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Key Agronomic Fertilization Practices That Influence Yield of Naranjilla (*Solanum quitoense* Lam.) in the Ecuadorian Amazon

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Abstract: An application of a balanced nutrition will improve the soil as well as enhance the yield of naranjilla (*Solanum quitoense* Lam.) grown in the Ecuadorian Amazon. A field experiment was carried out in Palora, 16 de Agosto (Morona Santiago province) and Fátima (Pastaza province) to find which variables are related with the yield of the naranjilla crop and the yield response when the crop receives complete nutrition with N, P, K, Ca, Mg, and S plus lime and with the omission of each of these nutrients. A Random Complete Block Design with three replications was used in the three environments. The naranjilla crop had higher yields (18.14 Mg ha^{-1}) in the complete treatments (N, P, K, Ca, Mg, and S) and without S and Mg, consequently, these two last nutrients did not limit the production. When N, P, K, and Ca were not applied, the yields fell to 14.62 Mg ha^{-1}. The main environmental effect showed that Palora had the highest fruit yields (19.73 Mg ha^{-1}), followed by 16 de Agosto (13.57 Mg ha^{-1}) and finally Fátima with 11.04 (Mg ha^{-1}). These preliminary results showed that with the treatments without S (18.55 Mg ha^{-1}), without Mg (18.42 Mg ha^{-1}) and complete (17.46 Mg ha^{-1}) the highest yields were obtained, consequently, the production was not affected by the absence of these elements; the opposite happened when N, P, K, and Ca were not present.

Keywords: naranjilla; yield; mineral nutrition

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1. Introduction

The naranjilla fruit (*Solanum quitoense* Lam.) In recent years has positioned itself in the national and international market for its exquisite flavor, nutritional properties (vitamins A, B, and C, calcium, iron and antioxidants). Its aroma has captivated the attention of consumers from all over the globe including Asia, Europe and North America [1,2].

In Ecuador there are around 10,000 hectares of production of naranjilla fruit [3]. In the Amazon, the highest production of this fruit is located in the Ecuadorian Amazon (Napo, Morona Santiago, and Pastaza provinces [3,4]), with yields ranging from 5.49 to 6.04 Mg ha^{-1} year. However, the low profitability of the crop which is reflected in its low yields, is mainly due to poor agronomic management. References [3,5] mentioned if the crop receives technical management (plant nutrition depending on the phenological stage, use of rootstocks, pruning, rotation of pesticides and training system), yield can reach from 25 to 30 Mg ha^{-1} year and generating a profitability of 119 to 164% more than with conventional management.

One of the practices widely used by Amazonian producers is the elimination of the primary forest to sow this fruit tree. This crop is very demanding in nutrients and the yields decrease year after year, without an improved fertilization program, forcing farmers to more deforestation [5]. Moreover, the nutrients stored in the upper layer disappear in the first year of cultivation, for this reason in subsequent sowings the producers tend to fertilize without any technical recommendation and they cannot achieve the yields obtained in the first year after cutting the primary forest [6].

Therefore, fertilization is a determining factor for the yield and quality of the fruit in the naranjilla crop [7,8] indicates that this fruit crop requires high amounts of nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), and phosphorus (P) for its growth and production. They also mention that when the concentration of N is high, a better yield and greater leaf area are achieved, and they indicate that K is directly related to the development of the areal part of the plant. On the other hand, [9] pointed out that the soil conditions (nutrients) of each field where naranjilla is cultivated has to be considered its fertilizer management. In addition, when the soil pH is less than 5.2, it is recommended to apply lime to avoid a 50% reduction in yield [5]; also the use of minor elements (boron, copper and zinc), organic fertilizers and mycorrhizae, enables vigorous growth of plants that could tolerate stress, caused by direct sunlight [10].

This study will allow to obtain the bases to solve questions such as: Which nutrients limit the yield of *S. quitoense*? The absence of which mineral elements does not affect the yield? Can edaphic fertilization compensate for the deficit between the effective nutrition required by the crop and the nutrient content in the soil? Is there an influence of the environment on yield? since the hypotheses of this research was that this fruit crop requires fertilization with all the nutrients to obtain higher yields and that the environment is decisive for the expression of this productive characteristic. However, more research is required to corroborate the answers to these questions.

This research was carried out with the objective of finding which crop variables were correlated with the yield of *S. quitoense* and the response when the crop receives complete nutrition with N, P, K, Ca, Mg, and S plus lime and with the omission of each one of these nutrients; due to the hypothesis that this crop requires all the mineral elements to obtain better yield and it is also influenced by the environments.

2. Materials and Methods

2.1. Fertilization Practices

Three environments were selected for this experiment: Fátima, Palora and 16 de Agosto, located in the Amazon region of Ecuador. Fátima, province of Pastaza, is located at 1000 m.a.s.l. (77°57′47.7′′ W; latitude 1°25′35.1′′ S), shows a mean temperature of 20.4 °C and 4222 mm of rainfall. The environments 16 de Agosto and Palora are located in the Palora county, province of Morona Santiago at 921 and 864 m.a.s.l., respectively. The coordinates for 16 de Agosto are longitude 77°55′6.8′′ W and latitude 1°44′43.1′′ S and for Palora are longitude 77°57′50.3′′ W and latitude 1°40′14.5′′ S. Mean temperatures is 20 °C and rainfall of 3351 and 3122 mm year^{-1} for 16 de Agosto and Palora, respectively. Naranjilla plants variety INIAP Quitoense-2009 were used for this experiment for all the above locations.

A complete randomized block design with factorial 9 (treatments) × 3 (locations) was used with three replicates per treatment, for a total of 27 experimental units in each environment. The size of the net plot was 15 m^2 which included six plants for each replication. Plants were fertilized from the day of transplanting until the reproductive phase (flowering, fruiting and harvesting), which is a period of one year after transplanting. The treatments were: A full treatment with all macronutrients (N, P, K, Ca, Mg, and S), a treatment with the omission of nitrogen (−N), a treatment with the omission of phosphorus (−P), a treatment with the omission of potassium (−K), a treatment with the omission of calcium (−Ca), a treatment with the omission of magnesium (−Mg), and a treatment with the omission of sulfur (−S), all the treatments plus lime. In addition, there were a control (no nutrients) plus lime (control +lime) and a control without lime (control —lime). The nutrient sources used in this experiment were ammonium nitrate (38% N), calcium oxide (40% Ca), di-ammonium phosphate (18% N, 48% P), calcium nitrate (12% N, 17% Ca), potassium sulfate (46% S, 51% K_2O), magnesium oxide (19% Mg), magnesium sulfate (12% Mg, 20% S), and potassium chloride (60% K).

The amount of nutrients that was applied was calculated according to the procedure described by [5], which considers: (a) Requirements of the crop to produce 30 tons of fruit per hectare, (b) contribution of nutrients by the soil according to its fertility (Table 1), and (c) efficiency of the fertilizer.

Table 1. Soil agrochemical characteristics.

Environment	pH	ppm			meq/100 mL			%	%			Texture
		NH4	P	S	K	Ca	Mg	OM	Sand	Silt	Clay	
Palora	5.3	48.5 H	4.05 L	8.1 L	0.1 L	1.43 L	0.49 L	12.70 H	54	31	15	Loam-sandy
16 de Agosto	5.1	49.5 H	4.95 L	8.3 L	0.2 L	1.78 L	0.60 L	12.70 H	49	37	14	Loam
Fátima	5.2	42.0 H	6.35 L	7.2 L	0.1 L	1.13 L	0.48 L	13.45 H	53	35	12	Loam-sandy

H: High; L: Low.

We applied 72 g N plant^{-1}, 60 g P plant^{-1}, and 32 g K plant^{-1} Ca, 16 g plant^{-1}, and 12 g S and Mg plant^{-1}, respectively. For nitrogen, 20% of it was applied at transplanting and the rest in four fractions at three, six, seven and a half months and ten months of age. At the time of transplanting, 50% of K, P, Ca, Mg, and S were also applied and the other two fractions of K were applied at four and eight months, and the remaining 50% of P, Ca, Mg, and S were placed at six months.

Two months after sowing, the formation pruning was carried out, which consisted in the elimination of basal shoots. In addition, four well distributed secondary branches were selected to form the crown of the tree. In addition, sanitary and maintenance pruning were carried out every two months, to eliminate lower branches, intersecting branches, excess leaves, diseased branches, and fruits affected by pests; this allowed the plants to have good air circulation and greater entry of light. In order to avoid the plant overturning and branch breaking due to the fruit weight at the production, individual cane stakes of 2.5 m high were used as training system, they were placed next to the plant and then branches were tied to the stake and between them with plastic tape. Phytosanitary controls were carried out every 22 days using preventive and curative products such as chlorothalonil, mancozeb, cymoxanil and metalaxyl, abamectin, and lambdacyhalothrin. In the study areas, rainfall of 3122 to 3351 mm year-1 was recorded, thus the water requirement of the crop was supplied.

The following variables were evaluated, plant height and plant diameter at nine months of crop age (fruiting started), height was measured with a tape measure from the base of the root neck to the apex of the younger matured leaf. The diameter was recorded with a digital caliper (Mitutoyo, model IP-67) five centimeters above the graft attachment point [11]. In addition, the days elapsed from sowing to 50% flowering (days to flowering), fruit setting (days to fruiting) and fruits with different maturity degrees (Figure 1) [12,13]. The yield was also evaluated by weighing all the fruits (g plant^{-1}), the number of fruits per plant and per category were counted (1st category = fruits > 60 mm, 2nd category = 55 to 60 mm, 3rd category = 46 to 54 mm, 4th category $\leq$ 45 mm) [11,12]. The fruits were harvested with a number 4 maturity degree (75% yellow-orange color, Figure 1) [14], every 15 days for 260 days [5].

2.2. Data Analysis

2.2.1. Multivariate Statistics

A principal component analysis (PCA) was used as an exploratory tool in order to find relations among variables and relations among samples, detect outliers and quantify patterns among multivariate data. Principal component analysis has been previously use to identify key agronomic practices which influences crop production [15–18]. The analysis was performed using the R (3.2.4) program coupled with the multivariate data analysis

(MDA) tools package (doi: 10.5281/zenodo.59547). A principal component analysis model was used to identify the main nutrients that affect naranjilla yield. The practices identified were: A full treatment with all macronutrients (N, P, K, Ca, Mg, and S), a full treatment without nitrogen (−N), a full treatment without phosphorus (−P), a full treatment without potassium (−K), a full treatment without calcium (−Ca), a full treatment without magnesium (−Mg), a full treatment without sulfur (−S), no nutrients applied plus lime (C +lime) and no nutrients applied without lime (C —lime).

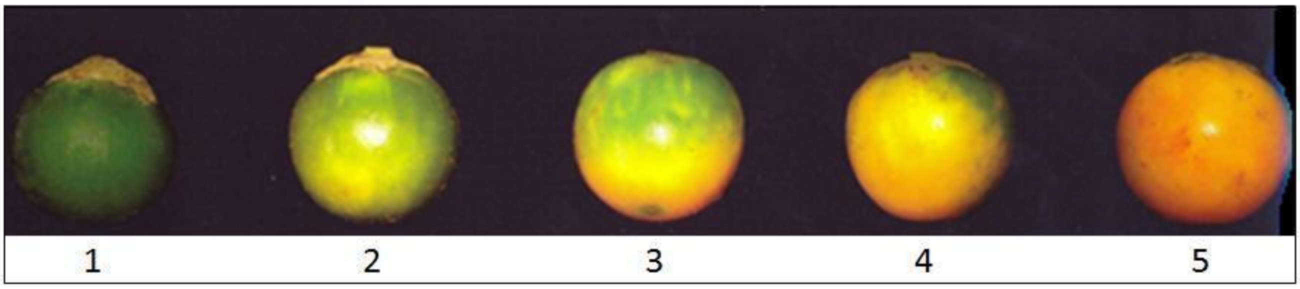

Figure 1. Naranjilla maturity degrees according to [13]. Note change of color, fruits are harvested at category number 4 for commercial purposes.

2.2.2. Response Analysis

The responses identified by PCA due to different fertilizer practices (fertilization) were modeled as:

$$Y_{ijkl} = \mu + L_i + B_{((i)j)} + T_k + LT_{ik} + \varepsilon_{(ijk)l}. \quad (1)$$

9 Agronomic fertilization practices k = 1 to 9; 3 environments = I = 1,2,3; 3 blocks j = 1, 2, 3; where:

Y_{ijkl} = denotes the observation at the ith environment in the jth block for the kth fertilizer practice.

μ = grand mean.

L_i = fixed effect of the ith environment.

$B_{((i)j)}$ = random effect of the jth block in the ith environment NID (0, $\sigma_b{}^2$).

T_k = fixed effect of the kth agronomic fertilization practice.

LT_{ik} = interaction effect between the ith environment and the kth fertilizer practice.

$\varepsilon_{(ijk)l}$ = Random experimental error (0, $\sigma_e{}^2$).

The variables identified by PCA that had correlation with yield were separated to perform a univariate analysis. The univariate data was analyzed using SAS 9.3 mixed model procedure. Interactions and main effects were considered significant at $p < 0.1$. Variables were checked for assumptions of normality and homogeneity of variances based on plot of residuals vs. predicted values. Transformations were performed as needed to comply with the normality assumption. The transformations were based on the Box-Cox power transformation series [19]. Least square means were separated using LSD mean separation procedure in SAS proc mixed. The LSD differences are reported at 0.1 significance level and the means were order using mean separation into groups by letters [20].

3. Results

3.1. PCA Modeling and Correlation Analysis

A non-parametric Spearman test was performed previous to the PCA modeling and showed that environment, and the different fertilization practices were not correlated. Across all environments, individual correlations showed that yield was correlated to number of fruits (0.94), fruits > 60 mm (0.9), fruits between 55 and 60 mm (0.76), plant diameter (0.67), and plant height (0.67) in all the environments, thus PCA allowed to find patterns and correlations in the data by environment. The PCA model with scaling and centering showed that only five components were necessary to explain structural information and also explicated around 90% of the variability. The first 2 components explain more than 65% of the variance (Table 2). For our experiment, the others explain just some random variation.

Table 2. Cumulative variance explained by components in the three environments of this study. The variance explained by each component and the cumulative variance are presented. With five components around 90% of the variance is explained in all environments.

	16 de Agosto		Palora		Fátima	
Component	**Explained Variance**	**Cumulative Variance**	**Explained Variance**	**Cumulative Variance**	**Explained Variance**	**Cumulative Variance**
Component 1	52.50	52.50	56.07	56.07	61.58	61.58
Component 2	16.37	68.87	13.41	69.48	12.37	73.95
Component 3	10.10	78.97	11.81	81.29	8.89	82.85
Component 4	6.87	85.84	6.47	87.76	6.34	89.19
Component 5	5.19	91.03	3.94	91.70	4.10	93.29

3.2. PCA Modeling by Environment

3.2.1. 16 de Agosto Environment

Scaling was performed because the variables were expressed in different units. The highest yield was obtained in the full treatment and without S (Figure 2). The loadings plot showed that yield was positive correlated with the number of fruits, fruits > 60 mm, fruits between 55 and 60 mm, plant diameter and plant height and negative correlated with days to flowering and days to fruiting. The scores plot (panel A) showed that the full treatment and full treatment without S tended to the upper left corner toward higher yield. This can be visually seen in the colored scale (Figure 2).

3.2.2. Palora Environment

The model for the second environment, showed that the full treatment and treatment without S were related to higher yields, but in a less clear clustering than in 16 de Agosto. Naranjilla yield were correlated with number of fruits, fruits > 60 mm, fruits between 55 to 60 mm, diameter of fruits at harvest and height of plant at harvest (Figure 3).

3.2.3. Fátima Environment

The model for Fátima showed that the just the full treatment is pointing toward high yields. There is not a clear pattern toward a treatment that shows consistent higher yields as in 16 de Agosto. However, naranjilla yield are still correlated with number of fruits, fruits > 60 mm, fruits between 55 to 60 mm, diameter of fruits at harvest and height of plant at harvest (Figure 4).

3.3. Univariate Analysis

A univariate analysis was performed for fruit yield. The main effects and interactions between the environments and the fertilizer practices (fertilization) were as well analyzed (Table 3). The analysis showed that there was no interactive effect between environment and fertilizer practice (p = 0.92). However, there was a highly significant effect of the environment (p = 0.0003) and the fertilizer practice (p = 0.0097).

The main effect for environment showed that Palora environment provided the highest fruit yield (19.73 Mg ha^{-1}), followed by 16 de Agosto (13.57 Mg ha^{-1}) and finally Fátima with 11.04 (Mg ha^{-1}). Fertilizer practices (fertilization) showed different effects on fruit yield. The highest yield obtained by the treatments (-S) and (-Mg) were numerically superior to the full treatment (one ton more); however, these treatments were not statistically different from the full treatment (Table 4). The effect of this fertilization practices and environments was corroborated as well in the PCA analysis.

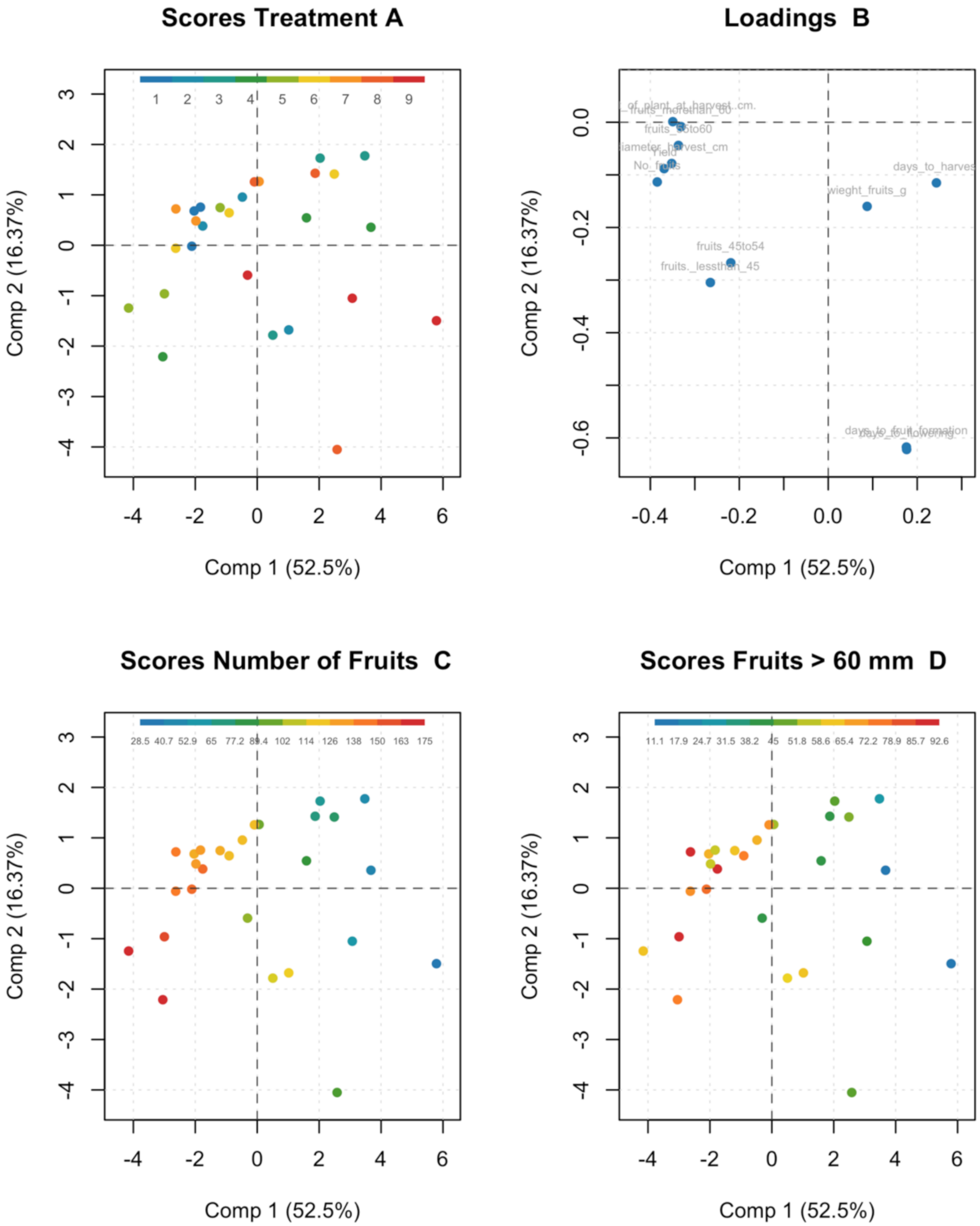

Figure 2. Principal component analysis on naranjilla fruit at 16 de Agosto environment. Panel B is the loading plot and panels A to D the score plots. The principal component 1 and 2 are plotted in panel A and B showing the fertilization practices and the corresponding variables. Panels C to D provide a representation of the score plot colored with respect to the amount of a given variable (from low to high). Treatments 1 to 9. (1) full treatment with all macronutrients (N, P, K, Ca, Mg, and S), (2) a full treatment without nitrogen (−N), (3) a full treatment without phosphorus (−P), (4) a full treatment without potassium (−K), (5) a full treatment without calcium (−Ca), (6) a full treatment without magnesium (−Mg), (7) a full treatment without sulfur (−S), (8) no nutrients applied plus lime (Control +lime) and (9) no nutrients applied without lime (Control −lime).

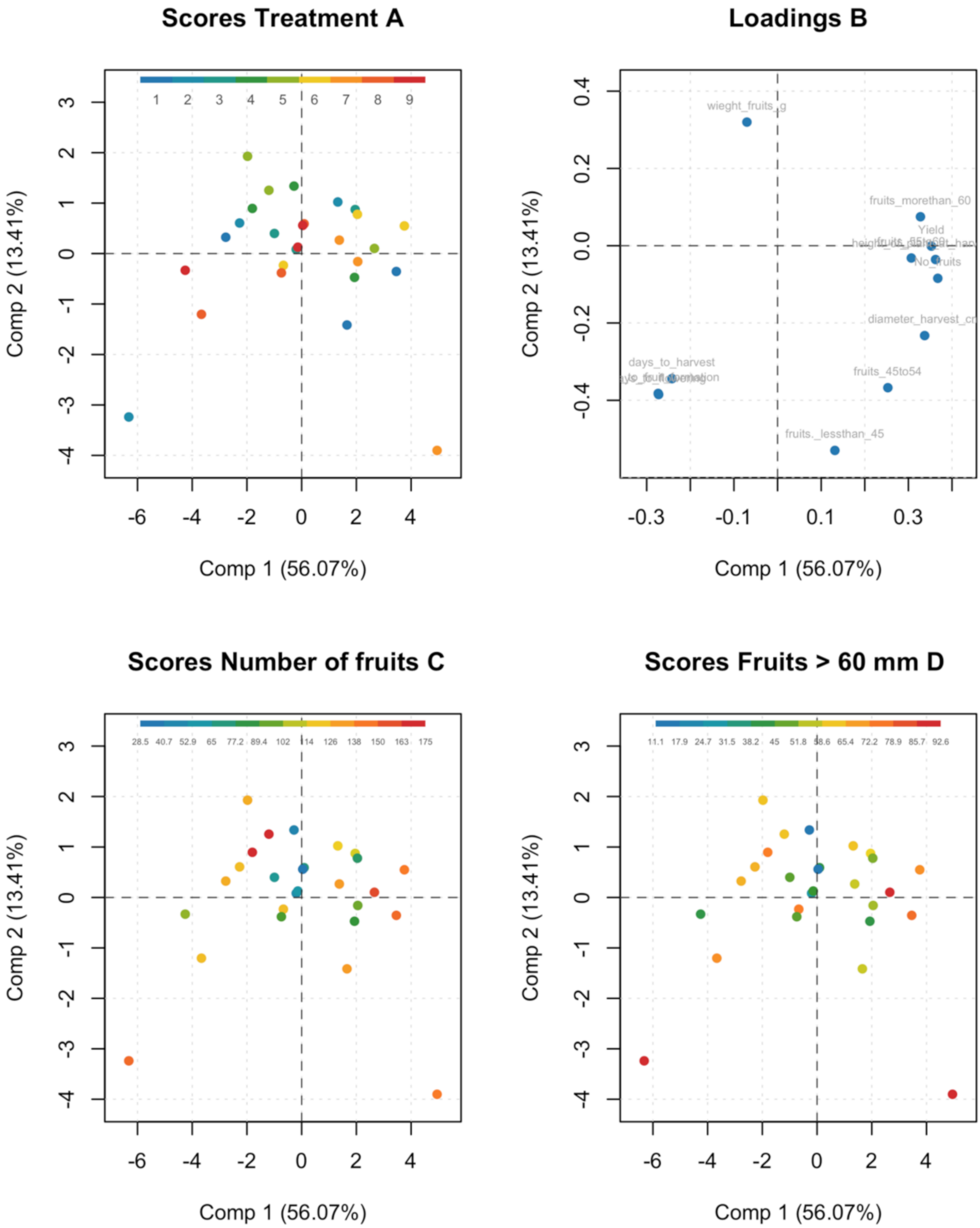

Figure 3. Principal component analysis of naranjilla fruit in the Palora environment. Panel A is the score plot and panel B is the loading plot. Panels C to D provide a representation of the score plot colored with respect to the amount of a given variable (from low to high). Treatments 1 to 9. (1) full treatment with all macronutrients (N, P, K, Ca, Mg, and S), (2) a full treatment without nitrogen (−N), (3) a full treatment without phosphorus (−P), (4) a full treatment without potassium (−K), (5) a full treatment without calcium (−Ca), (6) a full treatment without magnesium (−Mg), (7) a full treatment without sulfur (−S), (8) no nutrients applied plus lime (Control +lime) and (9) no nutrients applied without lime (Control −lime).

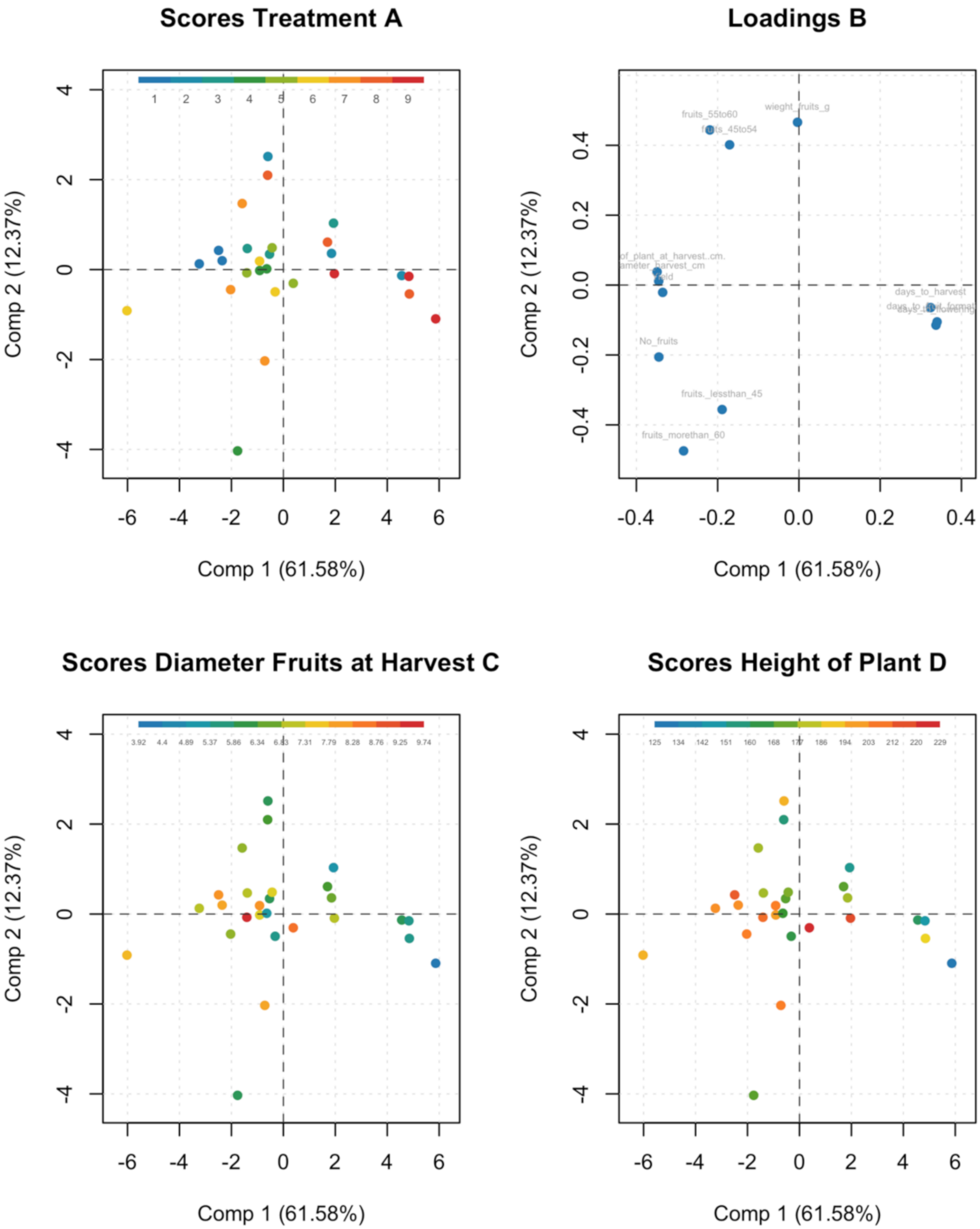

Figure 4. Principal component analysis of naranjilla fruit in the Fátima environment. Panel A is the score plot and panel B is the loading plot. Panels C and D provide a representation of the score plot colored with respect to the amount of a given variable (from low to high). Treatments 1 to 9. (1) full treatment with all macronutrients (N, P, K, Ca, Mg, and S), (2) a full treatment without nitrogen (−N), (3) a full treatment without phosphorus (−P), (4) a full treatment without potassium (−K), (5) a full treatment without calcium (−Ca), (6) a full treatment without magnesium (−Mg), (7) a full treatment without sulfur (−S), (8) no nutrients applied plus lime (Control +lime), and (9) no nutrients applied without lime (Control —lime).

Table 3. Main effects and interaction effect for fruit yield determined for each factor: Environment and fertilizer practice. Mean values are reported. Within a column and within a given factor, means followed by the same letter are not statistically different (alpha = 0.1).

	Fruit Yield Mg ha^{-1}
Environment	**
Fertilizer practice	**
Fertilizer practice × Environment	NS

NS not significant; ** significant at $p \leq 0.01$.

Table 4. Mean values for fruit yield determined for each factor: Environment and fertilizer practice. Mean values are reported. Within a column and within a given factor, means followed by the same letter are not statistically different (alpha = 0.1).

Environment	**Fertilizer Practice**	**Fruit Yield Mg ha^{-1}**
	(−N)	13.59 bc
	(−P)	13.76 bc
	(−K)	15.05 abc
	(−Mg)	18.42 a
	(−Ca)	16.08 ab
	(−S)	18.55 a
	Full	17.46 ab
	C +lime	11.42 cd
	C −lime	8.69 d
Palora		19.73 a
16 de Agosto		13.5 b
Fátima		11.04 c

For days to flowering, days to fruiting, days to harvest, plant height and stem diameter, it was determined that there was no consistent interaction between the environment and fertilization (p = 0.06, 0.06, 0.24, 0.71, 0.36), respectively. However, these variables had a highly significant effect on the environment ($p \leq 0.0001$, < 0.0001, < 0.0001, < 0.0001, 0.02) and fertilization (p = 0.0001, 0.0001, 0.0003, 0.0002, 0.0001), respectively.

In the sites of Palora and 16 de Agosto, naranjilla production began 38 and 28 days earlier than in Fátima. In addition, in these same environment plants had the highest plant height and stem diameter. For the variables days to flowering and days to fruiting, the treatments (−S) and (−Mg) were not statistically different from the full treatment. For the variables days to harvest, plant height and stem diameter, it was observed that the control treatment without lime (C —lime) presented precocity, small plants and smaller diameters (Table 5).

Table 5. Mean values of physical and phenological variables.

Environment	**Fertilizer Practice**	**Days to Flowering**	**Days to Fructification**	**Days to Harvest**	**Plant Height (cm)**	**Plant Diameter (cm)**
	(−N)	144 a	152 a	152 cd	152.44 cd	5.27 cde
	(−P)	118 bc	127 bc	158 bc	158.33 bc	6.19 abcd
	(−K)	118 bc	127 bc	165 abc	165.11 abc	6.09 bcd
	(−Mg)	111 c	119 c	178 ab	178.22 ab	7.29 a
	(−Ca)	118 bc	127 bc	170 abc	169.89 abc	6.58 abc
	(−S)	116 c	124 c	178 a	178.33 a	7.09 ab
	Full	106 c	115 c	181 a	181.22 a	7.27 a
	C +lime	134 ab	143 ab	151 cd	150.78 cd	5.27 de
	C −lime	144 a	153 a	135 d	135.11 d	4.98 e
Palora		111 b	119 b	222 b	168.30b	6.23 ab
16 de Agosto		113 b	122 b	232 b	184.37a	6.69 a
Fátima		146 a	155 a	260 a	137,15c	5.76 b

Average values are reported. Within a column and within a given factor, the means followed by the same letter are not statistically different (alpha = 0.1).

4. Discussion

The flowering, fruiting and harvest stages occurred at 111 to 146, 119 to 155, and 222 to 260 days, respectively. Results that differ from those reported by [5], who stated that the flowering of the naranjilla occurs at 83 to 108 days, fruiting from 81 to 106 days and the harvest occurs from 215 to 238 days. However, the days to harvest in this study coincided with the results obtained by [21], who mentioned that the naranjilla fruiting occurs between 222 and 280 days and pointed out that the determining parameters in the phenology of the crop are heat units, precipitation, cumulative irradiance, and temperature. To this must be added the influence of the environment, soil type, soil texture, differences in soil fertility, and the effect of fertilization [22]. On the other hand, in the three environments, plant height and stem diameter were in ranges from 137.15 to 184.37 cm and from 5.76 to 6.69 cm, respectively; values that are within the ranges reported by [5,11], who mentioned that the height of the naranjilla plant in the productive stage varies from 83 to 180 cm, with diameters greater than 5 cm.

The strong relationship that occurs between yield and fruit number and diameter is due to the fact that these variables are components of this factor [23]. This argument is confirmed by [21] who stated that the number of fruits per plant is a parameter that is closely related to total production; that is, a greater number of fruits per plant with the same production per unit area shows that the fruits are smaller, therefore, this parameter allows determining the destination of the production, that is, for fresh market, large fruits are preferred (category 1 and 2) and small fruits (categories 3 and 4) are used for industry [24]. This same criterion is used in deciduous fruit trees where the number of fruits is considered a fundamental component of the yield [25]. On the other hand, the correlation of yield with plant height is possibly due to the fact that naranjilla plants in the height month reach their height maturity and fruit production [26].

The highest yield was obtained with the treatment without S (19.0 Mg ha^{-1}), which agrees with the study carried out by [27], who obtained similar yields in the treatment without S (21.0 Mg ha^{-1}) and complete treatment (N, P, K, Ca, Mg, and S) (23.0 Mg ha^{-1}). The same was observed at the nursery level with naranjilla plants and in the field with *Zea mays* L. and *Brassica oleracea* L. var acephala where in the absence of S, the plants show a positive response in the development of leaf area and yield [28–30]. The opposite happened in *S. tuberosum*, *Glycine max*, *Triticum aestivum* L., and *Allium cepa* L., where the yield increased when S was applied [31–34].

On the other hand, in the treatment without Mg, high yield of naranjilla fruit was also obtained (18.42 Mg ha^{-1}). Similar results were observed in *Physalis peruviana* L., where, in the absence of magnesium, the fruit size, number of fruits, and yield were similar to the treatment where the crop received all the nutrients [35]. However, the results of this study differ from those found by [27], who indicated that in the absence of this element, the naranjilla fruit yield was lower (12.0 Mg ha^{-1}) than when all the nutrients were provided to the crop (18.0 Mg ha^{-1}). The same occurs at the nursery level, where in the absence of this element, plant height is reduced by 40% and leaf area growth by 14%, compared to those plants that received complete fertilization [28]. This reduction in yield was also observed in fruits, grass, tobacco, tubers, vegetables, cereals, oilseed crops, tea, and other crops, where in the absence of this element the yield is reduced by 8.5% [36].

The highest yield obtained in Palora is possibly due to the variation of abiotic factors such as climatic conditions such as temperature and solar radiation [37,38]. Palora can reach until 80 light hours monthly and temperatures between 18 and 29 °C and rarely less than 16 °C. In this environment, plants showed early flowering and fruiting, factors influenced by the heliophany.

In this study, no interaction was found between fertilization practice and the environment. Similar results were found by [22]. However, these authors mention that the nutrient content in the soil was the main factor that led to the differences in the yield and quality in their study. In addition [18], they mentioned that the quality of naranjilla fruit improves when the crop is provided with all the nutrients (N, P, K, Ca, Mg, and S).

The lowest yield in the treatment without lime (C —lime) can be due to the fact that the acidity of the soil was not adjusted, mainly affecting the growth and production of the crop due to the lack of availability of nutrients such as Ca, Mg, P, and K which are important for the growth and production of naranjilla. In addition, the non-application of lime in the soil causes the accumulation of toxic elements such as Al and Mn that reduce plant growth and crop yield [39–41]. Similar results were found in studies with *Phaseolus vulgaris L.* and *Vigna radiata*, where the yield was reduced by 73 to 313% when lime was not applied to acid soils [42,43]. Therefore, [38] indicated that the application of lime in an acidic soil is necessary to significantly increase the yield of the crops by 13 to 67%.

5. Conclusions

These preliminary results showed that naranjilla (*S. quitoense*) yield was not affected by the absence of the S and Mg, their values were similar to the full treatment, thus these nutrients did not limited yield; while in the absence of N, P, K, and Ca the yield decreased. In addition, lime application neither influenced yield. The control (without nutrients) showed the lowest yield, thus it is required edaphic fertilization to compensate the crop nutrient requirements in soils of the Ecuadorian Amazon.

Palora environment showed the highest yield, followed by 16 de Agosto and Fátima, respectively; showing that there was an effect of the environment in the crop yield. In the Ecuadorian Amazon, this kind of research is essential to start to understand the fertilization of this crop and determine the limitations in yield because of the nutrient application. However, it is recommended to continue the evaluation for at least two production cycles more to confirm the results of this study and also more questions can be answered in the following years of experimentation.

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References

1. Gaona-Gonzaga, J.; Montesdeoca-Espín, D.; Brito-Grandes, B.; Sotomayor-Correa, A.; Viera-Arroyo, W. Aprovechamiento de la naranjilla (*Solanum quitoense* Lam.) variedad INIAP Quitoense-2009 para la obtención de una bebida carbonatada. *Enfoque UTE* **2019**, *10*, 107–114. [CrossRef]
2. PROECUADOR. *Análisis sectorial de frutas exóticas*; Instituto de Promoción de Exportaciones e Inversiones. Available online: https://issuu.com/pro-ecuador/docs/analisissectorialfrutas (accessed on 9 July 2020).
3. Torres-Navarrete, A.; Vargas-Burgos, J.; García-Quintana, Y.G.; Torres-Navarrete, E.; Arteaga-Crespo, Y. Influence of socioeconomic variables in the naranjilla (*Solanum quitoense* Lam.) production in the rural community of Wamani in the Ecuadorian Amazon. *Acta Agron.* **2018**, *67*, 65–72. [CrossRef]
4. Vargas-Tierras, Y.; Prado-Beltrán, J.; Nicolalde-Cruz, J.; Casanoves, F.; Virginio-Filho, E.; Viera-Arroyo, W. Characterization and role of Amazonian fruit crops in family farms in the provinces of Sucumbíos and Orellana (Ecuador). *Cienc. Tecnol. Agropecu.* **2018**, *19*, 501–515. [CrossRef]
5. Revelo, J.; Viteri, P.; Vásquez, W.; León, J.; Gallegos, P. *Manual of the Ecological Cultivation of the Naranjilla*; INIAP: Quito, Ecuador, 2010; pp. 59–97.
6. Symanczik, S.; Gisler, M.; Thonar, C.; Schlaeppi, K.; Van der Heijden, M.; Kahmen, A.; Boller, T.; Mäder, P. Application of mycorrhiza and soil from a permaculture system improved phosphorus acquisition in naranjilla. *Front. Plant Sci.* **2017**, *8*, 1263. [CrossRef] [PubMed]

7. Medina, C.; Lobo, M.; Martínez, E. Revisión del estado del conocimiento sobre la función productiva del lulo (*Solanum quitoense* Lam.) en Colombia. *Cienc. Tecnol. Agropecu.* **2009**, *10*, 167–179. [CrossRef]
8. Varela, J.; Velásquez, J.; Mejía, M. Physiological response of lulo (*Solanum quitoense* Lam) to different concentrations of N, P, K and Mg in the nutritive solution. *Acta Agron.* **2001**, *51*, 53–59.
9. Gómez-Merino, F.C.; Trejo-Téllez, L.I.; García-Albarado, J.C.; Cadeña-Íñiguez, J. Lulo (*Solanum quitoense* [Lamarck.]) como cultivo novedoso en el paisaje agroecosistémico mexicano. *Rev. Mex. Cienc. Agríc.* **2014**, *5*, 1741–1753. [CrossRef]
10. Franco, G.; Bernal, J.; Giraldo, M.; Tamayo, P.; Castaño, O.; Tamayo, A.; Gallego, J.; Botero, M.; Rodríguez, J.; Guevara, J.; et al. *El cultivo del lulo: Manual técnico*; Corpoica: Manizales, Ecuador, 2002; pp. 30–40.
11. Arizala, M.; Monsalvo, Á.; García, C.B.; González, C.S.; Burbano, T.C.L. Evaluación de solanáceas silvestres como patrones de lulo (*Solanum quitoense* Lam) y su reacción a *Fusarium* Sp. *Rev. Cienc. Agrí.* **2011**, *28*, 147–160.
12. Muñoz, L. Evaluación agronómica de materiales de lulo Solanum sp, frutal de alto potencial para zonas tropicales. Available online: https://conectarural.org/sitio/material/evaluaci%C3%B3n-agron%C3%B3mica-de-materiales-de-lulo-solanum-sp-frutal-de-alto-potencial-para-zonas (accessed on 3 October 2020).
13. Ochoa-Vargas, L.M.; Balaguera-López, H.E.; Ardila-Roa, G.; Pinzón-Sandoval, E.H.; Álvarez-Herrera, J.G. Crecimiento y desarrollo del fruto de lulo (*Solanum quitoense* Lam.) en el municipio de San Antonio del Tequendama (Colombia). *Cienc. Tecnol. Agropecu.* **2016**, *17*, 347. [CrossRef]
14. INEN. *Norma Técnica Ecuatoriana NTE INEN 2 302:2009. Frutas Frescas. Naranjilla. Requisitos*; Instituto Ecuatoriano de Normalización: Quito, Ecuador, 2009. Available online: https://archive.org/details/ec.nte.2303.2009/page/n1/mode/2up (accessed on 9 July 2020).
15. Wang, X.; Xing, Y. Evaluation of the effects of irrigation and fertilization on tomato fruit yield and quality: A principal component analysis. *Sci. Rep.* **2017**, *7*, 1–13. [CrossRef]
16. Sharifi, P.; Astereki, H.; Pouresmael, M. Evaluation of variations in chickpea (*Cicer arietinum* L.) yield and yield components by multivariate technique. *Ann. Agrar. Sci.* **2018**, *16*, 136–142. [CrossRef]
17. Beyzi, E.; Güneş, A.; Arslan, M.; Şatana, A. Effects of foliar boron treatments on yield and yield components of fenugreek (*Trigonella foenum graecum* L.): Detection by PCA analysis. *Commun. Soil Sci. Plant Anal.* **2019**, *50*, 2023–2032. [CrossRef]
18. Vargas, Y.; Díaz, A.; Suárez, A.; Viera, W. Use of multivariate statistics to determine fertilization practices that affect fruit quality of naranjilla (*Solanum quitoense* Lam.). *Fruits* **2020**, *75*, 216–223. [CrossRef]
19. Box, G.E.P.; Cox, D.R. An Analysis of transformations. *J. R. Stat. Soc. Ser. B* **1964**, *26*, 211–243. [CrossRef]
20. Saxton, A.M. A macro for converting mean separation output to letter groupings in PROC MIXED. In Proceedings of the 23rd SAS Users Group International, Nashville, TN, USA, 22–25 March 1998; pp. 1243–1246.
21. Jurado, J.C.; Jeréz, L.J.; Burbano, T.C.L.; Benavides, C.A. Comportamiento agronómico de injertos de lulo de castilla *Solanum quitoense* Lam. en patrones de Solanum Spp. *Rev. Cienc. Agrí.* **2013**, *30*, 54–64.
22. Romaneckas, K.; Adamavičienė, A.; Šarauskis, E.; Balandaitė, J. The impact of intercropping on soil fertility and sugar beet productivity. *Agronomy* **2020**, *10*, 1406. [CrossRef]
23. Lagos-Santander, L.K.; Lagos-Burbano, T.C.; Duarte-Alvarado, D.E.; Criollo-Escobar, H.; Angulo-Ramos, N.F. Evaluación del rendimiento y calidad del fruto de parentales e híbridos de lulo de Castilla. *Rev. UDCA Act. Div. Cient.* **2019**, *22*. [CrossRef]
24. Ardila, G.H.; Fischer, G.; García, J.C. La poda de tallos y racimos florales afecta la producción de frutos de lulo (*Solanum quitoense* var. septentrionale). *Rev. Colomb. Cienc. Hortícolas.* **2015**, *9*, 14. [CrossRef]
25. Zhang, D.; Wang, C.; Li, X.; Yang, X.; Zhao, L.; Xia, S. Correlation of production constraints with the yield gap of apple cropping systems in Luochuan County, China. *J. Integr. Agric.* **2019**, *8*, 1714–1725. [CrossRef]
26. Borja, H.; Patiño, S.; Ortiz, C.; Ramírez, J. Rendimiento del *Solanum quitoense* Lam, en monocultivo y cultivos mixtos en la región de Urubá, Colombia. *Rev. Politécnica* **2012**, *8*, 77–84.
27. Valverde, F.; Espinoza, J.; Bastidas, F. Management of the nutrition of the naranjilla cultivation (*Solanum quitoense* Lam.) in the production zones of the Amazon Region and the Northwest of Pichincha. *Inf. Agronómicas* **2009**, *1*, 8–14.
28. Vargas, M.I.V.; Calderón, L.; Pérez, M. Efecto de las deficiencias de algunos nutrientes en plantas de lulo (*Solanum quitoense* var. quitoense) en Etapa de Vivero. *Rev. Facultad Cienc. Básicas.* **2009**, *5*, 64–81. [CrossRef]
29. Kaur, J.; Chatterjee, A.; Franzen, D.; Cihacek, L. Corn response to sulfur fertilizer in the Red River Valley. *Int. J. Dev. Res.* **2019**, *111*, 2378–2386. [CrossRef]
30. Teuber, O.; Samarappuli, D.; Berti, M. Nitrogen and sulfur fertilization in Kale and Swede for grazing. *Agronomy* **2020**, *10*, 619. [CrossRef]
31. Alfaro, M.; Bernier, R.; Iraira, S. Efecto de fuentes de azufre sobre el rendimiento y calidad de trigo y pradera en dos Andisoles. *Agric. Técnica.* **2006**, *66*, 283–294. [CrossRef]
32. Moreira, A.; Moraes, L.A.C.; Provenzano, R.S.; Cabrera, R.A.D. Effect of sulfur source and rates on yield and yield components of soybean in subtropical soils. *J. Plant Nutr.* **2020**, *43*, 2081–2091. [CrossRef]
33. Przygocka-Cyna, K.; Barłóg, P.; Grzebisz, W.; Spiżewski, T. Onion (*Allium cepa* L.) Yield and Growth Dynamics Response to In-Season Patterns of Nitrogen and Sulfur Uptake. *Agronomy* **2020**, *10*, 1146. [CrossRef]
34. Rahman, M.W.; Islam, S.; Islam, M.M.; Hossain, M.S. Effect of sulphur on the yield and quality of potato varieties in tista meander floodplain soil of Bangladesh. *IJPSS* **2019**, *30*, 1–8. [CrossRef]

35. Martínez, F.; Sarmiento, J.; Fischer, G.; Jiménez, F. Efecto de la deficiencia de N, P, K, Ca, Mg y B en componentes de producción y calidad de la uchuva (*Physalis peruviana* L.). *Agron. Colomb.* **2008**, *26*, 389–398.
36. Wang, Z.; Hassan, M.U.; Nadeem, F.; Wu, L.; Zhang, F.; Li, X. Magnesium fertilization improves crop yield in most production systems: A meta-analysis. *Front. Plant Sci.* **2020**, *10*, 1727. [CrossRef]
37. Li, Y.; Cui, S.; Chang, S.X.; Zhang, Q. Liming effects on soil pH and crop yield depend on lime material type, application method and rate, and crop species: A global meta-analysis. *J. Soils Sediments* **2018**, *19*, 1393–1406. [CrossRef]
38. Li, W.; Yang, M.; Wang, J.; Wang, Z.; Fan, Z.; Kang, F.; Wang, Y.; Luo, Y.; Kuang, D.; Chen, Z.; et al. Agronomic responses of major fruit crops to fertilization in China: A meta-analysis. *Agronomy* **2019**, *10*, 15. [CrossRef]
39. Calva, C.; Espinosa, J. Efecto de la aplicación de cuatro materiales de encalado en control de la acidez de un suelo de Loreto, Orellana. *Siembra* **2017**, *4*, 110–120. [CrossRef]
40. Goulding, K.W. Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom. *Soil Use Manag.* **2016**, *32*, 390–399. [CrossRef]
41. Upjohn, B.; Fenton, G.; Conyers, M. *Soil Acidity and Liming*, 3rd ed.; NSW Department of Primary Industries; Available online: https://ausveg.com.au/app/data/technical-insights/docs/soil-acidity-liming.pdf (accessed on 18 October 2020).
42. Buerkert, A.; Cassman, K.G.; Piedra, R.; Munns, D.N. Soil acidity and liming effects on stand, nodulation, and yield of common bean. *Agron. J.* **1990**, *82*, 749–754. [CrossRef]
43. Varma, D.; Meena, R.S.; Kumar, S. Response of mungbean to fertility and lime levels under soil acidity in an alley cropping system of Vindhyan Region, India. *Inter. J. Chem. Stud.* **2017**, *5*, 1558–1560.