EFFECT OF SOWING DENSITY ON PLANT GROWTH AND DEVELOPMENT OF QUINOA, GENOTYPE 4.5, IN THE BRAZILIAN SAVANNAH HIGHLANDS

EFEITO DA DENSIDADE DE SEMEADURA NO CRESCIMENTO E DESENVOLVIMENTO DE QUINOA, GENÓTIPO 4.5, NO PLANALTO CENTRAL

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ABSTRACT: Successful quinoa cultivation in the Brazilian Savannah (Cerrado) relies on variety adaptation to its climate and soil conditions. Selected genotypes should be managed properly for maximal commercial yield. Experimentation in various parts of the world has been conducted to determine the population density that results on best use of water, light and nutrients, with soil cover during the biological cycle. The species originated in the Andean Altiplano, under cold nights and low moisture availability; it spread out to valleys and only in the last decades has gained space in other environments. This experiment with genotype 4.5, possessing biological cycle of 120 days, studied the effect of densities, varying between $100x10^3$ to $600x10^3$ plants ha^{-1}, on yield and related parameters. Except for plant height, negatively associated with density increase, grain and biomass yield, harvest index and 1,000 grain weight were not affected. The probable explanation for these results is the extraordinary capacity of quinoa to compensate for missing plants, by increased vigor and branching, although number of days to maturity tends to increase.

KEYWORDS: *Chenopodium quinoa*. Yield. Grain weight. Biomass. Harvest index. Plant height

INTRODUCTION

Defining suitable plant population is a factor of success in the commercial production of quinoa. Sowing density depends on various conditions, such as genotype growth habit, sowing date, climatic conditions and soil fertility (CARBONE RISI, 1986; SANTOS, 1996).

Quinoa plant cycle (number of days between emergence and maturity) is affected by latitude and altitude. In the environmental conditions of the Brazilian Savannah (Cerrado) Highlands, with latitudes between 15 and 16^oS, accessions sampling the species diversity showed variations between 80 and 150 days (SPEHAR; SANTOS, 2002). The early types were selected from Altiplano accessions, while late ones came from Andean valleys ancestry. Quinoa is classified as short day plant and may respond to day length variation, even though its centre of origin is located in the latitude of 14 ºS (probably, Lake Titicaca, between Bolivia and Peru). Selected genotypes did not show plant cycle differences when sown in December or April-May, in the Brazilian Savannah (SANTOS, 1996; ROCHA, 2008).

Positive correlation between stem diameter and yield, as well as field observations, indicate that low population density, in commercial sowings, ensues increased stem diameter, branching and yield per plant (SPEHAR; SANTOS, 2005).

Seed size is another factor that may affect stand uniformity. The sowing depth is critical at emergence and the technical recommendation is not to cover the seeds with more than 2 cm soil. Otherwise, emergence may be reduced, resulting in crop failure. In general, sowing rates have been high, to compensate for possible stand reduction (SPEHAR et al, 2007 a).

Experimentation in several locations has shown that distance between rows may vary between 0.20 and 0.5 m. Densities of up to $2x10^6$ plants ha^{-1}, evaluated soon after emergence, have shown considerable reduction to about $0.75x10^6$ plants ha^{-1} at maturity (WAHLI, 1990). Moreover, in some circumstances, either fertility or water stress, plant cycle elongated under low stand (CARBONE RISI, 1986; SANTOS, 1996)

Commercial quinoa cultivation, in the USA, has been based on initial populations of $1.5x10^6$ ha^{-1}, while row and broadcast sowings in the countries of origin may reach 10 times that value (JOHNSON; WARD, 1993). In contrast, in Central-Southern Chile, $240x10^3$ ha^{-1} has been the recommended population in quinoa. In the Brazilian Savannah, where there are mild temperatures, conditioning exuberant plant development, reduced population, within limits, is expected to yield satisfactory results on late maturity genotypes, such as BRS Piabiru (SPEHAR; SANTOS, 2007b).

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In the savannah, a density of 40 to 50 viable seeds m^{-1} row has shown to be sufficient for suitable ground cover; in broadcast or relay sowing the number is as high as 150 a 250 seeds m^{-2}. At these rates, the initial population may be higher than $1x10^6$ plants ha^{-1} (SPEHAR et al, 2007 a). In practical terms, satisfactory yields have been obtained when 10 a 15 kg ha^{-1} viable seeds are drill sown; in broadcasting the rate may reach 25 kg ha^{-1} de (SPEHAR; SANTOS, 2002). The recommendations for the savannah are based on practical knowledge, looking for ground cover. There are no investigations about the effect of population densities on growth and development parameters. This work had the objective to establish relations and to quantify the effects of density levels on mid cycle, adapted quinoa, genotype 4.5.

MATERIAL AND METHODS

The experiment was conducted during the dry season, under irrigation, at Fazenda Dom Bosco, located in Cristalina, GO, Brazil. The geographical coordinates and soil type are, respectively: 16º 14' S and 47º 27' W, at an altitude of 976 m.a.s.l; the soil is a Red Diastrophic Latosol, of clay texture.

Prior to the start, seeds of quinoa, genotype 4.5, kept in cold room, were evaluated for germination and vigor, indicating a minimum of 80% rate. These seeds were obtained from uniform seed multiplication fields. Genotype 4.5 is characterized by having a plant cycle of 120 days, either in summer or in winter (dry season) sowing (ROCHA, 2008). It originated from individual plant selection, on valley type populations. After successive selection cycles, progeny tests indicated phenotypical uniformity. It shows adaptability to tropical savannah conditions, reaching high grain and biomass yields (ROCHA, 2008).

Before the experiment was installed, soil samples were collected at the depth of 0-20 cm, for physical and chemical analyses. The analyses, conducted at the soil laboratory of Embrapa Savannah Research Centre, indicated the following values: i) Physical – 11.0, 17.0, 69.5 and 2.5% sand, silt, clay and organic matter; ii) Chemical – pH 5.68 (H_2O), Al 0.00, Ca 2.52, Mg 0.73 ($cmol_c$), P 7.54 and K 79.25 (mg L^{-1}). Maintenance fertilization was based on mineral element availability in the soil and the crop requirements (SPEHAR; SANTOS, 2007 c). No lime was applied, since the values for pH, calcium (Ca) and Magnesium (Mg) were sufficient for grain crop production. The fertilization, done before sowing, in rows opened by the drilling, consisted of 450 kg ha^{-1} of formulated 2-25-15, corresponding to nitrogen (N), phosphorus (P) and potassium (K), equivalent of N, P_2O_5 e K_2O.

The experimental area had been kept on no tillage and sowing was done manually on the rows opened by the planter. The crop residues from previous cultivation were kept between rows, helping to suppress weeds (SPEHAR; SANTOS, 2007 a) and to recycle nutrients (SPEHAR et al, 2007 b). The field was cultivated with maize in the summer, on no till. Before sowing, the experimental area was desiccated with glyphosate, in the dose of 2.5 L ha^{-1}, to eliminate weeds that grew after maize harvest and the experiment.

Sowing was performed on 30th of April 2007 with a density of 40-50 viable seeds m^{-1}, maintaining equidistance in distribution. The high seed rate was adopted for compensations due to emergence failure. The final expected density was of 15 to 20 plants m^{-1}. There was no thinning, in order to recover plots with high plant density.

Thirty days after emergence, there was a side dressing application of N, in the form of urea, at the rate of 200 kg ha^{-1} according to recommendation (SPEHAR et al., 2007 b).

During plant growth and development Clorpirifos insecticide was applied to prevent possible caterpillar attack, in the rate of 0.4 -0.8 ml ha^{-1}. To prevent soil borne disease damage and damping off, tebuconazol was applied at the rate of 400 ml ha^{-1}.

Water supply was made by central pivot irrigation system, at seven-day average intervals. The mean temperature was recorded during the experiment, indicating overall average of 21^{o}C. Irrigation was stopped when quinoa reached physiological maturity. This was characterized by leaf dehiscence and changes in panicle color. Harvest was performed on 4 September 2007.

Plot identification was based on recommended density for the savannahs, of 400.000 plants ha^{-1} (SANTOS, 1996). Higher and lower values were included, based on previous evaluation and sampling in the multiplication field. Thus, lower limits were placed at 100,000 plants, while the upper limits at 600,000 plants ha^{-1}. The experimental design was completely randomized, where each plot consisted of one 2.0 m row length, discarding borders, in the space 0.5 m, with an area of 1.0 m^2.

The effect of plant density was estimated by response of the following parameters: i) plant height – average plant height taken from a measuring tape placed in the plot middle; ii) number of days between emergence and physiological maturity – evaluated visually, on color change (green to yellow) and grain threshing by the panicle (at least 70%); iii) dry matter yield – harvested plants, cut at the basal point, were placed in polystyrene bags, kept open and hanged above the floor, with weight evaluation until reaching constant value, transformed into t ha^{-1}; iv) grain yield – after threshing, the harvested grains were exposed to ventilation to separate residues and dust, adjusting the values to 13% moisture and transforming the values into t ha^{-1}; v) harvest index (HI) – calculated on the ratio of grain weight to total dry matter weight, expressed in percentage, to reflect the respective proportion; vi) 1.000 grain weight – determined by the mean over 100 grain weight samples, multiplied by 10; vii) population density – number of plants m^{-1}, possessing previously defined densities of 100,000 to 600,000 plants ha^{-1}, with 100,000 intervals.

To eliminate the fine material of the grains, such as calcium oxalate and the perigon, adjustments had to be done, to adjust for the small seed size. For final cleaning, the threshed plots passed through a vacuum blower model Seedsorter, Motoyama Engineers. Grain yield and the other parameters were analyzed for regression on population density. A graphical representation was made to indicate the response of each parameter on density increment.

RESULTS AND DISCUSSION

The graphic representation for plant height, biomass and grain yields, harvest index and 1.000 seed weight, with respective regression equations and the R^2, are found in Figures 1 to 5.

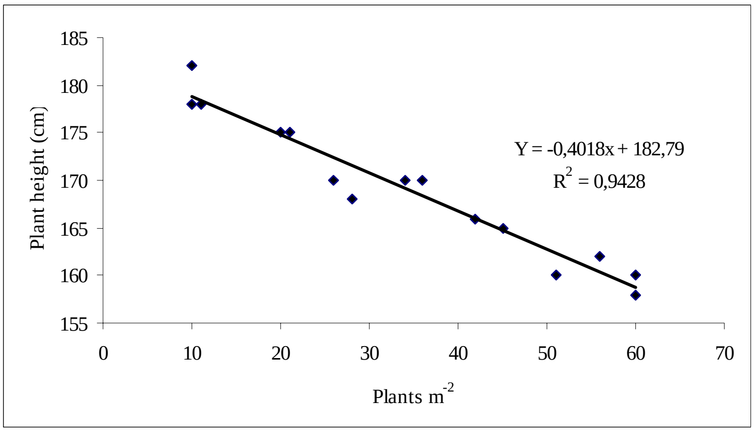

Figure 1. Plant height response to population density in quinoa, genotype 4.5. Fazenda Dom Bosco, Cristalina, GO, Brazil, 2007.

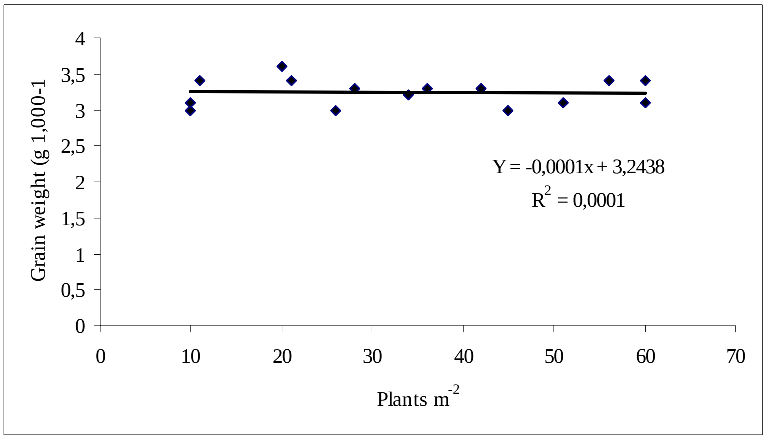

Figure 2. Grain weight response to population density in quinoa, genotype 4.5. Fazenda Dom Bosco, Cristalina, GO, Brazil, 2007.

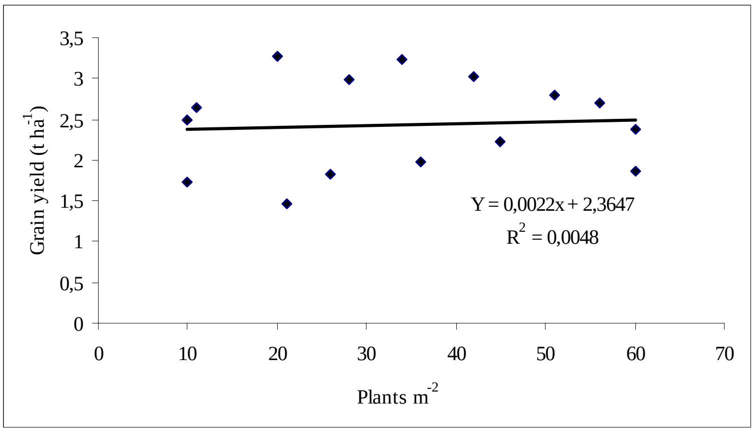

Figure 3. Grain yield response to population density in quinoa, genotype 4.5. Fazenda Dom Bosco, Cristalina, GO, Brazil, 2007.

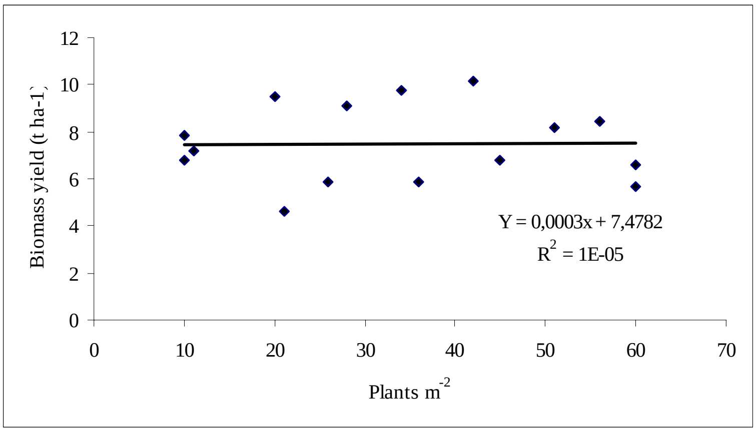

Figure 4. Biomass production response to population density in quinoa, genotype 4.5. Fazenda Dom Bosco, Cristalina, GO, Brazil, 2007.

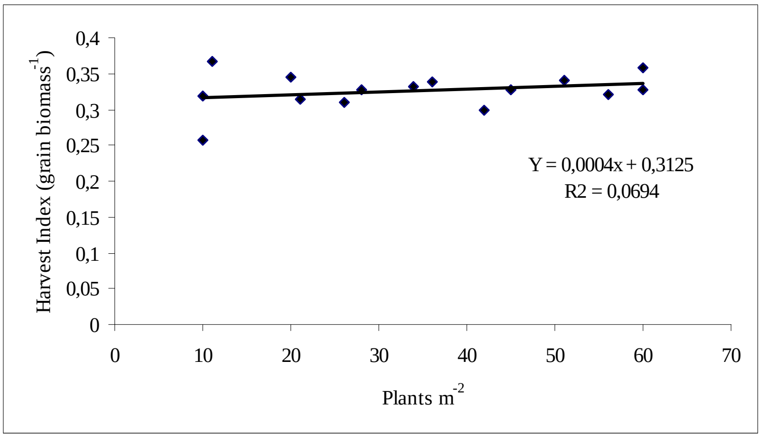

Figure 5. Harvest index response to population density in quinoa, genotype 4.5. Fazenda Dom Bosco, Cristalina, GO, Brazil, 2007.

Plant height decreased when the density increased from 100,000 to 600,000 ha^{-1}. The regression line defining response to density was highly significant value (R^2=0.94), with plants reducing 20 cm in the greatest density. Genotype 4.5, possessing biological cycle of 120 days, had, however, plant height sufficient for combine harvest in all densities. In the highest density, the number of observed branchings was smaller, when compared with low density. Moreover, plants in the high density reached maturity slightly earlier than in low density, as visually evaluated. The equation allowed predicting that, for every increment of 100,000 plants ha^{-1}, there was a reduction of 4.0 cm in plant height. These results illustrate the ability of quinoa to compensate for height for density (SPEHAR; SANTOS, 2005). Plant height decrease may be related to the high density limit. If higher densities were used, it might be possible that plant height would increase in competition for light.

The analyses of 1,000 seed weight, biomass and grain yield and harvest index did not show effect of density, resulting non-significant R^2 values. Thus, in the range of 100,000 to 600,000 plants ha^{-1}, quinoa genotype 4.5, responds equally, under the savannah conditions. These densities include recommended values for other genotypes (SANTOS, 1996). Average grain yield of genotype 4.5, across densities, was 2.5 t ha^{-1}, confirming the potential predicted in pioneer work (SPEHAR; SOUZA, 1993).

The probable explanation for the lack of response to increasing density has more to do with quinoa growth under higher temperatures than to the environment of origin. The same genotype, if cultivated in the Peruvian-Bolivian Altiplano, would have an approximate biological cycle of 180 days. Or, it would take much longer to cover the ground and compete with weeds, before development took place. This would be a plausible justification for using high population densities in that region (JOHNSON; WARD, 1993; WAHLI, 1990).

In the savannah, under low population densities, quinoa increases the number of branches, compensating, in part, for the missing plants (SPEHAR; SANTOS, 2002). Thus, the yield/plant ratio, not analyzed here, is expected to show higher values in low densities; likewise, stem diameter should increase (SPEHAR; SANTOS, 2005). This assertive allows inferring, within limits, that quinoa has yield stability. Other implications in weed control at low densities were not undertaken in this study, whereas it is a problem in the Andean region (WAHLI, 1990). One could expect that without proper ground cover the problem may intensify. In the present case, under no-tillage, with previous crops residues covering the ground, weed population tented to be low and equal for all densities. Insertion of quinoa in no-till cultivation has been proposed, using late maturity cultivar BRS Piabiru in integrated pasture-grain crop systems (SPEHAR; SANTOS, 2002)

Biomass and grain yield are interdependent, equally affecting harvest index (SPEHAR; SANTOS, 2005). Or, plant competition within row, at high densities, was not great enough to alter relations among these parameters. Similarly, variations in density did not affect 1,000 seed weight. The latter has a strong genetic component, although may be affected by climatic and soil conditions of the savannah (ROCHA, 2008).

These results illustrate how quinoa reacts to a range of population density, under savannah dry season-irrigated cropping. Low population may affect crop uniformity, bringing consequences to grain quality and yield due to weed competition and uneven maturity (SPEHAR et al., 2007). The use of highly dense sowings does not present advantage in savannah cultivation, contrary to these results turn evident the capacity of quinoa plants to compensate, at low stand, by additional branching to cover the empty spaces. It would be interesting, however, to include higher populations in experiments including combinations of row spacing and densities to confirm the effects on crop management and the limits to yield and other agronomic parameters.

CONCLUSIONS

Quinoa, genotype 4.5, with biological cycle of 120 days in the Brazilian Savannah, shows compensating growth capacity and, within the limits of 100,000 to 600,000 plants ha^{-1}, equalizes biomass and grain yield, harvest index and grain weight.

Plant height shows reduction with increasing density, in the row spacing of 50 cm, when population increases from 100,000 to 600,000 plants ha^{-1}.

Plants at low densities tend to increase branching, to fill the gaps, and to delay maturity.

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RESUMO: O cultivo de quinoa no Cerrado depende de adaptação varietal às condições de clima e solo. Genótipos selecionados devem ser manejados apropriadamente para atingir máximos rendimentos em lavoura comercial. Experimentação em várias partes do mundo tem sido conduzida para determinar a densidade populacional que resulte na melhor utilização de água, luz e nutrientes, com cobertura do solo durante o ciclo biológico. A espécie é originária do Altiplano Andino, crescendo sob noites frias e baixa disponibilidade de água; dispersou pelos vales e há apenas algumas décadas tem ganhado espaço em outros ambientes. Este experimento com o genótipo 4.5, possuindo ciclo biológico de 120 dias, objetivou contribuir ao entendimento sobre os efeitos de densidades populacionais, variando entre $100x10^3$ e $600x10^3$ plantas ha^{-1}, em rendimento e outros parâmetros relacionados. Exceto em altura de plantas, negativamente associada ao aumento de densidade, a produção de grãos e de biomassa, o índice de colheita e o peso de 1.000 grãos não mostraram diferenças significativas. A possível explicação para estes resultados é a capacidade extraordinária da quinoa em compensar a redução de estande, por aumento no vigor e no número de ramificações, ainda que o ciclo tenda a aumentar.

PALAVRAS-CHAVE: Chenopodium quinoa. Rendimento. Peso de grãos Biomassa. Índice de colheita. Altura de planta

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