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GROWTH OF POTATO PLANTS (*Solanum tuberosum* L., CV Romano), IN HUAMBO PROVINCE, ANGOLA, UNDER TWO PLANTING DENSITIES

Crecimiento de plantas de papa (*Solanum tuberosum* L., cv Romano), en la provincia de Huambo, Angola, bajo dos densidades de plantación

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ABSTRACT. The growth dynamics of potato plants (*Solanum tuberosum* L.), under the edaphoclimatic conditions of Huambo, Angola, with two row distances, were evaluated by planting “seed” tubers (35-45 mm caliber), in October 2011, 2012 and 2013, under two densities of plantation (0,75 x 0,30 and 0,90 x 0,30 m, distances between rows and between plants, respectively). The dynamics of the average height of the main stem, the fresh and dry masses of the tubers were evaluated, which were adjusted by means of the regression analysis to different mathematical functions, in order to estimate their dynamics and obtain different indicators, the nutritional status was diagnosed 45 days after planting, in 2013, by means of foliar analysis. The tubers were started before plants reached their maximum Absolute Growth Rate (TAC) in stem lenght, which suggests the establishment of a competition for assimilates between organs. The fresh mass of the tubers was more influenced by the density of plantation, with an advance in the growth with superior values of the TAC and the maximum fresh mass, in the minor. The plants showed a deficient nutritional status; however, planting at lower density reached a less unfavorable level. The dynamics of the evaluated variables, showed that the climate is suitable for the development of the plants and point to the water supply during the “linear” growth of the tubers, and to the mineral nutrition, as aspects for a future optimization of the crop.

Key words: height, tuber weights, growth analysis, distances between rows

RESUMEN. Se evaluó la dinámica de crecimiento de la papa (*Solanum tuberosum* L.) a partir de la evaluación de variables morfoagronómicas, en las condiciones edafoclimáticas de la provincia de Huambo, Angola, bajo dos distancias entre surcos, plantando tubérculos semilla de 35-45 mm, en octubre de 2011, 2012 y 2013, a las distancias entre surcos de 0,75 y 0,90 m y entre plantas de 0,30 m. Se evaluó la dinámica de la longitud del tallo principal y de la masa fresca y seca de los tubérculos, ajustándose por medio del análisis de regresión a diferentes funciones matemáticas; el estado nutricional se diagnosticó a los 45 días después de la plantación, en el año 2013, por medio del análisis foliar. Los tubérculos se iniciaron cuando las plantas no habían alcanzado la máxima Tasa Absoluta de Crecimiento en longitud de sus tallos, lo que sugiere el establecimiento de una competencia por asimilados entre órganos. La masa fresca de los tubérculos resultó más influida por los tratamientos, con un adelanto en el crecimiento, con valores superiores de la TAC y la masa fresca máxima, en la menor densidad. Las plantas mostraron un estado nutricional deficiente; no obstante, la plantación a menor densidad alcanzó un nivel menos desfavorable. Las dinámicas de las variables evaluadas, evidenciaron que el clima resulta adecuado para el desarrollo de las plantas y señalan al suministro hídrico durante el crecimiento “lineal” de los tubérculos, y a la nutrición mineral, como aspectos para una futura optimización del cultivo.

Palabras clave: longitud, masas tubérculos, análisis del crecimiento, distancias entre surcos

INTRODUCTION

The potato (*Solanum tuberosum* L.) has served as food support for the poorest population and fulfills this role on a global scale (1), becoming the fourth most important food crop in the world.

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The nutritional quality, adaptability to different climates and cultivation methods make the potato suitable for these purposes (2). It is grown in environments that differ substantially in latitude, altitude, photoperiod and temperatures.

The average global yield of the crop in 2016 was 19.58 t ha^{-1} (3) and in the African continent, the average annual yields remain in the order of 14.7 t ha^{-1}, while other authors indicate the 12 potato producing countries in Africa (3,4), being last in Angola, with yields in 2016 of 5,9 t ha^{-1} (3).

Several factors affect the obtaining of optimum yields of the potato tuber, among which is the use of planting distances and densities (5), the supply of nutrients (6) and the water supply (7).

In Huambo province, Angola, in 2014 the potato was cultivated in approximately 23 715 ha $year^{-1}$ with an estimated production of 201,440 t (8) and there are no published agricultural research results on the agronomic management of the crop, nor is the growth behavior of the plants under these particular conditions known, the latter being able to limit the obtaining of higher yields.

It is for the above reasons that the present work was developed with the objective of studying the growth dynamics of potato plants from the evaluation of morphoagronomic variables, in the edaphoclimatic conditions of Huambo province, Angola, under two distances between rows.

MATERIALS AND METHODS

The research was developed in the Experimental Center of Chianga, Huambo municipality, belonging to the Institute of Agronomic Research (IIA), between parallels 12º 33’ and 12º 46’ of South latitude and meridians 15º 49’ and 15º 52’ of longitude East of the Greenwich meridian, at an altitude from 1 650 to 1 740 m a.s.l.

The soil of the experimental area is classified as Rhodic Kandiustalf (9) and to determine the main characteristics of its fertility, two samples were composed of 30 subsamples each, taking 2 kg of soil in the whole experimental area at depths of 0.00-0.15 m and 0.15-0.30 m, respectively, prior to planting the experiments and were analyzed using the methods established in the Laboratory of the Agricultural Research Institute (IIA) of Huambo, Angola, as described: the pH was determined by the potentiometric method with a soil: water ratio of 1: 2.5 (m: V); For organic matter, the Walkley and Black method was used; the assimilable P was extracted using the method of Bray and Kurtz No. 1, and was determined colorimetrically by the development of the blue color by the reduction of the molybdophosphoric complex; the interchangeable cations were extracted with the solution of NH4OAc 1 mol L^{-1} at pH 7 and Ca and Mg were determined by atomic absorption spectrophotometry and K by flame photometry.

For the experimentation, seed tubers of national production of the cultivar of Roman potato, recommended by the Provincial Directorate of Agriculture, Development and Fisheries of Huambo, were used; the 35-45 mm caliber were selected, using a manually manufactured calibrator. They were stored under diffuse light until multiple sprouting. At the time of planting, another selection was made to eliminate unfit tubers and thus guarantee the quality of the seed to be planted.

The seed tubers were planted on October 13, 15 and 21, during the years 2011, 2012 and 2013, respectively. As treatments, distances between rows of 0.75 m and 0.90 m were considered, with a distance between plants of 0.30 m. Two plots of 16 m long x 16 m wide (256 m^2) were established, with 1 137 plants and 948 plants for the distances between rows of 0.75 m and 0.90 m, respectively.

During the development of each plantation, average temperatures and precipitation were recorded daily (Figure 1), taken at the IIA Meteorological Station, located 200 meters from the experimental field.

The first fertilization was done at the time of planting, with the application of 600 kg ha^{-1} of the complete formula 12-24-12 (N, P_2O_5, K_2O), supplemented with the application of 220 kg ha^{-1} of KCl; a second fertilization was performed 30 days after planting (DAP), with 133 kg ha^{-1} of N using urea as a carrier.

The cultural tasks, except the soil preparation were developed manually and according to the Rules of Vegetable Production of the Angola´s Ministry of Agriculture. No irrigation was applied, so that the satisfaction of the hydric demands of the crop was made based on the rainfall that occurred during the experimental period.

The growth dynamics of potato plants was evaluated in the plants developed in each of the treatments and dates, from 21 DDP and up to 91 days DDP (January of the year after planting), for which They carried out weekly samplings to ten plants taken at random in each experimental plot.

In each plant, the average length of the main stem from the soil surface to the terminal bud was measured, with a graduated rule with±1 mm error and expressed in centimeters.

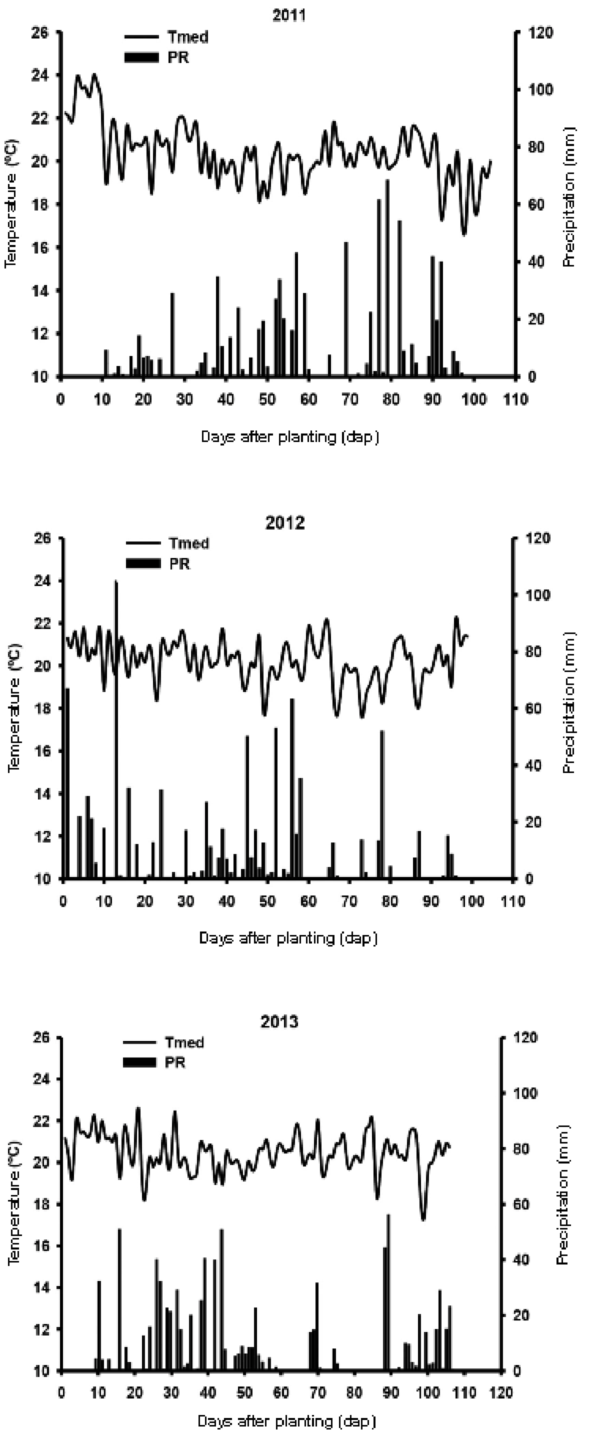


Figure 1. Daily record of precipitation (mm, Pr) and average temperatures (^{0}C) (Tmed), during the development of the plants, in the three years of experimentation

For the determination of the fresh mass of the tubers per plant (MFT plant^{-1}), these were washed with water to remove the adhered soil and dried in air to later determine their mass by weighing in technical scales with ± 0,01 g of mistake; the dry mass of the tubers per plant (MST plant^{-1}) was estimated from three representative samples of the tubers present in each treatment, which were crushed and weighed 100 g of each, which were placed in metal containers previously tared and placed in a forced air circulation oven at 80 ºC, until reaching a constant mass.

The dynamics of the means of the variables evaluated (dependent variable) were plotted and adjusted by means of regression analysis, with the use of the exponential polynomial functions of the second degree (equation I) and gamma (equation II), taken as independent variable to the days after planting (DAP):

$$Y=e^{(a+bx+cx2)} \quad (I)$$
$$Y=b_o e^{b1x} X^{b2} \quad (II)$$

The function of best fit and biological representation of the primary data was selected, following the principles of the functional method of Growth Analysis (10).

From the first and second derivatives, from each mathematical equation obtained, the Absolute Growth Rate (TAC) was estimated, according to the formula described by Torres (10,11), as well as the moment of occurrence of the maximum TAC of the tubers and their magnitude, the moment of the cessation of the growth of the tubers and the maximum magnitude reached by these.

For the diagnosis of the nutritional status of the plants, the fourth fully developed and expanded leaf of 40 plants sampled at random in each row distance was taken, at 45 DAP in the 2013-2014 plantation, which were washed with distilled water and dried in an oven at 75 °C; subsequently, they were milled and sieved through a 2 mm mesh, performing the analyzes in triplicate, according to the methodology used in the IIA Laboratory, as described below:

digestion at 2 g of the sample, with 25 mL of concentrated H_2SO_4, using as a catalyst CuSO4 tablets; N was determined by titrating 0.1 mol L^{-1} NaOH with the distillate collected in H_3BO_3; the P for the development of the yellow color of the vanadium-molybdate blue-phosphoric complex; K by flame photometry and Ca and Mg by atomic absorption spectrophotometry.

The results of the foliar analysis were determined by standard error (ES) and coefficient of variation (CV) statistics; to compare the nutritional status of the plants, a Student's "t" test was performed at 0.01 % error probability.

The values obtained for each nutrient were compared with references established at different latitudes.

RESULTS AND DISCUSSION

The pattern of the dynamics of the length of the main stem was similar in the three years (Figure 2) and the functions used for the adjustment (Table 1) satisfactorily described the behavior of the real values.

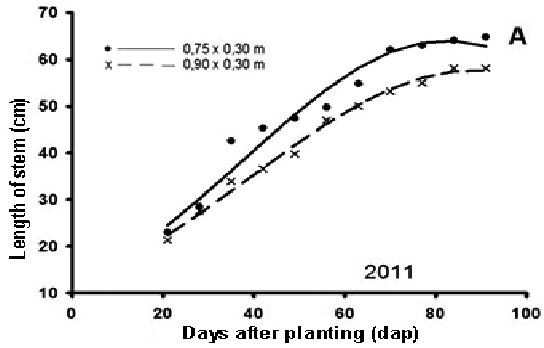
In general for each year, there were no differences between the two treatments tested at the time (DAP) of reaching the maximum Absolute Growth Rate (TACmax) in length of the main stem (Figure 2), although this moment did vary between years and, in general, the treatment plants of 0.75 m between rows showed higher values for this variable.

The difference between treatments at the time of reaching the maximum length of the main stem of the plants ($T_{Longmax}$) did not present a regularity in the three years, although these were relatively insignificant and only in the first year of experimentation (2011-2012) was of seven days, with an earlier stop of growth in the treatment of 0.75 m (Figure 2). The results in the present investigation showed that at 20 DAP, lengths between 17 and 22 cm were obtained, after which the plants started an accelerated increase for both distance treatments between rows.

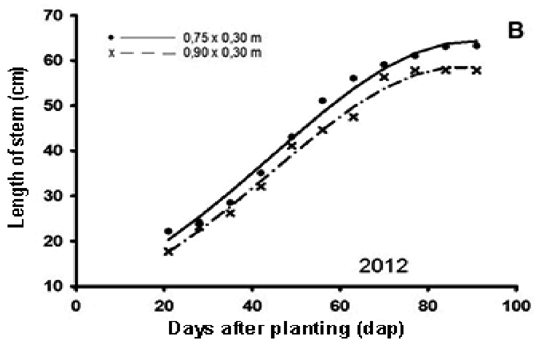
The variable fresh mass of the tubers per plant showed a sigmoidal behavior with the age of the crop in all the treatments and years of experimentation (Figure 3), presenting a satisfactory adjustment to the functions chosen for the description of the growth dynamics (Table 2).

For both distances studied and in the three years evaluated, the initiation of the tubers of the plants occurred between 20 and 28 DAP (Figure 3). After its initiation, there was a sustained increase in the fresh mass of the same; in this way, a new site of consumption and competition was established, between the growth in length of the stems (tending to decrease) and the growth of the tubers (tending to increase), by the products of photosynthesis elaborated by the foliage, at early ages of the development of plants.

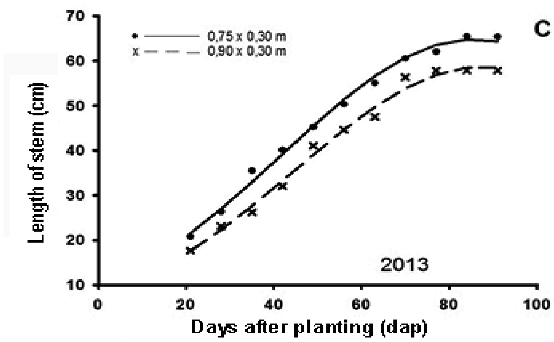
Consequently, the TAC_{max} were achieved at an early stage in the development of the plants, between 50 and 64 DAP approximately and always earlier in the treatment of 0.90 m between furrows, with a difference, from 8 to 13 days with relation to 0.75 m, depending on the year of planting. The magnitudes of these TAC_{max} were always higher in the treatment with lower planting density.



	Treatments	
	0,75	0,90
t TAC máx (days)	38	39
TAC máx (cm.ddp⁻¹)	38,5	34,3
t Longmáx (days)	82	89
Longmáx (cm)	61,0	57,7



	Treatments	
	0,75	0,90
t TAC máx (days)	45	43
TAC máx (cm.ddp⁻¹)	38,7	35,6
t Longmáx (days)	90	88
Longmáx (cm)	64,3	58,7



	Treatments	
	0,75	0,90
t TAC máx (days)	42	44
TAC máx (cm.ddp⁻¹)	39,3	37,4
t Longmáx (days)	87	88
Longmáx (cm)	64,8	58,7

Figure 2. Estimated dynamics of the average stem length (cm) of potato plants (*Solanum tuberosum* L.) at different distances between rows and variables derived from them

Table 1. Equations for the dynamics of the average length of the main stem (cm) as a function of the days after planting (DAP), from the adjustment by means of the regression analysis of the experimental data, of potato plants (*Solanum tuberosum* L.), under two distances between rows

Treatments	2011-2012	2012-2013	2013-2014
Average length of the main stem (cm)			
0,75 m	**Y**= $e^{(2,4+0,04X-0,0003X^2)}$	**Y** = $e^{(2,2+0,04X-0,0002X^2)}$	Y = $e^{(2,2+0,05X-0,0003X^2)}$
	R^2 = 94,7	R^2 = 98,1	R^2 = 99,2
0,90 m	**Y** = $e^{(2,4+0,04X-0,0002X^2)}$	**Y** = $e^{(1,9+0,05X-0,0003X^2)}$	Y = $e^{(2,2+0,04X-0,0002X^2)}$
	R^2 = 98,9	R^2 = 99,1	R^2 = 99,6

Table 2. Equations for the dynamics of the average fresh mass of tubers per plant (g) as a function of the days after planting (DAP), from the adjustment by means of the regression analysis of the experimental data, of potato plants (*Solanum tuberosum* L.), under two distances between rows

Treatments	2011-2012	2012-2013	2013-2014
Fresh mass of tubers per plant (g pl^{-1})			
0,75 m	**Y** = $-29,9e^{-0,1x}X^{10,6}$	**Y** = $e^{(-2,1+0,2X-0,001X^2)}$	**Y** = $e^{(-2,1+0,2X-0,001X^2)}$
	R^2= 98,4	**R^2**= 98,1	**R^2**= 98,1
0,90 m	Y = $-19,3e^{-0,1x}X^{7,7}$	Y = $-19,9e^{-0,09x}X^{7,9}$	Y = $-19,9e^{-0,09x}X^{7,9}$
	R^2= 97,9	**R^2** = 98,3	**R^2** = 98,3

The maximum fresh mass and the time of development in which it is reached, showed differences between treatments (Figure 3), earlier and always with a higher magnitude in the treatment of lower planting density. Considering the generality of the crop for the experimental conditions in Huambo province, the maximum value of fresh mass of the tubers was reached in an approximate period of time between 78 and 85 DAP.

As for the fresh mass of the tubers per plant, their dry mass showed a sigmoidal behavior when related to the days after planting, in all the treatments and campaigns (Figure 4), presenting a satisfactory adjustment to the functions used to the estimation of its dynamics (Table 3).

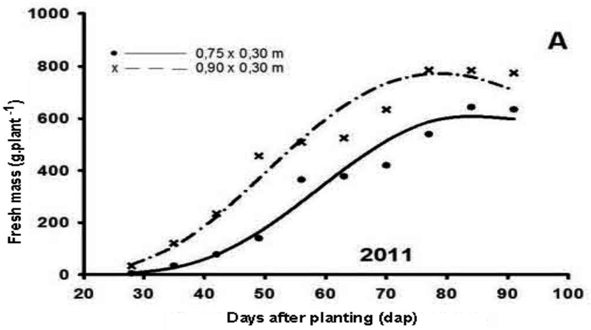
The moments of reaching the TAC_{max} of the growth of the tubers, based on the dry mass and their values (Figure 4), did not coincide in a general way with what was achieved for the fresh dough, with a delay being found, in 66 % of the treatments and years of planting, to achieve maximum growth intensity.

A similar situation was presented for the moment of achieving the maximum dry mass of the tubers, which is usually reached later compared to that shown by the fresh dough. It was shown that not necessarily, the accumulation of fresh dough is coupled to a similar behavior in the dry mass of the tubers, which allows us to interpret that, although they are related variables, the factors that govern the accumulation of fresh dough are not the same to those of the dry mass (12).

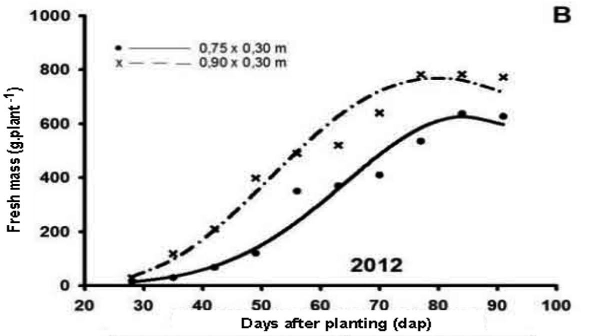
Even when the functional analysis allows to obtain an overview of the same, it was possible to detect in all the years under study, the influence of distance treatments between rows, in the evaluated variables, showing the greater average length of the main stem the treatment of 0.75 m and the largest fresh and dry masses, the treatment of 0.90 m. On the other hand, the growth curves of the tubers showed the early start of the tubers and their duration in a period of approximately 90 DAP.

Authors pointed out that the initiation of tuberization is a process influenced by environmental factors such as temperature and photoperiod (13) 7 and 14 mm, mediated by the levels of endogenous growth regulators (14); resulting in an increase in the volume of the cord and the bark of the stolon, due to cell division and expansion.

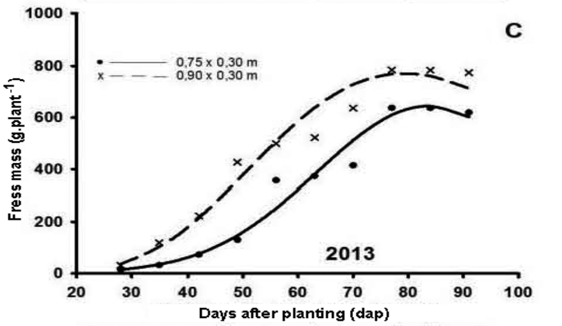
The geographical location of Huambo province, Angola, makes the photoperiod for the development of the crop is around 12 hours, which causes the growth of the tubers is favored, taking into account that, in general, the short photoperiod accelerates the start of tuberization. The export of assimilates from the leaves is greater in short days than in long days (15).



	Treatments	
	0,75	0,90
t TAC máx (days)	59	50
TAC máx (g.pta.ddp^{-1})	329,0	397,3
t MF tmáx (days)	85	79
MF máx (g pta^{-1})	619,5	773,3



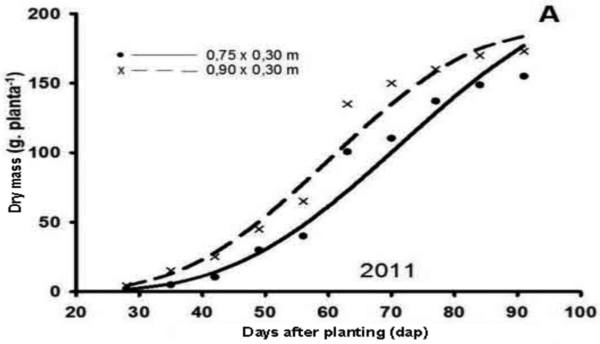
	Treatments	
	0,75	0,90
t TAC máx (days)	64	51
TAC máx (g.pta.ddp^{-1})	380,0	395,9
t MF tmáx (days)	85	79
MF máx (g pta^{-1})	626,5	741,8



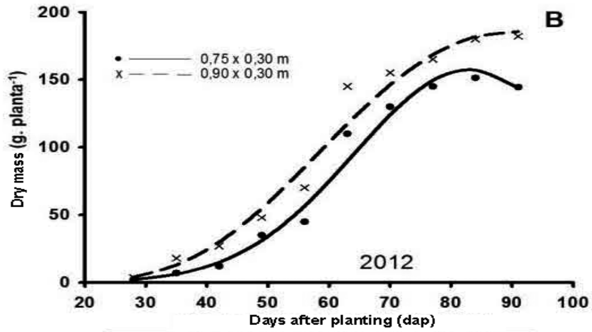
	Treatments	
	0,75	0,90
t TAC máx (days)	64	51
TAC máx (g.pta.ddp^{-1})	390,8	396,5
t MF tmáx (days)	84	79
MF máx (g pta^{-1})	644,3	771,0

TTACmax: time in which the maximum Absolute Growth Rate is reached; TACmax: value of the maximum Absolute Growth Rate; TMFmax: time in which the maximum value of the fresh tuber mass is reached; MFmax: maximum value of the fresh mass; pta: plant; dist.: distance

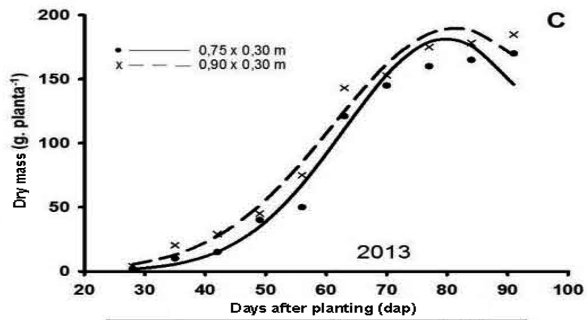
Figure 3. Estimated dynamics of the fresh tuber mass (g per plant^{-1}) of potato plants (*Solanum tuberosum* L.) at different distances between rows and variables derived from them



	Treatments	
	0,75	0,90
t TAC máx (days)	71	60
TAC máx (g.pta.ddp^{-1})	118,56	94,50
t MS tmáx (days)	97	96
MS máx (g pta^{-1})	171,26	185,45



	Treatments	
	0,75	0,90
t TAC máx (days)	64	58
TAC máx (g.pta.ddp^{-1})	95,78	95,56
t MS tmáx (days)	83	90
MS máx (g pta^{-1})	157,69	185,67



	Treatments	
	0,75	0,90
t TAC máx (days)	60	61
TAC máx (g.pta.ddp^{-1})	90,75	115,14
t MS tmáx (days)	80	81
MS máx (g pta^{-1})	181,27	189,27

TTACmax: time in which the maximum Absolute Growth Rate is reached; TACmax: value of the maximum Absolute Growth Rate; TMFmax: time in which the maximum value of the fresh tuber mass is reached; MFmax: maximum value of the fresh mass; pta: plant; dist.: distance

Figure 4. Estimated dynamics of the dry tuber mass (g per plant^{-1}) of potato plants (*Solanum tuberosum* L.) in different distances between rows and variables derived from them

Table 3. Equations for the dynamics of the average dry mass of tubers per plant (g) as a function of the days after planting (DAP), from the adjustment by means of the regression analysis of the experimental data, of potato plants (*Solanum tuberosum* L.), under two distances between rows

Treatments	2011-2012	2012-2013	2013-2014
Dry mass of tubers per plant (g pl^{-1})			
0,75 m	$Y = -23,1e^{-0,07x}X^{7,7}$	$Y = e^{(-4,6+0,2X-0,001X^2)}$	$Y = e^{(-3,5+0,2X-0,001X^2)}$
	$R^2 = 98,10$	$R^2 = 97,9$	$R^2 = 97,2$
0,90 m	$Y = -19,6e^{-0,07x}X^{6,9}$	$Y = -17,7e^{-0,06x}X^{6,4}$	$Y = e^{(-1,2+0,15X-0,0009X^2)}$
	$R^2 = 97,0$	$R^2 = 98,5$	$R^2 = 97,3$

This allows us to point out that the photoperiod conditions in Angola are suitable for a rapid tuberization initiation, since this is in the range of 12.4 to 12.7 hours.

On the other hand, the prevailing average temperatures, on the dates of planting used, were between 20 and 21 ˚C (Figure 1), which are adequate for the process of tuber initiation and development, and remained relatively low throughout the period of growth, taking into account what is stated, that the negative effects of the increase in temperatures depends on the stage of development of the plant, presenting a more pronounced effect on growth and yield as they appear earlier in the development of plants (16).

For an optimal growth and development of the potato crop it is required that the temperatures are in the range between 15 to 25 °C, these must be lower during the night to achieve the optimum for the photosynthetic activity, facilitate the transport of photoassimilates, the final dry mass and the greater proportion of the mass of tubers to the total (17).

The crop was developed without the application of irrigation and the accumulated rainfall during the development of the plants was in the order of 835; 959 and 889 mm, on the dates of planting in 2011; 2012 and 2013, respectively (Figure 1). It could think that these volumes guarantee the adequate development of the tuber since the precipitations were between 400 to 800 mm during the biological cycle of the plant, quantities that are required to achieve an optimal growth and development of the potato plants; however, the distribution of rainfall was not regular, with periods of little rainfall, especially during the “linear” growth of the tubers, one of the stages most affected by water deficiency (18), and which are approximately related to the detentions of this one that are appraised between the 50 and 80 DDP in the three dates (real points, Figure 3).

To produce high quality tuberous yields, plants require an adequate supply of soil resources (water and mineral nutrients) and atmospheric resources, such as CO_2, O_2 and Photosynthetically Active Radiation (RFA). More than 90 % of the dry mass of a potato plant is obtained in the process of photosynthesis, in which CO_2, fixed and reduced to carbohydrates, is determinant for the production of tubers and other vegetable organs.

In general, the cultivation of the potato develops a long-lasting foliage, which favors the interception of a high proportion of the RFA, which to intercept 90 to 95 % of the RFA, has been found that the critical Foliar Area Index (IAF) should be close to three (19), an aspect that is also closely linked to the distance of planting.

In this regard, when determining the influence of planting density (45, 25, 16 and 8 plants m^{-2}), on the production of mini tubers larger than 10 mm in diameter and physiological growth indicators, under greenhouse and hydroponics conditions in the Gigant variety (20), they concluded that the growth rate (TAC) of the whole plant was positively influenced by the density and stage of crop development, while the TAC of the tubers, at a lower density, was superior to the treatment with 45 m^{-2} plants; the photosynthetic efficiency and the transfer of carbohydrates to the tuber, measured as Net Assimilation Rate (TAN) and Net Economic Assimilation Rate (TAEN), were 118 to 160 % higher in the density of 8 plants m^{-2}, which It could have happened in the fresh and dry mass of the experiments in this investigation.

It was found that the treatment of the distance between rows of 0.90 m caused plants of lower height and greater fresh and dry mass of the tubers, with respect to the distance of 0.75 m. One of the causes may be that as the distance of planting increases there is a lower self-shading between the plants and with this a greater use of the RFA by the plants is achieved, which translates into a greater production of photoassimilates than guarantees the necessary substances for the tuberization process.

In turn, other studies indicated that the production of total dry mass is the result of the efficiency of the foliage of the crop in the interception and use of solar radiation available during the growth cycle (21); This is summarized in internal growth factors related to the genotype and external factors related to the environment and management practices used during the crop cycle.

Table 4 shows the results of the foliar analysis performed at 45 DAP, which is part of the stage of greatest demand for nutrients by the plant.

Table 4. Results of the potato leaf analysis at 45 DAP, in the fourth fully developed and expanded leaf, at a distance between plants of 30 cm, in a Rhodic Kandiustalf soil of Huambo, Angola

Nutrient	Distance between rows	
	0,75 m	0,90 m
Nitrogenous	43,6 ± 0,81 b	52,2 ± 0,63 a
CV	12,44	8,16
t	-7,89**	
Phosphorus	1,30 ± 0,21 b	2,10 ±0,33 a
CV	12,18	10,14
t	-18,21**	
Potassium	20,52 ± 0,45 b	37,31 ± 0,63 a
CV	1,48	11,16
t	-25,5**	
Calcium	7,12 ± 0,11 b	11,20 ±0,14 a
CV	5,55	3,96
t	-43,37**	
Magnesium	1,61 ± 0,22 b	12,2 ± 0,33 a
CV	9,53	8,4
t	-13,92**	

n = 40. (2013-2014)
± Standard error. CV: Coefficient of Variation. t: Student's t
All the nutrients expressed in mg g^{-1}
Stocks with different letters in the same row differ significantly at a confidence level of 99%

At a lower planting density, the highest foliar concentrations of nutrients N, P, K, Ca and Mg were found, expressing a better nutritional status of the plant, which suggests that at the distance between rows of 0.90 m, the plants were able to assimilate a greater quantity of the applied fertilizer, in comparison with the plants developed to 0.75 m, manifesting the latter a greater competition for nutrients.

Notwithstanding the foregoing, when comparing the results of the foliar analyzes obtained, with Critical Indexes of nutrients established for potato plants under Cuban conditions (22), it was observed, in general, an inadequate nutrition of the plants for the main macro nutrients, in the two distances between rows studied.

To a large extent, the nutritional status of the plants corresponded to the low availability of nutrients and the acidity of the soil (Table 5).

Table 5. Some properties that characterize soil fertility Rhodic Kandiustalf from Huambo, Angola, used in experimentation

Depth of soil (cm)	pH Units	MO (mg g^{-1})	P (mg kg^{-1})	K^+	Ca^{2+}	Mg^{2+}
0-15	4,90	28,8	7,00	0,23	15,00	2,00
15-30	4,60	24,5	8,29	0,12	15,50	2,50

The importance of nitrogenous nutrition for the proper development of the crop is well known and different researchers report results that point to the interaction with planting density (5), water supply (23) and time of application (24).

For P, a low availability was considered in the arable horizon. A cause of this manifestation is the effect that caused the acidity of the soil since the availability of P is higher at pH values between 5.5 and 7.0.

When considering the degree of soil acidity, the P of the applied fertilizer could react with the hydrated oxides of Fe and Al and be precipitated by the formation of phosphates of those cations; in turn, be adsorbed by chemically bonding to the respective cations present on the surface of the minerals in the soil.

All the above, allows to explain the low phosphoric availability of the soil and, due to inadequate phosphoric nutrition manifested by the plant and reflected in the foliar analyzes, it can be inferred that the dose of applied phosphoric fertilizer was not enough to increase the P satisfactory levels nor to guarantee an adequate growth and development of the crop.

In particular, insufficient levels of potassium cause alterations in the internal quality of the tubers (26) and it has also been suggested that they present an interaction with planting densities (27).

The potato presents a radical fibrous system, branched, underdeveloped and superficial, issues that limit the absorption of nutrients, so it demands high levels of nutrients in the soil, also attending to its high growth rate of foliage and tubers.

The unsatisfactory nutritional status of potato plants, grown in the described soil-climatic environment (acid soil and poor in nutrients and high irregular supply of rainfall), is another element to consider when considering crop yields obtained in the conditions of production.

CONCLUSIONS

- ♦ The plants obtained in the different distances between rows (0.75 and 0.90 m), presented a development of the aerial part (stems), smaller in dry mass to the indicated by different authors; In addition, the initiation of the tubers was early, with a duration of this process lower than that indicated in the temperate countries. This behavior of the plants led to the obtaining of yields potentially lower than those reached for cultivation in other countries.
- ♦ In general, the treatments caused variations in the growth of the length, both at the moment and in the magnitude values of this growth, being more significant in the maximum height reached, where the distance between the narrowest furrows caused greater increases.
- ♦ The fresh mass of the tubers was the yield variable most influenced by the distance between rows, specifically the one of 0.90 m because it is the widest and which caused an advance in the growth in fresh dough with higher values of the rate absolute growth (TAC) and the maximum fresh mass.
- ♦ There was no definite pattern for the behavior of the dry tuber mass for the different treatments used; on the other hand, there was no correspondence of the growth dynamics of the tubers, expressed as a function of the fresh mass and the dry mass.
- ♦ The start of tuberization occurred at all times before the aerial organs reached their maximum TAC, which suggests that competition must have been established for assimilated between the aerial part of the plant and the tubers.
- ♦ The nutritional status of the potato plant according to the result of the foliar analysis was generally deficient; nevertheless, the planting at lower density reached a more favorable nutritional level, although without reaching the optimal level.
- ♦ It is shown that, in Huambo province, Angola, ambient temperature conditions are adequate for the development of tubers of potato plants and periods of low water supply to the crop can occur, when the plants receive this only at from the rainfall.
- ♦ The conditions of low pH of the soil and its nutrient content, cause an insufficient nutritional status in plants, which cannot be compensated by chemical fertilization, probably with an imbalance in the composition of each nutrient; this points to the need to improve these soils and to develop more detailed nutrition and fertilization studies for these edaphic conditions, with the integrated management of the nutrient supply, with organic fertilizer and chemical fertilizers.
- ♦ The results point to the water supply, especially during the period of “linear” growth of the tubers, and mineral nutrition, as aspects to be taken into account for a future optimization of the crop.

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