

OPTIMIZATION OF PLANTING GEOMETRY AND HAULM KILLING DAYS FOR INCREASING PRODUCTION OF SEED SIZE TUBERS IN POTATO

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ABSTRACT: A field experiment was conducted for two consecutive years 2018-19 and 2019-20 with high bulking early potato cultivar Kufri Khyati at Central Potato Research Institute, RS, Gwalior in split plot design with six planting geometries as main plots *viz* S₁-60×20 cm (Control), S₂-66×15 cm, S₃-66×20 cm, S₄-75 ×15 cm, S₅-75×20 cm and S₆-paired row and three haulm killing dates as sub plots *viz* 70, 80 and 90 days after planting. For growth parameters, only planting geometry 66×15 cm recorded significantly higher plant height (52.6 cm) over other planting geometries. 75×15 cm (52.6) and 75×20 cm (50.2) planting geometry recorded non significant but higher compound leaves/plant over other plant geometries. Days to haulm killing did not influence the growth parameters *viz*, stem, compound leaves and plant height. Significant increasing trend was recorded for number and weight of seed size and total tubers with increasing planting geometry over wider plant geometry 75×20 cm (285 thousand/ha, 17.41 t/ha seed size tuber and 671 thousand/ha, 34.52 t/ha for total tuber) and highest was recorded in paired row planting (487 thousand/ha, 29.52 t/ha seed size tuber and 1040 thousand/ha, 45.93 t/ha total tuber). Paired row planting with 70 days of haulm killing recorded significantly highest seed size (516 thousand/ha) and total tuber number (1092 thousand/ha). By number 60×20 cm planting geometry at 80 days of haulm killing (51.15% and 0.957) and by weight paired row planting at 70 days of haulm killing (73.15% and 0.367) recorded significantly highest seed size tubers percent and best seed: non seed ratio over other factor combinations. Planting geometry 66×15 cm at 80 days haulm killing (11.3) and 75×15 cm at 90 days of haulm killing (11.7) recorded significantly highest seed multiplication rate by number and weight respectively. Paired row planting with 70 days haulm killing gave highest seed size tuber yield, per cent seed size tuber and best seed: non seed ratio but planting geometry with 66×20 cm and haulm killing at 70 days found to be economically viable option for the farmers with higher B:C ratio (1.75) for seed production of variety Kufri Khyati.

Key words: Seed production, planting geometry, haulm killing, Potato, seed: non seed ratio

INTRODUCTION

One of the main economic problems in the production of high-quality seed potatoes is their cost to end users. The cost of seed represents the greatest proportion of the total production cost and account for 30 to 50% of the total production expenses depending on the country or region (Kabir *et al.*, 2004; Karim *et al.*, 2010). In India this cost ranges from 40 to 50% of the total production costs (Beata 2020, Chakraborti *et al.*, 2013) and single most important factor in potato cultivation and hence good

quality seed is required for optimization of potato production (Chakraborti *et al.*, 2013). Kufri Khyati is a high yielding early maturing variety having moderate resistance to late blight, yields higher than the other early maturing cultivars and performs well both under very early (60 days) and early (75 days) harvests (Kumar *et al.*, 2009). This variety when cultivated under seed production for 70-80 days produces 43-47 % by number and 27-35 % by weight (small and large) non seed size tubers (Sadawarti *et al.*, 2017).

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Seed tuber size is an important factor to decide the seed rate per unit area because it affects total yield and graded or marketable tuber yields (Singh and Kushwah, 2010 and Dagne *et al.*, 2019). Seed rate depends on the size of tubers used in potato planting. Seed tubers of 25–125 g (30–55mm) are recommended as seed size tubers (IMSCS, 2013). Obtaining seed size tuber is important for achieving higher potential of the cultivars. The tuber size profile can be reduced or expanded by altering inter and intra row seed spacing, controlling days of growth by planting late or killing vines/haulm early, regulating inputs like fertilizer and water, applying growth regulators, and manipulating seed tuber physiological age. (Kumar *et al.*, 2009). When potatoes are grown for seed, cultural practices need to be used in order to maximize the production of seed size tubers (Sanli, 2015). Planting geometry influence yield, tuber size distribution, tuber, stem density and net returns of potato cultivars (Love and Thompson-Johns, 1999; Bussan *et al.*, 2007; Zamilet *et al.*, 2010; Nasir and Akassa, 2018 and Dawinder., 2020). Increasing the planting density may lead to a decrease in the average weight of the tuber and the percentage of the large size tubers (Love and Thompson-Johns 2006; Gasimova *et al.*, 2010; Mahmoodabad *et al.*, 2010; Somarin *et al.*, 2010). An ideal combination of plant population, row width, and in-row seed spacing for a particular variety were the major factors for optimizing tuber size and increasing grower's revenue (Rex and Mazza 1989). Planting of seed tubers on ridges is widely followed method with some modifications from place to place. As against single-row geometry of planting on each ridge, paired-row planting on ridges at different spacing has also been tested keeping constant or variable seed rates (Mishra, 2013).

Haulm/ vine killing is one of the criteria used in seed potato production primarily to regulate tuber size profile (Singh and Kushwah, 2010; Kumar *et al.*, 2009 and Virtanen and Seppänen 2014). Haulm killing is done to stop tuber growth in order to reduce tuber size and to obtain a uniform size distribution with a maximum proportion of the tubers in the most profitable size class, strengthen tuber skins, and to reduce the risk of spread of virus infection by inhibiting plant-to-plant spread through vectors such as aphids (Struik and Wiersema 1999 and Kempenaar and Struik, 2007). The highest values of tuber yield was established with planting of seed tuber sizes of 35–45 mm (de Almeida *et al.*, 2016). Appropriate seed tuber size has very important implication on potato production. The number of sprouts that develop from a seed tuber is influenced by the size of seed tuber. In larger tubers, growth is faster because of greater food reserve availability for each sprout and generally produce more sprouts which may result in the production of too many stems and eventually produce too many tubers (Dagne, 2015). If larger seed is used, a greater quantity of seed is required for planting per unit area. It is avoided because it increases seed costs and reduce planter's accuracy (Singh and Kushwah, 2010). Conversely, smaller seed size tubers have less sprouts per unit due to the lesser amount of reserves available for sprout growth leading to small number of stems that produce only a few tubers, thereby reducing yield (Dagne, 2015). Big size seed will increase cost and seed that are too small may rot before emergence (Wang, 2008). Moreover in recent time it was also observed that frequent rainfall occurs in the month of December and January before the time of haulm killing due to climate change effect which prolongs the date of haulm killing. With this background present

experiment was conducted to optimize different combinations of planting geometry and haulm killing days for increasing proportion of seed size tubers in Kufri Khyati under changing climate scenario.

MATERIALS AND METHODS

A field experiment was conducted for two consecutive years in split plot design with high bulking early potato cultivar Kufri Khyati at Central Potato Research Institute, RS, Gwalior (26° N and 78° E, 207 m above sea level and receives annual rainfall 400–800 mm), during 2018-19 and 2019-20. The soil of the experimental field was silty clay loam having organic carbon 0.39%, available N 125, P 41 and K 330 kg ha⁻¹, pH 7.0 and EC 0.2 dS m⁻¹, Cu 0.9 ppm, Zn 0.94 ppm, Fe 17 ppm and Mg 0.88 ppm. Organic carbon content of soils is generally low because of high temperature in summers. Soil is heavy textured having high silt and clay contents. Treatments consisted of six planting geometry as main plot *viz* S₁-60 × 20 cm (Control), S₂-66 × 15 cm, S₃-66 × 20 cm, S₄-75 × 15 cm, S₅-75 × 20 cm and S₆-paired row and three haulm killing dates as sub plots *viz* 70, 80 and 90 days after planting. Well sprouted seed sized tubers weighing 40–50 g were planted in 23.10.2018 and 10.11.2019 as per geometry in plot size *viz*, S₁-10.8 M², S₂ and S₃- 11.88 M², S₄ and S₅-13.5 M² and S₆- 8.1 M² (Paired row). Fertilizer P and K were applied @ 60 and 100 kg ha⁻¹ respectively. Full doses of P and K and half dose of N were applied at the time of planting and remaining half dose of N was applied through urea at the time of earthing up which was done 25 days after planting (DAP). At planting, half dose of nitrogen with full dose of phosphorus and potassium were applied through ammonium sulphate, single super phosphate and muriate of potash, respectively.

Recommended seed production practices were followed during the crop growth season as mentioned in the seed plot technique. Thimet 10 G @ 10 kg/ha for controlling insects was applied at the time of earthing up and mancozeb @ 2 kg/ha sprayed as a preventive measure for late blight, leaf spot and other foliar diseases of potato. After emergence at 15–20 days interval, an alternate spray of imidacloprid @ 0.002%, triazophos@1.6 l/ha and thiamethoxam @130 g/ha was done to protect seed crop from insects. For controlling the weeds metribuzin mixed in 1000 l of water was applied @ 0.75 kg a.i. /ha. Haulm killing was done as per the schedule dates 70, 80 and 90 days after planting, respectively. Tubers were harvested 12-14 days after haulm killing on hardening of tuber skin. Observations on crop growth and yield attributes were recorded at 50 DAP and at harvest of the crop. Weekly weather data on max/min temperature, and relative humidity was recorded during crop growth in two year of experimentation and average max/min temperature and relative humidity is presented in table 1. Percent non seed size and seed size tuber, seed: non seed ratio and seed multiplication rate were calculated by following formulas

$$\text{Percent non seed tuber} = \frac{\text{Non seed size tuber yield number and weight}}{\text{Total tuber yield by number and weight}} \times 100$$

$$\text{Percent seed tuber} = \frac{\text{Seed size tuber yield by number and weight}}{\text{Total tuber yield by number and weight}} \times 100$$

$$\text{Seed: non seed ratio for number and weight} = \frac{\text{Non seed size tuber yield by number and weight}}{\text{Seed size tuber yield by number and weight}}$$

$$\text{Seed multiplication rate} = \frac{\text{Total tuber yield by number and weight/ha}}{\text{Seed rate by number and weight/ha}}$$

Data were pooled and analyzed statistically and means were separated according to the least significant differences (LSD) at 0.05 level of probability.

Table 1 Max/min temperature and relative humidity during crop growth

Crop period	Temperature (Degree Celsius)				Relative Humidity (%)			
	2018-19		2019-20		2018-19		2019-20	
Week	Max	Min	Max	Min	Max	Min	Max	Min
Oct 22-28	34.5	14.9	31.5	14.1	80.7	28.7	89.4	31.7
Oct-Nov 29-4	33.3	14.4	32	16.4	82.1	28.2	89.0	42.3
Nov 5-11	29.6	10.6	30.8	14.0	83.6	33.6	88.9	37.3
Nov 12-18	31.6	13.5	29.7	14.7	80.3	28.3	84.4	43.1
Nov 19-25	35.3	11.4	28.5	11.0	88.3	30.7	93.3	41.7
Nov-Dec 26-2	26.7	9.8	27.1	12.4	99.3	39.1	92.0	52.0
Dec. 3-9	26.8	7.2	24.0	6.7	93.6	33.3	94.7	43.3
Dec 10-16	22.4	6.8	21.3	9.5	90.4	57.7	95.9	62.3
Dec. 17-23	23.5	4.5	19.2	4.9	90.7	38.4	94.4	54.7
Dec. 24-31	22.8	3.5	13.5	2.3	94.5	36.8	96.6	75.9
Jan 1-7	24.0	6.2	21.7	6.6	94.7	46.7	96.3	59.0
Jan 8-14	21.7	5.5	20.4	5.6	93.6	41.3	93.3	72.6
Jan 15-21	23.8	4.6	18.3	7.6	91.7	34.9	96.1	70.7
Jan 22-28	20.6	9.0	22.8	5.2	92.4	74.9	88.4	45.6
Jan-Feb 29-4	20.6	5.8	22.2	6.0	92.8	58.6	94.0	56.9
Feb 5-11	22.8	9.0	22.4	4.9	85.6	61.3	93.7	44.9

RESULTS AND DISCUSSION

Plant emergence

Planting geometry did not show significant variation for final plant emergence, but it was in the range of 86.43% in 75×15 cm to 88.64% in 60×20 cm planting geometry (table 2). Lower planting geometry recorded non significant but higher plant emergence than higher planting density in mini tuber study (Hossain *et al.*, 2015). No significant differences was recorded in 70 and 80 days of haulm killing (Singh and Singh, 2016, Sadawarti *et al.*, 2017). Among the interaction between planting geometry and days of haulm killing, no significant difference was recorded at both the parameter level. None of the interactions among intra-spacing, haulm killing dates and N doses found significant for plant emergence (Singh and Singh, 2016; Sadawarti *et al.*, 2017 and Mandal and Das, 2020)

Growth attributing parameters

For stem/plant, planting geometry, days of haulm killing and their interactions did not show significant variation. Non significant differences were recorded for spacing combination for stems/plant (Kushwah and Singh, 2008; Akassa *et al.*, 2014; Arega *et al.*, 2018 and Mandal and Das, 2020). Singh *et al.* (2010) did not find significant difference in number of shoots under triple row, paired row and single row planting geometry with or without drip irrigation system. Similar results were recorded in present study. Only higher planting geometry 66×15 cm recorded significantly higher plant height (52.6 cm) over other planting geometries. Such increase in higher planting geometry could be attributed to increased competition among the stems for light and space as already reported by earlier workers (Barry *et al.*, 2000; Sharma *et al.*, 2013, Tesfaye *et*

Table 2 Growth parameters as influence by planting geometry and haulm killing days

Plant geometry / DOHK	Emergence %				No. of stem/ plant				Plant height (Cm)				No. of compound leaves/ plant			
	70		80		90		Mean		70		80		90		Mean	
	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
60 × 20 cm (Control)	86.85	88.71	90.37	88.64	4.7	4.2	4.7	4.5	48.0	47.2	50.7	48.6	44.0	51.0	47.7	47.7
66 × 15 cm	86.39	87.92	85.83	86.71	3.7	4.3	4.3	4.1	52.5	52.7	52.7	52.6	49.5	47.2	48.0	48.0
66 × 20 cm	89.26	85.74	89.26	88.09	4.0	4.5	4.3	4.3	49.2	49.3	49.2	49.2	52.0	49.2	49.5	49.5
75 × 15 cm	86.53	86.67	86.11	86.43	5.2	4.8	4.7	4.9	48.8	48.7	52.0	49.8	53.0	48.5	52.6	52.6
75 × 20 cm	86.48	89.45	88.89	88.27	4.3	4.8	4.5	4.6	49.7	50.5	47.7	49.3	49.8	52.5	50.2	50.2
Paired Row	86.85	87.41	89.81	88.02	5.2	4.7	4.3	4.7	50.0	51.0	48.0	49.7	52.5	47.7	49.9	49.9
Mean	87.06	87.65	88.38		4.5	4.6	4.5		49.7	49.9	50.0	2.10	49.5	50.1	49.3	49.3
CD _{0.05}	Plant geometry (A)				NS				NS				NS			
	DOHK (B)				NS				NS				NS			
	Factor(B)at same level of A				NS				NS				NS			
	Factor(A)at same level of B				NS				NS				NS			
DOHK- Days of haulm killing																

al., 2013; Singh and Singh 2016; de Almeida *et al.*, 2016; Mvumi *et al.*, 2018 and Singh *et al.*, 2019). Higher planting density of 50 ×15 cm recorded significantly higher plant height over 50×20 cm and 50×25 cm (Singh *et al.*, 2019). This confirms the present study. Days to haulm killing and factor level interactions did not show any significant difference for plant height. Delayed haulm killing from 70 to 80 days and at 5 days interval from 65 days under Gwalior and from 60 to 70 and 80 days under Modipuram conditions did not show any significant difference for plant height under seed production study (Singh and Kushwah, 2009, Sadawarti *et al.*, 2017 and Kumar *et al.*, 2001).

In present study, 75×15 cm (52.6) and 75×20 cm (50.2) planting geometry recorded non significant but higher compound leaves/ plant over plant geometries. Compound leaves per plant showed a gradual and significant increase with the decreasing plant density (Singh *et al.*, 2019). Reduction in number of leaves with increasing plant population can be attributed to the availability of limited space thus posing a barrier for the proper development of plant (Lal *et al.* 1981; Khurana and Pandita 1982; Kushwah 1989 and Singh *et al.* 1997). This confirms the results of present study. Days to haulm killing did not show any significant difference for compound leaves/plant and was in the range of 49-50 compound leaves/ plant. Delayed haulm killing from 70 to 80 days under Gwalior and Patna conditions did not show any significant for leaves/plant (Singh and Singh, 2016 and Sadawarti *et al.*, 2017) confirming the present study (Table 2).

Yield parameters

Grade wise non seed, seed and total tubers/ha

Measurement of different grades of tubers are important for quantification of seed size

tubers under seed production programme. Under the study, seed tubers were graded in three different sizes, viz. <25 g and >125 g (non seed size), 25-125 g (seed size) as per Indian minimum seed certification standards,

Non seed size tubers (<25 and >125g)

For <25 g grade by number, all the planting geometry except 60×20 cm recorded significantly higher <25 g tubers over 75×20 cm spacing (297 thousand/ha) and highest was recorded in paired row system (480 thousand/ha). Narrower distance increases undersize and small tubers (Kushwah and Singh, 2008; Akasa *et al.*, 2014 and Mangani *et al.*, 2015; Dawinder *et al.*, 2020). This confirms the present result where closer spacing gave higher small tuber than wider spacing. The highest yield of small-sized tubers at higher planting density (paired row) might be due to the fact that higher seed- piece spacing exerted a measurable effect on the yield of small potatoes. This is in agreement with Binalfew *et al* (2015). Significant decreasing trend for <25 g tuber was recorded with delay in haulm killing days and highest was recorded in early 70 days haulm killing (387 thousand/ha) and lowest in 90 days haulm killing (338 thousand/ha). In interactions, paired row at 70 days haulm killing (541 thousand/ha) and 60×20 plant geometry at 90 days haulm killing (274 thousand/ha) recorded highest and lowest tuber number respectively (Table 2). For weight, all the planting geometry recorded significantly higher <25 g tubers over 66×20 cm spacing (2.72 t/ha) and highest was recorded in paired row system (4.46 t/ha). Similar trend was recorded for haulm killing days as tuber number. In interactions, paired row at 70 days haulm killing (5.0 t/ha) and 66×20 cm plant geometry at 90 days haulm killing (2.56 t/ha) recorded highest

and lowest tuber number, respectively (table 4).

For >125 g grade by number, only lower planting density 66×20 cm (97 thousand/ha), 75×15 cm (83 thousand/ha) and 75×20 (89 thousand/ha) recorded significantly higher tuber number over paired row planting (73 thousand/ha) table 2. This may be because of few sinks available per unit area that resulted in less competition between the individuals at low plant densities where more resources were channeled to each individual tuber resulting in a high number of large sized tubers. This is in agreement with Mangani *et al.*, 2015. Yield both by number and weight of small sized tubers and total tubers increased significantly with closer plant spacing, while the yield of bigger size tubers increased with wider planting geometry (Kumar *et al.*, 2001; Kumar and Lal, 2006; Singh and Singh, 2016) irrespective of varieties (Mangani *et al.*, 2015). In present study, decrease in total number of tubers and increase in the proportion of large-sized tubers size with increase in intra-row spacing are in accord with the observations of Kumar *et al.*, 2001.

80 days (86 thousand/ha) and 90 days (110 thousand/ha) haulm killing recorded significantly higher >125 g tuber number over 70 days haulm killing (53 thousand/ha). Similar results were reported with 10 days delayed haulm killing from 60 to 70 and 80 days by Kumar *et al.*, 2001. In factor interaction, 66×20 cm plant geometry with 90 days haulm killing (123 thousand/ha) recorded highest and paired row at 70 days haulm killing (35 thousand/ha) lowest over sized tuber number (table 2). For weight, only 75×20 (13.61 t/ha) recorded significantly higher tuber weight over 66×20 cm planting (11.92 t/ha) and other planting geometries were at par. Eighty days (12.76 t/ha) and 90 days (16.20/ha) haulm killing recorded

Table 3 Grade-wise seed tuber number (000/ha) as influenced by planting geometry and haulm killing days

Plant geometry/ DOHK	Non seed size						Seed size						Total			
	<25g			>125g			25-125g									
	70 Days	80 Days	90 Days	Mean	70 Days	80 Days	90 Days	Mean	70 Days	80 Days	90 Days	Mean	70 Days	80 Days	90 Days	Mean
60× 20 cm (Control)	344	319	274	312	58	71	106	78	409	407	391	402	806	787	775	789
66×15 cm	378	360	438	392	59	74	100	78	455	446	441	448	892	880	979	917
66× 20 cm	368	367	328	355	60	108	123	97	391	382	378	384	819	858	829	835
75 ×15 cm	367	330	304	334	42	96	112	83	358	347	352	352	767	773	767	769
75× 20 cm	322	293	277	297	64	88	113	89	328	270	257	285	714	651	647	671
Paired Row	541	492	407	480	35	80	104	73	516	472	473	487	1092	1044	984	1040
Mean	387	360	338		53	86	110		409	387	382		848	832	830	
CD _{0.05}	Plant geometry (A)			24.3				6.6				29.4				29.0
	DOHK (B)			12.1				3.2				10.8				NS
	Factor(B)at same level of A			30.8				8.1				27.8				42.5
	Factor(A)at same level of B			34.2				9.1				36.4				44.4
DOHK- Days of haulm killing																

DOHK- Days of haulm killing

one and half times and twice respectively significantly higher >125 g tuber weight over 70 days haulm killing (8.12 t/ha). Significantly higher over size tubers were recorded with 80 days haulm cut (9.65 t ha⁻¹) over 70 days haulm cut (7.00 t ha⁻¹) Sadawarti *et al.*, 2017. Significant interactions were recorded at factor level combinations and 75×20 cm plant geometry at 90 days haulm killing (17.74 t/ha) recorded highest and paired row at 70 days haulm killing (5.81 t/ha) lowest over size tuber weight (table 4). This confirms that wider plant geometry with delayed haulm killing increases proportion of oversize tubers. Hence 70 days haulm killing found best with minimum proportion of oversize tubers in the present study

Seed size tubers (25-125g)

Seed size tubers (25-125 g) are very important for use as seed tubers in the successive crop season (Sadawarti *et al.*, 2019). In present study, significantly higher seed size tuber number was recorded all the other planting geometries over wider planting geometry 75×20 cm (285 thousand/ha) and highest was recorded in paired row (487 thousand/ha) followed by 66×15 cm (448 thousand/ha) table 3 and fig 1. Sadawarti *et al.*, 2017 reported that significantly higher seed size (405000 ha⁻¹) and total tuber (702000 ha⁻¹) number with closer intra row spacing of 15 cm over 20 cm intra-row spacing (337000 ha⁻¹ seed size and 605000 ha⁻¹ total tuber). Medium-sized seed tubers increased as spacing reduced, closer spacing of 50 cm × 25 cm and 60 cm × 25 cm produced higher medium size tuber number over wider spacings of 80 cm × 30 cm and 75 cm × 30 cm (Binalfewil *et al.*, 2015). In present study, 70 days haulm killing recorded significantly higher seed size tuber (409 thousand/ha) over 80 and 90 days of haulm killing which were at par with each other table 3 and fig 3.

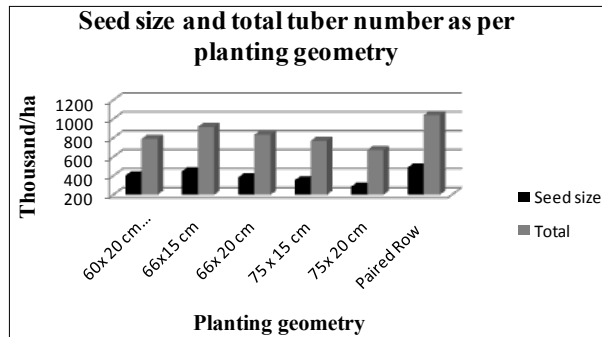


Fig 1 Seed size and total tuber number (thousand/ha) as per planting geometry

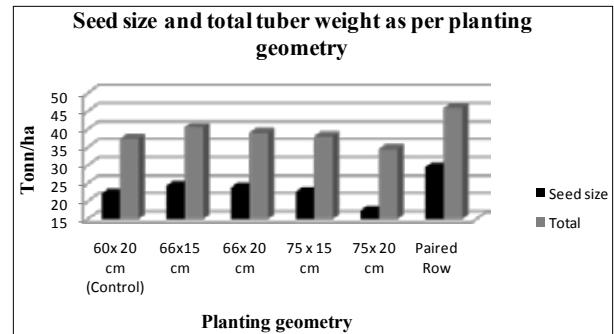


Fig 2 Seed size and total tuber weight (t/ha) as per planting geometry

The yield of small sized tubers reduced by 3.0 q/ha with an increase in crop duration by ten days (Kumar and Lal, 2006). Highest plant geometry paired row planting with 70 days of haulm killing (516 thousand/ha) and lowest planting geometry 75×20 cm at 90 days haulm killing (257 thousand/ha) recorded significantly highest and lowest seed size tubers over other factor combinations (table 3). Non-significant but highest seed size tuber number (432 thousand ha⁻¹ and 427 thousand ha⁻¹) was recorded in 15 cm intra-row spacing×80 days haulm killing×150 kg N and 15 cm intra-row spacing×70 days haulm killing×120 kg N respectively (Sadawarti *et al.*, 2017).

For weight similar increasing trend with increasing planting geometry as of tuber number was recorded and highest was in paired row planting (29.52 t/ha) table 4 and fig 2. Sadawarti *et al.*, 2017 reported significantly higher seed size (22.44 t ha⁻¹) tuber yield with closer intra row spacing of 15 cm over 20 cm intra-row spacing (19.81 t ha⁻¹ seed size). Similar result were obtained in closer spacing of 50×10 cm under Bangladesh conditions (Al Mamun *et al.*, 2016). But for haulm killing days reverse trend of tuber number was recorded for seed size tuber weight and 80 (23.48 t/ha) and 90 days haulm killing (24.12 t/ha) recorded significant increase in tuber weight over 70

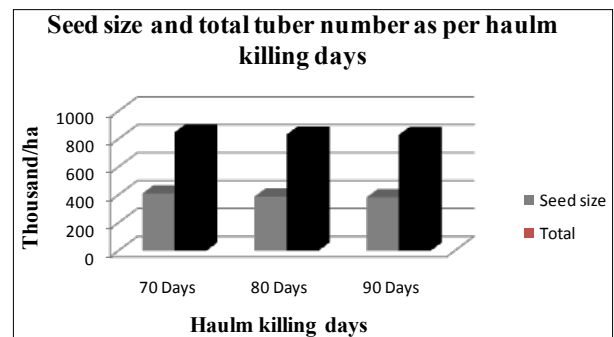


Fig 3 Seed size and total tuber number (thousand/ha) as per haulm killing days

days (22.39 t/ha) haulm killing days (table 4 and fig 4). All other factor combinations were significantly higher tuber weight over 75×20 cm planting geometry at 70, 80 and 90 days haulm killing. Paired row planting recorded highest seed size tubers over other combinations with non-significant

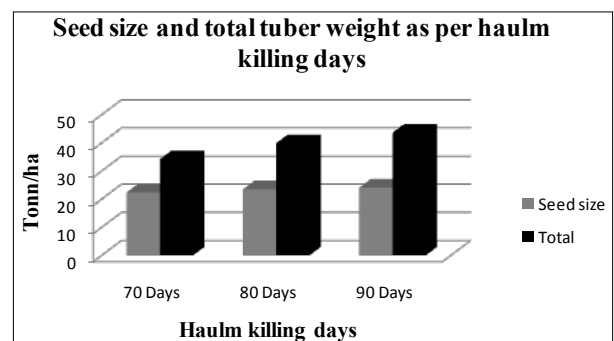


Fig 4 Seed size and total tuber weight (t/ha) as per haulm killing days

Table 4 Grade-wise and total seed tuber weight (t/ha) as influenced by planting geometry and haulm killing days

Plant geometry/ DOHK	Non seed size						Seed size						Total			
	<25g			>125g			25-125g									
	70 Days	80 Days	90 Days	Mean	70 Days	80 Days	90 Days	Mean	70 Days	80 Days	90 Days	Mean	70 Days	80 Days	90 Days	Mean
60 × 20 cm (Control)	3.09	3.57	2.95	3.20	8.58	10.61	16.57	11.92	20.43	24.19	22.03	22.22	32.10	38.38	41.55	37.34
66×15 cm	3.52	3.86	4.60	4.00	9.28	12.58	15.07	12.31	21.66	24.87	26.23	24.25	34.46	41.31	45.90	40.56
66×20 cm	2.64	2.95	2.56	2.72	8.84	12.69	15.64	12.39	22.69	24.03	24.93	23.88	34.17	39.68	43.13	38.99
75 × 15 cm	3.74	3.40	3.01	3.38	6.75	13.27	15.91	11.98	22.70	21.97	23.45	22.71	33.20	38.64	42.38	38.07
75× 20 cm	4.00	3.43	3.08	3.50	9.45	13.63	17.74	13.61	17.37	16.88	17.98	17.41	30.82	33.94	38.80	34.52
Paired Row	5.00	4.65	3.73	4.46	5.81	13.78	16.26	11.95	29.51	28.95	30.11	29.52	40.32	47.38	50.10	45.93
Mean	3.67	3.64	3.32		8.12	12.76	16.20		22.39	23.48	24.12		34.18	39.89	43.64	
CD _{0.05}	Plant geometry (A)			0.275				0.828				1.497				1.261
	DOHK (B)			0.140				0.389				0.592				0.751
	Factor(B)at same level of A			0.357				0.993				1.523				NS
	Factor(A)at same level of B			0.392				1.135				1.907				NS

DOHK- Days of haulm killing

DOHK- Days of haulm killing

difference at 70, 80 and 90 days haulm killing (table 4).Significantly higher yield as well as number of seed size tubers was recorded at narrow spacing (60 × 15 cm) and longer crop duration (haulm cutting at 80 days) in comparison to wider spacing and shorter crop duration (Singh and Singh, 2016). Similar trend was reported in present study.

Total tubers

Similar significant increasing trend like seed size tuber number and weight was recorded with increasing planting geometry for total tuber number and weight over lowest plant geometry 75×20 cm and highest was recorded in paired row planting (1040 thousand/ha and 45.93 t/ha) table 3 and fig 1. This might be due to the higher number of plants produced at closer plant geometry resulting in higher sinks and efficient use of available soil nutrients and other growth factors and ground being covered with green leaves earlier (earlier in the season, light is intercepted and used for assimilation), fewer lateral branches being formed and tuber growth starting earlier in plants grown at closer plant spacing than plants at wider spacing which led to the production of highest number of total tubers per hectare. This is in agreement with Zebeenay *et al.*, 2015; Mangani *et al.*, 2015; Arega *et al.*, 2018; Dagne *et al.*, 2019 and Mvumi *et al.*, 2018. Tuber yield in paired row planting was almost 40.0% higher than that in single-row planting at 60 × 20 cm spacing and about 85% more than that obtained in single-row planting at 45 × 15 cm spacing (Mishra, 2013). Mishra and Pandey, 2016 reported paired row planting geometry accompanied with furrow irrigation system was found to be the best cultural combination for tuber yield (35.2 t/ha). It appeared that plant population was major factor of increased tuber yield in case of paired-row planting. This confirms the

results of present study where higher tuber yield and number of tubers were obtained with paired row planting with furrow irrigation having highest plant population. Higher planting density resulted in higher mini tubers number per M² (Dimante and Gaile, 2015). Higher density of 60×10 cm (1247 thousand/ha) and 60 × 12.5 cm (1029 thousand/ha) recorded higher tuber number and tuber number decreased with wider intra row spacing but non-significant increase was reported in terms of tuber weight (Kushwah and Singh, 2008).

Highest yield at the closest spacing might have been due to the presence of the greatest number of plants. Foliage coverage increased with an increase in the plant density which was found to be related to higher tuber yield (Bremner and Radley, 1966). Mahmud *et al.* (2012) reported closer spacing increased the yield and that a higher foliage coverage percentage increased the yield by increasing the leaf area index and the photosynthetic area which favors production and the accumulation of more photosynthates in the tuber. Similar trend was observed by Rostami *et al.* (2015). In the present study increase in number of tubers per unit area with increasing plant population may be due to more number of plants or stems per unit area as tuber number is known to be directly related to stem number. Similar results were reported by Kushwah and Singh 2008; Malik *et al.*, 1999; Zamil *et al.*, 2010 and Singh *et al.*, 2019. Reducing the intra-row spacing significantly increased plant population and subsequently increased the yield performance (Masarirambi *et al.*, 2012 and Singh and Singh, 2016).

For total tuber number/ha no significant difference was recorded among days to haulm killing (table 3 and fig 3), but for weight significantly increasing trend was recorded with delay in haulm killing where

80 days (39.89 t/ha) and 90 days (43.64 t/ha) haulm killing recorded significantly higher tuber weight over 70 days haulm killing (34.18 t/ha) table 4 and fig 4. Similar trend with regard to total tuber number was reported by Kushwah and Singh, 2008 and Mahmud *et al.*, 2009 when haulm killing was done at 5 days interval and by Kumar *et al.* 2001 when haulm killing was done at 10 days interval from 60 to 70 and 80 days. Total tuber yield as well as processing grade yield increased significantly as the crop duration was increased from 70 to 90 days (Sandhu *et al.*, 2012). A significant increase was recorded in the yield of seed size, large size and total tubers with the increase of crop duration from 70 to 80 days (Garg *et al.*, 1999 and Singh and Singh, 2016). In interaction, All other factor combinations recorded significant increase in total tuber number over 75×20 cm plant geometry at 3 haulm killing days and highest was recorded in paired row planting with 70 days haulm killing (1092 thousand/ha).

Per cent non seed and seed size tubers

In terms of *non seed* tuber percentage by number, significantly increasing trend was reported with decrease in planting geometry and significantly highest was recorded in 75×20 cm plant geometry (57.62%) over lowest 60×20 cm plant geometry (49.25%). Significant increase in non seed size tuber was recorded with delay in haulm killing 80 days (53.69%) and 90 days (54.17%) over 70 days haulm killing (51.54%). Similar trend was reported by Mahmud *et al.*, 2009 wherein 65 days of haulm killing recorded significantly lowest nonseed tuber (28%) and highest in 80 days of planting (37.0%). In factor combinations, 75×20 cm plant geometry at 90 days haulm killing (60.25%) recorded significantly highest non seed size tubers over other factor combinations. For weight also similar trend was recorded as of number and significantly highest and lowest non seed

size tuber were reported in 75×20 cm plant geometry (49.20%) and paired row system (35.22%), respectively. Similar trend for haulm killing days and factor combinations was recorded for weight as of tuber number percent (table 5).

Increasing planting geometry increased the percent seed size tuber both in number and weight and highest was recorded in 60×20 cm plant geometry (50.75%) by number and paired row system (64.78%) by weight. Percent production of seed size tubers to total tubers (both on weight as well as number basis) was higher at narrow intra row spacing (Singh and Singh, 2016). Delay in haulm killing decreased the seed size % tuber both by number and weight and highest was reported in early 70 days haulm killing (48.16% by number and 65.12% by weight). The percentage of seed yield was 72% for 65 days after planting with significant decrease with delay in harvesting and least 63% at 80 days harvesting (Mahmud *et al.*, 2009). In factor level combinations, 60×20 cm plant geometry at 80 days haulm killing (51.15%) by number and paired row at 70 days haulm killing (73.15%) recorded highest seed size tuber percent over other factor combinations (table 4). Increasing plant density resulted in a gradual and significant reduction in the proportion of extra-large tubers, while increasing the proportion of seed size tubers (Singh *et al.*, 2019). This confirms the present finding where high density paired row planting gave highest seed size tuber percent.

Seed: non seed ratio

In present study, with increasing planting geometry seed: non seed ratio was better and best was recorded in 60×20 cm plant geometry (0.972) by number and paired row (0.556) by weight over lowest planting geometry 75×20 cm. Increase in plant density

Table 5 Percent non seed and seed tubers as influenced by planting geometry and haulm killing days

Plant geometry / DOHK	By Number						By weight											
	Percent Non seed tubers			Percent seed tubers			Percent Non seed tubers			Percent seed tubers								
	70 Days	80 Days	90 Days	Mean	70 Days	80 Days	90 Days	Mean	70 Days	80 Days	90 Days	Mean						
60 × 20 cm (Control)	49.63	48.85	49.27	49.25	50.37	51.15	50.73	50.75	36.35	36.92	46.98	40.08	63.65	63.08	70 Days	80 Days	90 Days	Mean
66 ×15 cm	48.99	49.40	54.95	51.11	51.01	50.60	45.05	48.89	37.19	39.82	42.86	39.96	62.81	60.18	57.14	60.04		
66 × 20 cm	52.35	55.42	54.45	54.07	47.65	44.58	45.55	45.93	33.63	39.41	42.23	38.42	66.37	60.59	57.77	61.58		
75 × 15 cm	53.20	55.12	54.18	54.17	46.80	44.88	45.82	45.83	31.59	43.17	44.65	39.80	68.41	56.83	55.35	60.20		
75× 20 cm	54.09	58.53	60.25	57.62	45.91	41.47	39.75	42.38	43.66	50.26	53.68	49.20	56.34	49.74	46.32	50.80		
Paired Row	52.78	54.82	51.95	53.18	47.22	45.18	48.05	46.82	26.85	38.91	39.90	35.22	73.15	61.09	60.10	64.78		
Mean	51.84	53.69	54.17	2.718	48.16	46.31	45.83	2.719	34.88	41.42	45.05	2.511	65.12	58.58	54.95	2.512		
CD _{0.05}	Plant geometry (A)			2.718													2.512	
	DOHK (B)			0.857													0.845	
	Factor (B) at same level of A			2.225													2.188	
	Factor (A) at same level of B			3.212													3.025	
DOHK- Days of haulm killing																		

resulted in a significant reduction in the proportionate yield of oversize tubers and improved large, seed size and under-size tuber yield at higher plant populations (Singh *et al.*, 2019). 70 days haulm killing recorded significantly best seed: noon seed ratio both for number (1.081) and weight (0.547) over poorest 80 and 90 days of haulm killing. The best ratio of seed and non-seed was 1:0.318 for 70 DAP and the poorest was 1:0.583 for 80 DAP (Mahmud *et al.*, 2009). In factor level combinations, 60×20 cm plant geometry at 70 days haulm killing (0.957) by number and paired row at 70 days haulm killing (0.367) recorded best seed: noon seed ratio over other factor combinations (table 6).

Seed multiplication rate (SMR)

Variations in SMR was recorded among planting geometry and for number, all the planting geometries recorded significantly higher SMR over 75×15 cm planting geometry (8.7) and highest was recorded in 66×20 cm planting geometry (11.0) table 6. For weight, all the planting geometries except paired row planting recorded significantly higher SMR over 66×15 cm planting geometry (8.0) and highest was recorded in 75×20 cm planting geometry (10.4). Wider spacing contributes the increase number and weight of tuber per plant and vice versa due to higher amount of reserve food and interplant competition for space, light, water and nutrient is less in the wider spacing (Hossain *et al.*, 2015). Wider spacing significantly increased SMR both by number and weight than narrow spacing (Kumar and Lal, 2006, Singh and Singh, 2016). Increased planting density showed a significant increase of progeny minitubers number per M², but it led to reduced multiplication rates (number of minitubers per planted plant) simultaneously (Dimante and Gaile, 2015). This confirms the present study. Significant decreasing trend

Table 6 Seed: non seed ratio and seed multiplication rate as influenced planting geometry and haulm killing days

Plant geometry/ DOHK	Seed: non seed ratio										Seed multiplication rate									
	By Number					By weight					By Number					By weight				
	70 Days	80 Days	90 Days	Mean	Days	70 Days	80 Days	90 Days	Mean	Days	70 Days	80 Days	90 Days	Mean	Days	70 Days	80 Days	90 Days	Mean	Days
60 × 20 cm (Control)	0.987	0.957	0.973	0.972	0.573	0.587	0.587	0.887	0.682	9.7	9.6	9.3	9.3	9.5	7.7	9.2	10.0	9.0		
66 × 15 cm	0.963	0.983	1.220	1.056	0.597	0.667	0.750	0.671	0.671	8.8	8.7	9.7	9.7	9.1	6.8	8.2	9.1	8.0		
66 × 20 cm	1.100	1.247	1.197	1.181	0.507	0.650	0.733	0.630	0.630	10.8	11.3	10.9	10.9	11.0	9.0	10.5	11.4	10.3		
75 × 15 cm	1.140	1.230	1.183	1.184	0.463	0.760	0.810	0.678	0.678	8.6	8.7	8.6	8.6	8.7	7.5	8.7	9.5	8.6		
75 × 20 cm	1.180	1.413	1.520	1.371	0.777	1.013	1.160	0.983	0.983	10.7	9.8	9.7	9.7	10.1	9.3	10.2	11.7	10.4		
Paired Row	1.117	1.213	1.083	1.138	0.367	0.637	0.663	0.556	0.556	9.8	9.4	8.9	8.9	9.4	7.3	8.5	9.0	8.3		
Mean	1.081	1.174	1.196	1.125	0.547	0.719	0.834	0.666	0.666	9.8	9.6	9.5	9.5	9.4	7.9	9.2	10.1			
CD _{0.05}				0.125				0.066	0.066					0.32				0.305		
DOHK (B)				0.037				0.023	0.023					0.20				0.186		
Factor (B) at same level of A				0.096				0.061	0.061					0.50				NS		
Factor (A) at same level of B				0.145				0.081	0.081					0.51				NS		
DOHK- Days of haulm killing																				

Table 7 Economics as influenced planting geometry and haulm killing days

Plant geometry/ DOHK	Number of tuber planted/ ha	70 days				80 days				90 days						
		Yield (q/ha)	Cost of cultivation (₹/ ha)	Gross return (₹/ ha)	Net return (₹/ ha)	B:C ratio	Yield (q/ha)	Cost of cultivation (₹/ ha)	Gross return (₹/ ha)	Net return (₹/ ha)	B:C ratio	Yield (q/ha)	Cost of cultivation (₹/ ha)	Gross return (₹/ ha)	Net return (₹/ ha)	B:C ratio
60 × 20 cm (Control)	83333	321.00	290984	481500	190516	1.65	383.80	321130	575700	254570	1.79	415.50	331547	623250	291703	1.88
66 × 15 cm	101010	344.60	317626	516900	199274	1.63	413.10	345855	619650	273795	1.79	459.00	363960	688500	324540	1.89
66 × 20 cm	75758	341.70	293603	512550	218947	1.75	396.80	317946	595200	277254	1.87	431.30	329175	646950	317775	1.97
75 × 15 cm	88889	332.00	302844	498000	195156	1.64	386.40	326984	579600	252616	1.77	423.80	339054	635700	296646	1.87
75× 20 cm	66667	308.20	271972	462300	190328	1.70	339.40	285814	509100	223286	1.78	388.00	315412	582000	266588	1.85
Paired Row	111111	403.20	351032	604800	253768	1.72	473.80	379870	710700	330830	1.87	501.00	396122	751500	355378	1.90
DOHK- Days of haulm killing																

DOHK- Days of haulm killing

was recorded for SMR by number and vice versa by weight with delay in haulm killing days (table 5). For factor level combinations, 66×20 cm planting geometry at 80 days of haulm killing (11.3) by number and 75×20 cm planting geometry at 90 days of haulm killing (11.7) by weight recorded significantly higher SMR over other combinations.

Economics

Highest cost of cultivation (₹ 351032, ₹379870 and ₹396122 /ha) was recorded with paired row planted crop due to higher seed cost higher requirement of labor for harvesting, transport charges and old gunny bags cost which also recorded highest gross return ((₹ 604800, ₹710700 and ₹751500 /ha for 70, 80 and 90 days of haulm killing) on account of higher seed tuber yield (table 7). Higher cost of planting material (Azimuiddin *et al.*, 2009) and increased cost of cultural practices were main cause of high cost of potato cultivation. Singh *et al* (2017) also reported highest gross return of ₹ 228,900/ ha with 30th October planted crop in Kufri Khyati on account of higher tuber yield in table potato crop in 90 days harvest crop. Similar treatment combination paired row planting with 70, 80 and 90 days of haulm killings) recorded highest net return ₹253768, ₹330830 and ₹355378 respectively. The lower net returns in other planting geometries are on account of lower yields. But highest B:C ratio was recorded in 66×20 cm planting geometry 1.75, 1.87 and 1.97 in 70, 80 and 90 days of haulm killing which is mainly due to lower seed rate thereby lower seed cost and comparatively higher seed yield over other treatments after paired row and 60×20 cm planting geometry. Highest B:C ratio of 2.4 was recorded with 60×20 spacing combination in Kufri Khyati in 90 day table potato crop (Singh *et al* 2017).

CONCLUSION

Among six planting geometry and three haulm killing days, though paired row planting with 70 days haulm killing gave highest seed size tuber yield, per cent seed size tuber by weight and best seed: non seed ratio and but in present investigation for seed production of variety Kufri Khyati planting geometry with 66×20 cm and haulm killing at 70 days found to be economically viable option for the farmers with higher B:C ratio (1.75).

CONFLICTS OF INTEREST

The authors confirm that this manuscript has no conflicts of interest

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