Optimum In-row Distances for Potato Minituber Production

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ADDITIONAL INDEX WORDS. *Solanum tuberosum*, plant spacing, planting density, economic analysis, marginal return rate, asexual propagation

SUMMARY. Two field trials were conducted in the Dominican Republic to determine the influence of in-row distances on 'Granola' potato (*Solanum tuberosum*) minituber yield and economic returns. Seedlings generated from in vitro microtubers were transplanted in open-field raised beds at in-row distances of 0.20, 0.25, 0.30, 0.35, and 0.40 m to compare their minituber yield. In-row distances affected potato minituber weight and number per hectare and per plant. Increasing in-row distances from 0.20 to 0.40 m produced a significant decline on minituber weight per hectare (from 12.6 to 8.7 t·ha^{-1}, respectively). Minituber weight per plant increased linearly with in-row distances, improving from 195 g/plant at 0.20 m to 269 g/plant at 0.40 m. Minituber number per hectare declined linearly as in-row distances increased from 0.20 to 0.40 m, with values ranging between 425,000 and 119,000 minitubers/ha. Maximum values for the number of minitubers per plant were found with 0.20 and 0.25 m, with an average of 6.5 minitubers/plant. However, as distances between plants increased to 0.30 m or farther, the average values decreased to 5 minitubers/plant or less. The results demonstrated that the in-row distances of 0.20 and 0.25 m between plants were the most appropriate from the horticultural standpoint. However, the partial budget analysis reflected that the 0.25 m spacing had the highest marginal return rate among the treatments.

Potato multiplication occurs through sexual seed and asexual tubers (Love et al., 2003). Although sexual potato seed is used to breed potato cultivars, commercial potatoes are produced from tubers. This facilitates implementation of potato multiplication programs, ensuring tuber quality and supply. Potato seed programs rely on open-field, greenhouse, or hydroponic/aeroponic production systems to obtain small tubers or "minitubers," which are used for further multiplications. Previous research has shown that the minituber performance under field conditions was independent from the technique used for its production (Farran and Mingo-Castel, 2006). To obtain minitubers, in vitro potato seedlings are transplanted in sterile potting medium and grown for 6 to 10 weeks, depending on the potato cultivar (Bryan and Meléndez, 1985). Producing minitubers from in vitro plantlets allows fast multiplication rates in seed programs and reduces the number of field generations needed to obtain certified tubers (Ranalli, 1997). After 6 to 12 weeks under diffuse-light storage, potato minituber sprouting occurs and these are planted in open-fields or shade houses to obtain basic potato minitubers (Love et al., 2003; Wurr, 1978). These minitubers are mostly between 5 and 15 mm in diameter and have the potential to produce complete potato plants. Karafyllidis et al. (1997) and Georgakis et al. (1997) found that the minituber size generally has no effect on their yielding capacity, although small minitubers (10 mm or less in diameter) may have limitations for open-field multiplication.

One of the main concerns among potato minituber producers is the lack of information on specific horticultural management recommendations for its multiplication, since these practices are somewhat different from commercial potato production. Among those practices, in-row spacing and planting densities are critical to improve tuber number during each planting cycle. Planting densities are the result of combining in-row and between-row distances in the field. In-row distances are easier to change than between-row distances because bedding equipment might not have the flexibility to change spacings. Therefore, one approach for studying planting densities is changing in-row distances, maintaining constant between-row distances.

It is well known that intraspecific competition can alter above- and belowground biomass partitioning of vegetable species (Radosevich et al., 1997; Roush et al., 1989). Previous studies have indicated that potato cultivars have distinctive partitioning between tuber number and weight, depending on time and spatial arrangement in the field (Avilés, 2001). Thus, planting density variations could influence above- and belowground biomass accumulation and, subsequently, tuber number and weight. Karafyllidis et al. (1997) determined that more minitubers and yield per area are expected in high planting densities in contrast with low densities. Another study showed that increasing planting densities reduces the proportion of large minitubers in favor of more small minitubers (Georgakis et al., 1997). Love and Thompson-Johns (2006) arrived to similar conclusions using in-row distances ranging between 8 and 91 cm apart.

For any potato seed program, obtaining many medium-size minitubers is more important than producing few large minitubers. Thus, it is desirable to obtain the largest number of minitubers (at least 5 mm in

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Units

To convert U.S. to SI, multiply by	U.S unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha^{-1}	0.8922
28.3495	oz	g	0.0353
2.2417	ton/acre	t·ha^{-1}	0.4461

diameter) in the smallest possible space. Currently, there is scarce information about the effect of in-row spacing on potato minituber production for subtropical conditions. The objective of this study was to determine the influence of in-row distance on 'Granola' potato minituber yield and economic returns.

Materials and methods

Two field studies were conducted in 2001 and 2005 at the Horticultural Experimental Station of the Instituto Dominicano de Investigaciones Agropeucarias y Forestales (IDIAF) located in Constanza, La Vega, Dominican Republic, and in a potato grower's field at the same location. The average annual temperature and rainfall at Constanza are 18 °C and 1026 mm, respectively. The Constanza-IDIAF station is located 1164 m above sea level and has a sandy clay Mollisol with a pH of 6.7 and an organic matter content of ~5%.

Six-centimeter-tall 'Granola' in vitro seedlings were transplanted in plastic trays filled with a commercial potting mix formulated with sphagnum peat moss, fine-grade vermiculite, gypsum, and dolomitic lime (Sunshine Mix-3; SunGro Horticulture, Seba Beach, Alberta, Canada). Potato seedlings were maintained for 2 weeks in a 60% light-reduction screen house. One week before transplanting, potting substrate was fertilized with 50 $kg·ha^{-1}$ of 15N–6.5P–12.3K. Irrigation was provided twice per day for 30 min with microsprinklers. Two-week-old seedlings in a four-true-leaf stage were transplanted in single rows on top of open-field beds. Beds were 0.35 m tall and were separated 0.75 m from centers. Following soil test recommendations, 545 $kg·ha^{-1}$ of 15N–6.5P–12.3K were sidedressed and split in two equal fertilizer applications at 7 and 45 d after transplanting (DAT). Sprinkler irrigation and manual weed control were used both seasons. Five in-row distances (0.20, 0.25, 0.30, 0.35, and 0.40 m) were established with four replications in a randomized complete block design. Plots were consisted of a single 10-m bed section (7.5 m^2/plot). Experimental units were manually harvested 75 DAT, and potato minitubers of 5 mm or more in diameter were counted and weighed.

Examined variables were minituber weight and number per hectare, and minituber weight and number per plant. Treatment means were adjusted using plant number per plot as a covariable before regression analysis (P = 0.05). Standard errors were used to separate treatment means (SAS, version 9.1; SAS Institute, Cary, NC). The relationships between in-row distances and minituber weight per plant and minituber number per hectare were described with a linear model ($y = a + bx$), where a is the y-axis intercept and b is the slope of the equation. A quadratic equation ($y = a + bx + cx^2$) represented the dependency of total minituber weight per hectare and in-row distances. A logistic model [$y = c + d/1 + e^{(-a + bx)}$] established the best relationship between minituber number per plant and in-row spacing, where y is the response variable, x is the in-row spacing, a and b are the parameters that determine the shape of the curve, and c is the lower asymptote (Halford et al., 2001; Martin et al., 2001).

For the economic analysis, the partial budget methodology was applied on the two most promising treatments (Perrin et al., 1988). This methodology uses a two-step procedure: 1) the dominance analysis and 2) the calculation of marginal return rates (MRR). The dominance analysis consists on sorting the treatments based on costs and listing them from the lowest to the highest, together with their respective net benefit. In moving from the lowest to the highest, any technology that costs more than the previous one but yields less net benefits is said to be "dominated" and can be excluded from further analysis (Evans, 2005; Perrin et al., 1988). The MRR indicates the percentage of net revenue gains of switching from one practice to another and it is calculated as follows:

$$\text{MRR}=[(\text{highest net income} \div \text{lowest net income}) - 1] \times 100 \quad [1].$$

Results and discussion

There were no significant treatment by trial interactions. Therefore, the data from two trials were combined for analysis and discussion. In-row distances affected potato minituber weight per hectare and per plant. A quadratic model ($y = 6.7 + 54.31x - 122.86x^2$; r^2 = 0.92) described the relationship between potato minituber weight per hectare and in-row distances, with minituber weight per hectare steadily declining as in-row distances increased (Fig. 1). Increasing in-row distances between 0.20 and 0.40 m produced a significant decline (–44%) on minituber weight per unit area (12.6 to 8.7 $t·ha^{-1}$, respectively). This response is partly attributed to a 50% reduction of the number of plants per hectare as in-row distances increased from 0.20 to 0.40 m (from 66,667 to 33,333 plants/ha, respectively). At the same time, minituber weight per plant increased linearly ($y = 121.4 + 368x$; r^2 = 0.87) with in-row distances (Fig. 2). This suggested that wider in-row distances reduced intraspecific competition, therefore causing a significant increase in minituber weight per plant from 195 g/plant at a distance of 0.20 m to 269 g/plant at 0.40 m.

In-row distances influenced the number of potato minitubers per hectare and per plant. Minituber number per hectare declined linearly ($y = 731.4 + 1530.2x$; r^2 = 0.92) as in-row distances increased from 0.20 to 0.40 m, with predicted values ranging between 425,000 and 119,000 minitubers/ha (Fig. 3). When calculated in a per plant basis, a logistic model characterized the relationship between potato minituber number per plant and in-row distances ($y = 4.4 + 2.2/1 + e^{(-20.8 + 75x)}$; r^2 = 0.84). Maximum values for the number of minitubers per plant were found with 0.20

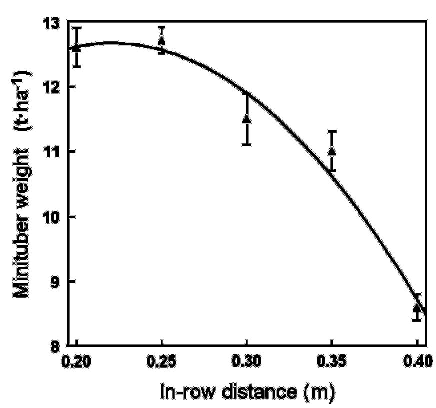

Fig. 1. Effect of in-row distances on 'Granola' potato minituber weight per hectare. Regression equation is: $y = 6.7 + 54.31x - 122.86x^2$; r^2 = 0.92 (1 m = 3.2808 ft, 1 $t·ha^{-1}$ = 0.4461 ton/acre).

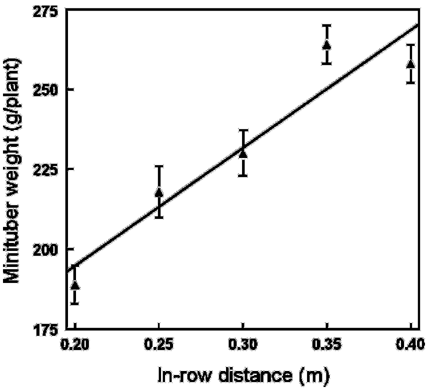

Fig. 2. Effect of in-row distances on 'Granola' potato minituber weight per plant. Regression equation is $y = 121.4 + 368x$; $r^2 = 0.87$ (1 m = 3.2808 ft, 1 g = 0.0353 oz).

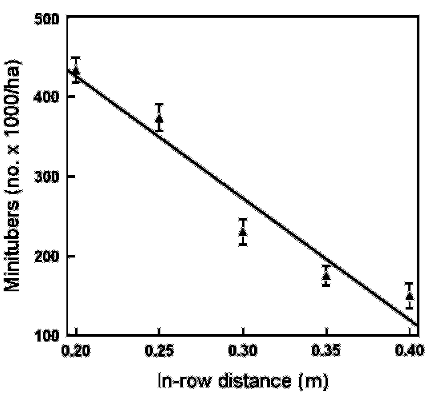

Fig. 3. Effect of in-row distances on 'Granola' potato minituber number per hectare. Regression equation is: $y = 731.4–1530.2x$; $r^2 = 0.92$ (1 m = 3.2808 ft. 1000 minituber/ha = 404.7 minitubers/acre).

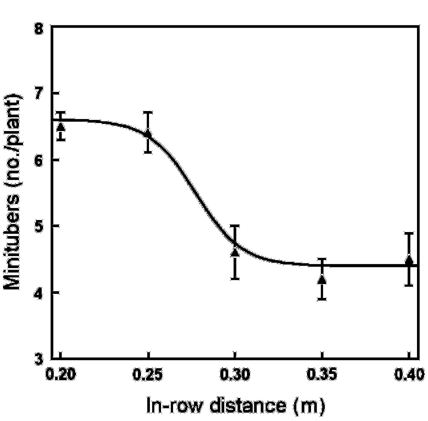

Fig. 4. Effect of in-row distances on 'Granola' potato minituber number per plant. Regression equation is $y = 4.4 + 2.2/1 + e^{(-20.8 + 75x)}$; $r^2 = 0.84$ (1 m = 3.2808 ft).

Table 1. Comparison of partial budgets and MRR for diverse in-row distances for potato minituber production (Constanza, Dominican Republic).

Cost components	In-row spacing[z] 0.25 m	0.35 m
Marketable yield		
Minituber weight ($t \cdot ha^{-1}$)[z]	12.80	11.01
Total gross revenue ($/ha)[y]	70,400	60,573
Variable costs		
In vitro seedlings ($/ha)	13,033	10,017
Potting medium ($/ha)	249	181
Pesticides ($/ha)	27	19
Hand labor ($/ha)	927	672
Fertilizers ($/ha)	53	39
Total ($/ha)	14,289	10,928
Revenues		
Net income ($/ha)[y]	56,111	49,645
MRR (%)[x]	13.0	

[z]1 m = 3.2808 ft, 1 $t \cdot ha^{-1}$ = 0.4461 ton/acre.
[y]$1.00/ha = $0.4047/acre; total gross revenue = minituber production multiplied by unit price of $5500/t ($4989.57/ton). Net income = total gross revenue minus total variable costs.
[x]MRR = [(highest net income ÷ lowest net income) – 1] × 100.

and 0.25 m, with an average of 6.5 minitubers/plant. However, as distances between plants increased to 0.30 m or farther, the average values significantly decreased to 5 minitubers/plant or less.

These results demonstrated that potato plants had differential production and distribution of photosynthates to minitubers depending on in-row distances. At 0.20 m between plants, potato plants produced many small minitubers (6.5 minitubers/plant and 29.1 g/minituber), whereas at a distance of 0.40 m between plants, there were fewer and larger minitubers (4.5 minitubers/plant and 57.3 g/minituber) (Fig. 4). Based on the previous values, total minituber production per plant was higher at an in-row distance of 0.40 m (258 g/plant) than at 0.20 m between plants (189 g/plant). Despite the increased minituber production per plant at wide in-row distances, potato minituber production schemes in open fields seek to obtain as many minitubers (5 mm of diameter or more) as possible in the same surface area. Therefore, the in-row distances of 0.20 and 0.25 m between plants were the most appropriate from the horticultural standpoint. Increasing in-row distances reduced intraspecific competition among potato plants, hence causing a major shift on the minituber production pattern from a few large minitubers at wider distances to many small minitubers at closer in-row spacings. These results agree with those reported by Karafyllidis et al. (1997) and Love and Thompson-Johns (2006), which showed that narrow in-row distances and high population densities reduced the proportion of large minitubers in favor of more small minitubers. These findings are important for commercial open-field minituber production programs because they allow for an increase minituber numbers and weight per unit area, which could increase economic returns.

The dominance analysis indicated that the two best yield options occur in plots planted at 0.25 and 0.35 m between plants (Table 1). Therefore, other distances were eliminated from further economic comparison. Partial budget analysis reflected that the 0.25 m spacing had a MRR of 13% better than with 0.35 m, indicating that potato producers would earn $0.13 extra for each dollar of net profit by planting 'Granola' potato for minitubers at an in-row distance of 0.25 m in comparison with 0.35 m. At the same time, growers would have the option of producing more potato plants in the same space (40% more plants per hectare) or reducing the amount of land used for seed production.

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