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Soil and plant nutrition

Root development and productivity of 'Pérola' pineapple as a function of fertigation management

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Abstract - The aim of this study was to evaluate root development and productivity of 'Pérola' pineapple as a function of split N and K fertilization and fertigation management. Four different split nitrogen and potassium fertilizations were evaluated in combination, as well as four different fertigation managements. Root samples were analyzed using the Safira software and surface area, length, root volume per soil volume, root diameter, dry mass, specific surface and specific length were quantified. Average fruit mass and average productivity were also quantified. The different split fertilizations and fertigation management alternatives caused changes in the root system of 'Pérola' pineapple. Regarding dry root mass per cm^3 of soil, irrigated and fertigated plants split in twenty-seven N applications and four K applications, was 0.106 $g.cm^3$, while irrigated and fertigated plants split in fifty-four N applications and four K applications was 0.523 $g.cm^3$. Regarding productivity and average fruit mass, monthly applications and in four K applications until the ninth month of plant age promote greater increments, while split nitrogen fertilization showed no influence.

Index terms: *Ananas comosus*; plant nutrition; digital analysis; Safira.

Desenvolvimento radicular e produtividade do abacaxizeiro 'Pérola' em função do manejo da fertirrigação

Resumo - O objetivo deste estudo foi avaliar o desenvolvimento radicular e a produtividade do abacaxizeiro 'Pérola' em função dos parcelamentos da adubação com N e K e manejo da fertirrigação. Foram avaliados quatro diferentes parcelamentos de nitrogênio e potássio em combinação; e quatro diferentes manejos de fertirrigação. As amostras de raízes foram analisadas no software Safira e quantificou-se a área superficial, o comprimento, o volume de raízes por volume de solo, o diâmetro das raízes, a massa seca, a superfície específica e o comprimento específico. Foram quantificadas também a massa média de frutos e a produtividade média. Os diferentes parcelamentos da adubação e as alternativas de manejo da fertirrigação causaram alterações no sistema radicular do abacaxizeiro 'Pérola'. Com relação à massa seca de raízes por cm^3 de solo, plantas irrigadas e fertirrigadas, parceladas vinte e setes vezes para N e quatro para K, foi de 0,106 $g.cm^3$, enquanto as plantas irrigadas e fertirrigadas, parceladas com cinquenta e quatro aplicações de N e quatro de potássio K, foi de 0,523 $g.cm^3$. Quanto à produtividade e à massa média de frutos, os parcelamentos mensais e em quatro aplicações de potássio, até o nono mês de idade, promovem maiores incrementos, enquanto os parcelamentos de nitrogênio estudados não influenciaram.

Termos para indexação: *Ananas comosus*; nutrição de plantas; análises digitais; Safira.

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Introduction

Brazil is the world's third largest pineapple producer (*Ananas comosus* L. Merril) only after Costa Rica and the Philippines. In 2018, around 2,650,479 tons of pineapple fruits were produced in Brazil, with average productivity of 37.04 t ha^{-1} (FAO, 2018). The three largest producers in the country are the states of Pará, Paraíba and Minas Gerais (IBGE, 2018).

Despite being a culture in which the use of fertigation is not usual, some producers have adopted the technique in order to optimize the production process and obtain higher productivity. This technique consists of applying fertilizers together with water in the irrigation system (TRANI et al., 2011). However, there is no further information on the effects of the technique, both in relation to production and to the root system.

Being a CAM plant, pineapple has relatively small root system. The root system is the organ responsible for the absorption of water and nutrients by plants (CASTRO et al., 2009), mainly finer roots. When adding fertilizers via fertigation, it is extremely important to check where in the soil profile roots are concentrated. When nutrients are applied in a concentrated manner to the fertigated region, it is assumed that deep root growth is not stimulated.

The use of fresh weight, dry weight and root length measures is very common in the evaluation of root systems (SANT'ANA et al., 2012; FONSECA et al., 2013; VILELA et al., 2015). However, there are computer programs that evaluate with more accuracy a greater number of characteristics related to plant development. Among these computational technologies, the Fiber and Root Analysis System - Safira (JORGE; RODRIGUES, 2008) stands out, which in addition to evaluating various characteristics of the root system, allows making a more detailed description of the root system, compared to traditionally used methodologies (COVRE et al., 2015).

The aim of this work was to evaluate the development of the root system and productivity of 'Pérola' pineapple as a function of split nitrogen and potassium fertilization and fertigation management alternatives.

Material and methods

The experiment was conducted at the Experimental Farm of the "Centro Universitário Norte do Espírito Santo" (CEUNES), Federal University of Espírito Santo (UFES) located in the municipality of São Mateus, Latitude 18º40'32''S, Longitude 80 39º51'39 ' 'W and altitude of 37.7m above sea level. According to the Köppen classification, the climate is Aw type dry sub-humid, (ALVAREZ et al., 2013). Climatic data in the experimental period were obtained by INMET (2015) (Figure 1).

Seedlings used had from 25 to 35 cm in height, and planting was carried out in September 2014. The total experimental area was 2,000 m² and experimental plots consisted of double rows with 4.0 m in length and 5.20 m in width, totaling 80 plants per plot. The soil in the area is classified as Yellow Argisol with sandy-loam texture (EMBRAPA, 2018). Soil samples were taken at depth of 0-20 cm and its chemical attributes were evaluated (Table 1).

The experiment was installed following a randomized block design (RBD), with 4 replicates. Treatments consisted of different combinations of split N and K fertilization and fertigation management (Table 2).

Table 1. Chemical characterization of soil collected in the experimental area at depth of 0-20 cm before the installation of experiment with 'Pérola' pineapple.

pH	MO	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	H + Al	Al^{+3}	SB	CEC	V
	$dag.kg^{-1}$	-----$mg.dm^{-3}$-----				---------- $cmol_c.dm^{-3}$ ----------					%
4.8	1.5	8.5	34	5	0.9	0.4	1.5	0.2	1.3	1.5	47.1

H = Hydrogen; Al = Aluminum; SB = Sum of bases; CEC = Cation exchange capacity; V = Base saturation.

Table 2. Treatments composed of different combinations of split N and K fertilization and fertigation management.

Treatment*	Split N fertilization **	Split K fertilization **	Fertilization forms	Irrigation
IF4N70K	4	70	Fertigation	Yes
IF4N35K	4	35	Fertigation	Yes
IF4N9K	4	9	Fertigation	Yes
IF4N4K	4	4	Fertigation	Yes
IF7N70K	7	70	Fertigation	Yes
IF7N35K	7	35	Fertigation	Yes
NIF7N9K	7	9	Fertigation	No
IF7N4K	7	4	Fertigation	Yes
IF27N70K	27	70	Fertigation	Yes
NIF27N35K	27	35	Fertigation	No
IF27N9K	27	9	Fertigation	Yes
IF27N4K	27	4	Fertigation	Yes
NIF54N70K	54	70	Fertigation	No
IF54N35K	54	35	Fertigation	Yes
IF54N9K	54	9	Fertigation	Yes
IF54N4K	54	4	Fertigation	Yes
NINF4N4KOS	4	4	On the soil	No
INF4N4KOS	4	4	On the soil	Yes
IF27N35K10%	27	35	Fertigation	Yes
IF27N35K2/3	27	35	Fertigation	Yes

* Treatment nomenclature follows the organization: I - Irrigated; NI - Not irrigated; F - Fertigated; NF - Not fertigated; OS - Application on the soil; 54N, 27N, 7N, 4N – Split nitrogen fertilization until the seventh month of plant age; and 70K, 35K, 9K, 4K - Split potassium fertilization until the ninth month of plant age; 10%: Increasing doses at the rate of 10% per week; 2/3 - split fertilization corresponding to 2/3 of the recommended total after 1/3 applied at planting.

** N = 54: fertilization twice a week; N = 27: fertilization once a week; N = 7: fertilization once a month; N = 4: between October and November, between December and January, between February and March and in April.

** K = 70: fertilization twice a week; K = 35: fertilization once a week; K = 9: fertilization once a month; K = 4: between October and November, between January and February, between March and April and between May and June.

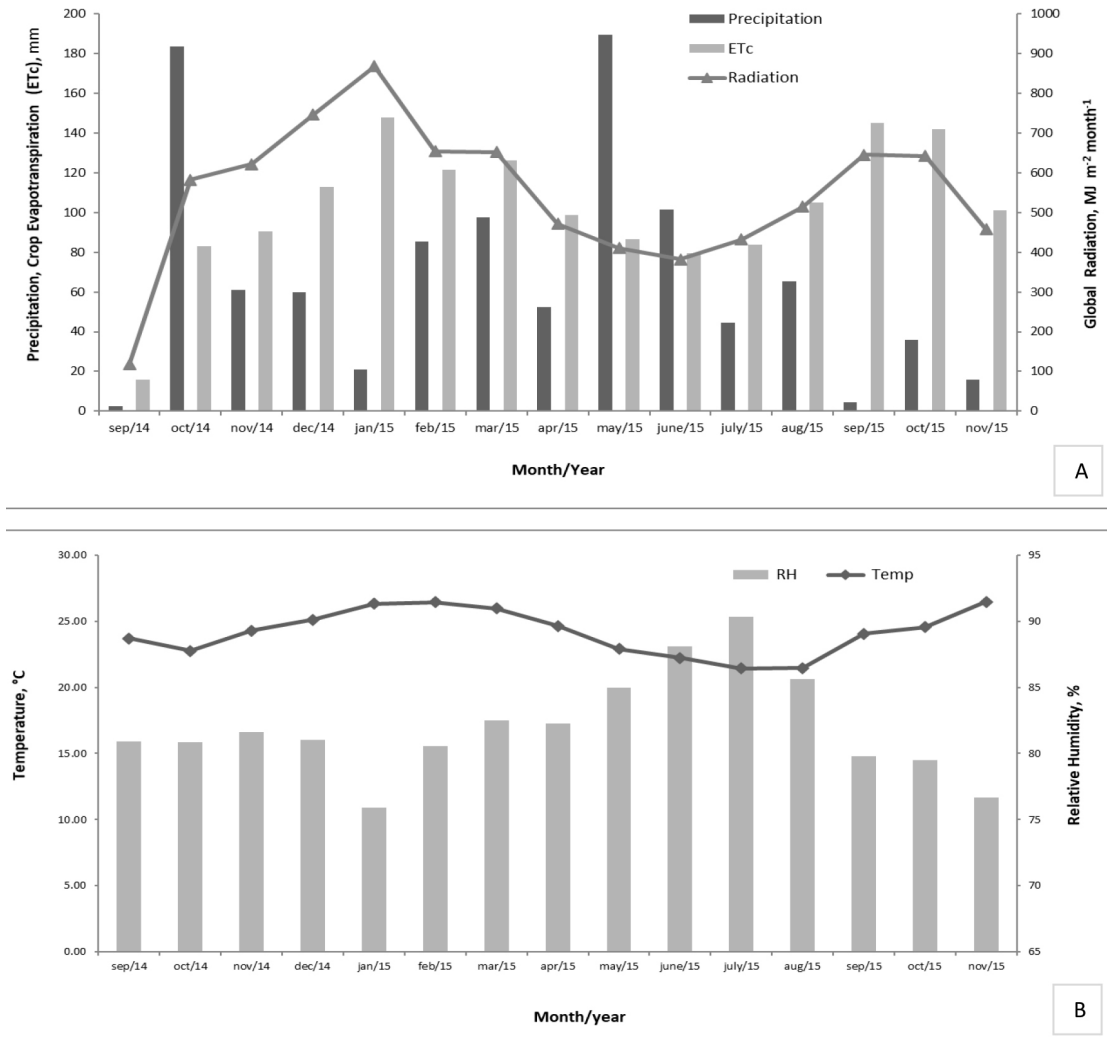

Figure 1. A - Monthly precipitation (mm), Crop Evapotranspiration (mm) and Global Solar Radiation (MJ m^{-2} $month^{-1}$); and B - Average monthly air temperature (ºC), Average monthly relative air humidity (%) recorded during the pineapple production cycle, São Mateus, ES. Source: INMET, (2015).

The amounts of fertilizers applied were determined according to recommendations of Benfica et al. (2011). The total amounts used in all treatments were 711 kg. ha^{-1} of N and 823 kg. ha^{-1} of K. The supply of micronutrients occurred by spraying foliar fertilizers. At the time of planting, phosphate fertilizer using 500 kg. ha^{-1} of P_2O_5 was applied all at once to the bottom of the furrow. The common sources of nitrogen, potassium and phosphorus used in the experiment were urea (45% N), potassium chloride (58% K) and simple superphosphate (18% P_2O_5), respectively.

Fertilization was started 45 days after planting for split N and K fertilizations in four applications and the other treatments 32 days after. N fertilizations were distributed until the seventh month of plant age, while K fertilizations approximately until the ninth month.

Drip system was adopted, with spacing of 1.30 m between lateral rows and 0.21 m between emitters, at flow rate of 1.4 L h^{-1} and water application intensity at 100 kPa. Irrigations were carried out based on the replacement of the crop evapotranspiration (ETc) estimated through the water balance in the soil (BERNADO et al., 2008) in control volume corresponding to depth of 0.40 m.

For the introduction of soluble fertilizers in the irrigation system, flow bypass tank with 15 cm in diameter, 40 cm in height and 7.1 L in volume was used. Fertilizers were diluted, filtered and subsequently injected. Fertilizer injections were performed in 6 cycles with average injection time of approximately 20 minutes, totaling final flow rate of approximately 2.12 L min^{-1} for each treatment.

For the evaluation of the root system, after fruit harvesting, trenches were made in the soil in order to determine the volume of soil with the greatest presence of roots around the plant. In this place, soil samples with roots were collected using a probe (7 cm in diameter and 30 cm in length and 1153.95 cm^3 in volume) at distance of 10 cm from the plant.

In the laboratory, root samples were washed in running water, digitalized with Sony digital camera of 18.2 Megapixels and analyzed by the Safira software (JORGE; RODRIGUES, 2008). Thus, the surface area (root area per root volume ($mm^2\ cm^{-3}$), length (root length per root volume - $mm\ cm^{-3}$), volume (root volume per soil volume- $mm^3\ cm^{-3}$), root diameter (mm), dry mass (g), specific surface (root area per root mass - $mm^2\ g^{-1}$) and specific length (root area per root mass - $mm^2\ g^{-1}$) were measured. Productivity ($kg.\ ha^{-1}$) was calculated from the average fruit weight (weighed with crown) multiplied by planting density.

Root development data were transformed by the $\sqrt{x} + 1$ function, submitted to analysis of variance and comparison of means by the t test, and productivity by the tukey test, at 5% probability, with the aid of the Sisvar software (FERREIRA, 2011). However, data were presented in their original form.

Results and discussion

Split fertilization and fertigation management had significant effects on all the development characteristics of the 'Pérola' pineapple root system. However, there was great similarity between the different combinations (Tables 3 and 4). Despite this, NINF4N4KOS treatment stands out, whose plants showed greater root development, which corresponds to plants that have not been irrigated, fertilized in a conventional manner and with the smallest split N and K applications. It is also worth mentioning that in the IF27N4K treatment, whose plants were fertigated, nitrogen was split into twenty-seven applications and potassium into four applications. Plants submitted to this treatment showed root development inferior to the others.

Table 3. Volume (Vol), diameter (Dia), length (Len) and dry matter (DM) of 'Pérola' pineapple roots as a function of split fertilization and fertigation management alternatives.

Treatments	Vol ($mm^3\ cm^{-3}$)	Dia ($mm\ cm^{-3}$)	Len(mm)	DM ($g\ cm^{-3}$)
IF27N4K	665,570 b	76,220 b	791,2875 c	0,106 e
IF54N4K	1297,122 ab	85,057 ab	1114,117 bc	0,523 a
IF54N9K	957,590 b	87,465 ab	1087,382 bc	0,114 de
INF4N4KOS	911,897 b	87,857 ab	999,480 bc	0,192 bcde
NIF54N70K	1108,192 b	89,182 ab	1300,417 bc	0,224 bcde
IF27N35K10%	1157,325 b	95,232 ab	1248,147 bc	0,256 bcde
IF27N9K	1394,670 ab	99,650 ab	1527,167 abc	0,270 bcde
IF27N70K	1413,625ab	110,645 ab	1634,332 abc	0,260 bcde
IF4N70K	1577,322 ab	117,957 ab	1630,211 abc	0,207 bcde
NIF7N9K	1297,000ab	120,960 ab	1490,050 abc	0,257 bcde
IF54N35K	1864,000 ab	129,922 ab	1845,987 abc	0,354 bcde
IF4N4K	1418,605 ab	133,117 ab	1656,515 abc	0,198 abcd
NIF27N35K	1675,177 ab	133,710 ab	1865,230 abc	0,250 bcde
IF7N4K	1368,537 ab	138,317ab	1681,370 abc	0,157 cde
IF4N35K	1717,200 ab	142,630 ab	1825,260 abc	0,307 abcde
IF7N35K	1665,897 ab	144,530 ab	2037,607 abc	0,286 bcde
IF4N9K	1933,755 ab	154,680 ab	2030,495 abc	0,316 abcde
IF27N35K2/3	1878,562 ab	154,875 ab	2252,950 ab	0,303 abcde
NINF4N4KOS	2553,262 a	159,272 ab	2727,357 a	0,407 ab
IF7N70K	1786,727 ab	174,002 a	2139,717 ab	0,354 abc
CV(%)	32.53	27.50	29.84	6.14

Treatment nomenclature follows the following organization: I - Irrigated; NI - Not irrigated; F - Fertigated; NF - Not fertigated; OS - Application on the soil; 54N, 27N, 7N, 4N – Split nitrogen fertilization until the seventh month of plant age; and 70K, 35K, 9K, 4K - Split potassium fertilization until the ninth month of plant age; 10%: Increasing doses at the rate of 10% per week; 2/3 - split fertilization corresponding to 2/3 of the recommended total after 1/3 applied at planting.

** N = 54: fertilization twice a week; N = 27: fertilization once a week; N = 7: fertilization once a month; N = 4: between October and November, between December and January, between February and March and in April.

** K = 70: fertilization twice a week; K = 35: fertilization once a week; K = 9: fertilization once a month; K = 4: between October and November, between January and February, between March and April and between May and June.

Means followed by the same letters, lowercase in column, do not differ by the t test, at 5% probability. CV: Coefficient of variation (%).

Table 4. Surface area (SA), specific surface (SS) and specific length (SL) of 'Pérola' pineapple roots as a function of split fertilization and fertigation management alternatives.

Treatments	SL (mm g^{-1})	SA (mm^2 cm^{-3})	SS (mm^2 g^{-1})
IF27N4K	88,973 c	2436,740 c	275,796 c
INF4N4KOS	194,766 bc	3207,702 bc	623,530 bc
IF54N9K	190,087 bc	3445,007 bc	604,113 bc
NIF54N70K	355,678 bc	4053,690 bc	1127,081bc
IF27N35K10%	367,236 bc	4003,425 bc	1184,803 bc
NIF7N9K	432,525 bc	4687,237 abc	1374,693 bc
IF54N4K	440,374 bc	3917,317 bc	1534,140 bc
IF7N4K	285,581 bc	5144,870 abc	877,253 bc
IF27N9K	485,411 bc	4906,817 abc	1565,121 abc
IF27N70K	557,984 abc	5141,715 abc	1756,090 abc
IF4N4K	416,886 bc	5169,010 abc	1308,307 ab
IF4N70K	418,832 bc	5343,277 abc	1407,855 ab
IF7N35K	681,363 abc	6251,060 abc	2080,092 abc
NIF27N35K	513,677 abc	5943,687 abc	1643,521 abc
IF4N35K	776,275 abc	5869,955 abc	2565,849 abc
IF7N70K	900.823 ab	6617,585 ab	2840,834 ab
IF54N35K	773.673 abc	6138,625 abc	2634,626 abc
IF27N35K2/3	747,282 abc	6972,900 ab	2297,269 abc
IF4N9K	729,623 abc	6557,935 abc	2371,321 abc
NINF4N4KOS	1206,168 a	8798,967 a	3924,324 a
CV(%)	52.11	30.62	53.45

Treatment nomenclature follows the following organization: I - Irrigated; NI - Not irrigated; F - Fertigated; NF - Not fertigated; OS - Application on the soil; 54N, 27N, 7N, 4N – Split nitrogen fertilization until the seventh month of plant age; and 70K, 35K, 9K, 4K - Split potassium fertilization until the ninth month of plant age; 10%: Increasing doses at the rate of 10% per week; 2/3 - split fertilization corresponding to 2/3 of the recommended total after 1/3 applied at planting.
** N = 54: fertilization twice a week; N = 27: fertilization once a week; N = 7: fertilization once a month; N = 4: between October and November, between December and January, between February and March and in April.
** K = 70: fertilization twice a week; K = 35: fertilization once a week; K = 9: fertilization once a month; K = 4: between October and November, between January and February, between March and April and between May and June.
Means followed by the same letters, lowercase in column, do not differ by the t test, at 5% probability.
CV: Coefficient of variation (%).

It should be highlighted that pineapple has few roots, with fasciculated and superficial radicular system, usually found in the first 15 to 20 cm of soil depth (REINHARDT et al., 2000). In addition to the low root volume, pineapple is a CAM plant, capable of tolerating severe water deficits and high relative air humidity. Although the experiment has twenty different treatments, the root system of evaluated plants did not show significant differences in terms of volume, diameter, length and dry matter.

Fertigation has been used in several cultures due to the reduction of labor (COELHO et al. 2001). In addition, in drip fertigation, the entire soil volume explored by the absorption roots receives nutrients in a short period of time, which allows for almost simultaneous absorption by a larger amount of roots. It is worth mentioning that the pineapple culture, more precisely the 'Pérola' cultivar, has thorns, which makes people circulation difficult. In the same way, if there is need for the application of some type of insecticide, the irrigation system can also be used. However, the possibility of more frequent fertilizer distribution has been highlighted. Split K and N application via irrigation water is recommended due to the mobility of these nutrients in the soil, especially in sandy soils. Thus, there is tendency to decrease lixiviation losses. In addition, due to the high K solubility, this practice becomes viable (BORGES; SILVA, 2011).

For the average mass of crowned fruits (kg) and for productivity (kg $plant^{-1}$), significant differences were observed in split potassium fertilizations. However, the same was not observed in split nitrogen fertilizations (Table 5).

In terms of productivity, monthly splits in four potassium applications until the ninth month of plant age were the most efficient, so that the average fruit masses were 1.504 kg and 1.494 kg and productivities of 57851,680 kg ha^{-1} and 57478,370 kg ha^{-1}, respectively. For nitrogen fertilizers, the average mass of crowned fruits was 1,463 kg and the average productivity was 56253,721 kg ha^{-1}. Although there are no differences between split nitrogen fertilization schemes, this overall average obtained is more than the estimated double, of 24,085 kg ha^{-1} for Brazil in 2019 (IBGE, 2019).

Table 5. Average mass of crowned fruits (kg) and productivity (kg ha^{-1}) of 'Pérola' pineapple resulting from split nitrogen (N) and potassium (K) fertilization. São Mateus - ES, 2015

Splits	Fruit mass (kg)	Productivity (kg ha^{-1})
Split Nitrogen fertilization		
N= 54	1.472 a	56.650.16 a
N= 27	1.505 a	57.888.22 a
N= 7	1.416 a	54.495.19 a
N= 4	1.459 a	56.121.88 a
Overall average	**1.463**	**56.253.721**
Split Potassium fertilization		
K= 70	1.467 ab	56.443.990 ab
K= 35	1.388 b	53381.410 b
K= 9	1.504 a	57851.680 a
K= 4	1.494 a	57478.370 a
Overall average	**1.463**	**56.253.721**

Means followed by the same letter do not differ statistically from each other at 5% significance level using the Tukey test.
N = 54: fertilization twice a week; N = 27: fertilization once a week; N = 7: fertilization once a month; N = 4: between October and November, between December and January, between February and March and in April.
K = 70: fertilization twice a week; K = 35: fertilization once a week; K = 9: fertilization once a month; K = 4: between October and November, between January and February, between March and April and between May and June.

Veloso et al. (2001) evaluated the response of 'Pérola' pineapple to the addition of nitrogen and potassium in northeastern Pará and found that nitrogen fertilization had no effect on production and mass of crowned fruits, similar to results obtained in this study. Oliveira (2014), on the other hand, evaluated the effect of nitrogen and potassium fertilization levels of 'BRS Imperial' pineapple and observed significant increase in the average fruit mass and productivity with nitrogen fertilization, while potassium did not influence production variables. Teixeira et al. (2002) evaluated split nitrogen, phosphorus and potassium fertilization in 'Smooth Cayenne' pineapple and found increase in the average fruit mass and productivity, resulting from the interaction of split nitrogen and potassium fertilization, which variables were influenced by the splitting scheme.

The different results found by the above authors may be due to the cultivar under study, since they have specific genetic characteristics and can behave differently regarding the use of nutrients.

Conclusions

Different combinations of split fertilizations and fertigation management cause few changes in the root system attributes of 'Pérola' pineapple.

Split K fertilization applied monthly or distributed into four applications until the ninth month of plant age promotes greater increases in average fruit mass and productivity. Distinct split nitrogen fertilizations do not influence productivity.

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