT		
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	0.876	0.073	12.063	< 2.00e-16***
Season 2	0.261	0.073	3.586	4.67e-04***
Season 3	0.383	0.073	5.268	5.23e-07***
Season 4	-0.651	0.073	-8.965	2.05e-15***
Season 5	0.401	0.073	5.521	1.63e-07***
WC	0.133	0.036	3.656	3.65e-04***
ACA	-0.022	0.036	-0.612	0.542
LS:ACA	0.152	0.063	2.419	0.017*

SV: source of variation; PH: plant height (m); SD: pseudostem diameter (m); NL: number of leaves; logNT: log of the number of tillers.

cause changes in productivity (Rodrigues *et al.*, 2019). This may explain the negative effects of LT and the biostimulant ACA on nutritional imbalance and reduced growth in height and diameter of banana trees.

Table 3 shows a decrease in NL of 0.27 (p value: 0.006) when applying LT only and a reduction of 0.37 leaves when LT and ACA were concomitantly applied (p value: 0.029). Table 3 also shows an increase in logNT of 0.13 (p value: 3.65e-04) when applying LS alone and a greater value, approximately 0.15 (p value: 0.017), when LS and ACA are applied together.

Both the increase in tillers caused by LS and ACA and the reduction in the number of banana leaves in full vegetative growth caused by LT and ACA are undesirable characteristics according to banana farmers, as observed in Table 3. The production of many tillers reduces the size of banana bunches due to intra- and intermaternal competition for assimilated light, water and nutrients (Bhende *et al.*, 2018), and a reduction in active leaves decreases the photosynthetic capacity of the plant as a result of the reduced leaf area for capturing photosynthetically active radiation (Bolfarini *et al.*, 2020; Zhang *et al.*, 2020).

Biostimulants based on algae extract, such as ACA, produce some plant hormones, in addition to containing carbohydrates and macro- and micronutrients that improve plant performance (Silva *et al.*, 2016; Gomes *et al.*, 2018). According to Renaut *et al.* (2019), the application of Acadian favors root growth and, consequently, better formation of the aerial part of the plant due to high concentrations of the nutrient P and the presence of auxins, a class of growth phytohormones. Given these properties, together with the better nutrient availability provided by LS, ACA increased the number of tillers per plant (Table 3).

The energy expenditure for the emission of new tillers may have reduced the emission of new leaves in the evaluated banana trees, especially under the action of the biostimulant ACA, as shown in Table 3. This process requires the regular removal of tillers before they become very large, as they reduce soil irradiation and drain much of the nutrients assimilated by the mother plant (Bhende *et al.*, 2018; Muzira *et al.*, 2020).

The maintenance of active leaves in banana plants depends on the performance of crop treatments such as defoliation of old or damaged leaves, removal of excess shoots, potassium and nitrogen fertilization and irrigation management (Martins *et al.*, 2020; Muzira *et al.*, 2020). Ca is also important in maintaining sap balance in plants and may reduce the flow of phloem to drains (new leaves), where there is nutritional imbalance (Santos *et al.*, 2017), since the individual action of the algae *L. calcareum* also reduced the number of leaves (Table 3).

The production and cycle duration variables that showed significance at 1% or 5% in the F test were as follows: NPB, ABW and VC. No variables needed to be transformed (Table 4).

The production and cycle duration variables that showed significance at 0.1%, 1% or 5% in the t test were as follows: ABW, NPB and VC (Table 5).

The intercept value in each linear model represented the overall mean of each variable plus the effect of the sum of the factors ($\sum_i^k \tau i = 0$). The t test-estimated effects of the factors or their combinations on each variable that was significant according to the F test (Table 4) represented a gain or reduction in the response variable with increasing dose (Table 5).

Table 4: F values, including their significance at 1% (**) and 5% (*), for production variables and cycle duration for each factor in the experiment with the ´Prata Anã` banana clone Gorutuba

SV	NCB	ABW	VC
WC	0.580	0.144	0.982
CT	5.217*	0.008	0.001
LT	0.145	1.072	3.333
ACA	0.145	0.380	2.133
LS:CT	0.000	1.991	1.242
LS:LT	1.739	8.932**	5.102*
LS:ACA	1.739	0.000	0.327
CT:LT	1.739	0.006	0.294
CT:ACA	0.000	0.427	0.074
LT:ACA	0.435	0.200	3.051

SV: source of variation; NCB: number of clusters per bunch; ABW: average bunch weight (kg); VC: vegetative cycle (days).

Table 5: Summary of the model estimates and t test results for the production and cycle duration variables, considering only the factors selected after the reduction of the linear model and including the significance at 1% (**) and 5% (*), for the ´Prata Anã` banana clone Gorutuba

NCB				
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	9.400	0.139	67.688	< 2.00e-16***
CT	-0.500	0.220	-2.277	0.031*
ABW				
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	0.990	0.023	42.363	< 2.00e-16***
WC	0.017	0.037	0.453	0.654
LT	0.046	0.037	1.238	0.227
LS:LT	0.229	0.064	3.573	0.001**
VC				
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	311.000	2.977	104.456	< 2.00e-16***
WC	-4.750	4.708	-1.009	0.322
LT	8.750	4.708	1.859	0.074
LS:LT	-18.750	8.154	-2.300	0.030*

SV: source of variation; NCB: number of clusters per bunch; ABW: average bunch weight (kg); VC: vegetative cycle (days).

For NPB, a reduction of 0.5 (p value: 0.031) was estimated when the highest dose of CT was applied in relation to the commercial dose, with a standard error of ± 0.220 (Table 5). An increase in MBW of 0.229 kg (p value: 0.001) was also estimated when the highest dose of LS:LT was applied in relation to the commercial dose, with a standard error of ± 0.064 kg (Table 5).

For the cycle duration variables, an estimated reduction in the number of days from planting to harvest was considered positive due to the potential for faster financial return to the rural producer. VC presented an estimated reduction of 18.75 days (p value: 0.030) with a standard error of ± 8.154 days when a higher dose of LS:LT was applied compared to the lower previous dose (Table 5).

NPB was reduced by CT application (Table 5). CT has a zeolite structure due to its source material and is enriched with NPK (Lira-Saldivar *et al.*, 2017; Tsintskaladze *et al.*, 2017). According to Campisi *et al.* (2016), zeolites have a high cation exchange capacity and high retention capacity for NH_4^+. They are porous aluminum silicates of volcanic origin with excellent storage of water and soil nutrients such as K, Mg, Ca and Na (De Smedt *et al.*, 2015).

The retention of ammonium in the porous structure of zeolites helps reduce nitrate leaching and provides N for longer periods (Tsintskaladze *et al.*, 2017). The accumulation of ammoniacal N delays bunch emergence, producing bunches with spaced clusters that are easily damaged during transport. An excess of N may favor vegetative growth and the emission of bunches with a smaller number of clusters, as in the case of this study.

Combined LS:LT treatment, which was significant for the growth of the Prata Gorutuba banana tree, also had a positive effect on banana production by increasing AWB (Tables 3 and 5). Studies on this variety and the use of these products for AWB gain are not found in the literature. Thus, the observed effect can be attributed to the high potential of the calcareous algae LT combined with the agricultural benefits of LS (Xia *et al.*, 2014; Yao *et al.*, 2014; Olivier *et al.*, 2020). Both are products with high neutralizing power (NP > 90%), indicative of intense and rapid corrective action of soil acidity (Melo & Furtini Neto, 2003; Negreiros *et al.*, 2019; Olivier *et al.*, 2020; Yao *et al.*, 2014).

For the cycle duration variables, an estimated reduction in the number of days was considered positive due to the potential for faster harvesting of bunches by the banana grower. The same combination of factors that increased ABW also reduced VC (Table 5).

LS:LT successfully shortened VC in the Prata Gorutuba banana tree due to the accelerated reaction of Ca and Mg oxides in the soil and the consequent increase in the availability of N and K, which are essential during the growth period until the emission of male and female flowers (Bolfarini *et al.*, 2020; Olivier *et al.*, 2020).

Table 6: F values, including the significance at 1% (**) and 5% (*), for postharvest variables for each factor selected for the experiment with the ´Prata Anã` banana clone Gorutuba

SV	MFW	MFD	TTA
WC	0.327	2.574	5.356*
CT	0.239	0.001	0.725
LT	1.050	0.097	6.271*
ACA	4.263	4.614*	2.718
LS:CT	3.516	0.691	0.686
LS:LT	7.131*	9.515**	0.248
LS:ACA	0.012	0.164	2.560
CT:LT	0.271	0.968	0.224
CT:ACA	0.004	0.006	0.030
LT:ACA	0.115	1.751	0.020

SV: source of variation; MFW: mature fruit weight (kg); MFD: mean fruit diameter (mm); TTA: total titratable acidity (% or g/100 g).

The postharvest variables that showed significance at 1% or 5% in the F test were as follows: MFW, MFD and TTA (Table 6). TTA was the only variable that required lambda transformation.

The postharvest variables that showed significance at 0.1%, 1% or 5% in the t test were the following: MFW, MFD and TTA. TTA was subjected to lambda transformation (Table 7).

The intercept value in each linear model represented the overall mean of each variable plus the effect of the sum of the factors ($\sum_i^k \tau i = 0$). The t test-estimated effects of the factors or their combinations on each variable that was significant according to the F test, as shown in Table 6, represented a gain or reduction in the response variable with increasing dose (Table 7).

Table 7: Summary of the model estimates and t test results for postharvest variables, considering only the factors selected after the reduction of the linear model, including the significance at 0.1% (***), 1% (**) and 5% (*), for the experiment with the ´Prata Anã` banana clone Gorutuba

		MFW		
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	1.040	0.090	11.552	1.47e-10***
WC	0.032	0.058	0.553	0.586
LT	0.058	0.058	0.992	0.333
LS:LT	0.260	0.101	2.584	0.017*
		MFD		
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	30.772	0.933	32.976	< 2.00e-16***
WC	1.031	0.602	1.711	0.102
LT	0.200	0.602	0.332	0.743
ACA	-1.380	0.602	-2.291	0.033*
LS:LT	3.433	1.043	3.290	0.004**
		TTA		
SV	**Estimate**	**Standard error**	**t value**	**Pr (> | t |)**
(Intercept)	-183.460	52.070	-3.523	0.002**
WC	77.860	33.610	2.316	0.031*
LT	-84.250	33.610	-2.506	0.020*

SV: source of variation; MFW: mature fruit weight (kg); MFD: mean fruit diameter (mm); TTA: total titratable acidity (% or g/100 g).

For MFW, an increase of 0.260 kg (p value: 0.017) was estimated when the highest dose of LS combined with LT was applied compared to the commercial dose, with a standard error of ± 0.101 kg (Table 7).

Regarding MFD, an increase of 3.433 mm (p value: 0.004) was observed when the highest dose of LS combined with LT was applied compared to the commercial dose, with a standard error of ± 1.043 mm. A reduction in MFD was also obtained when ACA was applied at a higher dose, with a value of 1.380 mm (p value: 0.033) and standard error of ± 0.602 mm (Table 7).

Finally, as shown in Table 7, an increase in TTA was observed when the highest dose of LS was applied in relation to the commercial dose (p value: 0.031). Separate application of LT at a higher dose reduced (p value: 0.020) the total acidity of the fruit pulp, an interesting organoleptic characteristic that gives better flavor to Prata Gorutuba bananas.

WC combined with LT increased MFW and MFD (Table 7), which can be corroborated by the estimated increases in other variables, such as PH, SD and ABW (Tables 3 and 5). Taller and more vigorous plants of the same variety tend to produce, on average, larger clusters and, consequently, higher MFW and MFD values (Reis *et al.*, 2016). This observed increase may be attributed to the adjustment of soil pH by the two products in combination, resulting in greater availability of K for translocation to the fruits (Nomura *et al.*, 2019; Bolfarini *et al.*, 2020); K is the main macronutrient absorbed by the banana plant and is also responsible for the postharvest quality of the clusters.

Finally, in Table 7, an increase in TTA was observed when applying LS, but this effect was not able to reduce the malic acid content in the pulp of the selected fruits. In contrast, separate application of LT reduced the total acidity of the fruit pulp due to the increase in soil pH and higher availability of K in the pulp (Costa *et al.*, 2015), an interesting organoleptic characteristic that gives better flavor to Prata Gorutuba bananas.

Similar effects of LT were reported in red pitaya (*Hylocereus undatus* (Haw.) Britton & Rose, with an observed gain in fruit quality (Costa *et al.*, 2015), and in the 'Kent' mango (*Mangifera indica* L.), with improved nutritional status (Lobo *et al.*, 2019).

Thus, it is suggested that a future trial be conducted with the combination of factors mentioned above; this trial should be conducted in the same region, during the same cultivation cycle, with the same variety and with the central design level (commercial dose), in contrast to conventional irrigation management applied by banana farmers in the study region.

CONCLUSIONS

The factors LS, CT, LT and ACA, previously screened in a previous assay, can be maintained at three dose levels (half, commercial and double) without altering cultivation performance.

Agricultural experimental efficiency can be achieved by performing a single trial with only 35.71% of the number of total plots used in the previous screening experiment (84 plots).

The results indicate good effects of LS, CT, LT and ACA on the development, production and quality of the fruits of Prata Gorutuba banana trees, with special emphasis on LT when applied alone or in conjunction with the other three factors.

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