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Effect of Crop Geometry on Growth, Yield and Quality of Sweet Potato (*Ipomoea batatas* L.) Genotypes

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ABSTRACT

Field experiments were conducted in 2018 and 2019 at the National Potato Research Programme (NPRP), Lalitpur (1360 masl), Nepal, to determine the effect of crop geometry on the growth, yield, and quality of sweet potato genotypes. The experiment was laid out on sandy loam soil in a factorial randomized complete block design (RCBD) with three replications and comprised of a total of twelve treatment combinations of four crop geometry (60cm×25 cm, 60cm×30 cm, 70cm×25 cm, and 70cm×30 cm) and three genotypes (CIP 440015, CIP 440267 and Local White). Among the different crop geometries and genotypes evaluated, 70cm×30 cm plant spacing and Local White genotype were found statistically superior to enhance marketable tuberous root weight per plant (0.572 and 0.541 kg), tuberous root diameter (62.59 and 61.0 mm), shoot fresh weight (509 and 524 g), and tuberous root yield per plant (616 and 620 g). The genotype, Local White yielded higher among the genotypes. The reducing sugar content was influenced significantly by crop geometry and genotypes. The pooled mean showed the highest (15.48 and 17.26 %) reducing sugar in closer geometry 60 cm × 25 cm and Local White genotype respectively and the lowest (11.54 %) in the genotype CIP 440015. CIP genotypes, on the other hand, were high in ß carotene content, whereas the Local genotype had a negligible amount (0.35 mg/100g). On hectare level, our result showed that highest plant density of 66,666 plants ha^{-1} (60 cm × 25 cm) could give the highest yield per unit area due to greater crop biomass. Our findings suggest that crop geometry can have a considerable impact on sweet potato production. As a result, the geometry of sweet potatoes can be wide or narrow depending on our needs and the area available in our study area or a similar situation.

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Introduction

Sweet potato (*Ipomoea batatas* Lam.), a hexaploid (2n= 6×=90 crop) tropical perennial cultivated as an annual, is one of the world's most important underexploited crops. It is the world's seventh and fourth most important food crop in tropical countries (Waramboi et al., 2010). It is also the third-largest cultivated root crop in the world, after potato and cassava (FAO, 2015; Markos and Loha, 2016). In 2019, the global production of sweet potatoes amounted to approximately 91.8 million metric tons (FAOSTAT, 2019). Asia accounts for 80.7 percent of world sweet potato production followed by Africa (16 %), the Americas (2.6%), Oceania (0.6%), and Europe (0.1%) (FAOSTAT, 2019).

Sweet potatoes are typically grown in less fertile marginal soils with limited water supply. Despite these conditions, the crop can be considered very important in promoting nutritional security, especially in agriculturally backward areas with poor quality soils (Srinivas, 2009). It is a good source of dietary fiber, minerals, and vitamins (Vimala et al., 2011; Low et al., 2007). Orange flesh sweet potatoes (OFSP) are high in carotenoids and ß-carotene (Jakahata et al., 1993). Because of these nutritional properties, OFSP is an excellent food security crop and a valuable tool in the global fight against vitamin A deficiency in areas where vitamin A-rich food materials are scarce.

It is known in Nepal by the name of *Sakhar Khand* and grown throughout the mid-hills and terai in the kitchen garden for home consumption (Gautam, 1991). It is grown under unirrigated conditions throughout the country up to 1800 masl (Gautam, 1998). Nepal government paid no attention to sweet potato production, it is considered a neglected crop, and statistical records are not maintained.

People eat sweet potatoes during festivals like *Makar Sakranti and Shiva Ratri* as a religious value. Farmers usually plant local cultivars of indigenous red and white type sweet potatoes that require long-duration to produce tuberous roots.

Sweet potato requires a moderate temperature range of 21-26°C and is susceptible to frost damage, limiting production in temperate regions. It thrives in climates with an average temperature of 24 °C (Kay, 1973). Its growth is severely restricted at temperatures below 10 °C. Nutritional insecurity, particularly vitamin A deficiency, has occurred in ethnic communities and scheduled cast groups of Nepal. Thus, sweet potato would play an important role in food security in flood-prone and marginalized areas of the mid-hills and terai. In this connection, research works on sweet potato were initiated in few years, and also private sector involvement in sweet potato cultivation has been increased. The production of tuber is low and at the same time quality is inferior in indigenous varieties in Nepal. Among the various factors responsible for low production, inappropriate crop geometry and poor selection of varieties are important. Thus, sweet potato yield could be increased by using a suitable plant density and improved cultivars. According to Singh and Singh (2002), establishing an optimum population per unit area of the field is critical to achieving maximum yield.

Norman (1963) reported that both too narrow and too wide spacing affect yields due to competition (for nutrients, moisture, air, radiation, and so on) and inefficient utilization of the growth factors. Normally, as population increases yield also increases proportionally, and once a certain level is reached, yield begins to decline. Some other factors influence spacing: soil fertility, moisture availability, crop growth pattern, and cultural practice. The sweet potato spacing used by the National Potato Research Programme is 60 cm × 30 cm (NPRP, 2014). Despite the lack of research, the majority of sweet potato farmers use narrow spacing. Regardless of cultivar type, sweet potato farmers in Nepal plant the crop at varying spacing. Sweet potato planting density has a significant impact on growth and yield (Onunka and Nwokocha, 2003). The present study was conducted to determine the response of crop geometry on the growth, yield, and quality of sweet potato genotypes.

Materials and Methods

Experimental Site

Field experiments were carried out in 2018 and 2019 at National Potato Research Programme (NPRP), Khumaltar, Lalitpur, Nepal. The site is located at longitude 85º19'E and latitude 27º39'N with a mean altitude of 1360 m above sea level. Soil samples were collected with the help of screw augur from a depth of 0-30 cm from the experimental fields before planting. The composite soil samples were analyzed in soil laboratory and the soils were sandy-loam type (Table 1). Monthly weather data (Table 2) of the respective year was received from the Department of Hydrology and Meteorology (DHM), Babarmahal, Kathmandu, Nepal.

Experimental treatments and design

The experiment was laid out in a factorial randomized complete block design (RCBD) with three replications and comprised of total twelve treatment combinations of four crop geometry (60cm×25 cm, 60cm×30 cm, 70cm×25 cm, and 70cm×30 cm and three genotypes (CIP 440015, CIP 440267 and Local White). The equivalent number of plants per hectare for each spacing are shown in Table 3. The genotypes used in the experiment were two advanced OFSP along with local genotype conserved under the *in-vivo* condition of NPRP, Lalitpur, Nepal (Table 3). The experimental land was ploughed, harrowed, pulverized, and ridged before planting. The gross plot size was measured 3 m × 2.4 m (7.2 m^2) consisting of 3 and 4 rows for 70 cm and 60 cm row spacing, respectively. Spacing between each plot and block was kept as 0.75 and 1m, respectively. At planting time, the recommended N: P2O5: K2O fertilizers were applied at rates of 30:30:50 kg per hectare, with urea serving as the N source. Manure was applied as compost (20 mt ha^{-1}). Sweet potato vines (middle portions) of each genotype were cut with three nodes and planted on ridges with about two nodes buried in the soil uniformly for all treatments. The sweet potato vines were planted on 18th and 19th August, 2018 and 2019, respectively. During the crop growing period, all crop management practices such as cultivation, weeding, and so on are carried out as needed.

Data Collection, Measurements, and Statistical Analysis

Data on growth, yield, and quality parameters were recorded during the study period. Measurements were done on five plants chosen randomly from each plot and averaged for the variable. Vine internode length was measured using a 30 cm ruler. Length of main vine, vine internode, and root diameter was measured with a measuring tape and Vernier caliper respectively. The percentage of the ground cover was recorded at 60 days after planting (DAP); while other morphological and storage root characters were scored at 90 and 120 DAP respectively. The experimental plots were harvested on 19th and 20th December, 2018 and 2019 respectively. Shoot fresh weight was recorded by cutting five randomly sampled plants per plot at the soil surface just before harvesting. Tuberous roots were also graded as marketable (>50 g) and unmarketable (<50 g) by weight basis and number and weight was taken accordingly. The total tuberous root weight per harvested plot was recorded with the help of electronic balance and the estimated yield per hectare was calculated based on tuberous root weight/plot.

Table 1. The chemical properties of experimental soils

Year	pH	N %	P_2O_5	K_2O	OM %	Sand %	Silt %	Clay %	Soil texture
2018	6.62	0.18	164 mg/kg	137 mg/kg	4.75	-	-	-	Sandy loam
2019	4.85	0.20	107.12 kg/ha	428 kg/ha	4.16	23.8	66.0	10.2	Sandy loam

Table 2. Monthly weather during cropping season of 2018 and 2019 experimentation period at Khumaltar, Lalitpur, Nepal

Months	Rainfall (mm)		Temp. (°C) 2018		Temp. (°C) 2019		Relative humidity (%)	
	2018	2019	Min	Max	Min	Max	2018	2019
August	322.0	172.8	20.5	27.7	20.9	29.2	77.3	78.7
September	53.2	264.3	19.2	28.4	19.3	27.0	76.2	82.4
October	0	3	11.8	25.9	14.4	25.7	72.1	76.1
November	0	0	6.9	22.8	10.4	24.0	69.4	69.4
December	0.9	29.2	3.6	18.5	3.7	18.2	70.8	62.8

(DHM, 2021)

Table 3. Plant population density and sweet potato genotypes used for experiment

Crop geometry (S)	Plants ha^{-1}	Genotypes (G)	Origin	Source
60cm×25 cm (S1)	66,666	CIP 440015 (G1)	USA	CIP, Peru, Lima
60cm×30cm (S2)	55,555	CIP 440267 (G2)	Vietnam	CIP, Peru, Lima
70cm×25 cm (S3)	57,142	Local White (G3)	Lamjung, Nepal	Farmers, Nepal
70cm×30 cm (S4)	47619	-	-	-

Dry matter (DM), moisture, reducing sugar, and beta carotene contents were analysed by the AOAC method (AOAC, 2005). Dry matter (%) content was determined by chopping and mixing of tubers into small pieces and drying 100-gram sample in hot air oven at 80°C for the first six hours and then at 65°C till constant weight was obtained (Kumar et al., 2006).

$$\text{Dry matter (\%)} = \frac{\text{Dry weight of sample(g)}}{\text{Initial weight before drying (g)}} \times 100$$

Reducing sugar (%) was determined by the di-nitrosalicyclic colorimetric method (Miller, 1959). Light absorbance was recorded in a spectrophotometer (Agilent Technologies, Cary 60 UV-VIS, USA) at 510 nm. The ß-carotene content of the sweet potato tuber samples was determined by the solvent partition method as described in Rangana (2007). The data were analysed by using Genstat version 18 software for windows (VSN International, 2016). Means were separated by Duncan's Multiple Range Test at 5% level of significance.

Results

Growth Parameters

In 2019, ground cover was highly significant (P≤0.001) among the crop geometry (Table 4). The highest (100.0 %) ground cover was recorded at 60 cm × 25 cm followed by 70 cm × 30 cm (99.88%). The pooled data over the years revealed that ground cover was highly significant among the genotypes, but had no significant effect among crop geometry. The average ground cover was higher (100.0%) in 2019 than in 2018 (95.33%). Genotype CIP 440015 exhibited better (99.5%) ground cover than Local White (97.6%).

The vine length and vine internode diameter varied with the genotypes but significantly not affected by the crop geometry. The pooled value showed that Local White vines were significantly longer (274.0 cm) than other genotypes, whereas CIP 440015 had significantly the highest (5.55 mm) vine internode diameter compared to other genotypes. Likewise, vine internode length was also not varied significantly by the different crop geometry but varied with the genotypes (Table 6). The longest vine internode length (8.19 cm) was recorded in Local White and the shortest (4.81 cm) in the genotype CIP 440015. The pooled result showed that the interaction effect of crop geometry and genotypes showed a non-significant variation on ground cover, vine length, vine internode diameter, and vine internode length (Table 5 and 7).

Yield Parameters

The marketable tuberous root yield per plant and root diameter was significantly influenced by different crop geometry in different genotypes (Table 6). The pooled value indicated that the highest (0.527 kg) root weight was observed at 70 cm × 30 cm followed by 70 cm × 25 cm (0.468 kg). The average root weight was higher (0.468 kg) in 2018 than in the year 2019 (0.443kg). The highest mean value (62.59 mm) of root diameter was recorded at wider spacing 70 cm × 30 cm, while the lowest (50.79 mm) mean value was at closer spacing 60 cm × 25 cm. Genotype Local White yielded the highest tuber weight per plant and root diameter (0.541 kg and 61.0 mm) than other CIP genotypes. In tuberous root diameter, a highly significant interaction effect of geometry and genotype was observed (Table 7).

The pooled result showed the significant differences in tuberous fresh root and shoot weight per plant by crop geometry and genotypes. Figure 1 shows that the highest tuberous root yield (616 g) and shoot fresh weight (509 g) per plant was achieved with the 70 cm × 30 cm. Tuberous root weight and shoot fresh weight per plant were differed significantly in different genotypes. Pooled mean showed the highest tuber (620 g) and fresh shoot weight (524g) per plant was recorded in the genotype Local White (Figure 2).

The marketable tuberous root yield (mt ha^{-1}) was significantly affected by geometry in 2019 (Table 8). The highest yield value (26.16 mt ha^{-1}) was recorded from closer spacing S_1 (60 cm × 25 cm), followed by S_2 (60 cm × 30 cm) however, the lowest yield value (20.17 mt ha^{-1}) was noticed in S4 (70 cm × 30 cm). The pooled value showed significant variations on this parameter among the genotypes evaluated. The genotype Local White produced the highest marketable root yield (27.22 mt ha^{-1}), whereas the other two genotypes are significantly at par with each other. Unmarketable tuberous root yield was significantly affected by crop geometry in 2018, where the highest yield (3.05 mt ha^{-1}) was found at 60 cm × 25 cm spacing but the lowest (1.89 and 1.95 mt ha^{-1}) was at 60 cm × 30 cm and

70 cm × 30 cm. Unmarketable yield was significantly different among genotypes in 2018 and 2019, but the mean value was not significant.

The population density of 66,666 plants per hectare with planting at 60 cm × 25 cm produced the highest total tuberous root yield of 32.54 mt ha^{-1} in 2019 and 27.61 mt ha^{-1} in 2018 and mean yield (30.08 mt ha^{-1}). The results are only significant in 2019 and two years mean yields showed non-significant differences among crop geometry. Though the tuberous root yield (mt ha^{-1}) did not significantly different, the highest mean yield of tuberous roots (30.08 mt ha^{-1}) was recorded at 60 cm × 25 cm followed by 60 cm × 30 cm (28.54 mt ha^{-1}), while lowest mean yield (25.37 mt ha^{-1}) was recorded at wider crop geometry 70 cm × 30 cm (Table 8). Significant differences occurred in total tuberous root yield (mt ha^{-1}) among the sweet potato genotypes evaluated except in the experimental year 2018. The genotype Local white produced the highest (38.02 mt ha^{-1}) total tuberous root yield in 2019, whereas the mean yield was (31.87 mt ha^{-1}). The genotype CIP 440015 produced the least mean tuberous root yield (25.26 mt ha^{-1}) compared to all other genotypes tested. Interaction between crop geometry and genotype was not significant on marketable, unmarketable, and total tuberous root yield (mt ha^{-1}) (Table 9).

Table 4. Effect of crop geometry and genotype on ground cover, vine length and vine internode diameter of sweet potato during the years 2018 and 2019

Treatments	Ground cover (%)			Vine length (cm)			Vine internode diameter (mm)		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
A. Crop geometry (S)									
S1 (60 cm × 25 cm)	98.0	100.0a	99.00	145.89	144.5	145.2	4.52	4.61	4.56
S2 (60 cm × 30 cm)	96.44	99.44c	97.94	158.60	150.3	154.5	4.48	4.91	4.69
S3 (70 cm × 25 cm)	91.89	99.66bc	95.78	146.33	150.8	148.6	4.56	4.73	4.64
S4 (70 cm × 30 cm)	91.67	99.88ab	95.78	148.44	142.3	145.4	4.54	4.78	4.66
P- value	0.109	<.001	0.240	0.633	0.913	0.696	0.969	0.220	0.761
LSD (0.05)	6.24	0.2251	3.805	22.916	29.82	17.61	0.334	0.283	0.246
B. Genotypes (G)									
G1 (CIP 440015)	99.17[a]	100.0[a]	99.5[a]	87.70[b]	82.0[b]	84.8[b]	5.26[a]	5.83[a]	5.55[a]
G2 (CIP 440267)	89.00[b]	99.25[b]	94.1[b]	83.93[b]	84.4[b]	84.2[b]	4.31[b]	4.18[b]	4.24[b]
G3 (Local White)	95.33[a]	100.0[a]	97.6[a]	277.82[a]	274.0[a]	276.2[a]	4.0[c]	4.26[b]	4.13[b]
P -value	0.003	<0.001	0.006	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	5.41	0.1950	3.295	19.846	25.83	15.25	0.289	0.245	0.813
CV	6.8	0.2	5.9	15.6	20.8	17.8	7.6	6.1	7.9
S	NS	***	NS	NS	NS	NS	NS	NS	NS
G	**	***	**	***	***	***	***	***	***

NS=Not significant, * Significant at P<0.05, **Significant at P<0.01, *** Significant at P<0.001, Same small letters in column are not significantly different by DMRT at 0.05 level of Significance

Table 5. Interaction effect of crop geometry and genotype on ground cover, vine length and vine internode diameter of sweet potato during the years 2018 and 2019

Treatments	Ground cover (%)			Vine length(cm			Vine internode diameter (mm)		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
S1G1	100.0	100.0[a]	100.00	89.40	94.6	92.00	5.50	5.79	5.64
S1G2	95.00	100.0[a]	97.50	66.06	97.7	81.9	4.12	4.24	4.18
S1G3	99.00	100.0[a]	99.50	282.20	241.3	261.8	3.94	3.81	3.87
S2G1	100.0	100.0[a]	100.00	87.00	79.3	83.2	5.02	5.80	5.41
S2G2	89.33	98.33[c]	93.83	91.93	90.5	91.2	4.34	4.31	4.33
S2G3	100.0	100.0[a]	100.00	296.86	281.2	289.0	4.07	4.61	4.34
S3G1	98.66	100.0[a]	99.33	88.66	82.9	85.8	5.29	5.92	5.60
S3G2	85.00	99.0[b]	92.00	88.93	76.1	82.5	4.35	4.06	4.20
S3G3	92.00	100.0[a]	97.00	261.40	293.5	277.4	4.02	4.22	4.12
S4G1	98.00	100.0[a]	99.00	85.73	71.0	78.4	5.22	5.83	5.53
S4G2	86.66	99.66[a]	93.17	88.80	73.5	81.1	4.42	4.12	4.27
S4G3	90.33	100.0[a]	95.17	270.80	282.4	276.6	3.97	4.39	4.18
P value	0.815	<.001	0.895	0.618	0.380	0.783	0.639	0.203	0.457
LSD (0.05)	10.82	0.389	6.591	39.692	51.66	30.50	0.579	0.490	0.426
CV (%)	6.8	0.2	5.9	15.6	20.8	17.8	7.6	6.1	7.9
S × G	NS	***	NS	NS	NS	NS	NS	NS	NS

NS=Not significant, * Significant at P<0.05, ** Significant at P<0.01, *** Significant at P<0.001; Same small letters in column are not significantly different by DMRT at 0.05 level of significance

Table 6. Effect of crop geometry and genotype on vine internode length, marketable tuber weight per plant and tuberous root diameter of sweet potato during the years 2018 and 2019

Treatments	Vine internode length (cm)			Marketable tuberous root weight/plant (kg)			Tuberous root diameter (mm)		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
A. Crop geometry (S)									
S1 (60 cm × 25 cm)	6.17	6.68	6.42	0.386^{c}	0.392^{b}	0.389^{c}	50.85^{b}	50.73^{c}	50.79^{c}
S2 (60 cm × 30 cm)	5.1	7.53	6.36	0.420^{bc}	0.457^{ab}	0.438^{c}	54.58^{b}	55.41^{b}	55.0^{b}
S3 (70 cm × 25 cm)	5.40	6.17	5.78	0.497^{ab}	0.438^{ab}	0.468^{ab}	55.49^{b}	55.62^{b}	55.55^{b}
S4 (70 cm × 30 cm)	5.46	6.36	5.91	0.569^{a}	0.484^{a}	0.527^{a}	63.79^{a}	61.39^{a}	62.59^{a}
P- value	0.439	0.371	0.613	<0.001	0.038	0.001	0.002	<0.001	<0.001
LSD (0.05)	1.291	1.688	1.168	0.081	0.062	0.066	5.952	3.674	3.284
B. Genotypes (G)									
G1 (CIP 440015)	4.53^{b}	5.09^{b}	4.81^{b}	0.443	0.382^{b}	0.412^{b}	53.88^{b}	55.80^{b}	54.84^{b}
G2 (CIP 440267)	4.28^{b}	6.45^{b}	5.37^{b}	0.473	0.353^{b}	0.413^{b}	52.41^{b}	51.82^{c}	52.11^{b}
G3 (Local White)	7.86^{a}	8.51^{a}	8.19^{a}	0.488	0.594^{a}	0.541^{a}	62.26^{a}	59.75^{a}	61.00^{a}
P -value	<0.001	<0.001	<0.001	0.420	<0.001	<0.001	0.001	<0.001	<0.001
LSD (0.05)	1.118	1.462	0.012	0.070	0.0537	0.0572	5.155	3.182	2.844
CV	23.8	25.8	28.6	17.8	14.3	21.7	10.8	6.7	8.8
S	NS	NS	NS	***	*	**	**	***	***
G	***	***	***	NS	***	***	**	***	***

NS=Not significant, * significant at P<0.05, ** highly significant at P<0.01, *** at P<0.00; Same small letters in column are not significantly different by DMRT at 0.05 levels

Table 7. Interaction effect of crop geometry and genotype on vine internode length, marketable tuber weight per plant and tuberous root diameter of sweet potato during the years 2018 and 2019

Treatments	Vine internode length (cm)			Marketable tuberous root weight/plant (kg)			Tuberous root diameter (mm)		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
S1G1	4.60^{cd}	4.67	4.63	0.422	0.305	0.363	49.76^{cd}	54.01^{cd}	51.89^{de}
S1G2	4.36^{cd}	6.27	5.31	0.371	0.375	0.373	45.74^{d}	48.23^{d}	46.98^{e}
S1G3	9.55^{a}	9.09	9.32	0.366	0.497	0.431	57.06^{bcd}	49.95^{d}	53.51^{cd}
S2G1	4.46^{cd}	5.13	4.79	0.349	0.425	0.387	46.82^{d}	53.76^{cd}	50.29^{de}
S2G2	3.25^{d}	9.16	6.21	0.439	0.363	0.401	47.25^{d}	47.13^{d}	47.19^{e}
S2G3	7.86^{ab}	8.31	8.09	0.472	0.583	0.527	69.67^{a}	65.35^{a}	67.51^{a}
S3G1	4.55^{cd}	5.41	4.98	0.453	0.409	0.431	53.80^{cd}	53.23^{cd}	53.52^{cd}
S3G2	5.83^{bc}	5.33	5.58	0.495	0.315	0.405	53.75^{bcd}	54.21^{cd}	53.98^{cd}
S3G3	5.80^{cd}	7.78	6.79	0.544	0.591	0.567	58.91^{abc}	59.40^{abc}	59.16^{bc}
S4G1	4.46^{cd}	5.15	4.81	0.550	0.388	0.469	65.10^{ab}	62.20^{ab}	63.65^{ab}
S4G2	3.66^{cd}	5.07	4.37	0.584	0.358	0.471	62.88^{ab}	57.69^{bc}	60.29^{b}
S4G3	8.23^{a}	8.85	8.54	0.573	0.706	0.604	63.38^{ab}	64.28^{ab}	63.83^{ab}
P value	0.040	0.244	0.234	0.610	0.061	0.814	0.039	0.010	<0.001
LSD (0.05)	2.236	2.924	2.023	0.141	0.1074	0.114	10.310	6.363	5.689
CV	23.8	25.8	28.6	17.8	14.3	21.7	10.8	6.7	8.8
S × G	*	NS	NS	NS	NS	NS	*	*	***

NS=Not significant, * significant at P<0.05, ** Significant at P<0.01, *** Significant at P<0.001; Same small letters in column are not significantly different by DMRT at 0.05 level of significance

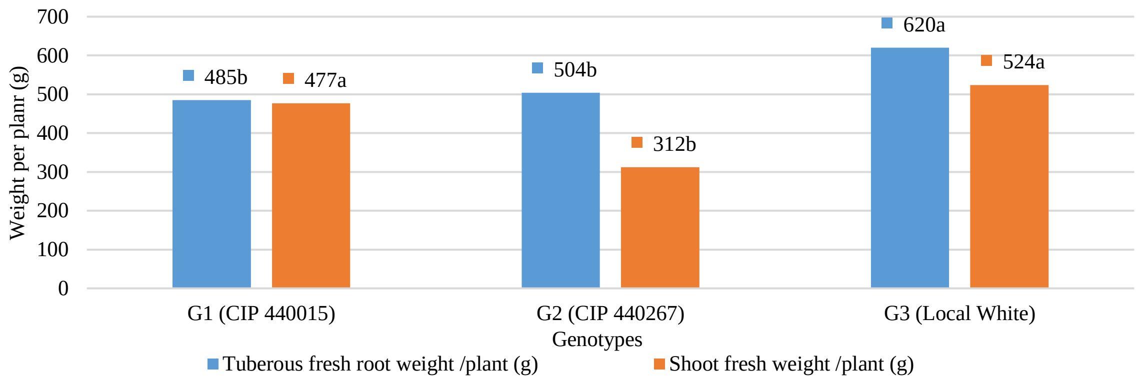

Figure 1. Effect of crop geometry on average fresh root and shoot weight per plant during 2018 and 2019

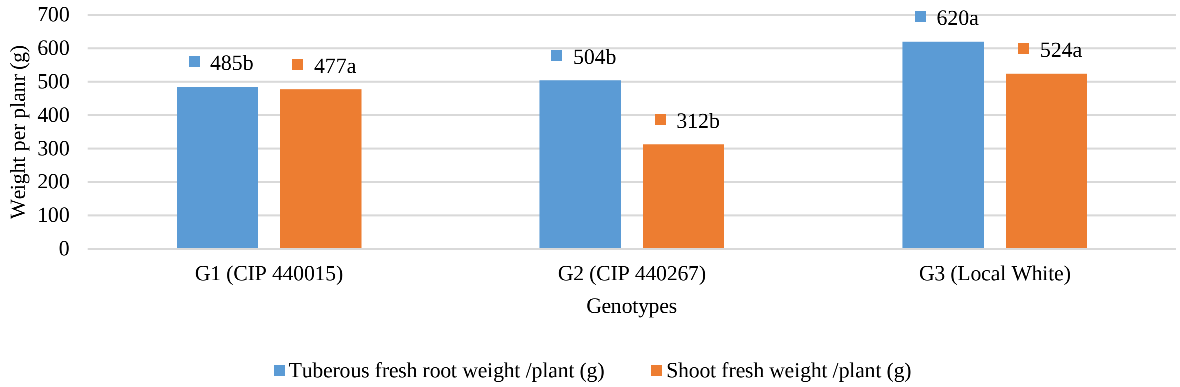

Figure 2. Effect of genotypes on average fresh root and shoot weight per plant of sweet potato during 2018 and 2019

Table 8. Effect of crop geometry and genotype on marketable, unmarketable and total tuberous root yield (mt ha^{-1}) of sweet potato during the years 2018 and 2019

Treatments	Marketable tuberous root yield (mt ha^{-1})			Unmarketable tuberous root yield (mt ha^{-1})			Total tuberous root yield (mt ha^{-1})		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
A. Crop geometry (S)									
S1 (60 cm × 25 cm)	24.56	26.16^{a}	25.36	3.05^{a}	6.37	4.71	27.61	32.54^{a}	30.08
S2 (60 cm × 30 cm)	23.32	25.38^{a}	24.35	1.89^{b}	6.50	4.19	25.21	31.88^{a}	28.54
S3 (70 cm × 25 cm)	23.03	21.91^{b}	22.47	2.08^{b}	6.45	4.26	25.11	28.35^{b}	26.73
S4 (70 cm × 30 cm)	23.12	20.17^{b}	21.65	1.95^{b}	5.49	3.72	25.06	25.67^{b}	25.37
P- value	0.889	0.001	0.127	0.013	0.347	0.716	0.652	<.001	0.106
LSD (0.05)	4.570	3.084	3.425	0.759	1.294	1.711	4.912	3.047	3.991
B. Genotypes (G)									
G1 (CIP 440015)	22.78	20.14^{b}	21.46^{b}	2.54^{a}	5.06^{b}	3.80	25.32	25.10	25.26^{b}
G2 (CIP 440267)	23.41	18.96^{b}	21.19^{b}	2.80^{a}	6.65^{a}	4.72	26.21	25.61	25.91^{b}
G3 (Local White)	24.33	31.12^{a}	27.72^{a}	1.39^{b}	6.90^{a}	4.14	25.72	38.02	31.87^{a}
P -value	0.720	<0.001	<0.001	<0.001	0.005	0.457	0.910	<0.001	<0.001
LSD (0.05)	3.958	2.671	2.966	0.657	1.121	1.482	4.254	2.638	3.457
CV	19.9	13.5	21.9	34.6	21.3	60.7	19.5	10.5	21.6
S	NS	**	NS	*	NS	NS	NS	***	NS
G	NS	***	***	***	**	NS	NS	***	***

NS=Not significant, * significant at P<0.05, ** Significant at P<0.01, *** Significant at P<0.001; Same small letters in column are not significantly different by DMRT at 0.05 level of significance

Table 9. Interaction effect of crop geometry and genotype on marketable, unmarketable and total tuberous root yield (mt ha^{-1}) of sweet potato during the years 2018 and 2019

Treatments	Marketable tuberous root yield (mt ha^{-1})			Unmarketable tuberous root yield (mt ha^{-1})			Total tuberous root yield (mt ha^{-1})		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
S1G1	27.25	20.35	23.80	3.74	5.76	4.75	30.99	26.11	28.55
S1G2	23.06	25.02	24.04	3.53	6.25	4.89	26.59	31.27	28.93
S1G3	23.38	33.12	28.25	1.88	7.11	4.50	25.26	40.24	32.75
S2G1	19.36	23.60	21.48	2.26	4.72	3.49	21.63	28.32	24.97
S2G2	24.38	20.18	22.28	2.09	6.50	4.29	26.47	26.68	26.57
S2G3	26.21	32.36	29.29	1.30	8.26	4.78	27.52	40.62	34.07
S3G1	21.59	20.43	21.01	2.08	4.63	3.36	23.68	25.06	24.37
S3G2	23.08	15.73	19.41	2.91	8.08	5.50	26.00	23.81	24.91
S3G3	24.41	29.55	26.98	1.23	6.63	3.94	25.65	36.19	30.92
S4G1	22.93	16.77	19.55	2.05	5.13	3.59	24.98	21.30	23.14
S4G2	23.12	14.92	19.02	2.65	5.76	4.21	25.77	20.68	23.22
S4G3	23.31	29.44	26.37	1.12	5.59	3.36	24.44	35.03	29.73
P value	0.576	0.205	0.972	0.746	0.205	0.930	0.583	0.493	0.978
LSD (0.05)	7.916	5.342	5.932	1.314	2.242	2.964	8.508	5.277	6.913
CV	19.9	13.5	21.9	34.6	21.3	60.7	19.5	10.5	21.6
S ×x G	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS=Not significant

Table 10. Effect of crop geometry and genotype on dry matter, reducing sugar, and beta carotene content of sweet potato during the years 2018 and 2019

Treatments	Dry Matter (%)			Reducing Sugar (%) DWB			Beta carotene (mg/100g) FWB		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
A. Crop geometry (S)									
S1 (60 cm × 25 cm)	22.56	27.47^{a}	25.01^{a}	17.07^{a}	13.88^{a}	15.48^{a}	8.90	9.84^{a}	9.37
S2 (60 cm × 30 cm)	23.17	22.70^{b}	22.93^{b}	14.89^{b}	13.03^{ab}	13.96^{ab}	9.26	9.98^{a}	9.62
S3 (70 cm × 25 cm)	21.93	22.76^{b}	22.35^{b}	14.97^{b}	12.05^{b}	13.51^{b}	8.64	9.20^{b}	8.92
S4 (70 cm × 30 cm)	22.79	22.70^{b}	22.75^{b}	13.19^{b}	13.08^{ab}	13.14^{b}	9.02	9.46^{ab}	9.24
P- value	0.217	<.001	<.001	0.002	0.023	0.040	0.548	0.035	0.098
LSD (0.05)	1.205	1.204	1.308	1.749	1.119	1.692	0.893	0.564	0.558
B. Genotypes (G)									
G1 (CIP 440015)	23.20	24.43	23.82	13.49^{b}	9.60^{c}	11.54^{c}	12.82^{b}	13.85^{b}	13.33^{b}
G2 (CIP 440267)	22.59	24.08	23.34	12.92^{b}	13.60^{b}	13.26^{b}	13.72^{a}	14.63^{a}	14.18^{a}
G3 (Local White)	22.04	23.21	22.63	18.69^{a}	15.84^{a}	17.26^{a}	0.33c	0.38^{c}	0.35^{c}
P -value	0.096	0.062	0.116	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	1.044	1.043	1.133	1.515	0.969	1.465	0.774	0.489	0.483
CV	5.5	5.2	8.4	11.9	8.8	18.1	10.2	6.0	9.0
S	NS	***	***	**	*	*	NS	*	NS
G	NS	NS	NS	***	***	***	***	***	***

FWB=Fresh weight basis, DWB= Dry weight basis, NS=Not significant, * significant at P<0.05, **Significant at P<0.01, *** Significant at P<0.001. Same small letters in column are not significantly different by DMRT at 0.05 level of significance

Table 11. Interaction effect of crop geometry and genotype on dry matter, reducing sugar, and beta carotene content of sweet potato during the years 2018 and 2019

Treatments	Dry Matter (%)			Reducing Sugar (%) DWB			Beta carotene (mg/100g) FWB		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
S1G1	23.69^{ab}	29.62^{a}	26.66	13.81	9.19^{ef}	11.50^{b}	11.62	13.62	12.62
S1G2	21.76^{b}	26.64^{b}	24.20	16.21	19.83^{a}	18.02^{a}	14.35	15.08	14.71
S1G3	22.20^{ab}	26.15^{bc}	24.18	21.18	12.63^{cd}	16.91^{a}	0.73	0.847	0.790
S2G1	24.31^{a}	22.43d^{efg}	23.37	13.60	10.16^{ef}	11.88^{b}	14.03	14.48	14.25
S2G2	23.17^{ab}	21.69^{efg}	22.43	11.78	11.13^{de}	11.46^{b}	13.41	15.08	14.24
S2G3	22.02^{ab}	23.97^{cde}	23.00	19.29	17.81^{b}	18.55^{a}	0.35	0.393	0.372
S3G1	21.73^{b}	21.58^{fg}	21.66	14.44	10.52^{ef}	12.49^{b}	12.47	13.47	12.97
S3G2	22.38^{ab}	24.39^{cd}	23.39	11.18	9.84^{ef}	10.51^{b}	13.36	13.99	13.67
S3G3	21.67^{b}	22.31^{defg}	21.99	19.28	15.78^{b}	17.53^{a}	0.08	0.147	0.115
S4G1	23.03^{ab}	24.10^{cd}	23.57	12.07	8.52^{f}	10.30^{b}	13.16	13.82	13.49
S4G2	23.05^{ab}	23.61d^{ef}	23.33	12.49	13.59^{c}	13.04^{b}	13.75	14.41	14.08
S4G3	22.27^{ab}	20.40^{g}	21.34	15.00	17.13^{b}	16.07^{a}	0.13	0.153	0.143
P value	0.514	<0.001	0.150	0.051	<0.001	<0.001	0.103	0.489	0.050
LSD (0.05)	2.087	2.086	2.266	3.029	1.939	2.930	1.547	0.978	0.966
CV	5.5	5.2	8.4	11.9	8.8	18.1	10.2	6.0	9.0
S × G	NS	***	NS	NS	***	***	NS	NS	NS

NS=Not significant, * significant at P<0.05, ** Significant at P<0.01, *** Significant at P<0.001; Same small letters in column are not significantly different by DMRT at 0.05 level of significance

Quality Parameters

Dry matter (%) was significantly differed due to geometry in 2019, where the highest (27.47%) dry matter percent was recorded at S1 (60 cm × 25 cm) than the other three geometry which is significantly at par each other (Table 10). Pooled data also showed significant differences in DM content among the different crop geometry. The highest value (25.01%) was noticed at 60 cm × 25 cm followed by 60 cm × 30 cm (22.93%). No variation was noticed on dry matter content among three genotypes with the non-significant result. The reducing sugar content was highly influenced significantly (P<0.001) by crop geometry and genotypes. The pooled mean showed the highest (15.48 and 17.26 %) reducing sugar in closer geometry 60 cm × 25 cm and Local White genotype respectively and the lowest (11.54 %) in the genotype CIP 440015. The average value for this parameter was higher (15.03%) in 2018 than in the year 2019 (13.01%). Pooled mean data (Table 10) revealed that no significant influence was observed on Beta carotene content by different geometry, but it was significant in 2019. Beta carotene content was found significantly different among the genotypes in both years. Based on pooled mean data, both CIP genotypes had high Beta carotene content (13.33-14.18 mg/100gm), but the value was very low (0.35 mg/100gm) in the genotype Local White (Table 10).

Discussion

The results of the present investigation showed significant variation in growth, yield, and quality parameters among the crop geometry and genotypes. The ground cover (%) was significantly affected by crop geometry in the year 2019, while vine length, vine internode diameter, and length were differed significantly by genotypes in each year (Table 4 to 7). Variation in ground cover due to genotypes can be attributed to vine length variation (Kumar et al., 2011). Better ground cover was observed at closer spacing due to more plant population. In the study of Zamil et al. (2010), they had also reported the widest spacing 60 cm × 25 cm gave the lowest foliage coverage (65.45%), which was significantly different from the closest spacing of 60 cm × 15 cm. Variation in ground coverage might be due to the effect of genotypic character. In 2019, the interaction effect between geometry and genotype was significant on percent ground coverage which might be due to the effect of both genotypic characters and different plant populations among geometry. The vines of genotype Local White were significantly longest than other genotypes (Table 4) because usually majority of local genotypes exhibited longer vine than exotic due to their growth habit. With an increase in vine internode length, there was a corresponding increase in vine length among tested genotypes. In this study, the longest vine internode length was also observed in Local White, whereas the highest vine internode diameter was in CIP 440015. Variation in these parameters to genotype might be due to its genetic feature and similar findings were reported by Srivastava et al., (2016) in potato. The present results on growth parameters are supported by the reports of Delgado and Yermanos (1975).

Different geometry caused significant differences in marketable tuberous root weight per plant, average tuberous root diameter, tuberous root number per plant, and total tuberous root weight per plant in different genotypes in both the years. The highest value of these parameters was at wider spacing S_4 (70 cm × 30 cm) while the lowest was from the closer spacing. This might be due to wider spacing allows the individual plant to utilize more water, nutrient, light, and air. Similar results were observed by Rashid and Shakur (1986) and Sirkar et al. (1998) in carrot. The findings showed the total tuberous root weight (0.617 kg/plant) in 2018 and (0.616 kg/plant) in 2019 was recorded under wider spacing S4 (70 cm × 30 cm) which were significantly higher over closer spacing S1, S2, and S3, respectively and similar findings were reported by Koodi et al (2017) and Jamaati-e-Somarin et al (2009) in sweet potato. Plants that were widely spaced had less competition for nutrient uptake, water, light, and air, which resulted in higher yield parameters. Similar results were observed by Rajadurai (1994) in sweet potato and reported narrow spacing decreased the yield per plant. Variation in tuberous root yield per plant among genotypes might be due to the genetic potential of the genotype. A similar result was reported by Rahman et al (2013) in sweet potato variety.

At closer spacing, more number of small-size tubers were harvested while at wider spacing larger-sized tubers were harvested in each year. Closer spacing is expected to reduce tuber diameter due to increased competition for nutrients, space, and sunlight, but this will result in a decrease in total tuber yield per plant. Similar results were observed by Rajadurai (1994) in sweet potato. Increase of plant density, decrease mean tuber size probably as a result of lack of available nutrient element and intra competition for other growth factors (Berga and Caeser, 1990). Among genotypes, Local White yielded more large sized tubers than other genotypes. The genotype can influence the difference in tuber size diameter. A similar result was found by Rahman et al (2013) in sweet potato variety and indicated the difference in tuber diameter due to genotypic difference. Shoot fresh weight per plant was significantly varied by crop geometry and genotypes in each experimental year. The highest shoot fresh weight was observed in wider spacing of 70 cm × 30 cm and the genotype Local white. This may be due to the availability of more space for plants and less nutrition competition for vine growth. Local White's production of the longest vine may be the cause of the highest above shoot fresh weight per plant among the tested genotypes. Better growth of the aboveground shoot system leads to increased photosynthate formation and translocation in the tuber, resulting in higher yield (Malik, 1995; Bukema and Zaag, 1990).

The best results with highest tuber yield at hectare level were obtained with planting at 60 cm × 25cm in each year. Increasing plant density from 47619 plants ha^{-1} (70 cm × 30) to higher levels of 66,666 plants ha^{-1} (60 cm × 25cm) increased the production of total tuberous root yield (mt ha^{-1}) (Table 8). In 2019, closer spacing (60 cm × 25 cm) resulted in significantly higher marketable and total tuberous root yield (mt ha^{-1}) than wider spacing (70 cm × 30 cm), whereas the result was not significant in 2018. In a study carried out by Sultana and Siddique (1991), the maximum weight of tubers per hill was produced at the widest spacing and the highest yield of tubers was obtained from the closest spacing and the lowest was in the widest spacing. The yield of tubers per hectare was decreased with the increasing plant spacing. Rajadurai (1994) found that narrow spacing increased hectare yield. Increased planting space, on the other hand, increased the population of large-sized tubers. Alvin et al. (2007) reported that increasing plant densities results in increased tuber yield per area. Similarly, Jamaati-e-Somarin et al. (2009) found that as planting density increased, tuber yield decreased per plant but increased per unit area.

Significant ($P<0.001$) difference occurred in marketable and total tuberous root yield among the genotypes evaluated. The highest mean total tuberous root yield (31.87 mt ha^{-1}) was recorded in Local White. Our study exhibited the total tuberous root yield varied from 25.20 mt ha^{-1} to 38.02 mt ha^{-1} among genotypes (Table 8). The current finding is more or less in good agreement with Omiat et al. (2005), who indicated that the varietal effect had a significant influence on the total tuberous root yield of sweet potato. The differences in total tuberous root yield could be attributed to varietal differences among the sweet potato genotypes (Antiaobong, 2007).

In this study, tuberous root yield (kg/plant and mt ha^{-1}) was higher in 2019 than in the year 2018. The difference in average tuberous yield between 2018 and 2019 was 3.86 mt ha^{-1} (Table 8). This might be due to variation in soil characteristics, temperature, rainfall, and relative humidity of the experimental site between the years (Table 1 and 2). The year 2019 produced a higher yield than 2018 due to more rainfall during the growing season, suitable soil pH, and fertile soil. Good soil fertility and an adequate supply of moisture usually support good growth and root yield of sweet potato (Yahaya et al. 2015).

Dry matter and reducing sugar content revealed significant variation among the crop geometry (Table 10). Two year mean data indicated that the highest value (%) of dry matter and reducing sugar content was noticed at closest spacing compared to widest spacing. This variation might be due to the better moisture holding capacity and availability of nutrients in the soil due to favorable conditions created by geometry. Other reasons are space availability for plants and the effect of light and surrounding temperature and genotypes. Our study exhibited the dry matter content increased with decreased spacing. In contrast, different results were reported by Kadam and Karthikeyan (2006) in tomato, and Qawasmi et al (1999) in capsicum.

The reducing sugar and ß carotene content were significantly changed due to genotypes. The two year mean data showed the highest reducing sugar was recorded in the Local White genotype, but the value of ß carotene was very low. Similarly, the highest ß carotene was observed in CIP genotypes, while reducing sugar content was low than Local genotype. Teow et al (2007) reported significant variations in respect to ß carotene content among sweet potato genotypes, and orange flesh had higher ß carotene content than white flesh. The present results are in agreement with the result of Ingabire and Hilda (2011) in sweet potato. Bhattarai et al (2017) also reported that local white genotypes are more sugary than orange-fleshed sweet potato due to high carbohydrate content. The interaction between geometry and genotypes had a significant effect on dry matter and reducing sugar content in 2019 and the mean value, respectively (Table 11). It might be due to the combined effect of plant geometry and genotypic characteristics.

Conclusion

This work reveals that closer plant densities increased the total yield per hectare but decreases the yield per plant in sweet potato. Local White genotype yielded more than CIP genotypes. CIP genotypes, on the other hand, had a high ß carotene content, whereas the Local genotype had a negligible amount. These genotypes are potential sources of Vitamin A because they are high in ß carotene. Based on results obtained it may be concluded that crop geometry 70 cm × 30 cm with Local White genotype enhanced growth as well as yield and yield attributing characteristics which ultimately increased the tuberous root yield per plant. So, it could be recommended that sweet potato should be grown at a spacing of 70cm × 30 cm for sustaining the higher tuberous root yield. Whereas, based on total tuber yield per unit area, it could be recommended that sweet potato should be grown at a spacing of 60cm × 25 cm for attaining the maximum production.

Our results suggest that plant density can have a considerable impact on the production of sweet potato. It is therefore important to increase the production and productivity of the crop by adopting different agronomic practices that include the determination of optimum plant density. Thus, the spacing for sweet potato can be wide or narrow depending on our needs and area available in study area or in a similar condition. Despite being the most productive, the genotype Local White can be more sugary, with the highest reducing sugar and the lowest ß carotene content. The CIP OFSP genotypes were high in ß carotene while having a low sugar value and a considerable tuberous root yield. Thus, the genotype chosen for cultivation is determined by taste, nutritional value, and yield, as well as sweet potato farmers' needs.

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Conflict of interest

The authors declare no conflict of interest.

Authors' contribution

P. Bhattarai was the lead investigator and also responsible for data collection from the field, literature search, and write-up. K. M. Tripathi, D. M. Gautam, and A. K. Shrestha were responsible for guidance and monitoring research activities. All the authors read and approved the final manuscript.

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