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Effect of Mechanical Planting Density on Agronomic Performance of Organic Potato (*Solanum tuberosum* L.) Culture

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ABSTRACT

The demand for organic and quality agricultural product has increased in recent years, as population is increasing. Urban society is becoming concerned about organic food quality product. However, crop management options are extremely limited in organic systems, often leading to reduced yields. The objective of this study was to evaluate the effect of mechanized planting density on crop yield of organic potato (*Solanum tuberosum* cv. 'Spunta') conducted on the experimental plot of the Higher Institute of Agronomy, Chott-Mariem, Sousse, Tunisia. The experimental field was characterized by a sandy loam texture. Planting potatoes tubers was performed mechanically by a double row planter. Four planting densities were tested (19, 14.3, 16.6 and 12.5 plants/m^2). Results showed that d4 density (40 cm between plants and 80 cm between lines, which implies 12.5 plants/m^2) give the best growth parameters (fresh and dry weight of aerial parts, number of stems/plants and leaf area) and yield parameters (fresh and dry weight of tubers, tuber yield). In fact, d4 density (12.5 plants/m^2) gives more than 3 stems per plants than others densities and 3000 cm^2 leaf area. Concerning fresh and dry yield of potato aerial parts, d4 density gives respectively 320 g/plant and 29.28 g/plant. Regarding to potato caliber, d2 density (40 cm between plants and 70 cm between lines, which means 14.3 plants/m^2) gives the highest percentage of larger caliber (> 55 mm). Tubers yield was higher with d4 density (15 tonnes/ha).

Keywords: organic potato, mechanized planting, planting density, growth, yield

Abbreviations: d1, planting density (19 plants/m^2); **d2**, planting density (14.3 plants/m^2); **d3**, planting density (16.6 plants/m^2); **d4**, planting density (12.5 plants/m^2)

INTRODUCTION

Organic farming is defined as a production system according great importance to the relationship between plants, animals, humans and the environment (Miliare 1995). In Tunisia, and within a short period, organic farming has experienced huge growth with a net increase in area from 300 ha in 1997 to over 260.000 ha in 2008. This development is reflected in the number of organic farmers that has increased from 6 farmers in 1997 to more than 700 farmers in 2008 (CTAB 2008).

However, the organic production of potatoes is perhaps beyond the reach of the majority of farmers: organic fertilization assumes the availability of balanced nutrient compost and a sufficient farm area to allow long rotations (Fraser 2004). Regarding yields, they remain below expectations because of manual plantation system that requires much manual labor and time without ensuring regular depth distribution and tubers spacing between rows and on the ranks. These constraints affect yields and lead to an increase in the cost price of products (Vergniaud 1996). Moreover, soil type, weed pressure, especially perennials, and the itinerary followed in preparing the seed bed influences the yield of organic gardening (Vedie *et al.* 2009). For their part, Cambouris *et al.* (1996) showed that soil type influences significantly the yield and potential productivity of soils is an important component to integrate into the specific management of potato. Bouchard (1992) reported that plantation of potato is a step which has great effect on the volume and quality of crop yield. The density and depth of plantation are the factors which have the greatest impact on potato yield crop. According to Baarveld *et al.* (2002) potato can be cultivated in rows spaced from 50 to 100 cm apart, and a spacing ranging from 21 to 50 cm between plants in the same row depending on the size of the seed. Other authors (Tamia *et al.* 1999; Baarveld *et al.* 2002) reported that the yield of a potato crop is related to planting density. Moreover, the success of a potato culture requires mechanical planting allowing high regularity of depth and density of plantation (Ducattillon *et al.* 2007). According to Anonymous 2 (2007), planting densities varies from 400 to 500 tubers /ha are when the plants are spaced 26-32 cm in row and 75 cm between rows. Kojfer (2005) recommends having 4-5 plants/m^2 with a sufficient volume of soil. Piess and Heusser (2005) reported that increasing row spacing allows for significant savings of hours of machinery and labor and increases productivity at planting, maintenance, top killing and harvesting. The spacing between rows varies primarily according to the requirements of cultivar, seed size and environmental conditions, and depending on the desired size of the tubers at harvest (Bouchard 1992). Fraser (1998) reported that total yields of potato have increased steadily during the first years of testing to achieve an average ranging from 30-32 t/ha. The distance between hillocks depends on the farm equipment; it ranges from 0.75-0.9 m. However, a large spacing contributes on more substantial hillocks, which affects the success of weed control, tuber quality and the protection against downy mildew (De Reycke 2005).

For all these reasons the use of mechanical planting represents a solution for planting potato plants of different sizes of, at regular distances and depths, without damaging seeds (Oestges 1993).

The objective of this work was to study the effects of different mechanical plantation densities on the agricultural behavior of potato grown organically.

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Fig. 1 Potato planter machine with double rows.

MATERIALS AND METHODS

Trials

These tests are performed on a certified organic plot of the Higher Institute of Agronomy of Chott Meriem, Sousse, Tunisia. The plot of 480 m^2 was characterized by a sandy loam soil. The irrigation water used is characterized by a salinity of 1.07 g/l and a pH of 8.08. Tillage was applied on the considered soil at once 25 cm depth with a moldboard plow and twice with a tine cultivator at 12 cm depth.

Materials

Planting potato tubers was performed using a double row planter (GRUSE) equipped with an automatic distribution and powering system (**Fig. 1**). The adjustment of the spacing on the line is done by changing the speed ratio between the drive wheels and the drive shaft of the belt feeder. The adjustment between the lines is ensured by lateral sliding of bodies' planters on the chassis of the machine.

Two plant spacing, 30 and 40 cm, and two line spacing, 70 and 80 cm, were tested, which gave the following planting combinations:

Density 1 (d1): spacing between plants of 30 cm and spacing between lines of 70 cm = 19 plants/m^2.

Density 2 (d2): spacing between plants of 40 cm and spacing between lines of 70 cm = 14.3 plants/m^2.

Density 3 (d3): spacing between plants of 30 cm and spacing between lines of 80 cm = 16.6 plants/m^2.

Density 4 (d4): spacing between plants of 40 cm and spacing between lines of 80 cm = 12.5 plants/m^2.

Parameters measured

1. Vegetative growth parameters

a. Number of stems per plant. We counted the number of stems per plant on the chosen sample. This measurement was taken from the 45th day after planting.

b. Fresh and dry weight of aerial parts. At four different dates (45, 60, 75 and 90 days after planting (DAP)), 9 plants/treatment were pulled from different elementary plots. The pulled plants were separated from the underground part at the neck level. Then they were weighed. A sample of 100 g of fresh material from the aerial part, taken from each plant, is cut into pieces and then placed in an oven at 80°C, when its weight has stabilized and no longer varies, we measured the dry weight (DW). The fresh weight (FW) of the entire aerial part of the same plant was reduced to obtain DW.

c. Leaf area. Leaf area was determined on four separate dates (45, 60, 75 and 90 days after planting), on leaves sampled from plants of each treatment. Leaf area was determined using a planimeter.

2. Production parameters

a. Fresh and dry weight of tubers. Only the underground parts of the plant, devoid of tubercles, were weighed, which corresponds to the FW. A sample of 50 g weight was collected from the roots of each plant; it was cut into pieces and then placed in an oven at 80°C. When weight stabilized, root DW was determined by reducing the portion of total wet weight of the plant considered. During the trial, plants were uprooted four times to determine these parameters every 15 days from 45 DAP, in each case, 9 plants/treatment and per date of measurement. Separated from the underground part of each plant, the tubers were washed then weighed to determine FW. From each plant, a sample of 50 g of tubers was collected and cut into pieces and placed in an oven at 80°C until weight stabilized. This was the DW of tubers.

b. Calibration of the harvest. Tubers developed by each plant were calibrated as follows:

1: Small: diameter < 35 mm; 2: Average: 35 mm < diameter < 55 mm; 3: Large diameter > 55 mm.

c. Yield. This was the most important parameter determined since it would indicate any differences that may have existed between the four densities tested. This was determined by weighing the yield of potato tubers of each treatment. Final yield was calculated as tonnes/ha.

Statistical analysis

Statistical analysis of data was based on analysis of variance (ANOVA) using SPSS v. 13. Means were compared using Duncan's multiple range test at $P < 0.05$.

RESULTS AND DISCUSSION

Vegetative growth parameters

1. Number of stems/plant

Planting at a spacing of 70 cm between rows and a spacing of 40 cm between plants (d2) was characterized by the lowest average number of stems (2.4 stems/plant) (**Fig. 2**), significantly lower than d1, d3 and d4 with an average number of stems/plant of about 3.1. This could be explained by the fact that the number of stems is proportionally related to the number of axillary buds from the mother tuber; these parameters are closely related to each other physiologically and morphologically. The number of stems generally affects yield improvement thereafter. Struik *et al.* (1991) and Baarveld *et al.* (2002) also showed that the number of potatoes stems/unit area is related to planting density.

2. Fresh and dry weight of aerial part

The FW of vegetative parts (**Fig. 3A**) depended on the treatment and measurement date. In fact, 75 DAP (**Fig. 3A**), d2 and d4 gave the highest FW. At 90 DAP, d4 was distinguished from other densities by the largest FW although, unlike other densities, the FW of the vegetative part de-

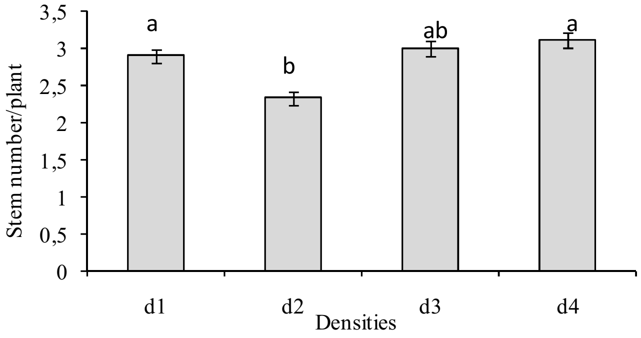

Fig. 2 Effect of plant density on stem number per plant. Means followed by the same letter are not significantly different at $P < 0.05$ according to DMRT. n = 9

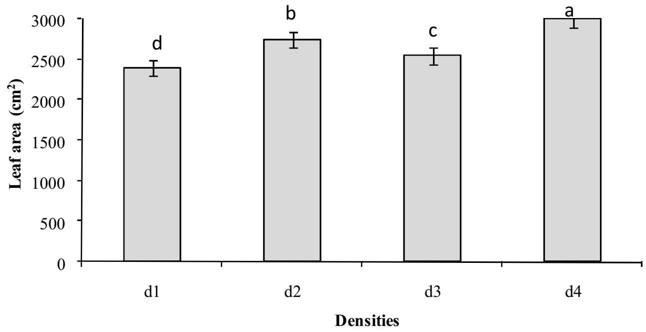

Fig. 4 Effect of plantation density in leaf area plant at 75 days after plantation. Means followed by the same letter are not significantly different at $P < 0.05$ according to DMRT. n = 9

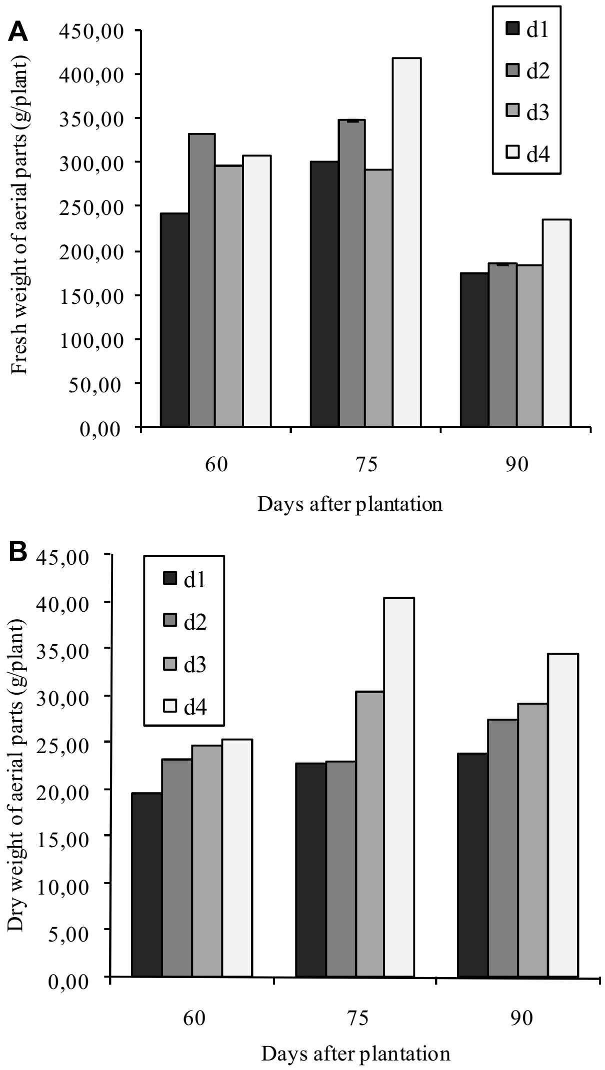

Fig. 3 Effect of plantation density in (A) fresh and (B) dry weight of aerial part of plants. n = 9

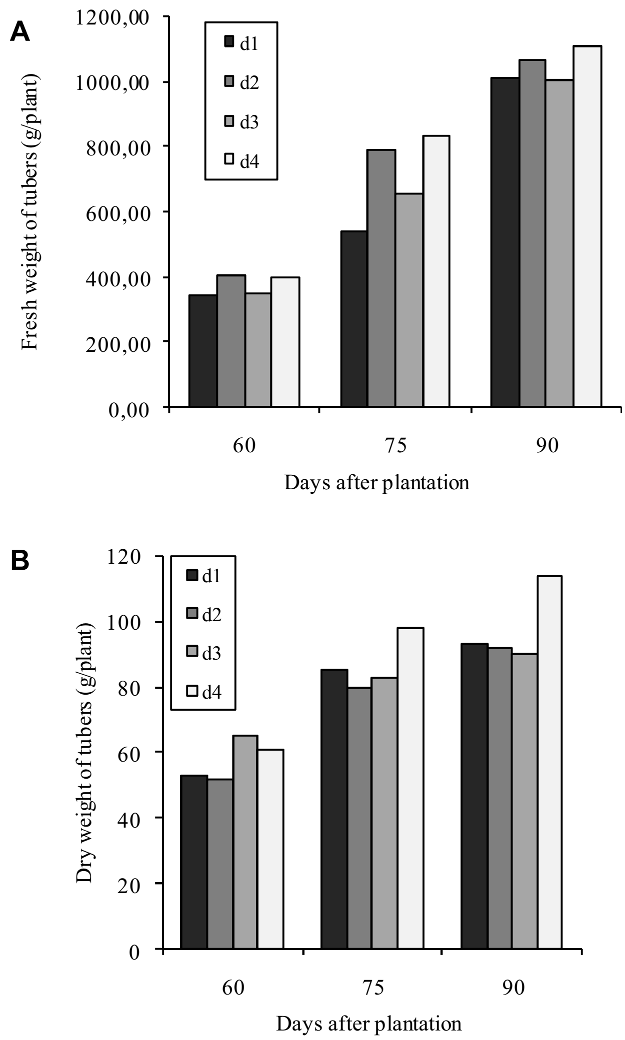

Fig. 5 Effect of plantation density in (A) fresh and (B) dry weight of tubercles. n = 9

creased at the end of the crop cycle due to plant senescence. Statistical analysis (**Table 1**) reveals a significant effect of both density and measurement date on FW of aerial parts. d4 gave the highest aerial parts FW and was significantly different from others densities. Considering the DW of the aerial part (**Fig. 4**), this parameter also depended on the type of treatment and the measurement date. Indeed, 75 and 90 DAP, the DW of the aerial part of d4 was higher than others. The DW of the aerial part did not differ significantly between different densities, possible because of the thickening of leaves and stems, the number of secondary stems and the development of leaf surfaces. Fresh material at 90 DAP decreased compared to that measured at 75 DAP, especially at d3 and d4. This can be explained by the fact that the leaves at this stage are in the process of senescence and retained their biomass. Statistical analyses (**Table 2**) showed a significant effect of density and measurement date on DW of aerial parts. d4 gave the highest DW of potato aerial parts.

3. Leaf area

The average leaf area/plant was statistically higher at d4 among the tested densities (**Fig. 4**).

Table 2 Dry weight (DW) of potato aerial part.

Density	d1	d2	d3	d4
DW (g)	21.87 d	24.90 c	26.93 b	33.33 a

Means followed by the same letter are not significantly different at $P < 0.05$ according to DMRT. n = 9

Table 3 Fresh weight (FW) of potato tubers.

Density	d1	d2	d3	d4
FW (g)	720.89 b	725.44 b	749.67 b	807.78 a

Means followed by the same letter are not significantly different at $P < 0.05$ according to DMRT. n = 9

Table 4 Dry weight (DW) of potato tubers.

Density	d1	d2	d3	d4
DW (g)	74.78 bc	77.00 ac	79.33 b	91.00 a

Means followed by the same letter are not significantly different at $P < 0.05$ according to DMRT. n = 9

Table 5 Effect of plantation density in tuber caliber.

Density Caliber (%)	d1	d2	d3	d4
Small (diameter < 35 mm)	13.3 g	2.1 h	13.7 g	14.3 g
Average (35 mm < diameter < 55 mm)	44.3 cd	40.4 e	43.5 cd	32.1 f
Large (diameter > 55 mm)	42.4 de	57.5 a	44.8 c	53.6 b

Means followed by the same letter are not significantly different at $P < 0.05$ according to DMRT. n = 9

Table 6 Final yield of potato.

Density	d1	d2	d3	d4
Yield (t/ha)	12.9 c	13.7 b	12 d	15 a

Means followed by the same letter are not significantly different at $P < 0.05$ according to DMRT. n = 9

Production parameters

1. Fresh and dry weight of tubers

The FW of tubers (**Fig. 5A**) was closely linked with the type of treatment and the measurement date. The FW of tubers was higher for d2 at 75 DAP and for d2 and d4 at 90 DAP. This may be related to good nutrition of the plant that contributes to a better development of roots, leaves, and therefore a perfect tuberization, knowing that the densities d2 and d4 are characterized by a spacing of 40 cm between tubers in a row. There were significant differences between densities and measurement date (**Table 3**). d4 gave the highest FW of potato tubers and was significantly different from others densities. The DW of tubers (**Fig. 5B**) also depended on the type of treatment and the measurement date. At 75 DAP, d1 and d4 form a group characterized by the highest DW although at 90 DAP, d4 had the highest tuber DW. This may be related to the proper development of the vegetative part and the FW of the tuber in d4. **Table 4** shows a significant effect of density and measurement date on potato tuber DW. d4 was significantly different from other densities and was characterized by the highest mean value (91 g/plant).

2. Harvest

d2 and d4 showed the highest percentage of tubers of large caliber, 53 and 57%, respectively (**Table 5**). The same densities formed 14 and 2%, respectively tubers of small caliber. In contrast, d1 and d3, each led to over 40% of tubers of medium size, almost 13% of tubers of small caliber and just over 40% of tubers of medium size. It thus appears that a reduction in planting density of mother tubers, especially by increasing row spacing, led to a production dominated by tubers of large caliber. In contrast, planting at high density led to a balanced production of tubers of medium and large caliber.

3. Yield

d4 had the highest potato tuber yield (15 tons/ha) (**Table 6**). The yield was 13.7, 12.9 and 12 tones/ha, respectively for d2, d1 and d3. Thus, d2 and d4, characterized by a high spacing in the row (40 cm), gave the best tuber yield. Improvement of yield is affected mainly by the spacing between potato tubers in a row.

CONCLUSION

This study examined the effects of mechanized planting density in different combinations (30 and 40 cm between plants and 80 and 70 cm between rows) on the yield of an organically grown potato crop. The main findings were:
- Compared to other treatments, the plantation density d4 (40×80 cm) resulted in the best vegetative growth;
- Treatments characterized by low planting density (d4) resulted in the highest levels of fresh matter of the aerial part of the plant;
- d2 (40 × 70 cm) and d4 (40 × 80 cm) resulted in the highest proportion of large tubers. d2 and d1 resulted in the lowest proportion of small tubers;
- d2 and d4 resulted in the highest yields at harvest (13.7 and 15 tons/ha, respectively).

Finally, plantation density has the greatest effect on crop yield and tuber caliber although the choice of planting density depends on final characteristics of agricultural product and consumer’s preferences.

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