Plant Density and Fungicide Application Effects on Disease Occurrence and Productivity in Onion

Densidade de plantas e aplicação de fungicida na ocorrência de doenças e na produtividade de cebola

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Mônica G. Harms
Doutora em Agronomia pela Universidade Estadual de Ponta Grossa
Universidade Estadual de Ponta Grossa
Endereço: Av. General Carlos Cavalcanti, 4748 - CEP 84030-900, Ponta Grossa - PR, Brasil
Email: monicagharms@gmail.br

Maristella Dalla Pria
Doutora em Fitopatologia pela Escola Superior de Agricultura Luiz de Queiroz
Universidade Estadual de Ponta Grossa
Endereço: Av. General Carlos Cavalcanti, 4748 - CEP 84030-900, Ponta Grossa - PR, Brasil
Email: mdallapria@uepg.br

Bráulio Luciano Alves Rezende
Doutorado em Agronomia pela Universidade Estadual Paulista Júlio de Mesquita Filho
Endereço: Instituto Federal Suldeminas- Campus Muzambinho, Estrada de Muzambinho, Km 35 - MG, 37890-000, Muzambinho - MG, Brazil
Email: blrezende76@gmail.com

André Manoso C. Prestes
Engenheiro Agrônomo pela Universidade Estadual de Ponta Grossa
Universidade Estadual de Ponta Grossa
Endereço: Av. General Carlos Cavalcanti, 4748 - CEP 84030-900, Ponta Grossa - PR, Brasil
Email: a.prestes@outlook.com

Polyana Elvira T. P. Christmann
Doutoranda em Agronomia pela Universidade Estadual de Ponta Grossa
Universidade Estadual de Ponta Grossa
Endereço: Av. General Carlos Cavalcanti, 4748 - CEP 84030-900, Ponta Grossa - PR, Brasil
Email: polyanaelvira@gmail.com

ABSTRACT

Experiments were conducted on the 2010 and 2011 harvests to assess the effects of plant density and fungicide applications on leaf disease occurrence and bulb productivity of Bella Dura hybrid onions (Allium cepa). The experimental design consisted of split-plot randomized blocks where the plots denoted the presence or absence of fungicide (metiram + pyraclostrobin; 2.5 kg p.c. ha$^{-1}$) and the subplots represented the plant densities (12, 14, 16, 18, 20 and 22 plants m$^{-1}$). The interaction between plant density and fungicide use was observed in the first experimental year by assessing mildew (Peronospora destructor) and purple spot (Alternaria porri) severity at 119 days after emergence (DAE) and in the second year by assessing mildew at 104 days after transplantation (DAT) and purple...
spot severity at 111 DAT. No significant difference in total productivity and mean bulb mass and diameter occurred between the densities tested in the 2010 harvest, regardless of fungicide spraying. The mean bulb mass and diameter decreased with plant density in 2011. Maximum total productivity was recorded at a density of approximately 18 plants m⁻¹.

**Keywords**: *Allium cepa, Alternaria porri, Peronospora destructor*, purple spot, mildew, plant population.

**RESUMO**

Experimentos foram conduzidos nas safras de 2010 e 2011 para avaliar os efeitos da densidade de plantas e aplicações de fungicidas na ocorrência de doenças foliares e produtividade de bulbos de cebola híbrido Bella Dura (*Allium cepa*). O delineamento experimental consistiu em blocos ao acaso com parcelas subdivididas em que as parcelas denotaram a presença ou ausência de fungicida (metiram + piraclostrobina; 2,5 kg pc ha⁻¹) e as subparcelas representaram as densidades das plantas (12, 14, 16, 18, 20 e 22 plantas m⁻¹). A interação entre densidade de plantas e uso de fungicida foi observada no primeiro ano experimental avaliando a severidade do mífido (*Peronospora destructor*) e da mancha púrpura (*Alternaria porri*) aos 119 dias após a emergência (DAE) e no segundo ano avaliando o mífido 104 dias após transplante (DAT) e severidade da mancha púrpura em 111 DAT. Não houve diferença significativa na produtividade total e massa média e diâmetro do bulbo entre as densidades testadas na safra de 2010, independentemente da aplicação do fungicida. A massa e o diâmetro médios do bulbo diminuíram com a densidade de plantas em 2011. A produtividade total máxima foi registrada na densidade de aproximadamente 18 plantas m⁻¹.

**Palavras-chave**: *Allium cepa, Alternaria porri, Peronospora destructor*, mancha púrpura, mífido, população de plantas.

**1 INTRODUCTION**

The onion crop (*Allium cepa*) stands out among the vegetable species for its consumption volume and economic value. It is ranked among the three most important vegetable crops worldwide, alongside potato and tomato (SCHMITT; SANTOS, 2009). China, with recorded yields of 24.0 million tons (FAOSTAT, 2019), is the leading onion producer. Brazil is the ninth largest onion producer, with a total production of 1.57 million tons, mean productivity of 28.3 t ha⁻¹, and 55.3 thousand hectares of planted area (IBGE, 2017). In Brazil, onion is the third most important vegetable in the economy (HIGASHIKAWA et al., 2017).

The lack of crop management and technical information on the cultivation system, especially regarding disease occurrence and plant population, are some of the factors responsible for low bulb productivity and commercial quality (HARMS et al., 2015).

The number of plants per hectare is a critical aspect in bulb productivity and commercial production. An increase in the plant population would contribute to improving both the environment and the cultivar exploitation, thereby increasing productivity. The solution lies in identifying and establishing an optimal population that ensures higher productivity (BAIER et al., 2009).
Based on the need for producing average bulbs (50–70 mm in diameter), farmers have sought new plant spatial distributions for harvesting bulbs, conforming to the consumer size demands. In the field, competition for water, light, and nutrients causes bulb size and total productivity to vary with the plant population (RESENDE; COSTA, 2005b).

Lopes et al. (2004) studied the effect of plant density on bulb productivity in three inter-row spacing distances of 0.20, 0.30, and 0.40 m, respectively, and a 0.08-m spacing between plants, noting that the highest commercial yield and lowest bulb fresh mass were obtained at the smallest spacing of 0.20 × 0.08 m.

Resende and Costa (2006) reported that the productivity at 0.10-m inter-row spacing (37.80 t ha⁻¹) was higher than that at 0.15-m inter-row spacing (34.40 t ha⁻¹). They assessed linear decreases in productivity with the spacing between plants, recording the highest yields (43.4 t ha⁻¹) at 0.10-m spacing between plants. However, onion productivity increased with the decrease in inter-row spacing and spacing between plants, similar to that reported by other researchers (STOFFELLA, 1996; BOFF et al., 1998; SANTOS et al., 2000).

In a study by Menezes Júnior and Vieira Neto (2012), testing five planting densities (200; 250; 300; 400 and 600 thousand plants ha⁻¹), the authors observed an increase in productivity of 8.34 t ha⁻¹, when the planting density was changed from 200 to 600 thousand plants ha⁻¹. With increasing plant spacing, Yuri et al. (2018) found a reduction in the yield of non-commercial bulbs (scrap).

Plant population also affected disease progression because of its association with the spread of infective units of pathogens and crop microclimate, the wind flow and soil shading, and varying relative humidity. Thus, plant density directly affects the leaf moisture, light, and relative humidity, which are key climatic factors for the development of several diseases in the onion plant (BOFF et al., 1998).

These researchers, when studying the effect of spacing (0.10 × 0.20 m, 0.08 × 0.40 m, and 0.10 × 0.50 m) on the occurrence of leaf diseases in the onion crop, observed that the smallest spacing had the highest severity of disease. They also reported that regardless of the spacing, fungicide spraying decreased the mean disease severity. Thus, the present study aimed to assess the plant density and fungicide use on leaf disease occurrence and productive characteristics of Bella Dura hybrid onions.
2 MATERIALS AND METHODS

In the 2010 and 2011 harvests, two experiments were conducted in the municipality of Ponta Grossa - PR, located at 25° 13’ latitude and 50° 03’ longitude, and at an altitude of 900 m. The soil is a typical dystrophic Tb HAPLIC CAMBISOL, with clayey texture (EMBRAPA, 2006).

The experimental design consisted of randomized blocks with four replicates in the 2010 harvest and three replicates in the 2011 harvest. Treatments were arranged in a split-plot design, with plots characterized by the absence or presence of treatment with fungicide (metiram + pyraclostrobin; 2.5 kg p.c. ha⁻¹) and the plant densities were represented in the subplots. The densities used were as follows: 12 plants m⁻¹ (363,636 plants ha⁻¹), 14 plants m⁻¹ (424,242 plants ha⁻¹), 16 plants m⁻¹ (484,848 plants ha⁻¹), 18 plants m⁻¹ (545,454 plants ha⁻¹), 20 plants m⁻¹ (606,060 plants ha⁻¹), and 22 plants m⁻¹ (666,666 plants ha⁻¹).

In 2010, hand sowing was performed on June 26, 2010, in rows spaced at 0.33 m, with a total of six rows per subplot (1.65 × 4.0 m). Plant emergence occurred 17 days after sowing (DAS). The nitrogen, phosphorus, and potassium (NPK) fertilizer with formula 5-25-25 was used at a dosage of 300 kg ha⁻¹ for side dressing. Side dressing (36-00-12) was performed at 62 and 82 days after emergence (DAE).

Weed control was carried out through manual weeding and herbicide application (ioxynil octanoate - 1.0 L p.c. ha⁻¹) at 23 and 36 DAE. Fungicide application was carried out at 56 and 117 DAE. Disease occurrence was monitored weekly until the onset of the first symptoms. The first and the second assessments were done at 119 DAE and 137 DAE, respectively, taking into account the percentage of leaf tissue affected by mildew and purple spot in 16 plants from the central rows of each plot using a diagrammatic scale (Azevedo, 1997). The bulbs were harvested from the plot usable area (2.97 m² plants from the central rows) where 80% of the plants showed shoot damping off (top collapse) at 148 DAE. The bulbs were then stored in a ventilated shed for 30 days for curing.

In the 2011 harvest, the seedlings were transplanted on 07/06/2011. The farming methods applied were similar to those used in 2010. Side dressing was performed at 54 and 80 days after transplantation (DAT) and herbicide was applied at 19 and 34 DAT. The first fungicide application was performed at 89 DAT on detecting the onset of the first symptoms. During the crop cycle, two more applications of the same fungicide were performed at 100 and 110 DAT. Mildew and purple spot severity assessments occurred at 90, 97, 104 and 111 DAT. Harvesting was conducted at 158 DAT (12/19/2011).

The mean bulb mass and diameter, and total productivity were quantified in both experiments. The data obtained were subjected to analysis of variance using the F test and the means of fungicides, where significant, were compared using the Tukey’s test at 5% probability and plant densities.
determined as significant, they were further subjected to a regression analysis. Data expressed as a percentage were transformed into arcsin $\sqrt{x/100}$ for analysis. The analyses were performed using the Statistical Analysis Systems (STAT) software (V. 2.0; STAT, 2001).

3 RESULTS

No significant interaction was observed between plant density and fungicide application, or between the treatments alone, based on the results of total productivity, bulb diameter and mass from the 2010 harvest. The mean values thus obtained, of total productivity, bulb mass and diameter were 30.54 t ha$^{-1}$, 32.90 g and 37.22 mm, respectively. In the 2011 harvest, the highest bulb fresh mass (79.21 and 62.93 g in the presence or absence of fungicide, respectively) was observed at the lowest plant density (Figure 1). Conversely, the lowest bulb fresh mass was obtained at a density of 22 plants m$^{-1}$, both in the presence and absence of fungicide, with values of 58.44 and 41.46 g, respectively.

FIGURE 1 - Mass (g) of onion (Allium cepa) bulb, hybrid Bella Dura, in different plant density, in the presence and absence of fungicide. Ponta Grossa/PR, 2011.

Similar results were reported by Resende and Costa (2005b), who showed that the bulb fresh mass increased linearly with the spacing between plants. They reported bulbs with higher mean fresh mass at 0.15-m inter-row spacing (102.57 g bulb$^{-1}$) than at the 0.10-m inter-row spacing (85.88 g bulb$^{-1}$).

The mean bulb diameter showed a linear response in the absence of fungicide (Figure 2). The highest value was recorded at the density of 12 plants m$^{-1}$ (45.94 mm), and the least was observed at the density of 22 plants m$^{-1}$ (39.07 mm). Regin et al. (2004) observed that the total bulb yield increased with plant density, although with a decrease in bulb diameter.
Plant density had a quadratic effect on total productivity (Figure 3). The highest total bulb productivity was projected in a population of 17.45 plants m\(^{-1}\), which would produce a total of 22.09 t ha\(^{-1}\) in the absence of fungicide, according to the adjusted regression equation. Conversely, fungicide application had no effect on bulb productivity at the different plant densities, reaching a mean productivity of 27.33 kg ha\(^{-1}\).

Harms et al. (2015) assessed that the total productivity of the Bola Precoce cultivar increased linearly with plant density, both in the presence and absence of fungicide. They found a 28% increase in productivity upon fungicide application when compared to the densities of 12 (14.22 t ha\(^{-1}\)) and 22 (18.21 t ha\(^{-1}\)) plants m\(^{-1}\).
A significant interaction was observed between plant density and fungicide application in the assessment of mildew and purple spot severity performed at 119 DAE in the 2010 harvest. No significant difference in purple spot severity was found between application and no application of fungicide at each density tested (Table 1). No significant difference was observed between the different plant densities either, when analyzing each density in the absence of fungicide. However, a significant difference occurred between the densities tested in the presence of fungicide. Purple spot severity at a density of 22 plants m\(^{-1}\) (7.98%) was higher than at a density of 12 plants m\(^{-1}\) at which the maximum severity reached was 6.54% (Table 1).

The data corroborate the findings by Boff et al. (1998), who reported that high densities cause increased foliar disease severity. Mildew severity was not affected by plant density with no application of fungicide, reaching 12.2% mean disease severity. The maximum disease severity (15.25%) was assessed at 14 plants m\(^{-1}\), differing significantly from the plant density of 12 plants m\(^{-1}\), at which severity was 10.85%, on application of fungicide.

The results from the assessment of mildew and purple spot severity performed at 137 DAE show no significant interaction between plant density and fungicide use. Thus, the data were analyzed separately. No significant differences in mildew severity were observed between the densities studied or when comparing it to plants with or without fungicide application. A significant difference in purple spot severity was observed between fungicide application and no application, signifying that fungicide use contributed to reduced disease severity (Table 2). Domingues and Töfolli (2009) assessed the lowest disease levels in the plots sprayed with the fungicide pyraclostrobin + metiram at doses of 2.0 and 3.0 kg ha\(^{-1}\) when studying the fungicide efficacy in controlling purple spot.

No significant interaction was observed between plant density and fungicide use, based on the results obtained from the 2011 harvest in the assessments of mildew severity performed at 90, 97, and 104 DAT and purple spot severity at 90, 97, and 111 DAT. Therefore, the data were analyzed separately. No significant differences were also observed between the densities used in these assessments.
**TABLE 1** - Severity (%) of purple spot (*Alternaria porri*) at 119 DAE and 104 DAT, and mildew (*Peronospora destructor*) at 119 DAE and 111 DAT in Bella Dura hybrid onions (*Allium cepa*), at different plant densities, in the absence or presence of fungicide (Ponta Grossa/PR, 2010-2011).

| Treatment | Purple spot severity 2010 (119 DAE) |
|-----------|------------------------------------|
|           | Density (plants m\(^{-1}\))       |
|           | 12  | 14  | 16  | 18  | 20  | 22  |
| Without fungicide | 7.40 | 6.66 | 7.02 | 6.58 | 6.99 |
| Aa*      | Aa  | 6.66 Aa | Aa  | Aa  | Aa  |
| 6.54     | 7.84 | 7.26 | 8.27 | 7.98 |
| With fungicide | Ab  | Aab | 8.05 Aa | Aab | Aa  | Aa  |
| C.V. (%) | Fungicide: 35.6 | Density: 9.4 |

**Mildew severity 2010 (119 DAE)**

| Treatment | Density (plants m\(^{-1}\)) |
|-----------|-----------------------------|
|           | 12  | 14  | 16  | 18  | 20  | 22  |
| Without fungicide | 13.12 | 11.54 | 13.14 | 11.39 | 11.44 | 12.49 |
| Aa        | Aa  | Aa  | Aa  | Aa  | Aa  | Aa  |
| 10.85     | 15.23 | 13.34 | 13.58 | 13.47 | 13.06 |
| With fungicide | Ab  | Ba  | Aab | Aab | Aab | Aab |
| C.V. (%)  | Fungicide: 27.7 | Density: 13.9 |

**Purple spot severity 2011 (104 DAT)**

| Treatment | Density (plants m\(^{-1}\)) |
|-----------|-----------------------------|
|           | 12  | 14  | 16  | 18  | 20  | 22  |
| Without fungicide | 26.90 | 26.58 | 26.32 | 28.43 | 25.54 | 25.60 |
| Aab       | Aab | Aab | Aa  | Ab  | Aab |
| 23.79     | 24.95 | 25.54 | 24.18 | 24.97 | 23.69 |
| With fungicide | Ba  | Aa  | Aa  | Ba  | Aa  | Aa  |
| C.V. (%)  | Fungicide: 6.4 | Density: 4.5 |

**Mildew severity 2011 (111 DAT)**

| Treatment | Density (plants m\(^{-1}\)) |
|-----------|-----------------------------|
|           | 12  | 14  | 16  | 18  | 20  | 22  |
| Without fungicide | 36.66 | 37.24 | 33.50 | 39.00 | 37.31 | 34.65 |
| Aa        | Aa  | Aa  | Aa  | Aa  | Aa  | Aa  |
| 31.87     | 32.43 | 31.42 | 31.12 | 28.62 | 30.03 |
| With fungicide | Aa  | Aa  | Aa  | Aa  | Baa | Aa  |
| C.V. (%)  | Fungicide: 18.5 | Density: 12.2 |

*Means followed by the same uppercase letter in columns and lowercase letter in rows are not different from each other according to the Tukey’s test at 5 % significance; Original data were transformed into arcsin √x/100 for data analysis; DAT: days after transplantation; C.V.: coefficient of variation.*
TABLE - 2 Severity (%) of mildew (*Peronospora destructor*) at 97 and 104 DAT and purple spot (*Alternaria porri*) at 137 DAE, in the absence or presence of fungicide in Bella Dura hybrid onions (*Allium cepa*). (Ponta Grossa/PR, 2010-2011)

| Treatment        | Mildew 97 DAT | Mildew 104 DAT | Mildew 137 DAT |
|------------------|---------------|----------------|----------------|
| Without fungicide| 21.15 A       | 32.06 A        | 34.56 A        |
| With fungicide   | 16.38 B       | 25.86 B        | 26.77 B        |
| C.V. (%)         | 11.77         | 7.91           | 28.8           |

* Original data were transformed into arcsin \(\sqrt{x/100}\) for data analysis; *Means followed by the same uppercase letter in columns are not different from each other according to the Tukey’s test at 5 % significance; DAT: days after transplantation; C.V.: coefficient of variation.

Plant density and fungicide application showed a significant interaction in the third assessment of purple spot severity performed at 104 DAT. No significant difference in disease severity was found between plant densities when analyzing each density within the fungicide application factor (Table 1). The fungicide application was noticeably efficient in controlling purple spot within each density, causing decreased purple spot severity at densities of 12 and 18 plants m\(^{-1}\) (Table 1).

A significant interaction between plant density and fungicide application was also observed in the fourth assessment of mildew severity performed at 111 DAT (Table 1). No significant difference was observed when analyzing the densities within the fungicide factor (presence or absence). The fungicide effect was only found at a density of 20 plants m\(^{-1}\), where disease severity was lowest on application. No significant differences were observed between application or no application of fungicide, at the other densities. Significant difference in the mildew severity parameter was only found at 97 and 104 DAT (Table 2) when analyzing the fungicide treatment separately. Disease severity was lowest on application of the fungicide.

4 DISCUSSION

In the 2011 harvest, the highest values of bulb fresh mass were observed at the lowest plant density (Figure 1), which may be related to the increased area of root exploration and the decreased competition for water, light, and nutrients between plants. Stoffella (1996), Boff et al. (1998), Kanton et al. (2002) and Harms et al. (2015) also estimated that bulb productivity and the ratio of bulbs with decreased mean mass increased with plant density when reducing inter-row spacing and the spacing between plants.

Resende and Costa (2005a) observed a gradual decrease in the number of bulbs with a diameter smaller than 35 mm and with spacing between plants, thus showing a reverse relationship between the increase or decrease in inter-row spacing and the spacing between plants and onion...
productivity. This finding suggests that the variation in the number of plants per unit area affects bulb productivity and quality and inadequate plant density is a contributing factor for low onion bulb quality and productivity.

The total productivity (Figure 3) increased gradually up to a density of 17.45 plants m\(^{-1}\), decreasing at densities of 20 and 22 plants m\(^{-1}\) where no fungicide was applied. The decrease in productivity in these densities, even producing a greater number of bulbs, is due to the production of a larger quantity of bulbs of small size and less mass.

Santos et al. (2000) assessed a significant decrease in bulb mass with the number of plants per area. They also found negative effects on productivity on increasing the spacing between plants. Increase in bulb mass of up to 57% associated with a 19.35% drop in total productivity occurred when the spacing between plants was increased from 0.05 to 0.10 m. An 18.59% decrease in bulb fresh mass was observed in the present study, accompanied by a 40.33% increase in total productivity when the plant density was increased from 12 to 17.45 plants m\(^{-1}\).

The inter-plant competition markedly affects the growth of the Bola Precoce onions (HARMS et al. 2015). The point at which plants compete for essential growth factors, including nutrients, light, and water, is reached when plant density per unit area is increased. High densities mostly produce an increase in the number of bulbs per area, albeit with decreased fresh mass and, consequently, a decreased commercial yield.

Thus, population assessment is important in onion cropping to obtain bulbs with good commercial quality. This can be achieved by maintaining an optimum plant population with adequate densities that yield the highest leaf area index for capturing the maximum solar radiation for photosynthesis while maximizing the allocation of the dry matter fraction to the vegetative and reproductive parts, thereby decreasing the competitive pressures (HAO; PAPADOPOULOS, 1999).

The mean productivity of 30.54 t ha\(^{-1}\) in the 2010 harvest and the maximum productivity at a density of 17.45 plants m\(^{-1}\) in the absence (22.09 t ha\(^{-1}\)) or presence of fungicide (27.33 t ha\(^{-1}\)) in the 2011 harvest are similar to the productivity reported in Brazil, in recent years, averaging 25.2 t ha\(^{-1}\) (IBGE, 2017).

Plant density also affects disease onset and progression because it directly effects the leaf moisture, light, and relative humidity, which are key climatic factors for disease progression in the onion crop, including mildew and purple spot. This explains the higher values of disease severity found at higher densities in some of the assessments.

The high severity of the purple spot disease observed in the present study may be explained by the characteristic features of the fungus, which shows enhanced growth at high temperatures, ranging from 24 to 28ºC, and high humidity. These factors were similar to those observed in the field
in our experiments which were conducted using sprinkler irrigation and at the beginning of summer in Paraná, when according to the Agronomic Institute of Paraná (Instituto Agronômico do Paraná – IAPAR; 2011), the average temperatures are around 21.4°C.

5 CONCLUSION

Plant density and fungicide applications had no effect on mean bulb mass and diameter, and productivity in the 2010 harvest. Fungicide application decreased the purple spot severity in the assessment performed at 137 DAE. Plant density affected the mildew and purple spot severity in the assessment performed at 119 DAE.

In the 2012 harvest, the decrease in mildew severity resulting from fungicide application occurred in the assessments performed at 97 and 104 DAT. Plant density affected mildew severity at 111 DAT and purple spot severity at 104 DAT.

Total productivity and bulb mass and diameter were affected by the plant density. Mean bulb mass and diameter decreased linearly with plant density. Maximum productivity obtained was at a density of approximately 18 plants m$^{-1}$.

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