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Evaluation of Potato (*Solanum tuberosum* L.) Planting Techniques in High Hills of Nepal

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Abstract: A field experiment was conducted in Phidim-8, Ithung, Panchthar district of Nepal, between February and July 2022 to evaluate potato planting techniques under high hills of Nepal. Five treatments were evaluated including drilling, bund, line planting, behind the plough and random planting. Each treatment was replicated four times in a single-factor randomized complete block design. Crop growth parameters, including plant height and stem diameter at 55 days after planting (DAP) were not significantly influenced by the cultivation technique treatments initially. However, later observations (70 and 85 DAP) showed significant influences. Plants grown in bunds exhibited the maximum height (14.3 cm and 35.5 cm at 70 and 85 DAP, respectively) of potato plants. Similarly, bund planting resulted in the maximum stem diameter at 70 DAP (0.85 cm) and 85 DAP (1.18 cm). Bund planting technique also resulted in the production of maximum number of tubers (11.10 tubers plant^{-1}), average tuber yield plant^{-1} (545 g tuber weight) and average tuber yield plot^{-1} (9.15 kg), and overall productivity (36.33 metric t ha^{-1}).

Keywords: Bund planting, Drilling, Line planting, Planting system, Mountain agriculture, Random planting, Potato cultivation techniques, Crop management.

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1. Introduction

Globally, potatoes (*Solanum tuberosum* L.) are the most important noncereal food crop (Aksoy et al., 2021; Bozan et al., 2023; Lizana et al., 2021). Archaeological evidence suggests the earliest potato domestication centered around the Andes region of South America, as early as 8,000 years ago (de Haan and Rodriguez, 2016). Potatoes exhibit a broad genetic diversity, resulting in a wide range of size, color, and quality traits (Altuntas and Mahawar, 2022).

Potato, a member of the Solanaceae family produces an underground starchy stem called a tuber. Potato tuber is a nutritional powerhouse and a staple food in many cultures around the world, providing major contributions to human nutrition, livestock feed, employment, and income (Zaheer and Akhtar, 2016; Zierer et al., 2021). Potato tuber provides essential carbohydrates for energy and serves as a source of diverse bioactive phytochemicals including amino acids, dietary fiber, fats, vitamins, minerals and phenolic compounds, contributing significantly to a balanced diet (Rasheed et al., 2022).

Potatoes thrive in diverse agroclimatic conditions, indicating their remarkable adaptability. This adaptability makes them a successful crop across various regions and a vital dietary staple worldwide (Divya et al., 2021). Genetic traits, environmental interactions, and farming practices collectively contribute to this wide adaptability, ensuring its continued success and productivity in varied agricultural landscapes (Devaux et al., 2021).

Agriculture remains a significant contributor to Nepal's national economy, employing a large portion of the population and ensuring food security (Jha et al., 2021). Potatoes are widely cultivated in Nepal, from southern Terai at an altitude of 100 meters above sea

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level to the lofty northern mountains reaching 4000 meters. Considering dietary importance, potato is ranked as the third most important crop after rice and maize (Devaux et al., 2021). It is the fourth most important food crop after rice, maize, and wheat in Nepal (MoALD, 2018) . Cultivated in over 125 countries, the potato is a global food source consumed by more than one billion people daily (Sahu et al., 2024; Zaheer and Akhtar, 2016). Nepal ranks among the top twenty countries in terms of potato contribution to the human diet. This trend is fueled by the adoption of improved potato cultivars that directly impact farmer's income and household food and nutrient security. Potatoes are an important vegetable crop in kitchen gardens and serve as a cash crop for smallholder farmers in the high hills of Nepal (Subedi et al., 2019; Timsina, et al., 2011).

Potatoes are a globally important staple food and are preferred for their affordability and accessibility. Chemically they are a rich source of carbohydrates, primarily as starch. Moreover, potatoes are a good source of protein, vitamins, minerals and other phytochemicals (Lal et al., 2020; Singh et al., 2020). These compounds work together to enhance the bioavailability of essential minerals in the body. Furthermore, potatoes have antinutrients like oxalates and phytates, which can hinder mineral absorption (Lal et al., 2020).

Potato is grown as a cash crop in Nepal and is now Nepal's second staple food crop after rice. Potato consumption, per capita, has nearly doubled since 1990, reaching 51 kg year^{-1}. It is grown in 193,997 ha with 16.05 t ha^{-1} productivity and 3.112 million ton production in Nepal (MoALD, 2018). Potato farmers in Nepal are facing wide yield gap as compared to neighboring countries, and globally, mainly due to various constraints (Adhikari et al., 2023). Reducing the yield gap by adopting suitable crop management practices can be helpful in meeting future food security with limited resources (Dadrasi et al., 2022; Gairhe et al., 2023).

Appropriate planting techniques can help to maintain suitable planting density with appropriate spacing (row and plant spacing) of crop plants, including potatoes (Dhakal et al., 2019; Getaneh and Laekemariam, 2021; Hiyat et al., 2020). Suitable spacing will allow adequate airflow, sunlight penetration, and tuber development. This spacing can vary depending on potato variety and desired tuber size.

Plantation depth and soil management techniques significantly influence soil aeration, moisture and temperature around the tuber. Earthing up or ridging around the base of the plants improves soil aeration, water penetration and retention around the tubers. Moreover, it also reduces soil evaporation and runoff (Sakadzo et al., 2019). Exposed potato tubers are more susceptible to pests (Svubure et al., 2015), reduces the yield and quality of potato tubers by increased production of unmarketable tubers, and thus affect the economic value of the potato produced. When tubers are exposed to light, amyloplasts are transformed into chloroplasts in tuber peripheral cell layers, which cause the accumulation of the green photosynthetic pigment (Nebiyu et al., 2015). Ridging significantly reduced tuber greening (Qasim et al., 2013).

2. Materials and Methods

2.1. Experimental Site

Evaluation of potato planting techniques in high hills of Nepal was conducted in Phidim Municipality-8, Ithung, Panchthar district of Nepal (Fig. 1) from February 11 to July 10, 2022, under rainfed conditions. The experimental site was located at 27°4'20''N latitude and 87°48'50''E longitude at an elevation of 2400 meters above sea level (masl). The climate of the experimental site was temperate, characterized by the winter season from November to February, the morning and nights are quite chilly throughout the year. Snowfalls occurred during January and February and the temperature remains below freezing point during these months.

Fig. 1. Map of Panchthar district, Nepal showing research site

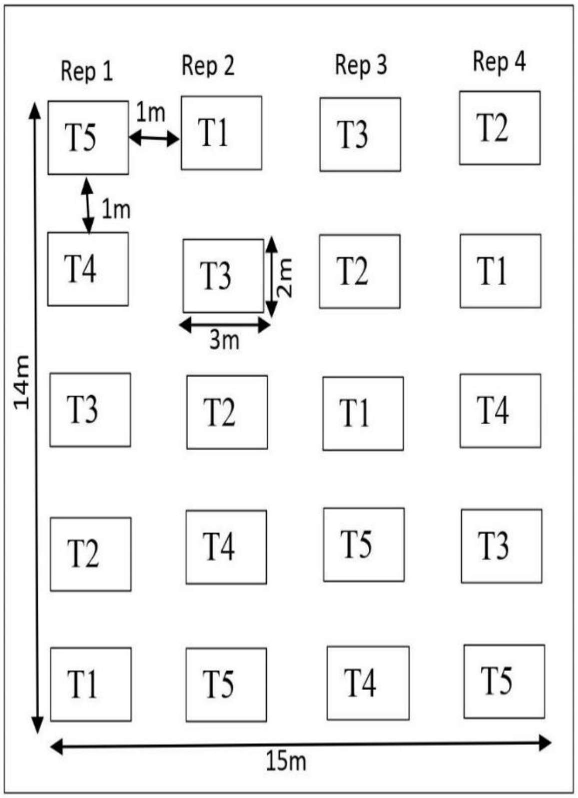

Fig. 2. Layout of experiment

2.2. Plant Material and Experimental Design

Potato tubers, of a local cultivar, Bittee, were obtained from a local supplier and stored before using in this experiment. Tubers were cleaned and extra outgrowths were separated. Tubers with uniform size were separated and after careful inspection, healthy and disease-free tubers were selected for plantation. For protection against soil-borne diseases, tubers were dipped in a fungicide solution [10 g carbendazim, (10 g) mixed in 20 liters of water] for 5 mins and subsequently shade dried for 1 hour.

The field experiment was performed using five planting method treatments arranged in a randomized complete block design (RCBD) with four replications (Fig. 2). Total experimental area was 210 m^2 (15 m × 14 m) containing 20 experimental units, each of an area 6 m^2 (3 m × 2 m). Tubers of potato cultivar Bitte were sown on February 11, 2022. Crop geometry was maintained at 60 cm × 25 cm in three treatments i.e. T1: Drilling, T2: Bund and T3: Line sowing. Five rows were formed in each experimental plot with 7 plants in each row. Treatments and replications were separated by a buffer zone of 1 m width (Non-experimental area).

Soft, well-drained, well-aerated and weed-free seedbed was prepared by three plowing followed by harrowing. Local crop management recommendations for potato cultivar Bitte were followed, including pest control and fertilizer application. Farmyard manure (FYM) recommended dose of fertilizers was used i.e., FYM: 1500 kg $ropani^{-1}$ (1 Ropani = 508.72 m^2; ≈3-ton ha^{-1}), Urea: 7 kg $ropani^{-1}$, (≈137.5 kg ha^{-1}) DAP: 11 kg $ropani^{-1}$ (≈216 kg ha^{-1}) and MOP: 5 kg $ropani^{-1}$ (≈98.3 kg ha^{-1}). Recommended fertilizers were soil incorporated before plantation.

2.3. Tagging and Weeding

For easy observation and data collection, plots were tagged on the planting day. Five plants from each plot were selected randomly and marked with red ribbons for identification during the measurement of physical parameters. Potato plants develop their canopy between 28-42 DAP. Adequate weed control measures are essential during this period to ensure successful crop establishment. The first manual weeding was done at 60, followed by a second weeding at DAP. Throughout the experiment period, the field was maintained free of weeds and stress. Data was collected at regular intervals throughout the growing period.

2.4. Earthing up and Harvesting

Proper earthing up in potatoes facilitates tuber development (Gebregwergis et al., 2021; Rumbidzai et al., 2022). Earthing up was done at 80 DAP to keep the soil loose, eradicate weeds, and cover up the tuber properly.

2.5. Harvesting

Due to the temperate climatic conditions of Ithung Panchthar, potato germination, growth and development took longer than in some regions. Potato was manually harvested after 150 DAP. Traditionally, potatoes were dug up with the long handle kodalis (hoes), spading forks, or potato hooks. Commercially, harvesting is done with large potato harvesters which scoop up the plant and surrounding earth.

2.6. Statistical Analysis

Data recorded during the experiment on potato planting techniques, was systematically arranged based on various observed parameters. Microsoft Excel 2019 and R Stat version 4.2.1 were used for data entry and analysis. Means were compared at 95% probability using Fisher's protected least significant difference Test (LSD, P = 0.05).

Table 1. Average plant height of potato at different growth stages, under different planting techniques

Treatment	Plant Height (cm)		
	55 DAP	70 DAP	85 DAP
Drilling	4.98±0.26[b]	9.325±0.55[c]	23.85±0.07[b]
Bund	7.30±0.74[a]	14.3±0.44[a]	35.65±0.02[a]
Line planting	6.88±0.84[ab]	12.27±0.54[b]	34.60±0.03[a]
Behind the plough	5.93±0.80[ab]	11.37±1.04[bc]	33.15±0.06[a]
Random planting	6.16±0.0.72[ab]	10.85±0.46[bc]	24.85±0.03[b]
F value	0.15 NS	0.001	0.01
LSD	1.94	1.97**	7.78*
CV%	20.23	11.04	16.60
Mean	6.24	11.62	30.42

Means followed by common letter(s) within the column indicate non-significant difference based on Fishers Protected LSD at 0.05 level of significance, * and ** significant at 5% and 1% level of significance, ns – non significant. (DAP, days after planting; CV, Coefficient of Variation; LSD, Least Significance Difference; Sem, Standard Error of mean).

3. Results and Discussion

3.1. Plant Height

At 55 DAP different planting techniques did not show significant variation in plant height. Initially, plants produced in different treatments had statistically similar plant height with an average plant height of 6.24 cm (Table 1). However, at 70 DAP plant height was significantly influenced by different planting techniques. Plants raised through the bund were the tallest (14.3 cm plant height) followed by line sowing and shortest plants (9.32 cm) were observed when potatoes were sown by drilling. The average plant height was 11.62 cm.

Similarly, at 85 DAP plant height showed significant variation among different planting systems. The tallest plants (35.65cm) were observed in treatment with the bund planting technique followed by line sowing (34.60 cm) and behind the plough (33.15 cm). The shortest plants (23.85 cm) were observed in plots where potatoes were sown with the drilling technique. Ridge plantation of potatoes produced the tallest plants (53.4 cm) as compared to the traditional method (Qasim et al., 2013). Increased plant height in ridge planted potatoes can be attributed to soft soil surface created by earthing up on ridges, leading to better growth and allowing the plants to reach their full height potential. Contrarily, drilling may compact the rhizosphere, hindering plant emergence and limiting the increase in plant height.

Singh and Singh (2020) investigated the response of potatoes under varying intra-row spacings. They found that different levels of intra-row spacing significantly influenced potato plant height, tallest potato plants were observed when grown at 8 cm spacing. With increasing plant spacings, the height of potato plants was reduced significantly.

3.2. Stem Diameter

The number of main stems of potatoes significantly varied under different planting techniques (Table 2). At 55 DAP Potato plants raised on the bunds produced maximum stem diameter (0.65±0.01 cm), followed by sowing behind the plough (0.59±0.03), line sowing (0.57±0.04) and random planting (0.51±0.04).

Table 2. Average number of main stem and stem diameter of potato at different growth stages under different planting techniques

Treatment	Average number of main stems	Stem Diameter (cm)		
		55 DAP	70 DAP	85 DAP
Drilling	3.25± 0.05[c]	0.47±0.03[b]	0.61±0.01[b]	0.91±0.07[b]
Bund	4.00± 0.14[a]	0.65±0.01[a]	0.85±0.01[a]	1.18±0.02[a]
Line sowing	3.70± 0.1[b]	0.57±0.04[ab]	0.73±0.05[ab]	1.14±0.03[a]
Behind the plough	3.35± 0.05[c]	0.59±0.03[ab]	0.69±0.09[b]	1.16±0.06[a]
Random planting	3.45± 0.12[bc]	0.51±0.04[b]	0.70±0.02[b]	1.09±0.03[a]
LSD	0.29***	0.12 NS	0.14*	0.16*
CV%	5.41	14.31	12.85	9.91
Mean	3.55	0.55	0.71	1.09

Means followed by common letter(s) within the column indicate non-significant difference based on Fishers Protected LSD at 0.05 level of significance, * and ** significant at 5% and 1% level of significance, ns – non significant. (DAP, days after planting; CV, Coefficient of Variation; LSD, Least Significance Difference; Sem, Standard Error of mean).

Table 3. Tuber per plant, plot and potato yield under different sowing techniques

Treatment	Total Tubers plant^{-1}	Tuber Yield Plant^{-1}	Total Tuber Yield Plot^{-1}	Productivity of Potato (mt/ha)
Drilling	8.40±0.25^{c}	256.0 ± 55.5^{d}	3.55± 0.71^{c}	17.06± 0.14^{d}
Bund	11.10±0.46^{a}	545.0± 66.62^{a}	9.15± 0.27^{a}	36.33± 0.26^{a}
Line planting	10.30±0.42^{b}	399.0± 30.24^{b}	8.10± 1.09^{ab}	26.60± 0.50^{b}
Behind the plough	9.55±0.26^{ab}	375.5± 31.38^{bc}	7.40± 0.07^{b}	25.03± 0.12^{bc}
Random planting	6.65±0.27^{c}	291.0± 48.77^{cd}	4.15± 0.84^{c}	19.40 ±1.20^{cd}
LSD	1.11***	97.98***	1.57***	6.53***
CV%	7.83	17.03	15.80	17.03
Mean	9.2	373.3	6.47	24.88

Means followed by common letter(s) within the column indicate non-significant difference based on Fishers Protected LSD at 0.05 level of significance, * and ** significant at 5% and 1% level of significance, ns – non significant. (DAP, days after planting; CV, Coefficient of Variation; LSD, Least Significance Difference; Sem, Standard Error of mean).

The least stem diameter (0.47±0.03) of stems was recorded when the potato was sown by drilling. At 70 DAP, stem diameter of the potato plant followed a similar trend (55 DAP). However, at 85 DAP, the trend of stem diameter of potato plants, was different and statistically similar, except for plants sown by drilling, which recorded the lowest stem diameter of potato plants.

3.3. Number of Stems Plant^{-1}

Highly significant variation in the average number of main stems under different cultivation techniques was observed (Table 2). Plants raised on the bunds produced maximum stems (4.0) plant^{-1}, followed by line planting and random planting. The least number of stems was recorded in experiment plots with drilling (3.25). The average number of tubers in the bunds was more, this might be due to aeration, which preserved soil moisture in field by making hills. A higher number of stems plant^{-1} can result in more tubers overall, however, increased competition between these stems reduces the size and weight of individual tubers (Shayanowako et al., 2015).

3.4. Tuber Yield Plot^{-1} (kg)

The data presented about average tuber yield plot^{-1} showed highly significant variation among different cultivation techniques (Table 3). Higher tuber yield tuber plot^{-1} was recorded in bund i.e. 9.15 kg, followed by line planting. Lowest average yield of tuber plot^{-1} was weighted on drilling which was 3.55 kg.

3.5. Tuber Yield Plant^{-1}

Table 3 shows a highly significant variation in the average tuber weight plant^{-1} among different cultivation techniques. The highest average weight of tuber plant^{-1} was recorded on bund which was 545 g followed by line sowing whereas the least weight was observed on drilling techniques, it was 256.0g. Getaneh and Laekemariam (2021) experimented to investigate response of potato sown at differing sowing spacings in Ethiopia. They concluded that with increasing plant spacing average marketable tubers plant^{-1}, total tuber number plant^{-1} and average tuber weight plant^{-1} increased with increasing plant spacings.

3.6. Number of Tubers Plant^{-1}

The analyzed data (Table 3) showed that cultivation techniques significantly influenced tubers plant^{-1}. The average number of potatoes was more in bund which was 11.10 followed by behind the plough and least number of tubers (6.65) were produced when potatoes were sown in random planting.

Qasim et al., (2013) also reported that the average number of potato tubers was 10.1 which was significantly different and higher when potatoes were planted on wide beds and covered by the soil from one side, whereas the lowest number of tubers i.e. 5.8 was found under random plantation following local farmers techniques. It may be due to more aeration, and adequate moisture on the bunds. Similarly, Tarkalson et al., (2011) reported that row spacing significantly influenced the density of potato tubers under irrigated conditions at the USDA-ARS Northwest Irrigation & Soils Research Lab in Kimberly, United States. Similar variations in potato production were observed under varying plant spacings (Bussan et al., 2007). Getaneh and Laekemariam (2021) experimented to investigate the response of potato sowing techniques in Ethiopia. They found that with increasing plant spacing average marketable tubers plant^{-1}, total tubers plant^{-1} and average tuber weight plant^{-1} increased with increasing plant spacings.

3.7. Potato Productivity (metric ton ha^{-1})

Total productivity of potatoes was significantly influenced by different planting techniques (Table 3). It was observed that potato productivity was highest on the bunds (36.33 mt ha^{-1}) followed by line sowing (26.60 mt ha^{-1}). The lowest productivity was observed in drill sowing (19.40 mt ha^{-1}).

Table 4. Comparison of potato tuber size distribution under different cultivation techniques

Treatment	Number of Tubers		
	Small Tubers (< 20 g)	Medium Tubers (20-50 g)	Large Tubers (> 50 g)
Drilling	2.32±1.41^{d}	1.30± 0.44^{d}	1.35± 0.38^{d}
Bund	3.60±0.44^{c}	4.25± 0.22^{a}	4.95± 0.22^{a}
Line planting	5.17±0.87^{a}	2.85± 0.17^{bc}	3.75 ±0.17^{b}
Behind the plough	4.20±1.73^{b}	2.90± 0.12^{b}	2.65± 0.09^{c}
Random planting	2.65±0.54^{d}	2.25± 0.09^{c}	1.75± 0.09^{d}
LSD	0.533***	0.63***	0.70***
CV%	9.64	15.25	15.93
Grand mean	3.59	2.71	2.89

Means followed by common letter(s) within the column indicate non-significant difference based on Fishers Protected LSD at 0.05 level of significance, * and ** significant at 5% and 1% level of significance, ns – non significant. (DAP, days after planting; CV, Coefficient of Variation; LSD, Least Significance Difference; Sem, Standard Error of mean).

Potato yield and quality are both impacted by tuber size (Onaran and Çalışkan, 2023). Several factors significantly influence potato tuber size and productivity, including the quantity of photosynthetic products available to the plant, the overall tuber growth and development, and the balance between the number of tubers per unit area and the average weight of each tuber (Andrade et al., 2021; Mangani et al., 2015; Zheng et al., 2016). Higher potato productivity was obtained when potatoes were sown on the bunds, this might be due to good emergence, a greater number of stems plant^{-1}, wider planting distance and earthing up. Due to wider planting space and bund made on land, it reduces inter-plant competition, moreover, plants spread well so more area was exposed to sunlight (Arega et al., 2018; Mangani et al., 2015).

It increases photosynthesis and thus increases starch accumulation which leads to higher yield. Similarly, earthing up sufficiently loose soil for adequate drainage and aeration. Aeration of soil has great effect on tuber setting and development while potato tubers planted haphazardly i.e. random planting showed poor results because of less emergence and narrow spacing (Doboch et al., 2022). These results are in agreement with the findings of other studies across the globe (Abuarab et al., 2019; Larkin et al., 2021).

3.7.1. Small Size Tubers (< 20 g) Plant^{-1}

Table 4 revealed that the average number of small tubers (< 20 g) were significantly influenced by different cultivation techniques. The highest number of small tubers was recorded on line sowing which was 5.17 followed by planting behind the plough. The lowest number (2.32) of small tubers was produced when potatoes were sown through drilling.

Average number of small tubers was seen more in line sowing this might be due to the thin soil layer which doesn't provide proper soil nutrients and moisture loss might be more in a thin layer of soil surface than in other techniques because of which tuber could not get sufficient amount of water to grow. Bussan et al., (2007) also found significant variation in the tuber weight of potatoes under varying plant spacings at the University of Wisconsin–Madison, Hancock Agricultural Research Station, USA. Soil properties and management practices significantly influence the tuber size distribution of potatoes (Andrade et al., 2021; Mhango et al., 2021; Sadawarti et al., 2023).

3.7.2. Medium Size Tubers (20-50 g) Plant^{-1}

The data presented in Table 4 revealed statistically significant differences in the average number of medium weight tubers (20-50 g) produced by various planting techniques. The highest number (4.25± 0.22) of medium weight tubers was seen when potatoes were sown on bund, followed by planting behind the plough (2.90± 0.12), line planting (2.85± 0.17) and random planting (2.25± 0.09). Drilling resulted in the lowest number of medium-sized tubers (1.30 ± 0.44 plant^{-1}).

3.7.3. Large Size Tubers (> 50 g) Plant^{-1}

Total number of tubers weighing over 50 g differed significantly between different cultivation techniques (Table 4). The highest number of tubers above 50 g were recorded on bund which was 4.95 followed by line sowing i.e. 3.75, behind the plough i.e. 2.65 and random planting i.e. 1.75. The lowest number of large tubers was observed when potato was sown through drill sowing (1.35± 0.38). This variation might be explained by the ease of earthing-up in bund planting. Bunds allow for better tuber cover, promoting growth and larger tuber size due to soft and friable soil. Moreover, wider spacing and mounds created in bund planting are likely to contribute to larger tuber development.

4. Conclusion

Evaluation of potato planting techniques in high hills of Nepal showed significant variation. Improved planting systems increase the growth and yield of potatoes whereas in traditional methods productivity was comparatively lower. It can be concluded that among different planting system of potatoes in the high hills of Nepal. Planting potatoes in bund showed significant variation in the growth and yield of potatoes. So, bund planting technique for cultivation of potatoes is the most suitable in the high hills of Nepal. In this way, improved cultivation practice increases the productivity of potatoes. Hence, to enhance commercial cultivation of potatoes with better growth and yield, potatoes should be grown on bunds and cultural operations like weeding and earthing up should be necessarily done to enhance the tuber quality. As in all planting systems the cost of cultivation is similar it is just about the time requirements to plant in different techniques differs. In bund cultivation weeding and earthing up is easier than in other techniques because of height raised, weeds cannot spread on the surface as in planting behind the plough and land planting. In random planting, these intercultural operations are difficult to perform.

List of Abbreviations: CV – Coefficient of Variation, DAP, days after planting, LSD –Least Significance Difference, SEm – Standard Error of mean.

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Author's Contribution: Eliza Ghimire designed and performed the experiments and wrote the manuscript. Nisha Karki and Samridhi Kafle analysed the data with the author. Sanu Krishna Maharjan supervised the research activities and contributed to the final version of manuscript. All authors discussed the results and contributed to final manuscript and approved it for publication.

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