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 cm³ of soil, irrigated and fertigated plants split in twenty-seven N applications and four K applications, was 0.106 g.cm³, while irrigated and fertigated plants split in fifty-four N applications and four K applications was 0.523 g.cm³. 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 cm³ de solo, plantas irrigadas e fertirrigadas, parceladas vinte e sete aplicações de N e quatro de potássio, foi de 0,106 g.cm³, enquanto as plantas irrigadas e fertirrigadas, parceladas com quinze e quatro aplicações de N e quatro de potássio K, foi de 0,523 g.cm³. 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.
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 Espirito Santo (UFES) located in the municipality of São Mateus, Latitude 18°40’32”S, Longitude 80°51’39” 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 m\(^2\) 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 |
|----|----|---|--------|---------|-----------|-----------|--------|---------|----|-----|---|
| 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.
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\(_2\)O\(_5\) 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\(_2\)O\(_5\)), 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 (ET\(_c\)) 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.

Figure 1. A - Monthly precipitation (mm), Crop Evapotranspiration (mm) and Global Solar Radiation (MJ m\(^{-2}\) month\(^{-1}\)); and B - Average monthly air temperature (°C), Average monthly relative air humidity (%) recorded during the pineapple production cycle, São Mateus, ES. Source: INMET, (2015).
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 (mm² cm⁻³)), length (root length per root volume - mm cm⁻³), volume (root volume per soil volume- mm³ cm⁻³), root diameter (mm), dry mass (g), specific surface (root area per root mass - mm² g⁻¹) and specific length (root area per root mass - mm² 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 √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 (mm³ cm⁻³) | Dia (mm cm⁻³) | Len(mm) | DM (g cm⁻³) |
|-------------|----------------|---------------|---------|-------------|
| IF27N4K     | 665,570 b      | 76,220 b      | 791,287 5 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 b     | 99,650 ab     | 1527,167 abc | 0,270 bcde  |
| IF27N70K    | 1413,625ab     | 110,645 ab    | 1634,332 abc | 0,260 bcde  |
| IF4N70K     | 1577,322 b     | 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    | 138,317 ab    | 1681,370 abc | 0,157 cde   |
| IF4N35K     | 1717,200 ab    | 142,630 ab    | 1825,260 abc | 0,307 abcd  |
| 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 abcd  |
| IF27N35K2/3 | 1878,562 ab    | 154,875 ab    | 2252,950 ab | 0,303 abcde |
| NINF4N4KOS  | 2553,262 a     | 159,272 a     | 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 (mm² cm⁻³) | SS (mm² 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   | 1127,081 bc  |
| 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 ab   | 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        |

CV: Coefficient of variation (%).

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** 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.

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 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.

**Acknowledgments**

The authors would like to thank the Federal University of Espírito Santo (UFES), the Espírito Santo Research Support Foundation (FAPES), the National Council for Scientific and Technological Development (CNPq), the Coordination for the Improvement of Higher Education Personnel (Capes) for the financial support.
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