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Inorganic Fertilizers Affect Yield and Flower Quality of *Alpinia purpurata* (Vieillard) K. Schumann, Pink Variety

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Abstract

Alpinia purpurata (Vieillard) K. Schumann, Pink variety, is a tropical plant that produces flowers all year round. However, there are no rules for their fertilization. The objective of this study was to determine the effect of NPK fertilization on the yield and flower quality of the *A. purpurata* Pink variety. The variables evaluated were those related to stems, flowers, and weight of biomass. One hundred ninety-two plants were sectioned into flowers, leaves, stems and rhizomes and analyzed for NPK. The fertilizer rate 182-21-331 was statistically superior in the number of stems with open flowers (2.7), flower diameter (6.5 cm) and flower length (23. 5 cm). The number of stems with open flowers correlated with N in leaves and stems (r^2 = 0.92 and 1.0) and with P in stems (r^2 = 0.93). The number of stems with commercial flowers correlated with K in stems and rhizomes (r^2 = 0.96 and 0.94, respectively). Flower length and diameter correlated with P and N in flowers (r^2 = 0.94 and 0.99, respectively). The optimal rate determined for K in order to produce the highest number of commercial stems was 234.7 kg/ha.

Keywords

Alpinia purpurata, Fertilizer Rates, Cut Flowers, NPK Content, Zingiberaceae

1. Introduction

Mexico has a strong agricultural culture and one of the growing sectors is floriculture [1]. The wide variety of climates and rich soils have given rise to a broad range of flowers, which are sold in domestic and foreign markets [2]. Ornamentals have gained ground in terms of exports and production value. In 2017, floriculture produced ca. 443.8 million USA dollars. In the same year, foreign trade of flowers was valued at 88.6 million US dollars. The main buyers were the United States and Canada, and the main products were roses, gladiolas, gerbera, bird of paradise, carnations, statice and daisies. Additionally, in this year, the area under flower cultivation and potted plants was 21,589 ha. The outstanding producer states based on the value of production of these crops were the State of Mexico, Puebla, Morelos, Mexico City, Baja California and Jalisco. Eighty percent of the total production is sold on the national market, and 20% is exported. Mexico has a window of opportunity in the European market as the demand for flowers has grown in recent years [1].

The production of tropical ornamentals is a growing economic opportunity, and the incorporation of new species is an important element of competitiveness [3]. Known as Red ginger (including a Pink variety), Alpinia, and Hawaiian (in Mexico), *Alpinia purpurata* Vieill is a tropical species of the order Zingiberales, which has found an important niche in the domestic and international trade of cut flowers. This plant produces flowers year round in long-lasting, colorful, visually impacting inflorescences and is considered the rose of tropical flowers [3].

Mineral fertilizers contribute significantly to increasing agricultural production. The use of chemical fertilizers enables better expression of plant genetic characteristics [4]. Kobayashi *et al.* [5] recommend fertilizing cultivated Red ginger plants once or twice a year with the formula 1:1:1 to 3:1:5, nitrogen, phosphorus and potassium (NPK) for the edaphoclimatic conditions of Hawaii to increase the yield and quality of the flower. Since, the quality of a plant depends on its nutrient content, this author cited that for *A. purpurata*, the acceptable nutrient content in green foliage and healthy is 2% N, 0.16% P, 1.8% K, 1.8% Ca and 0.4% Mg. For the microelements, considers that adequate levels, also in leaf tissue, are found in the ranges: 450 to 700 ppm of Manganese (Mn), 30 to 60 ppm of Fe, 10 to 15 ppm of Copper (Cu), 40 to 90 ppm Zinc (Zn) and 15 to 25 ppm Boron (B). For Brazil, Lamas [6] mentions fertilizer rates of 350 - 400, 200 - 250, and 300 - 350 kg/ha NPK for a plantation older than 13 months.

In Mexico and the state of Tabasco, there is no technological package, nor are the nutritional requirements known for the production of tropical cut flowers in the ecosystems where they are currently produced. Saldaña *et al.* [7] mentions that tropical flowers are produced in 9 of 17 municipalities of Tabasco and occupy an area of 111 ha. Authors, such as Teixeira and Loges [8], point out that the yield of these species is measured by the number of commercial flowers produced per shoot cluster, while flower quality is mostly determined by parameters such as length and diameter of the stem and length and diameter of the flower.

The production of commercial tropical flowers began in Tabasco 25 years ago, and according to Criley and Broschat [9], Tabasco has the edaphoclimatic conditions suitable for growing these species. However, the lack of adequate fertilization management frequently limits the production and quality of flowers. In Red ginger, for example, it is important to adjust nutritional requirements during its development to satisfy the precise needs during periods of greater demand, especially for the essential nutrients N, P and K [10]. Therefore, the objective of the study was to evaluate the effect of fertilization with N, P, and K on the production and quality of flowers and plant development of the *Alpinia purpurata* Pink variety (hereafter Pink ginger) as well as to determine an optimal physiological rate of fertilization.

2. Methods

2.1. Experimental Site

The study was carried out in a 10-year-old commercial plantation 2 km north of the city of Comalcalco, Tabasco, Mexico (18˚17'43.49" N and 93˚12'28.68" W). Comalcalco is located on the alluvial plain physiographic region. The climate is Am(f), tropical hot humid, with abundant rains in the summer, an annual precipitation of 2000 mm, and a dry season from March to May, with a mean annual temperature of 26.3˚C [11]. The soil type in the Pink ginger plantation was Eutric Fluvisol with a crumbly clay-silt textural class (clay 38%, silt 44% and sand 18%). The chemical soil characteristics are listed in **Table 1**.

Pink ginger plants were interspersed with Spanish cedar (*Cedrela odorata* L.), royal palm (*Roystonea* sp.) and roble (*Tabebuia rosea* (Berth.) DC) trees. The plantation density was 2,000 plants per ha distributed in a 5 × 1 m rectangular spatial arrangement covering 6 ha. Cultural management given to the plantation was manual and chemical weeding twice a year and drip irrigation during the dry season, as well as disease control with Ridomil at 1 l/ha.

Table 1. Chemical characteristics of the soil in an *Alpinia purpurata* Pink ginger variety plantation at Tabasco State, Mexico.

Soil depth	pH (H_2O)	EC	OM	Total N	P Olsen	K	Ca	Mg	CIC	Fe	Zn
	Rel. 1:2	ds m^{-1}	%		mg kg^{-1}	Cmol(+) kg^{-1}					
0 - 15 cm	6.84	0.01	3.49	0.17	12.67	0.27	15.70	3.34	12.64	45.37	2.13

Methods: the analyzes were carried out in accordance with the Official Mexican Standard NOM-021-RECNAT-2000, which establishes the specifications of fertility, salinity and soil classification.

2.2. Plant Material and Experimental Design

The plant material used was 48 Pink ginger clusters. Prior to the establishment of the experiment, the plant nutrient content was determined (**Table 2**). Based on both plant analysis and soil analysis as well as the plant density, the rate 61-07-110 kg of N-P-K ha^{-1} was estimated for the study plantation and used as a relative control for the experiment.

The experiment was set up under a design of complete random blocks with three replications. Sixteen treatments were defined based on the San Cristobal design [12] with combinations of four levels of N, P and K. The San Cristóbal Design is an experimental design used in agriculture, especially in fertilization studies. It is an effective tool for optimizing fertilizer use and maximizing agricultural production. Its main features include: the use of a second-order mathematical model to understand the influence of fertilizers on yield, the ability to explore a wide range of fertilizer levels efficiently, and the combination of factorial treatments and additional treatments for a thorough evaluation. The treatments were as follows: the absolute control (T1) 00-00-00 kg·ha^{-1}, 00-00-220, 00-14-00, 00-14-220, 61-07-110, 61-07-331, 61-21-110, 61-21-331, 122-00-00, 122-00-220, 122-14-00, 122-14-220, 182-07-110, 182-07-331, 182-21-110, and (T16) 182-21-331 kg/ha. The experimental unit was one cluster of plants.

Urea (46%), triple superphosphate (46%) and potassium chloride (60%) were the fertilizers used as the sources of NPK. The fertilizers were placed around the cluster at distances of 10 cm and 5 cm depth.

Table 2. Nutrient content of the commercial and non-commercial biomass from Pink ginger (*Alpinia purpurata*) plants before fertilization.

Pink ginger	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	S
	%						Mg/kg				
CB	0.85	0.28	1.32	0.73	0.27	0.15	87.6	4.84	89.68	28.26	0.18
NCB	1.02	0.23	1.84	0.73	0.25	0.19	82.1	4.00	35.80	92.84	0.37

CB, Commercial biomass, included 60 cm of stem, two upper leaves and the flower. NCB, Non-commercial biomass, included the rest of the plant. Methods: N semi-micro Kjeldahl, P, K, Ca, Mg, Na, Fe, Cu, Zn and Mn by digestion with HNO_3-$HClO_4$.

2.3. Measurements

The experiment was conducted from February 2013 to January 2014. Every two weeks, variables of floral stems, inflorescence and clusters were measured. The cluster area (cm^2) was determined based on the cluster diameter. The variables related to the stems were the total number of floral stems (stems with at least two leaves); stems with closed flower (completely closed bracts); stems with open flower (1 to 50% open bracts) and stems with commercial flower (50 to 100 open bracts); length and diameter (cm) of the floral stem. Stem diameter was measured at the middle of the stem length (with its flower). The variables related to the commercial flower (inflorescence) were the diameter and length (cm). The length of the apical leaf (cm) was measured from the base of the leaf lamina to the apex. The fresh and dry weights (g) of both the commercial biomass and the total biomass were determined in a 2.0 kg capacity analytical balance (Denver Instrument™). Commercial biomass was assessed as indicated in Table 2. Total biomass was the sum of the dry commercial and noncommercial biomass multiplied by the number of commercial flowers. Lengths were measured with a 5 m long tape measure (Pretul™), and diameters were measured with a Vernier (Inch™).

2.4. Plant Analysis

A plant per experimental unit was separated into flowers, leaves, stems and rhizomes. Then, each organ was sectioned and dried in an oven brand CRAFT Scientific Instruments at 65˚C to a constant weight. The dry samples were ground and taken to the Plant, Soil and Water Analysis Laboratory at Colegio de Postgraduados, Campus Tabasco. The contents of N, P and K were determined with the micro Kjeldahl, Olsen and gas chromatography methods, respectively, according to NOM-021-SEMARNAT-2000.

2.5. Statistical Analysis

Data were averaged by month. Then, previous tests of normal distribution and homogeneity of variances were performed, and the data were subjected to analyses of variance (ANOVA), means comparison (Tukey, $P \le 0.05$) and a Pearson correlation test. Correlations were performed between plant variables and NPK contents in flowers, leaves, stems and rhizomes. The statistical software SAS version 9.4 for Windows was used. In addition, the optimal physiological rate was estimated by using a simple linear regression model, according to Martínez [12]:

$$\hat{Y}i = \hat{\beta}0 + \hat{\beta}1X$$

where:

$$\hat{Y}i = \text{Estimated yield}\left(\text{number of total stems}\right)$$

$$\hat{\beta}0, \hat{\beta}1 = \text{Regression coefficients}$$

$$X = \text{N, P or K fertilizer rates}\left(\text{kg/ha}\right)$$

3. Results and Discussion

3.1. Effect of NPK Fertilization on Yield and Quality

The NPK fertilization rates had a significant effect on the number of stems with open flowers ($F_{15} = 1.89$, $P = 0.05$) and both the diameter ($F_{15} = 2.07$, $P = 0.04$) and length ($F_{15} = 1.89$, $P = 0.05$) of commercial flowers. There was no effect of fertilization on the other variables.

3.1.1. Number of Stems with Open Flowers

The highest number of floral stems with open flowers (2.67) was obtained with treatments 122-00-220 $kg{\cdot}ha^{-1}$ and 182-21-331 $kg{\cdot}ha^{-1}$. In contrast, the lowest number of stems (1.00) occurred with the 00-14-00 $kg{\cdot}ha^{-1}$ treatment (**Table 3**). Our high rates of N and K agree with the rates suggested by Lamas [6] for Red ginger plantations older than 13 months. A possible explanation is that N plays an essential role in growth since it is a constituent of chlorophyll, essential amino acids, proteins, enzymes, nucleoproteins, hormones, and adenosine triphosphate (ATP) and intervenes in many metabolic processes. Therefore, plants require very high amounts of N, comparable only to the requirements of K [13].

The number of stems with open flowers in this study was inferior to that found by Loges *et al.* [14], who obtained 5.5 stems with flowers per shoot cluster per month. However, the proportion 20:10:20 NPK used in that study was higher than that used in our study.

Table 3. Effect of NPK fertilization on yield variables of *Alpinia purpurata* Vieill Pink variety.

NPK treatment (kg/ha)		No. stems with open flower	Commercial flower	
			Diameter (cm)	Length (cm)
T1	00-00-00	1.67 ab	5.97 ab	20.57 ab
T2	00-00-220	1.67 ab	5.20 b	20.40 ab
T3	00-14-00	1.00 b	5.90 ab	22.00 ab
T4	00-14-220	1.67 ab	5.87 ab	20.07 ab
T5	61-07-110	2.33 ab	5.60 ab	20.20 ab
T6	61-07-331	1.67 ab	5.77 ab	21.47 ab
T7	61-21-110	2.00 ab	5.57 ab	20.33 ab
T8	61-21-331	1.33 ab	5.50 ab	17.73 b
T9	121-00-00	2.33 ab	5.77 ab	22.13 ab
T10	121-00-220	2.67 a	5.87 ab	22.40 ab
T11	121-14-00	2.00 ab	5.47 ab	21.60 ab
T12	121-14-220	2.33 ab	5.17 b	20.50 ab
T13	182-07-110	2.33 ab	5.77 ab	21.83 ab
T14	182-07-331	2.00 ab	5.83 ab	21.57 ab
T15	182-21-110	2.00 ab	5.60 ab	20.10 ab
T16	182-21-331	2.67 a	6.47 a	23.53 a

n = 72. Means with same letter in a column are significantly equal (Tukey, $P \leq 0.05$).

Atto and Osedeke [15] worked with *Zingiber officinale* Roscoe, another plant of the order Zingiberales. They obtained 6.0 stems by applying 200-160-100 and 9.4 stems when they supplied 200-80-50 kg/ha NPK. Moreover, they observed that when amounts of P and K decreased, the number of stems increased, a result that differs from our study. Pérez-Flores *et al.* [16], in the same plantation and plant species and variety, reported 3.9 stems with open flowers without fertilization treatment. The same authors reported for Red ginger 6.31 stems with open flowers in the same plantation and 2.3 for another plantation.

3.1.2. Diameter of Commercial Flower

The diameter of commercial flowers obtained with treatments 182-21-331 kg/ha, 122-14-220 and 00-00-220 kg/ha were significantly different among them and similar to the other treatments. The first one produced the highest diameter (6.47 cm), while the other two produced the lowest diameter (5.2 cm) (**Table 3**). With higher values of NPK, higher values for stem diameter were obtained. This result differs from that obtained by González and Mogollón [17] with 8-month-old *A. purpurata* Jungle King. With 150 kg/ha N, they obtained a diameter of 5.15 cm. Teixeira and Loges [8], with different varieties of *A. purpurata*, found a diameter of 8.63 cm of fully expanded inflorescences (43 days after emergence) when they applied a rate of 50 kg·ha^{-1} N. In the *A. purpurata* Red variety, Saldaña *et al.* [18]

obtained a diameter of 8.4 cm with a rate of 150-50-250 kg·ha^{-1}, whereas Peña *et al.* [19] obtained a flower diameter of 6.33 cm with a rate of 215-00-00.

3.1.3. Length of the Commercial Flower

The longest flower, 23.53 cm, was obtained with the application of 182-21-331 kg·ha^{-1}, while the shortest flower, 17.73 cm, was obtained with the application of 61-21-331 kg/ha (**Table 3**). These results differ from those obtained by González and Mogollón [17], who attained an *A. purpurata* "Jungle King" 9.34 cm long flower with the application of 150 kg·ha^{-1} N per year. These authors, using the same Jungle King variety in 2001, obtained flower lengths of 5.81 cm and 5.63 cm with rates of 150 and 300 kg/ha N per year, respectively. In addition, in a study to characterize *A. purpurata* cultivars, Teixeira and Loges [8] obtained lengths of 21.75 and 21.00 cm in "Jungle Queen" and "Jungle King", respectively, with the application of 50 kg/ha N. Additionally, Saldaña *et al.* [18], with a rate of 150-50-250 kg/ha, obtained a longer commercial flower length of 26.3 cm. Pérez-Flores *et al.* [16] reported flower lengths of 11.46 and 12.78 cm without any treatment for the same species, variety and plantation, as well as for another plantation.

According to Loges *et al.* [20] and Teixeira and Loges [8], *A. purpurata* is graded for sale by the size of the inflorescence: small 15 to 17 cm, medium 18 to 20 cm and large more than 20 cm. Then, the inflorescences obtained in our study are in the "large" class. Only the plants fertilized at a rate of 61-21-331 NPK produced "small" inflorescences (**Table 3**).

3.2. Effect of NPK Fertilization on Nutrient Content and Its Correlation with Yield and Quality

The results of the analysis of the Pink ginger leaves showed that the percentage contents of N, P and K were 1.78, 0.20, and 1.79 and 1.89, 0.19, and 1.87 for treatments 10 and 16, respectively, while for treatment 3, the percentages were 1.82, 0.22, and 1.70 (**Table 4**).

Our results were similar to those reported by Bertsch [21]: 1.95% N, 0.20% P and 1.86% K. According to Kobayashi *et al.* [5], the values of these elements present in Red ginger leaves should be 2.0% N, 0.16% P and 1.8% K. It is normal that some nutrients decrease in the leaves because minerals are heavily translocated toward the reproductive organs and because of the natural process of senescence. Additionally, relationships between nutrients can alter concentrations, for example antagonism or the excess or deficit of moisture in the soil [22]. Plants with water deficit retain photosynthesis, respiration and enzymatic processes. Growth, as the result of cell division and lengthening, depends on water conditions to respond to the supply of organic and inorganic compounds necessary for synthesizing new cytoplasm and new cell walls, expressed in increased organ size [23] [24].

The stems with open flowers highly correlated with the content of N in leaves ($r^2 = 0.92$, $P = 0.03$), P in stems ($r^2 = 0.93$, $P = -0.02$) and K in flowers ($r^2 = 0.80$, $P = 0.07$) (**Table 5**). This relationship can be attributed to the supply of nutrient elements, which is indispensable for obtaining commercial quality flowers [25]. Of these elements, N is the nutrient essential to development and floral differentiation. However, N can be lost through leaching, volatilization and denitrification. Therefore, it is important to incorporate N into the soil at different amounts and times so that it is available during the different phenological stages of the crop [26].

Table 4. Effect of fertilization dosages in the NPK content (%) of flower, leaf, stem and rhizome of *Alpinia purpurata* Vieill Pink variety, 12 months after application.

NPK (Kg ha^{-1}) treatment		Flower			Leaf			Stem			Rhizome		
		N	P	K	N	P	K	N	P	K	N	P	K
T1	00-00-00	0.93 l	0.23 h	1.77 l	1.82 l	0.20 o	1 .62 l	0.32 l	0.33 h	1.77 h	0.29 l	0.27 h	1.51 l
T2	00-00-220	0.84 l	0.29 h	1.74 l	1.88 l	0.29 h	1.67 l	0.35 l	0.44 h	1.76 h	0.29 l	0.43 h	1.53 l
T3	00-14-00	0.90 l	0.25 h	1.73 l	1.82 l	0.22 h	1.70 l	0.35 l	0.29 h	1.73 l	0.29 l	0.22 h	1.77 h
T4	00-14-220	0.77 l	0.28 h	1.66 l	1.84 l	0.23 h	1.75 l	0.31 l	0.40 h	1.71 l	0.29 l	0.41 h	1.61 l
T5	61-07-110	0.86 l	0.23 h	1.94 h	1.86 l	0.21 h	1.82 h	0.34 l	0.32 h	1.89 h	0.29 l	0.28 h	1.77 h
T6	61-07-331	0.75 l	0.28 h	2.15 h	1.75 l	0.24 h	2.10 h	0.37 l	0.42 h	1.95 h	0.31 l	0.39 h	1.71 l
T7	61-21-110	1.03 l	0.25 h	3.36 h	1.78 l	0.21 h	2.33 h	0.31 l	0.34 h	3.08 h	0.31 l	0.33 h	2.85 h
T8	61-21-331	0.95 l	0.20 h	1.92 h	1.95 o	0.20 o	1.91 h	0.46 l	0.32 h	1.96 h	0.34 l	0.25 h	1.93 h
T9	121-00-00	0.93 l	0.22 h	1.76 l	1.79 l	0.18 l	1.71 l	0.38 l	0.30 h	1.72 l	0.38 l	0.32 h	1.59 l
T10	121-00-220	0.80 l	0.23 h	1.71 l	1.78 l	0.20 o	1.79 l	0.31 l	0.29 h	1.80 h	0.29 l	0.23 h	1.69 l
T11	121-14-00	0.73 l	0.23 h	1.76 l	1.90 l	0.21 h	1.75 l	0.32 l	0.34 h	1.73 l	0.29 l	0.29 h	1.60 l
T12	121-14-220	0.83 l	0.23 h	1.63 l	1.83 l	0.20 o	1.56 l	0.37 l	0.33 h	1.49 l	0.26 l	0.29 h	1.32 l
T13	182-07-110	0.82 l	0.24 h	2.71 h	1.79 l	0.21 h	2.36 h	0.37 l	0.28 h	2.18 h	0.26 l	0.28 h	2.22 h
T14	182-07-331	0.92 l	0.23 h	1.99 h	1.95 o	0.18 l	1.98 h	0.43 l	0.23 h	2.14 h	0.57 l	0.23 h	2.02 h
T15	182-21-110	1.06 l	0.22 h	1.98 h	1.95 o	0.19 l	1.90 h	0.38 l	0.24 h	1.95 h	0.34 l	0.27 h	1.87 h
T16	182-21-331	0.86 l	0.22 h	2.10 h	1.89 l	0.19 l	1.87 h	0.39 l	0.27 h	2.01 h	0.34 l	0.25 h	1.76 h

NPK content: h, high; l, low; o, optimum (regarding to Bertsch [21]). Methods: N semi-micro Kjeldahl, P and K digestion with HNO_3-$HClO_4$.

Table 5. Correlation of the concentration of Nitrogen, Phosphorous and Potassium in flower, leaf, rhizome and stem with quality and yield variables of Ginger (*Alpinia purpurata*) Pink variety, in response to the application of 16 fertilization dosages.

Concentration	Nitrogen				Phosphorous				Potassium			
Yield variable	Flower	Leaf	Rhizome	Stem	Flower	Leaf	Rhizomea	Stem	Flower	Leaf	Rhizomea	Stem
Number of floral stems	0.22 −0.32	0.99 −0	0.38 0.24	0.45 0.2	0.79 0.07	0.56 −0.16	0.91 −0.03	0.45 −0.2	0.1 −0.43	0.62 −0.14	0.1 −0.42	0.05 −0.49
Stems with open flower	0.35 −0.25	0.92 −0.03	0.81 0.06	1 0	0.81 −0.06	0.84 −0.06	0.75 0.08	0.93 −0.02	0.8 0.07	0.42 0.22	0.75 0.09	0.72 0.1
Stems with closed flower	0.18 −0.35	0.66 0.12	0.79 −0.07	0.46 −0.2	0.28 −0.29	0.5 −0.18	0.68 −0.11	0.8 −0.07	0.84 −0.06	0.91 −0.03	0.66 −0.12	0.91 −0.03
Stems with commercial flower	0.09 −0.44	0.85 −0.05	0.33 −0.26	0.4 −0.22	0.33 −0.26	0.56 −0.16	0.22 −0.33	0.35 −0.25	0.78 0.08	0.55 0.16	0.94 0.02	0.96 −0.01

Continued

Cluster diameter		0.53	0.18	0.02	0.1	0.53	0.29	0.89	0.19	0.15	0.34	0.28	0.30
		0.17	0.35	0.58	0.43	−0.17	−0.28	−0.04	−0.35	−0.38	−0.25	−0.29	−0.28
Commercial stem diameter	Basal	0.08	0.73	0.62	0.43	0.97	0.82	0.31	0.30	0.65	0.71	0.24	0.57
		0.45	0.09	0.13	0.21	−0.01	0.06	−0.27	−0.28	0.12	0.10	0.31	0.15
	Half	0.48	0.06	0.94	0.94	0.74	0.80	0.27	0.37	0.37	0.39	0.94	0.5
		0.19	0.48	0.02	0.02	−0.09	0.07	−0.29	−0.24	−0.24	−0.23	−0.02	-0.18
	Superior	0.45	0.4	0.31	0.47	0.58	0.44	0.08	0.07	0.72	0.45	0.57	0.84
		−0.21	0.23	0.27	0.19	−0.15	−0.21	−0.46	−0.46	0.10	0.20	0.15	0.06
Stem length		0.39	0.1	0.26	0.24	0.53	0.91	0.15	0.17	0.55	0.81	0.8	0.69
		0.23	0.42	0.30	0.31	−0.17	−0.03	−0.38	−0.36	−0.16	−0.07	0.07	−0.11
Flower length		0.22	0.24	0.69	0.44	0.94	0.44	0.44	0.38	0.53	0.44	0.31	0.46
		−0.32	−0.31	0.11	−0.21	0.02	−0.21	−0.21	−0.24	−0.17	−0.21	−0.27	−0.20
Leaf length		0.29	0.47	0.61	0.38	0.29	0.82	0.68	0.86	0.24	0.26	0.19	0.16
		0.28	−0.19	0.14	−0.23	0.28	0.06	0.11	0.05	0.31	0.30	0.35	0.37
Flower diameter		0.99	0.52	0.5	0.97	0.6	0.15	0.23	0.17	0.77	0.6	0.75	0.7
		0.0041	−0.17	0.18	−0.01	−0.14	−0.38	−0.32	−0.36	0.08	0.14	0.09	0.11
Commercial wet weight		0.24	0.47	0.27	0.42	0.00	0.00	0.00	0.00	0.30	0.18	0.47	0.38
		−0.31	−0.19	−0.29	−0.22	0.74	0.75	0.68	0.67	0.30	0.35	0.20	0.23
Non-commercial wet weight		0.57	0.41	0.47	0.44	0.77	0.64	0.72	0.86	0.9	0.77	0.42	0.90
		0.15	0.22	0.19	0.21	0.08	0.13	−0.10	−0.05	−0.04	0.08	0.22	0.03
Commercial dry weight		0.7	0.58	0.93	0.59	0.12	0.13	0.03	0.22	0.4	0.11	0.69	0.55
		−0.10	0.15	0.02	0.15	0.40	0.39	0.54	0.33	0.23	0.41	0.11	0.16
Non-commercial dry weight		0.76	0.5	0.71	0.54	0.67	0.48	0.96	0.84	0.7	0.69	0.71	0.75
		−0.08	0.18	0.10	0.17	0.12	0.19	−0.01	0.06	−0.12	0.11	0.10	−0.09
Total biomass		0.79	0.19	0.46	0.19	0.85	0.59	0.69	0.83	0.1	0.63	0.58	0.19
		−0.07	0.34	0.2	0.34	0.05	0.15	−0.11	−0.06	−0.38	−0.13	−0.15	−0.35

In *Freesia hybrida* cv. Golden Wave (*Iridaceae*), P contributes to flower persistence and days to flowering, while deficiencies in this nutrient and N produce short stems [27]. Organic P tends to be absorbed in clays from which it passes to the soil solution. The type of soil present in the study site is Eutric Fluvisol, one of the richest soils in nutrients, with a clay-silt crumbly texture [28] and 3.49% organic matter. This could indicate that the soil contributes to the amounts of nutrients required by the crop.

Potassium is essential for crop growth and development. The demand for this element is greater than that of other elements, except for N. It is exceptionally mobile in the soil and plant tissues. This mobility makes it susceptible to leaching, especially in tropical zones where precipitation is high [29]. The percentages of N, P and K in the leaves of Pink ginger in treatment 16 were 1.89, 0.19 and 1.87, while in treatments 2 and 12, the percentages were 1.88, 0.29, and 1.67 and 1.83, 0.20 and 1.56, respectively (**Table 4**). In general, the tested fertilizer treatments induced leaf P contents similar to those achieved by Bertsch [21], who reported 0.20% P in Red ginger. However, the values for N and K were lower than those of this author, who reported values of 1.95% and 2.72%, respectively. In *Z. officcinale*, with the application of 300 kg/ha potassium chloride, leaf contents of 2.13% N, 0.24% P and 5.19% K were found [30]; these values are higher than those of our study for N and K. This may be because K is a nutriment required in high amounts to optimize yield in *Zingiberaceae* plants, as it is essential for carbohydrate synthesis, a constituent of the skeletons of raw carbon for production of the other chemical compounds of the plant, and thus importantly determines yield and quality [31].

The diameter of commercial flowers correlated positively with the N content in flowers ($r^2 = 0.99$, $P = 0.0041$) and stems ($r^2 = 0.97$, $P = 0.01$) (**Table 5**). This close relationship with N in the flower and stem is due to N being present in many essential compounds. For this reason, plant growth is slow if N is not supplemented [32]. Nitrates and amino acids are the main forms in which N is translocated in the vascular system to the upper parts of the plant. In xylem sap, amino acids rich in N are generally present in percentages of 70 to 80% [32]. The flowering and fruiting stages require energy, and carbohydrates accumulate in organs such as the inflorescences [33]. Lower concentrations of soluble sugars were found in the leaves of *Heliconia caribea* than in the floral structures. The soluble carbohydrate content during the flowering stage is maintained mainly by photosynthesis [34]. *Zingiberaceae* plants cultivated with a complete nutrient solution (N, P, K, Ca, Mg and S) exhibited a carbohydrate content in the floral stem double that found in leaves, suggesting the translocation of large quantities of carbohydrates during the flowering process [35].

The NPK content in Pink ginger flowers of plants fertilized with treatment 8 was 0.95, 0.20 and 1.92, and with treatment 16, the contents were 0.86, 0.22 and 2.10. According to Berstch [21], the N content in the *A. purpurata* flower should be 1.95%, P 0.14%, and K 1.86%. According to these values, our results for N (0.95%) were low, while those for P (0.20%) and K (1.92%) were high (**Table 4**). Nitrogen is taken up by the roots and translocated through the xylem toward the upper parts of the plant; it is highly mobile in the plant and is exported from senescent organs to regions of active growth [4]. Phosphorous matter is redistributed easily from one organ to the next in most plants and accumulates in young leaves, flowers, and seeds. Total P is found in greater quantities in fine-textured soils, and in tropical soils, it seems to be linked to organic matter [4]. Potassium is a nutrient required in high amounts to optimize yield in *Zingiberaceae* plants [31].

In general, the P content in the root cells and sap of the xylem is nearly 100 to 1000 times higher than that in the soil solution [32]. Floral length correlated positively ($r^2 = 0.99$) with the content of P in the flower (**Table 5**). Phosphorous is easily redistributed from one organ to another in the form of phosphate in most plants. It is lost in old leaves and accumulates in young leaves, in flowers and in developing seeds. Phosphorous is an essential part of many glucophosphates that participate in photosynthesis, respiration and other metabolic processes [13] [32]. Optimal nutrition with NPK increased the number of leaves formed by *Z. officinale* [31]. It is known that leaves photosynthesize molecules of glucose monosaccharides that can be transformed and translocated to the upper parts of the plant and intervene in the formation of flowers [32].

3.3. Determination of the Optimal Fertilizer Rate

Analysis of variance for regression coefficients showed statistical significance only for K rates ($F_{(1.2)} = 677.22$, Pr > F = 0.0015); the coefficient of determination of the simple linear regression analysis explained 99.7% of the variance of the yield. Then optimal physiological rate was estimated using the following model:

$$\hat{Y}i = 17.72094 + 0.00426K$$

where:

$$\hat{Y}i = \text{Estimated yield}\left(\text{number of total stems}\right)$$

$\hat{\beta}0, \hat{\beta}1$ = regretion coeficients = 17.72094 (t = 524.94, Pr > t ≤ 0.0001) and 0.00426 (t = 26.02, Pr > t = 0.0015), respectively.

$$K = \text{Potasium rates}\left(\text{kg/ha}\right)$$

The optimal rate for *K*:

$$K = \frac{1}{0.00426} = 234.741\,\text{kg/ha}$$

This response of Pink ginger variety to the application of the different rates of *K* could be due to the hypothesis that these species have nutritional aspects similar to those of *Musaceae*, where *K* plays an important role in the growth and development of commercial plantations. The intense growth of this species and the high production of green mass of the same denote a high level of utilization of nutrients that can be supplied through fertilizers.

According to González *et al.* [26], the absorption of *K* by plants is proportional to its content in a usable way in the soil, even at concentrations much higher than those required for maximum yield, which in the latter case causes its accumulation in tissues, a phenomenon known as "superfluous consumption". The maximum accumulation of *K* in an annual crop occurs during flowering. A return of significant amounts of K from the plant to the soil may then occur.

Soils may be naturally deficient in nutrients, or they may become deficient due to the extraction of nutrients by crops over the years or when using high- or permanent-yielding varieties (*i.e.*, Pink ginger), which are more nutrient-demanding than local varieties. However, there are some aspects of the plant related to the absorption, transport and use of nutrients that have genetic control. Some genotypes of the same species may vary in the rate of absorption and translocation of nutrients, in the efficiency in the use of these in metabolism and in tolerance to high concentrations of ions, among other aspects [26].

Potassium activates more than 60 enzymes that are essential for photosynthesis and respiration and necessary to form starch and proteins. This element is so abundant that it is one of the most important contributors to the osmotic potential of cells and therefore to their turgor pressure [32]. Then, the K that supplies 1 to 4% of the dry extract of the plant has many functions [36].

4. Conclusion

The continuous collection of cut flowers of *A. purpurata* for sale results in a significant extraction of nutrients from the system where it is grown. As with other crops, soil fertility is determined by the balance between addition and removal of nutrients. Therefore, in order to sustainability maintain the productivity and quality of flowers, it is crucial to replenish the nutrients that are extracted. In this study we conclude that fertilization with N and K positively influenced the yield and quality of the *A. purpurata* Vieill Pink variety. The plants fertilized with doses of 182-21-331 kg/ha NPK produced the highest number of stems as well as the largest commercial flowers in terms of both diameter and length. In addition, the NPK contents found in the leaves, stems, flowers and rhizomes met the requirements of the *A. purpurata* Vieill Pink variety for P and K but not for N. The optimal physiological rate determined for K was 234.7 kg/ha.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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