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Research Paper

Planting geometry and dehaulming schedule affecting productivity of seed potato (*Solanum tuberosum*)

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ABSTRACT

A field experiment was conducted during the winter (*rabi*) season of 2014–15 and 2015–16 at the Punjab Agricultural University, Ludhiana, to study the effect of planting geometry and dehaulming scheduling on grade-wise productivity and economic returns of potato (*Solanum tuberosum* L.). The experiment was conducted in a split-plot design with 3 planting geometries (65 cm × 11.5 cm, 65 cm × 15 cm and 65 cm × 18.5 cm) as main plots and 3 dehaulming schedules in subplots [80, 90 and 100 days after sowing (DAS)] replicated thrice. The results showed that, planting geometry and dehaulming timings significantly influenced tuber-size distribution, grade-wise tuber yield and economic returns of the crop. Among the planting geometries, the highest yields of small (<35 mm) (6.63 t/ha) and medium (35–45 mm)-size tubers (15.92 t/ha) were recorded with the closer planting geometry (60 cm × 11.5 cm), which was at par with planting geometry of 65 cm × 15 cm. Contrarily, the highest yield of large size (>45 mm) tubers (22.29 t/ha) was obtained with the wider planting geometry (65 cm × 18.5 cm) and it was also at par with 65 cm × 15 cm. The highest net returns (₹379,400/ha) were obtained with planting geometry 65 cm × 15 cm and the highest benefit: cost ratio with the wider planting geometry of 65 cm × 18.5 cm followed by 65 cm × 15 cm. The highest yield of small (7.19 t/ha)-and medium (16.15 t/ha)-size tubers were obtained with dehaulming scheduling at 80 DAS. However, delayed haulm cutting up to 100 DAS significantly increased the large size (24.84 t/ha) and total tuber yields (43.72 t/ha). The highest gross returns, net returns and benefit: cost ratio were also obtained with dehaulming at 80 DAS.

Key words: Dehaulming scheduling, Economic returns, Grade-wise productivity, Planting geometry, Seed potato

Potato (*Solanum tuberosum* L.) is the fourth most important agricultural crop after rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.), with a total cropping area of about 16.5 million ha (m ha) in 2019–20 around the world, contributing to ~12% of global production (FAOSTAT, 2022; CPRI, 2021). Its production has increased significantly in recent years in India, making it the second largest potato producer in the world with an area of 2.16 m ha and total production of 51.3 million tonnes (mt) during 2019–20 (FAOSTAT, 2022). In Punjab, it occupied an area of 0.11 m ha, with a production of 2.87 mt during 2019–20 (PAU, 2020). About 60% of the total area under potato cultivation in Punjab is under seed potato, as there is a great demand of seed potato from Punjab in states of West Bengal, Bihar, Maharashtra, Karnataka and Gujarat (Aulakh *et al.,* 2018). Since the requirement of seed potato is voluminous and it alone may represent 50–60% of total cost of production (Yadav *et al*., 2014), more emphasis should be given to seed potato production so as to meet the growing demand of seed tuber and to obtain higher income (Kumar *et al*., 2021). When potatoes are to be raised for seed purpose, cultural practices need to be aimed at maximizing the production of seed-size tubers and minimizing that of large-size tubers. The prevalent farmers' practices for potato cultivation produce higher proportion of large-size than the seed-size tubers. Thus, the existing agronomic practices for seed-potato production need to be refined to get maximum number of seed-size quality tubers at optimum physiological maturity.

Among various agronomic factors, the planting geometry, i.e., inter-and intra-row spacing, is one of the major factors affecting production, productivity and tuber-size distribution of potato (Alam *et al*., 2016). Moreover, the planting geometry also affects planting density, seed cost, plant development, yield, and the quality of the crop (Walia and Kumar, 2019; Rajpoot *et al*., 2021). Farmers in the

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study area are using different spacings, depending on the purpose of planting (either for consumption or for seed tubers) and on the availability of farm machinery. The yield of seed potato can be maximized at higher plant population (closer spacing) or by regulating the number of stems per unit area (Das *et al.,* 2020).

Dehaulming, a practice of cutting off aerial parts of a plant at 10-15 days before harvesting the crop, is considered as one of the prime factors that affects the quality and size of tubers. Dehaulming can be done after the yellowing of aerial parts because yellowing of the vine indicates the maturity of the potato (Lutaladio *et al.*, 2009). However, the timing of dehaulming varies with intended use of the crop such as for seed or ware purposes. Early dehaulming increases the yield of small-size tubers, while delay in dehaulming increases large-size tuber yield (Das *et al.,* 2020). Keeping the above facts in view, this experiment was initiated with the objectives to study the effect of planting geometry and dehaulming time on grade-wise tuber productivity and economic returns of potato under Punjab conditions.

MATERIALS AND METHODS

The field experiment was conducted during the winter (*rabi*) season of 2014–15 and 2015–16 at the Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, India, representing the Indo-Gangetic alluvial plains (30º56´ N, 75º52‘ E and 247 m above mean sea-level). The experimental site has subtropical to semi-arid climate with hot and dry summer (April to June), hot and humid monsoon (July to September), mild winter (October to November) and cold winter (December to February). The mean minimum and maximum temperatures show considerable fluctuation during the summer and winter, maximum air temperature above 38°C is common during the summer and frequent frosty spells in December–January. The average annual rainfall at Ludhiana is 755 mm, ~75% of which is received in summer monsoon (July to September) complemented by a few showers of low to medium intensity in winter.

The experiment was conducted in a split-plot design with 3 replications. The main plots consisted of 3 planting geometry, viz. 65 cm × 11.5 cm, 65 cm × 15 cm and 65 cm × 18.5 cm, and subplots consisted of 3 dehaulming schedules, viz. 80, 90 and 100 days after sowing (DAS). The soil of experimental site (0–15 cm) was loamy sand, with neutral *p*H (7.2), medium organic carbon (0.60%), low available N (260 kg/ha), high available P (42.1 kg/ha) and K (400 kg/ha). The electrical conductivity was within the normal range (0.24 m mhos/cm). An early-maturing (70–90 days) potato cultivar 'Kufri Pukhraj' was sown in mid-October by using medium–size (35–45 mm) seed tubers at inter-and intra-row spacing as per the treatments. The other crop-management practices followed were as per the recommendations of the Punjab Agricultural University, Ludhiana (Package of Practices for Cultivation of Vegetables, 2014–15). Haulm cutting was done starting from the first week of January to the last week of January as per the treatments and the crop was harvested in the first week of February. Dry-matter contents of tubers and haulm were recorded at 30, 45 and 60 days after sowing (DAS) and at haulm cutting by taking fresh and dry weight of samples. Plant samples were dried in a hot-air oven to constant weight, so as to work out dry-matter accumulation (DMA)/plant. Plant height, leaf-area index (LAI), number of stems and tubers/plant were recorded at haulm cutting. After harvesting, tubers were graded into 3 grade sizes, i.e. small-size (< 35 mm), medium-size (35–45 mm) and large-size (>45 mm), and were used for computation of total tuber yield/ha. The prevailing costs of inputs/ practices such as seed, fertilizers, pesticides, interculture, seed-bed preparation, sowing, irrigation and harvesting were considered for calculating the cost of cultivation of the crop. Values assigned for inputs and grade-wise yield are estimates for fresh market prices prevailing in the studied period. For calculating gross returns, potato tubers size less than 45 mm were considered as seed potato and tubers having size more than 45 mm were considered as ware potato. Tuber yield of both these grades of potato tubers was multiplied with their respective prices. The net returns were worked out by deducting the cost of cultivation from the gross returns and subsequently the benefit: cost ratio (B: C ratio) was calculated. Statistical analyses of the data were carried out using PROC GLM in SAS 9.4 software (SAS INC, Cary NC). Multiple comparisons were made using LSD at $P<0.05$ to determine significant effects.

RESULTS AND DISCUSSION

Effect of planting geometry

Growth attributes: The growth parameters, i.e. plant height, LAI and DMA, in tubers and haulm were influenced significantly by planting geometry (Table 1). The highest plant height (49.9 cm) and LAI (2.82) at the time of dehaulming were recorded with closely planted crop at 65 cm × 11.5 cm and were significantly higher than the wider spacing of 65 cm × 15 cm and 65 cm × 18.5 cm. The closer planting geometry (65 cm × 11.5 cm) resulted in 6.6 and 13.2% higher plant height and 6.0 and 12.8% higher LAI than the planting geometry of 65 cm × 15 cm and 65 cm × 18.5 cm respectively. The lowest plant height (44.1 cm) and LAI (2.50) were recorded with the planting geometry of 65 cm × 18.5 cm. The increased plant height with decrease in intra-row spacing might be due to failure of plants

Table 1. Influence of planting geometry and date of dehaulming on growth parameters of potato (pooled analysis)

Treatment	Plant height (cm) at dehaulming	LAI at dehaulming	DMA in tubers (g/plant)				DMA in haulm (g/plant)			
			30 DAS	45 DAS	60 DAS	At dehaulming	30 DAS	45 DAS	60 DAS	At dehaulming
Planting geometry (cm × cm)										
65 × 11.5	49.9	2.82	7.27	22.77	40.90	60.73	5.46	8.46	12.84	13.55
65 × 15	46.8	2.66	8.40	25.28	43.70	62.59	6.06	9.66	14.08	14.80
65 × 18.5	44.1	2.50	9.51	26.99	46.97	65.75	7.13	10.87	15.43	15.95
SEm±	0.81	0.04	0.25	0.62	0.68	0.67	0.25	0.31	0.37	0.34
CD (P=0.05)	2.6	0.14	0.82	2.03	2.22	2.17	0.80	1.00	1.19	1.11
Time of dehaulming (DAS)										
80	45.8	2.67	–	–	–	61.63	–	–	–	14.13
90	46.8	2.67	–	–	–	62.76	–	–	–	14.69
100	48.2	2.64	–	–	–	64.67	–	–	–	15.47
SEm±	1.03	0.11	–	–	–	0.90	–	–	–	0.50
CD (P=0.05)	NS	NS	–	–	–	2.62	–	–	–	NS

DAS, Days after sowing; LAI, leaf-area index

to spread horizontally, and hence it grew vertically to access air and light. Alam *et al.* (2016) also reported that, plant height increased with decreasing plant spacing. Higher LAI with closer planting geometry might be due to higher plant height and higher number of stems/m^2 (Rajpoot *et al*., 2019, 2021). Singh and Singh (2016) also reported higher number of leaves/plant with closer plant spacing.

The DMA by tubers and haulm increased with the advancement of the crop stage up to haulm cutting (Table 1). At all the growth stages, tuber and haulm DMA was the highest with wider planting geometry of 65 cm × 18.5 cm and it was significantly higher than planting geometries of 65 cm × 11.5 cm and 65 cm × 15 cm. At dehaulming stage, wider planting geometry of 65 cm × 18.5 cm resulted in 8.3 and 17.7% higher DMA in tuber and haulm, respectively, as compared to the closer planting geometry of 65 cm × 11.5 cm. The lowest tuber and haulm DMA was recorded with the closer planting geometry (65 cm × 11.5 cm) at all the growth stages. The highest DMA in wider planting geometry might be due to more availability of space for plant growth and thus, competition among the plants for photosynthates was less than the closer planting geometry (Rajpoot *et al*., 2019; 2021). Singh *et al.,* (2020) also reported the highest plant DMA at wider planting geometry compared to the narrower ones.

Yield attributes: The planting geometry did not significantly influence the numbers of stems/plant. However, number of tubers/plant, and number of stems and tubers per unit area were significantly affected by planting geometry (Table 2). The highest number of tubers/plant (11.36) was found with the wider planting geometry (65 cm × 18.5 cm) and it was statistically at par with planting geometry of 65 cm × 15 cm but significantly higher than the closer planting geometry of 65 cm × 11.5 cm. Kumar *et al.,*

Table 2. Planting geometry and date of dehaulming influence yield attributes, grade-wise and total tuber yield of potato (pooled analysis)

Treatment	Stems/plant	Stems/m^2	Tubers/plant	Tubers/m^2	Grade-wise tuber yield (t/ha)			Total tuber yield (t/ha)
					< 35 mm	35–45 mm	> 45 mm	
Planting geometry (cm × cm)								
65 × 11.5	4.73	62.9	9.58	127.5	6.63	15.92	19.44	41.99
65 × 15	4.81	49.5	10.97	113.0	6.32	15.23	21.15	42.71
65 × 18.5	5.06	42.0	11.36	94.3	5.77	13.63	22.29	41.69
SEm±	0.14	1.42	0.23	2.36	0.18	0.40	0.35	0.56
CD (P=0.05)	NS	4.6	0.76	7.68	0.58	1.31	1.14	NS
Time of dehaulming (DAS)								
80	4.76	50.2	10.44	109.1	7.19	16.15	17.16	40.50
90	4.99	53.2	10.75	111.8	6.30	14.99	20.88	42.17
100	4.84	50.9	10.72	113.9	5.23	13.64	24.84	43.72
SEm±	0.20	2.09	0.32	3.47	0.12	0.23	0.38	0.48
CD (P=0.05)	NS	NS	NS	NS	0.36	0.66	1.11	1.40

DAS, Days after sowing; LAI, leaf-area index

(2015) also reported lower number of tubers/plant with closer spacing compared to the wider planting geometry. The higher number of tubers/plant with the wider planting geometry might be owing to the imposing effect of sufficient space availability on number of tubers formed; more space meant that plants were able to exploit the available nutrients in the soil and the photosynthetic active radiation for growth than plant at closer spacing. Non-significant effect of number of stems/plant with respect to planting geometry might be owing to the fact that, number of stems apart from being a varietal character also depends on seed tuber size and their physiological status, hence, it was not influenced by planting geometries as the cultivar and seed size were uniform in all the planting geometries (Kumar *et al*., 2021). Das *et al.,* (2020) and Singh and Singh (2016) also reported non-significant effect of intra-row spacing on number of stems/plant. Contrary to the number of tubers and stems/plant, number of tubers and stems/m^2 were found the highest (127.5 and 62.9 respectively) with the closer planting geometry and these were significantly higher than rest of the planting geometries. The closer planting geometry (65 cm × 11.5 cm) ensued 42.8 and 35.2% higher number of stems and tubers/m^2, respectively, than the wider planting geometry (65 cm × 18.5 cm). Closer spacing was associated with increased plant stand which ultimately resulted in more number of stems/unit area. Singh and Singh (2016) also reported significantly higher number of shoots/unit area at closer spacing than the wider spacing. Increased number of tubers/unit area might be associated with the increased number of stems/unit area with increased the plant population by reducing the plant spacing, thus, the higher the number of stems/unit area, higher will be the number of tubers.

Tuber yield: The grade-wise tuber yield was significantly influenced by planting geometry treatments; however, the total tuber yield was not significantly affected with varied planting geometries (Table 2). The highest yields of small (< 35 mm)-and medium (35–45 mm)-size tubers (6.63 and 15.92 t/ha respectively) was recorded with the closer planting geometry (65 cm × 11.5 cm), which was at par with planting geometry of 65 cm × 15 cm but significantly higher than the wider planting geometry (65 cm × 18.5 cm). The lowest small-and medium- size tuber yields (5.77 and 13.63 t/ha respectively) was found in the wider planting geometry of 65 cm × 18.5 cm. The planting geometry of 65 cm × 11.5 cm gave 14.9 and 16.8%, and planting geometry of 65 cm × 15 cm gave 9.5 and 11.7% higher small- and medium-size tuber yield, respectively, as compared to the wider planting geometry of 65 cm × 18.5 cm. On the contrary, the highest yield of large-size (> 45 mm) tubers (22.29 t/ha) was obtained with the wider planting geometry of 65 cm × 18.5 cm and it was at par with the planting geometry of 65 cm × 15 cm but significantly higher than the closer planting geometry of 65 cm × 11.5 cm. The planting geometry of 65 cm × 18.5 cm and 65 cm × 15 cm gave 14.7 and 8.8% higher large-size tuber yield, respectively as compared to the planting geometry of 65 cm × 11.5 cm. The reduced planting geometry increased the plant density which reduced the availability of assimilates for individual tubers to grow and this might have resulted in increased yield of small-and medium-size tubers and decreased the yield of large-size tubers (> 45 mm) with reduced planting geometry (Dua *et al.,* 2008; Dhillon *et al.,* 2018). The total tuber yield did not vary significantly with planting geometry and ranged from 41.69 to 42.71 t/ha, the highest being with planting geometry of 65 cm × 15 cm.

Economic analysis: The highest cost of cultivation (₹145,400/ha) was recorded with the closer planting geometry of 65 cm × 11.5 cm and the lowest (₹109,400/ha) with wider spacing of 65 cm × 18.5 cm (Table 3). The increased cost of cultivation with reduced plant spacing might be due to increased plant population/ha which increased the seed rate/ha, thus resulting in higher cost of seed (Rajpoot *et al*., 2021). The seed rate for 65 cm × 11.5 cm, 65 cm × 15 cm and 65 cm × 18.5 cm planting geometries was 6.0, 4.6 and 3.8 t/ha respectively. Alam *et al.,* (2016) also reported the increased cost of cultivation with closer planting geometry. The gross returns from seed-size tuber were higher than that of the ware-size tubers irrespective of the treatments and it was owing to the higher price of seed potato as compared to the ware potato. The highest gross returns from seed potato (₹406,000/ha) and total tuber yield (₹510,900/ha) were obtained with the closer planting geometry (65 cm × 11.5 cm) and was statistically at par with the planting geometry of 65 cm × 15 cm. Contrary to this, gross returns from ware potato (₹120,400/ha) were the highest with wider planting geometry of 65 cm × 18.5 cm. This might be due to the fact that, closer planting geometry gave higher yield of seed-size tuber, while wider planting geometry gave higher yield of large-size tubers (Table 2). Dua *et al.* (2008) also reported higher gross returns with closer planting geometry which decreased with the increase in plant spacing. The highest net returns (₹379,400/ha) were found with 65 cm × 15 cm planting geometry and being significantly higher than net returns from the other planting geometries. The lowest net returns (₹360,100/ha) were obtained with the wider planting geometry (65 cm × 18.5 cm). Higher net returns obtained with 65 cm × 15 cm were owing to higher seed-size (< 45 mm) and total tuber yield but lower seed cost requirement in the treatment. Das *et al.,* (2020) also reported higher net returns with closer intra-row spacing as compared to wider spacing. The highest

Table 3. Planting geometry and date of dehaulming impact on economic returns of potato

Treatment	Cost of cultivation (‘000 ₹/ha)	Gross returns (‘000 ₹/ha)			Net returns (‘000 ₹/ha)	Benefit: cost ratio
		Seed potato	Ware potato	Total		
Planting geometry (cm × cm)						
65 × 11.5	145.4	406.0	104.9	510.9	365.5	2.51
65 × 15	122.8	388.0	114.2	502.2	379.4	3.09
65 × 18.5	109.4	349.1	120.4	469.5	360.1	3.29
SEm±	–	7.62	1.88	7.89	7.89	–
CD (P=0.05)	–	24.8	6.1	25.7	NS	–
Time of dehaulming (DAS)						
80	125.8	419.3	92.6	512.7	386.9	3.11
90	125.8	376.0	112.8	496.0	370.1	2.98
100	125.8	334.0	134.2	473.9	348.1	2.81
SEm±	–	4.92	2.04	5.43	5.427	–
CD (P=0.05)	–	14.4	5.9	15.8	15.8	–

Sale price (2014–15): Seed potato, ₹18,000/t; ware potato, ₹5,600/t; Sale price, (2015–16); Seed potato, ₹18,000/t; ware potato, ₹5,250/t

benefit: cost ratio (3.29) was obtained with planting geometry of 65 cm × 18.5 cm, followed by 65 cm × 15 cm. The planting geometry of 65 cm × 11.5 cm had the minimum benefit: cost ratio (2.51). Benefit: cost ratio declined under closer spacing, because the increase in gross returns was not in proportion to the cost of cultivation under closer spacing (Dua *et al*., 2008). Kumar *et al*., (2015) also observed higher B:C ratio with wider planting geometry of 67.5 cm × 25 cm than the 67.5 cm × 15 cm.

Effect of dehaulming

Growth attributes: The time of haulm cutting had non-significant effect on growth parameters, viz. plant height, LAI, and DMA, in haulms at dehaulming stage; however, had the significant effect on DMA in tubers at dehaulming (Table 1). The highest tuber DMA (64.67 g/plant) was observed when dehaulming was delayed up to 100 DAS and it was statistically at par with the dehaulming at 90 DAS (62.76 g/plant) but significantly higher than the dehaulming at 80 DAS (61.63 g/plant). The lowest DMA in tubers/plant was recorded with dehaulming at 80 DAS. Dehaulming at 100 DAS resulted in 4.9% higher tuber DMA/plant than the dehaulming at 80 DAS. Higher tuber DMA at 100 DAS might be due to availability of sufficient time for translocation of stored food from stems to tubers which increased the dry matter in the tubers (Kumar *et al.,* 2001).

Yield attributes: All the yield parameters, viz. number of tubers and stems/plant and per unit area, were not affected significantly by haulm-cutting treatments which might be due to the fact that stem production and tuber formation in potato is completed within 50 days (Beukema and Zaag, 1990); however, the dehaulming was started at 80 DAS. Das *et al.,* (2020) also found non-significant effect of dehaulming scheduling on number of stems.

Tuber yield: The dehaulming schedule exerted a significant effect on grade-wise and total tuber yield (Table 2). Dehaulming at 80 DAS enhanced the yield of small size (< 35 mm) (7.19 t/ha) and medium-size (35–45 mm) (16.15 t/ha)-tubers over dehaulming at 90 and 100 DAS. However, delayed dehaulming at 100 DAS significantly increased the large-size (> 45 mm) (24.84 t/ha) and total tuber yield (43.72 t/ha). Dehaulming at 80 DAS gave 37.5 and 18.4% higher yield of small-and medium-size tubers, respectively, as compared to the dehaulming at 100 DAS. However, dehaulming at 100 DAS resulted in 44.8 and 8.0% higher large-size and total tuber yield, respectively, than the early dehaulming at 80 DAS. The increase in large-size and total tuber yield owing to delay in date of haulm cutting may be attributed to the fact that, bulking of tuber continues till maturity and the cessation of bulking was dependent entirely on the date of haulm cutting (Paul *et al*., 2016). Therefore, delay in dehaulming increased the duration of bulking by 10 days which may have contributed to convert the small tubers into large ones, thus, resulted in significantly higher yield of large-size and total tubers. However, early dehaulming caused the early cessation of tuber bulking which caused the restricted growth of tubers and thus increased the production of small-and medium-size tubers. Similar findings were also reported by Das *et al.,* (2020) and Mandal and Das (2020).

Economic analysis: Dehaulming time is a non-monetary variable, hence the cost of production (₹125,800/ha) was not influenced by dehaulming schedule and any change in net returns was solely dependent on gross returns, which in turn was dependent on grade-wise tuber yield (Paul *et al*., 2016). Since the seed-size (small-and-medium) tuber yield increased significantly with early-haulm cutting at 80 DAS, the highest gross returns from seed potato (₹419,300/ha), total gross returns (₹512,700/ha), net returns (₹386,900/ha) and B:C ratio were obtained when the dehaulming was done at 80 DAS. The highest gross returns from ware potato were obtained with delay in dehaulming up to 100 DAS which was due to the higher yield of ware-size potato at this dehaulming scheduling. The lowest gross returns, net returns and B: C ratio were obtained with dehaulming at 100 DAS.

In the present investigation, it was found that higher yield of seed-sized tubers (< 35 and 35–45 mm) was obtained with planting geometry of 65 cm × 11.5 cm or 65 cm × 15 cm along with dehaulming at 80 DAS. The highest economic returns were also obtained with medium planting geometry of 65 cm × 15 cm as compared to the closer and wider planting geometries. So, it may be concluded from the study that, seed tubers should be planted at 65 cm × 15 cm and haulm cutting should be done at 80 DAS for obtaining higher productivity and profitability from seed-potato crop under Punjab conditions.

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