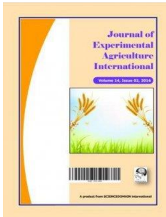

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Effect of Fertilization on Yield and NPK Contents in Red Ginger

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AMPG and NRB wrote the first draft of the manuscript. Author JPF designed the study and performed the fieldwork and the statistical analysis. Author AOLS participated in the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The aim of the research was to evaluate the effect of NPK fertilization on red ginger yield and nutrient content of mature plants.
Study Design: 16 treatments were defined from N, P and K combinations, with three replications in complete random blocks. The experimental unit was one cluster with stems.
Place and Duration of Study: The study was conducted from February 2012 to January 2013 on a 10-years-old commercial plantation. The plantation is located at 18° 17' 43.49'' NL and 93° 12' 28.68'' WL in Comalcalco, Tabasco, Mexico.
Methodology: Each 15 days along a year were recorded variables for the cluster, and for commercial stems and flowers. Then one plant per experimental unit was separated into flower, leaf, stem and rhizome to analyze NPK. With the data, an analysis of variance, means comparison (Tukey, $P \leq 0.05$), and Pearson correlation were performed.

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Results: With the doses of 216-00-00 kg NPK ha^{-1}, the plants developed the largest stem (2.17 cm) and flower (6.33 cm) diameters and the highest dry commercial (28.89 g) and total (199.3 g) biomass. The highest fresh weight of the non-commercial biomass (383.2 g) was found in plants fertilized with 322-04-90, but this value was statistically equal to that obtained with the doses 216-00-00 (335.81 g). The NPK content found in red ginger leaf, stem, flower and rhizome satisfied the requirements established for P, but not for N and K. The N content was the unique nutrient correlated to the yield of red ginger.

Conclusion: The fertilization with 216 kg N ha^{-1} was the best to favor red ginger yield.

Keywords: Alpinia purpurata; tropical flowers; plant nutrient content; red ginger production.

1. INTRODUCTION

Red ginger (*Alpinia purpurata* Vieill) is one of the most cultivated and demanded tropical ornamental species worldwide. When temperatures, humidity and fertilization are the required by the plant, red ginger flowering occurs all the year [1]. But, constant production of cut flowers suggests constant nutrients extraction and yield decrease in the future [2]. Therefore, fertilization is essential for successful cultivation of red ginger because can promote large benefits when used appropriately [3]. There are no specific rules for fertilizing tropical ornamentals since soil and climate conditions are different in each region. However, in this case, Soil and leaf analyses are highly recommended to determine the quantity of nutrients that should be applied [4,5].

Among nutrients N, P and K are key for plant growth and flowering [6]. Therefore, at least these elements should be analyzed both in the soil and in plant foliage. Kobayashi et al. [1] recommend that levels of 2%, 16% and 18% NPK in the foliage of *A. purpurata* indicate that the crop's nutritional state is good. They cited that in red ginger the amount of N applied is directly related to the number of floral stems produced by the plant.

Of the total N absorbed from the soil by the plant, if there is a low proportion of NO_3^- in the soil, a high proportion is reduced in the root, while if there is enough available NO_3^-, most is transported to the shoot where it can accumulate in both stem and leaves [7] of plants. In most plants, once absorbed, P is distributed from one organ to another; it accumulates in young leaves, in flowers and developing seeds and is lost in old leaves [8].

In research, [9] observed that application of simple superphosphate and organic fertilizers in *Alpinia zerumbet* crop resulted in a larger number of stems and leaves per stem. By the way, they reported higher levels of P in the plants to which chemical fertilizer was applied than in those fertilized with organic fertilizers.

The K deficiency in crops results in weaker stems that make plants sensitive to the action of wind and rain, particularly monocotyledons [7] such as ginger. Haque et al. [10] report that growth and yield of *Zingiber officinale* increase significantly in accord with increments in levels of K applied, up to 100 kg ha^{-1}.

Kobayashi et al. [1] recommend fertilizing ginger once or twice a year with formulas of 1:1:1 to 3:1:5 NPK. Lamas [5] recommends a dosage of 350-400, 200-250, 300-350 kg ha^{-1} NPK, respectively, for a plantation older than 13 months. It can be seen that fertilization is different for the conditions of each region [4]. Therefore, it is necessary to determine the nutritional requirements of red ginger where it is actually produced. Based on the above, the objective of this study was to evaluate the effect of application of different doses of N, P and K on yield and in the nutrient content of red ginger plants.

2. MATERIAL AND METHODS

2.1 Experimental Site

The study was conducted from February 2012 to January 2013 on a 10-years-old commercial plantation. The plantation is located 2 km north of the city of Comalcalco, Tabasco, Mexico, at 18 degrees 17 minutes 43.49 seconds north latitude and 93 degrees 12 minutes 28.68 seconds west longitude. Where the climate is Am(f) hot humid tropics with abundant summer rains; annual precipitation 2000 mm, with a dry season in March and April, and mean annual temperature of 26.5°C [11].

The soil type in the plantation was Eutric fluvisol, which is considered first class farm soil [12]. Its physical-chemical characteristics are pH 6.84 (in water), EC 0.01 ds m^{-1}, organic matter 3.49%, total N 0.17%, P Olsen 12.67 mg kg^{-1}, K 0.27 $cmol_c.kg^{-1}$, Ca 15.70 $cmolc.kg^{-1}$, Mg 3.34 $cmol_c.kg^{-1}$, cationic interchange capacity 12.64 $cmol_c.kg^{-1}$, Fe 45.37 mg. kg^{-1}, Zn 2.13 mg. kg^{-1}, clay 38%, silt 44% and sand 18%, textural class crumb silty clay.

The red ginger plantation was in the open and plants were interspersed among cedar trees (*Cedrela odorata* L.). Plant density was 2000 plants per ha, 5 m between rows and 1 m between plants. Cultural practices included manual weeding and drip irrigation during the dry season.

2.2 Plant Material and Experimental Design

The plant materials used were 48 red ginger clusters. Table 1 shows the nutrient content of the commercial and non-commercial biomass of the plants before the experiment. The commercial part included 60 cm of stem, two upper leaves and the flower. The non-commercial part included the rest of the plant. With the leaf and soil analyses, together with plant density, the dosage 108 kg N ha^{-1},-04 kg P ha^{-1} and-90 kg 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. The treatments were defined based on the San Cristobal design [13] with combinations of N, P and K, totaling 16 treatments. The treatments were: the absolute control (T1) 00-00-00 Kg ha^{-1}, 00-00-178, 00-10-00, 00-10-178, 108-04-90, 108-04-268, 108-14-90, 108-14-268, 216-00-00, 216-00-178, 216-10-00, 216-10-178, 322-04-90, 322-04-268, 322-14-90, and (T16)322-14-268 Kg ha^{-1}. The experimental unit was one cluster of plants.

The fertilizers used as the sources of NPK were urea (46% N), triple superphosphate (46% P_2O_5) and potassium chloride (60% K_2O). The fertilizers were placed around the cluster at a distance of 10 cm and. 5 cm of depth.

2.3 Measurements and Statistical Analysis

The yield variables assessed, every 15 days, were those of the cluster, the commercial floral stem and the flower. The cluster variables recorded were cluster area (cm^2), total number of floral stems (stems with at least two leaves), stems with closed flowers (bracts completely closed), stems with open flowers (1 to 50% open bracts), and stems with commercial flowers (50 to 100% open bracts). Each commercial stem was measured for length (cm) and diameter (cm, two cm from the stem base), length of the apical leaf (cm, from the base of the leaf lamina to its apex), fresh and dry weight (g) of the commercial and non-commercial biomass, and total biomass (g). Commercial and non-commercial biomass was assessed as indicated for Table 1. Total biomass was the sum of dry commercial and non-commercial biomass. On the commercial flower, diameter (cm, from mid-length of the inflorescence) and longitude (cm, from the base of the inflorescence to the apex) were measured.

N, P and K content were analyzed in one plant per experimental unit. Before analysis, the plant was divided into flower, leaf, stem and rhizome. Each organ was sectioned and placed in a drying oven at 50°C for constant weight. The dry samples were milled and sent to the Plant, Soil and Water Analysis Laboratory at the Graduate College - Campus Tabasco. Determinations of N, P and K content in the plant samples were done following NOM-021-SEMARNAT-2000 by the micro-Kjeldahl, Olsen and gas chromatography methods, respectively. Data were subject to two-way analysis of variance (ANOVA), means comparison (Tukey, ($P \leq 0.05$) and a Pearson correlation. The statistical software used was SAS V.9.4 for Windows.

Table 1. Nutrient content of the commercial and non-commercial biomass from Red Ginger (*Alpinia purpurata*) plants before fertilization

Red ginger	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	S
	%						mg kg^{-1}				
CB	0.68	0.27	1.39	0.61	0.20	0.09	70.46	4.76	76.00	20.32	0.24
NCB	1.36	0.24	1.57	0.83	0.31	0.05	99.0	4.88	40.72	26.50	0.74

CB, Commercial biomass. NCB, Non-commercial biomass. Methods: N semi-micro Kjeldahl, P, K, Ca, Mg, Na, Fe, Cu, Zn and Mn by digestion with HNO_3-$HClO_4$.

3. RESULTS AND DISCUSSION

3.1 Effect of NPK Fertilization on Yield

The ANOVA indicated an effect of NPK fertilization on diameter of floral stem ($F_{15,30}$= 1.94, P = .05), flower diameter ($F_{15, 30}$ = 2.34, P = .02), non-commercial biomass fresh weight ($F_{15, 30}$ = 2.89, P = .006), commercial biomass dry weight ($F_{15, 30}$ = 2.38, P = .02) and total biomass ($F_{15, 30}$ = 8.49, P = .0001). There was no effect of fertilization on the other variables. The largest stem diameter (SD) was obtained with treatment 216-00-00 (Table 2) which could be attributed to the fact that N in *Zingiberaceae* plants, such as red ginger, N is the most important macronutrient for growth and flowering.

Although many plant characteristics are determined genetically [7], in general, the SD recorded in this study are larger than those reported by Saldaña et al. [2]. These authors applied 150-50-250 kg ha^{-1} NPK and achieved SD of 1.73 and 1.62 cm in ginger at two different sites. Texeira and Loges [14], with a fertilization of 50 kg ha^{-1} N, reported a stem diameter of 2.02 cm in red ginger plants.

Several authors [5,15] stated SD could be homogenized by pruning very thin stems during crop development. This practice helps to obtain more uniform commercial stems. For commercialization, [14] classify red ginger stems by its diameter into type A (> 1 cm) and type B (< 1 cm). The stems obtained in this study were classified as type A.

The flower diameter (FD) obtained with treatment 215-00-00 (6.33 cm) was statistically superior to that obtained with treatments 5, 10 and 15 (Table 2). Texeira and Loges [14] reported a FD of 8.63 cm for totally expanded red ginger inflorescences. Saldaña et al. [2] reported a FD of 7.9 and 8.4 cm when 150-50-250 kg ha^{-1} NPK were applied to red ginger at two different sites.

The highest non-commercial biomass fresh weight (NCBFW) values were recorded for plants fertilized with 322-04-90 kg NPK ha^{-1} and 108-04-268 kg NPK ha^{-1}. Both values were statistically superior to that obtained with the absolute control but equal to that obtained with all the other treatments. This can be attributed to the absence of NPK macronutrients in the control since these elements are essential in the synthesis of molecules for growth [16]. Castro et al. [17] reported that N is the most important nutrient in growth and flowering of *Zingiberaceae* plants, and the N content in plants was 67% lower in plants without a complete fertilization. In *Tagetes* spp., higher N and P applications increase plant growth, flower yield and leaf nutrient content [6].

According to Castro et al. [17] who said that N is most important macronutrient for development of *Zingiberaceae* plants, the commercial biomass dry weight (CBDW) from plants fertilized with treatment 216-00-00 was statistically superior to that obtained from plants fertilized with treatment 00-10-178 (Table 2). These results, however, are lower than the 49.8 g reported by [4] for commercial red ginger dry matter.

The highest total biomass weight (TB) was obtained in plants fertilized with treatment 216-10-178. This weight was statistically equal to that recorded for treatments 9, 10 and 14, but different from weights recorded for the other treatments (Table 2). These results agree to [4], who reported TB values of 206 g per ginger stem.

3.2 Effect of NPK Fertilization on Nutrient Content and Its Relationship with Yield

The ANOVA indicated only the effect of the treatments on K content in the stem ($F_{15, 30}$ = 2.82, P = .008) and P content in the flower ($F_{15, 30}$ = 2.02, P = .05), leaf ($F_{15, 30}$ = 4.08, P = .0005) and rhizome ($F_{15, 30}$ = 2.16, P = .035).

Regarding K in the stem, treatment 00-10-178 was statistically superior to treatments 1, 3, 6, 8, 9 and 13 (Table 3). The K content in stem obtained with these treatments was similar to 1.85% reported by [4] as the level required by the plant.

In terms of stem N content, none of the treatments satisfied the N requirements of 0.78% reported by [4], but all the treatments surpassed the P content of 0.23% cited by the same author as the level required by the plant.

The P content in flowers of plants fertilized with treatment 00-10-178 was statistically equal to the absolute control (00-00-00). The P content in all of the treatments was equal to or superior to the flower P level recommended by [4], but the N and K contents were lower than the recommendations by the same author for the species and variety used in this study.

In general, the nutrient contents in red ginger leaf, stem and flower satisfied the level established for P but not for N or K. This could indicate that the soil utilized in this experiment presented levels of P sufficient for the nutritional demand of the species; but not in N or K. In soils of humid tropic available N and K are low [18]. Another explanation is that the analyses were done one year after fertilization and total N content and K diminish a year after soil fertilization due to leaching by high precipitation in wet tropical regions [18] and of course by the absorption of the plant.

N is a macronutrient present in higher content in new leaves as the consequence of its high mobility in the phloem [19]. In many species, P and N interact as the plant matures. In most plants, P is easily take off from one organ to another and is lost in old leaves, while accumulating in young leaves, flowers and developing seeds. K is an element that activates many essential enzymes in photosynthesis, respiration, and formation of proteins and starch; it also contributes in an important way to cell osmosis [8]. This can be observed in the positive correlation between N and P in the flower (r^2 = 88, *P* = .04) and in the stem (r^2 = 99, *P* = .005) and in the correlation of N in the leaf with P in the stem (r^2 = 98, *P* = .01) and N in the stem with K in the leaf (r^2 = 99, *P* = .005).

The N and P contents correlated with the yield variables. The TB correlated positively with N content in leaf (r^2 = 0.87, *P* = .04), rhizome (r^2 = 0.91, *P* = .03) and stem (r^2 = 0.97, *P* = .01). The SD correlated with N content in rhizome (r^2 = 91, *P* = - .03). The FD correlated with N in the stem (r^2 = 0.82, *P* = .006), NCBFW with N in the leaf (r^2 = 0.84, *P* = -.06), and CBDW correlated with N in the flower (r^2 = 93, *P* =.03). This can be due to the fact that N is essential to plant growth required by plants because is component of amino acids, proteins, nucleic acids, growth regulators and chlorophyll formation [3]. Another possible explanation is its presence in the rhizomes. The rhizomes contain a large quantity of nutrients and water, which are transferred in large proportions to the stem and leaves [20], thus permitting constant development and blooming of ginger, which requires constant mobility of N. This is important because the rhizomes, besides vegetative propagation [21], make the plants more resistant to adverse conditions [22] and can provide more dry matter to the flower stem and thus greater postharvest durability [5,23].

An adequate level of N in tissues results in good sized, vigorous plants with good green coloring and well-developed flowers [24]. According to the soil and plant analyses before treatment application (Table 1) and the plant analyses after treatment application (Table 3), and according to [4], the N concentration in flower and stem was lower than what is required by the plant, but in the foliage, it was similar to what is required by the plant.

Table 2. Effect of NPK fertilization on yield variables of red ginger

Treatment NPK (Kg ha^{-1})	SD (cm)	FD (cm)	NCBFW (g)	CBDW (g)	TB (g)
T1 00-00-00	1.77 ab	5.63 ab	235.56 b	23.90 ab	120.00 c
T2 00-00-178	1.87 ab	5.63 ab	359.75 ab	22.16 ab	94.05 c
T3 00-10-00	1.87 ab	5.50 ab	293.23 ab	21.32 ab	95.07 c
T4 00-10-178	1.80 ab	5.80 ab	268.49 ab	20.64 b	128.00 c
T5 108-04-90	1.87 ab	5.27 b	330.27 ab	27.51 ab	102.30 c
T6 108-04-268	2.07 ab	5.77 ab	318.01 ab	25.83 ab	122.40 c
T7 108-14-90	1.83 ab	5.47 ab	354.19 ab	27.20 ab	107.10 c
T8 108-14-268	1.83 ab	5.50 ab	380.13 a	24.75 ab	103.60 c
T9 216-00-00	2.17 a	6.33 a	335.81 ab	28.89 a	199.30 ab
T10 216-00-178	1.67 b	5.07 b	277.13 ab	22.45 ab	161.10 abc
T11 216-10-00	1.80 ab	5.57 ab	328.11 ab	25.26 ab	122.40 c
T12 216-10-178	1.83 ab	5.57 ab	348.50 ab	27.60 ab	228.80 a
T13 322-04-90	1.90 ab	6.03 ab	383.29 a	24.75 ab	109.10 c
T14 322-04-268	1.93 ab	5.73 ab	285.32 ab	24.15 ab	163.30 abc
T15 322-14-90	1.77 ab	5.30 b	343.79 ab	23.74 ab	136.90 bc
T16 322-14-268	1.87 ab	5.70 ab	330.30 ab	24.90 ab	96.37 c

SD - Stem diameter. FD - Flower diameter. NCBFW - Non-commercial biomass fresh weight. CBDW - Commercial biomass dry weight. TB - Total biomass.
n = 72. Means with same letter in a column are not significantly different (Tukey, P ≤ .05)

Table 3. Effect of fertilization doses in the N, P and K content (%) of red ginger flower, leaf, stem and rhizome, 12 months after application

Treatment (Kg NPK ha^{-1})	Flower			Leaf			Stem			Rhizome		
	N	P	K	N	P	K	N	P	K	N	P	K
T1 00-00-00	0.93 a	0.24 ab	1.45 a	1.91 ab	0.21 abc	1.52 b	0.35 a	0.30 a	1.58 b	0.32 a	0.32 a	1.32 a
T2 00-00-178	0.96 a	0.21 ab	1.77 a	1.97 ab	0.19 c	1.85 ab	0.38 a	0.26 a	1.86 ab	0.35 a	0.25 a	1.69 a
T3 00-10-00	0.93 a	0.21 ab	1.61 a	1.88 ab	0.20 c	1.55 ab	0.38 a	0.25 a	1.61 b	0.35 a	0.26 a	1.26 a
T4 00-10-178	0.93 a	0.29 a	2.22 a	2.00 ab	0.25 ab	2.05 a	0.38 a	0.34 a	2.45 a	0.33 a	0.38 a	1.55 a
T5 108-04-90	0.92 a	0.18 b	1.85 a	2.00 ab	0.19 c	1.61 ab	0.40 a	0.25 a	1.85 ab	0.49 a	0.26 a	1.65 a
T6 108-04-268	0.90 a	0.23 ab	1.67 a	1.87 ab	0.19 c	1.63 ab	0.46 a	0.29 a	1.66 ab	0.43 a	0.36 a	1.57 a
T7 108-14-90	0.99 a	0.22 ab	1.63 a	2.00 ab	0.19 c	1.58 ab	0.41 a	0.32 a	1.64 b	0.43 a	0.41 a	1.50 a
T8 108-14-268	0.95 a	0.27 ab	1.77 a	1.93 ab	0.21 abc	1.79 ab	0.43 a	0.30 a	1.52 b	0.40 a	0.31 a	1.58 a
T9 216-00-00	0.96 a	0.24 ab	2.11 a	1.94 ab	0.20 c	1.67 ab	0.46 a	0.23 a	1.57 b	0.35 a	0.23 a	1.46 a
T10 216-00-178	1.04 a	0.23 ab	1.88 a	2.23 a	0.25 a	1.65 ab	0.47 a	0.31 a	1.82 ab	0.35 a	0.39 a	1.78 a
T11 216-10-00	1.07 a	0.23 ab	1.77 a	2.00 ab	0.22 abc	1.66 ab	0.61 a	0.30 a	1.71 b	0.58 a	0.31 a	1.67 a
T12 216-10-178	0.99 a	0.23 ab	1.96 a	1.94 ab	0.20 bc	1.69 ab	0.40 a	0.27 a	1.97 ab	0.46 a	0.25 a	1.73 a
T13 322-04-90	1.02 a	0.22 ab	1.79 a	1.88 ab	0.21 abc	1.74 ab	0.49 a	0.30 a	1.62 b	0.35 a	0.27 a	1.67 a
T14 322-04-268	0.98 a	0.24 ab	1.81 a	1.70 b	0.21 abc	1.65 ab	0.37 a	0.33 a	1.76 ab	0.33 a	0.32 a	1.54 a
T15 322-14-90	1.03 a	0.24 ab	1.92 a	1.94 ab	0.21 abc	1.81 ab	0.46 a	0.29 a	1.95 ab	0.34 a	0.34 a	1.66 a
T16 322-14-268	0.99 a	0.25 ab	1.75 a	1.88 ab	0.21 abc	1.75 ab	0.46 a	0.28 a	1.76 ab	0.41 a	0.34 a	1.49 a

Means with same letter in a column are not significantly different (Tukey, $P \leq .05$)

4. CONCLUSIONS

The N, P and K fertilization effects were observed on the content of K in stem and of P in flower, rhizome and leaf.

The fertilization dose 216-00-00 kg NPK ha^{-1} was the best to favor red ginger yield. With this dose, the largest SD and FD, as well as the highest CBDW and TB per plant, were obtained.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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