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THE EFFECTS OF PLANT DENSITY AND EYE NUMBER PER SEED PIECE ON POTATO (*Solanum tuberosum* L.) TUBER YIELD

Arif ŞANLI, Tahsin KARADOĞAN, Sabri ERBAŞ, Bekir TOSUN

Süleyman Demirel University, Faculty of Agriculture, Field Crops Department, 32260 Isparta, Turkey

Corresponding author e-mail: arifsanli@sdu.edu.tr

Abstract

This study was carried out to determine effects of plant density and number of eyes per seed pieces on yield and tuber size of potato (Solanum tuberosum L. cv Agria) in Turkey during 2011 and 2012 crop seasons. Treatments were arranged as a split plot design with plant density (distance on rows 20, 25 and 30 cm) as main plots, eyes number (2, 4 and 6 eyes) per seed piece as sub plots. Total tuber yield, yield of Grade C (45-35 mm) and Grade D (35-25 mm) sized tubers significantly increased with the increasing planting density. Number of tubers per plant, average tuber weight, tuber yield per plant and yield of Grade A (>60 mm) sized tubers significantly decreased with the increasing of plant density. With the increasing number of eyes in seed pieces, while tuber number per plant and yield of Grade C and Grade D sized tubers increased, average tuber weight decreased. The highest total tuber yield (40.6 t/ha) and Grade B (13.0 t/ha) and Grade C (15.3 t/ha) were obtained in the distance of rows at 20 cm and four eyes cut seed tubers. In conclusion, with the increase of the planting density and eyes number in seed piece, we noticed some decline in marketability and an increase the yield of seed tubers.

Key words: *eye number, plant density, potato, tuber yield.*

INTRODUCTION

Potato is an important vegetable crop in Turkey and covers around 125,000 hectares with a production of 3.95 mil tons (Anonymous, 2013). 320 thousand tones seed potatoes are needed to plant production area in Turkey annually. In Turkey, like other developing countries, seed potato production is the main limiting factor. The cost of seed represents the greatest proportion of the total production costs that can account for 30 to 50% of the total production expenses depending on the country or region (Kabir et al., 2004; Karim et al., 2010). For this reason, the larger seed tubers are usually cut into pieces to get maximum number of seed, thus minimizing the seed cost. But it is not clear that how many eyes are to be kept in each cut tuber piece to obtain a higher yield (Kabir et al., 2004).

When potatoes are grown for seed, cultural practices need to be used in order to maximize the production of seed size tubers and decrease the yield of large tubers. Tuber number is positively correlated with stem number and tuber size at harvest is inversely proportional to the number of tubers per hill (Lynch and Rowberry, 1977; Iritani et al., 1983). However, tuber number may be manipulated by altering stem and tuber number through changes in seed piece size and physiological age of seed tuber. Higher plant density or larger seed pieces effectively reduce overall tuber size (Iritani et al., 1983). However, increasing seed pieces per hectare or seed piece size also increases costs.

There are strong relationships between tuber yield and stem density (Jarvis, 1977) and between tuber yields distribution in different size grades and stem density (Wurr, 1974). Thus control over stem numbers is a fundamental requirement if growers are to control tuber size aiming to produce seed, table or ware potatoes. The density of the potato crop consists of two components. The first component is the number of plants generally referred to as plant density and the second is the number of stems per plant (Wiersema, 1987). The number of eyes determines stem number per seed piece (Nielson et al., 1989). The number of eyes and stems produced per seed piece increased as cut seed piece increased (Nielson et al., 1989). Each stem from a single eye can be regarded as an independent production unit. Thus a sufficient number of strong stems should develop per seed tuber. However, as much as higher stem density results in greater yield, it also affects the size of tubers. Growth is limited when competition among stems is high. At higher stem density, the tubers produced remained smaller than at lower stem density, while the percentage of large tubers decreased (Gulluoglu and Arioglu, 2009).

Seed spacing have been reported to influence yield, tuber size distribution, tuber, stem density and net returns of potato cultivars (Love and Thompson-Johns, 1999; Zamil et al., 2010). As stem density increased, fewer tubers were produced and this was due to a reduced multiplication rate which was defined as number of tubers produced per seed tuber (Fleisher et al., 2011). This effect is due to increased inter-plant competition for water, light and nutrients. It is therefore, essential to understand how individual plants interact with each other and the environment and to possibly come up with the ideal crop density levels to optimize yields. Increasing the planting density may lead to a decrease in the average weight of the tuber, and to an increase the outcome of the amount and weight of the tubers per unit area (Gasimova et al., 2010; Mahmoodabad et al., 2010; Somarin et al., 2010). According to Zamil et al. (2010) when the nutrition area of potato plants decreases, the number of stems and tubers reduces tubers weight per one plant. The primary purpose of the current study was to study the influence of eye number per seed piece and plant density on the growth and yield of the potato in order to achieve maximum production of seed tubers.

MATERIALS AND METHODS

Field experiments were conducted at the research farms of Suleyman Demirel University, in Isparta province (Lakes Region, 37º45' N, 30º33' E, altitude 1035 m) during 2011 and 2012 crop seasons, using the cv. Agria. The soil of the experimental field was loam, low in organic matter (1.5%) and alkaline (pH 8.1). Nutrient content of the experimental area was determined for the entire location and it was divided two parts and each part was used to grow potato during first and second year of the study, separately. Total nitrogen content of the entire location was 0.21% (micro Kjelhdal method), extractable P and K contents were 19.8 mg/kg (Olsen method) and 179 mg/kg, respectively. Total precipitation between April to October was 226 mm and 201 mm for the first and second years of the experiment, respectively. For the same period, the long term average rain fall was 188 mm. Average daily temperature was 19.7°C and 18.8°C, for 2011 and 2012 crop seasons, respectively. Long term average daily temperature between April and October was 18.1°C.

The experiment was established as split plot design with three replications. In-row spacing (population density) was assigned to the main plots and eye number per seed piece was assigned to the sub plots. Population density involved at three levels; 20 cm, 25 cm and 30 cm. Cut seed tubers containing 2 eyes (15 g/piece), 4 eyes (30 g/piece) and 6 eyes (50 g/piece) were used as eyes number treatments. Each plot consisted of 4 rows having 6 m length. Potatoes were planted at three intra-row spacing of 20, 25 and 30 cm, while the inter row spacing was kept constant at 70 cm. All the seeds were planted by hand on 16 April in 2011 and 22 April in 2012. Basal fertilizer (20%N-20%P-20%K) was applied at the rate of 500 kg/ha prior to planting. Additional fertilization of ammonium sulphate (AS) was applied at 4 and 8 weeks after emergence at a rate of 200 kg/ha. Cultivation, hilling up and hand weeding were conducted as necessary. Irrigation was performed with sprinkler irrigation system when available soil moisture dropped below 50% in soil. Tubers were harvested at the second half of September for each growing year and yield and yield components were determined from middle row of each plot.

Data was subjected to the analysis of variance (ANOVA) procedure with SAS statistical program (SAS, 2009). Means were separated using Duncan's multiple range tests at the 0.05 significance level. Results were averaged over 2 years and analysis was performed on those results.

RESULTS AND DISCUSSIONS

According ANOVA results, differences between years and year interactions were not statistically significant for all studied traits.

Tuber Number per Plant

Intra-row spacing and eye number per seed piece significantly (P>0.01) influenced the number of potato tubers per plant (Table 1). Tuber number per plant increased with the increased eye number in cut seed tubers. Tuber number was found maximum (7.8 tuber/plant) in 6-eyed cut seed piece and minimum (4 tuber/plant) in the cut seed tubers containing 2 eyes (Table 2). Also, increase in in-row spacing led to significant increase in tuber number, the highest and the lowest tuber number was obtained at 30 cm and at 20 cm, respectively (Table 2). The combined effect of in-row spacing and eye number in cut seed tuber produced significant (P>0.05) variation in tuber number. The number of tubers per plant significantly increased in 6-eyed cut seed piece with increasing in-row spacing, while 2-eyed cut seed piece had the similar tuber number with the increasing in-row spacing (Table 2). Tuber production per plant are directly correlated with number of main stems per plant and significantly affected by inter-plant and intra-plant competition (Moorby, 1967; Bussan et al., 2007). Increasing plant density and decrease in the inter plant distances lead to decrease in the number of tuber per plant. It was could be due to per share of the light and food are reduced resulting in increased competition within plant. Many authors previously reported that tuber number per plant increased with the increasing distance between the in-rows of plants (Jones and Alben, 1989; Gulluoglu and Arioglu; Samarin et al., 2010; Tahmorespour et al. 2013; Ayupov et al., 2014). Several stems develop from individual seed tubers depending on size and physiological age of seed tubers (Gulluoglu and Arioglu, 2009). Cut seed tubers containing more eyes produced more stems. Since each stem is an independent production unit, an increase in their number will consequently translate to more tubers per plant. Similar results were reported by Wiersema (1987) and Shayanowako et al. (2014).

Table 1. Results of Analyses Variance (ANOVA) for the traits measured in the study

Source of variance	df	Tuber number per plant	Average tuber weight	Grade A	Grade B	Grade C	Grade D	Tuber yield per plant	Total tuber yield
Year (Y)	1	ns	ns	ns	ns	ns	ns	ns	ns
Rep (Year)	4	ns	ns	*	ns	ns	*	ns	ns
Distance in-rows (D)	2	**	**	**	**	**	**	**	**
Y x D	2	ns	ns	ns	ns	ns	ns	ns	ns
Rep x D (Y)	8	ns	ns	ns	ns	ns	ns	ns	ns
Eye number (E)	2	**	**	**	**	**	**	**	**
Y x E	2	ns	ns	ns	ns	ns	ns	ns	ns
D x E	4	*	**	**	**	**	*	**	**
Y x D x E	4	ns	ns	ns	ns	ns	ns	ns	ns
Error	24								
CV%		5.9	8.1	5.9	8.4	9.0	9.8	4.7	4.4

df, degrees of freedom ; ns, non-significant; * P<0.05; ** P<0.01

Average tuber weight

Average tuber weight was significantly (P>0.01) affected by both in-row spacing and eye number per seed piece and in-row spacing x eye number per seed piece interaction effect (Table 1). The lowest mean tuber weight was obtained from the closest in-row spacing (20 cm) and mean tuber weight values tended to increase with widening in-row spacing (Table 2). Average tuber weight decreased with increased eye number per seed piece. As plants planted containing 2-eyed tubers exhibited the highest tuber weight compared to those planted containing 4 or 6-eyed tubers (Table 2). The highest (171 g) and the lowest (76 g) average tuber weight was obtained from 4-eyed cut seed tubers at 30 cm in-row spacing and 4 and 6-eyed cut seed tubers at 20 cm in-row spacing (Table 2).

The competition between and within the plants increased with plant density increase (Karafyllidis et al., 1997) and this situation leads to decreased availability of nutrients for each plant and consequently, results in decline of mean tuber weight. Similarly, many researches stated that the crop established at closest planting produced larger but fewer tubers than that established at wider planting (Somarin et al., 2010; Masarirambi et al., 2012; Tahmorespour et al., 2013). Dehdar Masjedlo, (2002) reported that increasing plant density (decreasing distance between the rows of plants) increased tuber yield, number of main stems and the average number of tubers/m^2 but the average tuber weight was reduced. Individual tuber weight was found to be higher when tubers with fewer eyes per piece were used. It is possible that seed pieces having fewer eyes produced less number of stems and tubers per plant resulting in increased individual tuber weight. These finding are in agreement with observation by Shakh et al. (2001) who reported decreased average tuber weight with increased eye number per cut seed piece.

Tuber Size Grading

The effects of in-row spacing and eye number per seed piece and their interactions on tuber size grading was significantly (P>0.01) important (Table 1). While the Grade A tuber yield increased with the increase in in-row spacing, Grade C and Grade D tuber yield decreased. With the increasing eye number per seed peace, Grade C and D tuber yields significantly increased (Table 2). Mean yield of Grade A was higher in 4-eyed cut seed tuber (9.54 t/ha) than the cut seed tubers containing 2 or 6 eyes. Grade B tuber yield was lower in 2-eyed cut seed tuber (8.57 t/ha) (Table 2). The highest yield of Grade A tuber was obtained at 30 cm in-row spacing in 4 and 6-eyed (11.98 t/ha and 12.40 t/ha, respectively) cut seed tuber, while Grade B, Grade C and Grade D tuber yields had the highest at 20 cm in-row spacing with 4-eyed (12.95 t/ha), 4 and 6-eyed (15.23 t/ha and 14.13 t/ha, respectively) and 6-eyed (7.43 t/ha) cut seed tubers, respectively (Table 2).

The proportion of larger tuber was the highest at the wider spacing and the non-marketable yield increased with increasing stem density. This could be a result of greater competition for water, nutrients and sunlight during tuber bulking at closer in-row spacing resulting in fewer assimilates available for each individual tuber. By increasing planting density, the portion of small tubers increases, the portion of large ones declines, and the yield of seed fractions increases (Marin, 1986; Trusov, 1990). Our results confirm works of Wiersema (1987), Rex (1990) and Love and Thompson-Johns (1999) who reported a reduction in total marketability of tubers as plant population increased. Similarly, Allen (1992) reported that as plant density increased the weight and size of tubers produced per plant is reduced. The number of eyes determine stem and tuber number per seed pieces because each stem from a single eye can be regarded as an independent production unit (Nielson et al., 1989). However, higher stem density results in greater yield; it also affects size of tubers. Growth is limited when competition among stems is high. Thus, the grade of produced tubers by per plant also depends on planting density. At higher stem density, the tubers produced remained smaller than at the lowest stem density, while the percentage of large tubers decreased (Gulluoglu and Arioglu, 2009). The desired size of the potato depends on the intended use. For seed production, diameter of 25-60 mm tubers is preferred. The highest yield of Grade C and Grade D (more valuable for seed production) were obtained at 4 or 6-eyed cut seed tubers planted in closest in-row spacing, while larger tubers (Grade A) were higher at wider planting space. Plants established from large seeds produced smaller but numerous tubers whereas those established from small to medium sized seed produced few but large tubers as previously reported (Wurret al., 1993; Love and Thompson-Johns, 1999; Khan et al., 2010).

Tuber Yield per Plant

In-row spacing and eye number per cut seed tuber significantly (P>0.01) affected tuber yield per plant (Table 1). Mean tuber yield per plant increased with increasing in-row spacing and it was determined 512 g, 618 g and 737 g at 20, 25 and 30 cm in-row spacing, respectively (Table 2). Mean tuber yield per plant significantly (P>0.001) increased as eye number per cut seed pieces increased from containing 2-eyed tuber to 6-eyed tuber (Table 2).

Table 2. Effects of different in-row spacing and eye number in cut seed piece on measured traits

Eyes number	Distance in-rows (cm) Number of tubers per plant				Distance in-rows (cm) Average tuber weight (g)			
	20	25	30	Mean	20	25	30	Mean
2	5.5e	5.5e	5.6e	5.5c	81.7cd	97.8ab	103.0a	93.9a
4	7.4d	7.6cd	7.9bc	7.6b	75.7d	85.3c	97.3ab	86.1b
6	7.9bc	8.1b	8.8a	8.3a	66.7e	81.0cd	96.0b	81.2c
Mean	6.9b	7.1b	7.4a		74.5c	88.1b	98.6a	

Eyes number	Grade A yield (t/ha)				Grade B yield (t/ha)			
	20	25	30	Mean	20	25	30	Mean
2	7.3e	9.3d	10.3bc	9.0b	9.9e	9.0e	6.8f	8.6b
4	6.3f	10.4b	12.0a	9.5a	13.0a	12.0b	10.9cd	12.0a
6	4.8g	9.6cd	12.4a	8.9b	11.0cd	11.9bc	11.6bc	11.5a
Mean	6.1c	9.8b	11.6a		11.3a	11.0a	9.8b	

Eyes number	Grade C yield (t/ha)				Grade D yield (t/ha)			
	20	25	30	Mean	20	25	30	Mean
2	10.3b	6.9d	3.3f	6.8c	4.8d	3.8e	2.6g	3.7c
4	15.2a	8.4c	5.1e	9.6b	6.1b	4.8d	3.4f	4.8b
6	14.1a	10.3b	6.4d	10.3a	7.4a	5.5c	4.2e	5.7a
Mean	13.2a	8.5b	4.9c		6.1a	4.7b	3.4c	

Eyes number	Tuber yield per plant (g/plant)				Total tuber yield (t/ha)			
	20	25	30	Mean	20	25	30	Mean
2	455f	528e	572d	518c	32.3d	28.8e	22.9f	28.0b
4	547de	653c	782b	660b	40.6a	35.6bc	31.4d	35.9a
6	534e	672c	858a	688a	37.3b	37.2b	34.8c	36.4a
Mean	512c	618b	737a		36.7a	33.9b	29.7c	

Numbers with the same letters in each column, have no significant differences to each other

The interaction of in-row spacing and eye number per cut seed tuber also significantly affected to tuber yield per plant. The highest (858 g) and the lowest (455 g) tuber yield per plant were observed at 30 cm in-row spacing with 6-eyed cut seed tuber and at 20 cm in-row spacing with 2-eyed cut seed tuber, respectively. Tuber yield per plant decreased at 6-eyed cut seed tuber at 20 cm in-row spacing while increased at the 30 cm in-row spacing compared to tubers containing fewer eyes (Table 2).

Since higher number of tuber per plant and the highest average tuber weight were obtained from 30 cm in-row spacing, this treatment also gave higher tuber yield per plant. Increasing in tuber yield per plant in wider planting could be due to the availability of adequate space for root and tuber expansion and less competition for light, water and nutrients. Bremer and Taba (1966) and Allen and Wurr (1992) reported that planting density affects on tuber yield per plant significantly and with increasing distance between the rows, tubers yield per plant increases. Additionally, Ayupov et al. (2014) stated that increased density is reduced tuber yield per plant. Cut seed tubers containing more eyes were larger in size and larger seed tubers have a greater amount of reserve material than smaller seed tubers (Love and Thompson-Johns, 1999; Kabir et al., 2004). This resulted in higher relative growth rates of tubers with more eyes than those with fewer eyes. Similarly, Strange and Blackmore, (1990) and Shakh (2001) showed that tuber yield per plant increased as increasing the eye number per cut seed piece.

Total Tuber Yield

Total tuber yield was significantly (P>0.01) affected by in-row spacing and eye number per cut seed tuber (Table 1). As the planting density increased there was a corresponding increase in yield. Mean total tuber yield was higher at closest in-row spacing (36.70 t/ha) than wider in-row spacing (29.71 t/ha) (Table 2). Total tuber yield increased with increasing eye number per cut seed tuber, but differences between 4 and 6-eyed tubers were not statistically significant. There was a significant (P>0.01) interaction between in-row spacing and eye number per cut seed pieces (Table 1). Planting of 4-eyed cut seed tubers at closest in-row spacing gave the highest (40.55 t/ha) total tuber yield (Table 2). The lowest total tuber yield (22.94 t/ha) was obtained from 2-eyed cut seed tubers at 30 cm in-row spacing (Table 2). Differences between 6-eyed cut seed tuber planting at 20 and 25 cm in-row spacing and 4-eyed cut seed tuber planting at 25 cm in-row spacing was not significant in terms of total tuber yield (Table 2).

Major yield components such as number of tuber per plant, mean tuber weight and tuber yield per plant significantly decreased as planting distances became closer in this study due to increased inter-plant competition. Increase in number of tuber per hectare with increasing plant density and eye number per cut seed tuber may result in increase in tuber yield per unit area. Tuber yield per hectare reduced at wider in-row spacing due to reduction of hill number per unit area. Similarly, with the increased plant density, yield was decreased in each plant but increased per unit area (Asl Gorgani and Damavand, 1996; Alvin et al., 2007; Bussan et al., 2007; Tahmorespour et al., 2013). Additionally, Love and Thompson-Johns (1999) showed that the highest total yield occurred at the closest spacing, and then declined as spacing widened. Based on the increased eye number per cut seed tuber, the increase of tuber number and tuber yield per plant also caused increased of total tuber yield.However, total tuber yield of 6-eyed cut seed tubers planting at 20 cm in-row spacing was lower than that of 4-eyed cut seed tubers planting at the same spacing.

CONCLUSIONS

Seed potato tuber yield increase is a function of the number of tubers and their relative increase in size. The results obtained indicate that planting at narrow in-row spacing with 4 or 6-eyed cut seed tuber increase total and seed potato production as they contribute high seed potato yield. Seed (mother) tubers are used for seed potato production and are usually cut before planting because the cost of seed tuber is very high in Turkey. In order to maximize seed yield performance in potatoes, it is recommended that 4-eyed cut seed pieces should be planted at 20 cm in-row space.

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