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Research Paper

Performance of chicory (*Cichorium intybus* L.) in response to planting methods and seed rates under north-western Indian conditions

RENU BALA[1], BUTA SINGH DHILLON[2], AMANDEEP SINGH BRAR[3], PRITPAL SINGH[4] AND AMARJEET KAUR

Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141 004

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ABSTRACT

The study was conducted during the winter (*rabi*) season of 2016–17 and 2017–18 at Ludhiana, Punjab with the objective to evaluate the effect of sowing methods and seed rates on productivity, quality and economics of chicory (*Cichorium intybus* L.). The experiment was laid out in split-plot design keeping sowing methods, i.e. bed (1 row), bed (2 rows), ridge (1 row), ridge (2 rows), flat (60 cm) and flat (30 cm), in main plots and seed rates, i.e. 0.5, 0.75, 1.0 and 1.25 kg/ha, in subplots. Results revealed that, the higher plant population under bed (2 rows) and better yield attributes under ridge (1 row) resulted in the highest root yield and net returns. Although crop sown as flat (30 and 60 cm) also gave root yield similar to former sowing methods but roots obtained under flat sowing were physically distorted, i.e. forked and cracked. Growth, photosynthetic parameters and root yield and benefit: cost ratio showed increasing trend only up to 1.0 kg/ha seed rate but shoot yield increased linearly up to 1.5 kg/ha seed rate. Final plant population, plant height at harvesting, root length and shoot yield had direct positive effect on root yield but dry matter of root at harvesting had positive indirect effect on root yield via. plant population.

Key words : Chicory, Chlorophyll fluorescence, Inulin, Protein content, Root yield, Shoot yield

Root chicory also known as blue sailor, endive succory or coffee weed, finds a wide utility as salad, beverage additive and in pharmaceutical industry (Munoz, 2004). It is used in the production of a variety of food products and beverages. Dried chicory is produced by Roasted chicory cubes are converted into powder which is used as coffee additive (Park *et al.,* 2007). Root extracts of chicory particularly inulin add a distinct flavour to coffee and hence is used as coffee additive. Inulin, root extracts of chicory is also used as a food ingredient for fat and sugar replacement as a low-calories bulking agent for diabetics (Hui Ru *et al.,* 2002). Inulin has the capacity to reduce chances of atherosclerosis and have anti-thrombotic, anti-arrhythmic and diuretic properties (Nandagopal and Ranjitha, 2007). Chicory is also used for sugar extraction as it contains difructose anhydride III (DFA III), which has half the sweetness of sucrose and is known to stimulate the absorption of calcium and other minerals in mammalian gut. Owing to a wide range of uses, chicory is gaining importance as a root and fodder crop. Chicory performs well under varied soil types and can be grown up to an altitude of 6000 feet.

Sowing method is a soil-management tool, which affects the soil physical and biological activities including soil temperature and soil moisture. Since, plants are able to change root morphology in response to soil moisture and temperature (Khan *et al.,* 2016), hence, performance of the chicory is likely to be greatly influenced by method of sowing. Konopinski (2013) reported higher root yield of chicory from the ridge-sown crop than that of flat sowing due to the fact that in flat-planting method, less soil depth is available for root development than ridge and bed methods. Ridges are formed by using loose soil aggregates thus ensure deep soil coherence up to deeper soil layers. Ridge and bed remain loose, allows better access of air to root-system thus favours high seedling emergence and better penetration of roots, ultimately resulting into higher yield (Ahmad *et al.,* 2010). The underground part of chicory is the main economic yield component. Therefore, the soil physical conditions near the plough sole depth affect its root growth and ultimately yield. Suitable sowing methods also enable to maintain optimum plant population for using resources uniformly and efficiently. Seed rate and row-to-row spacing are the most important agronomic factors,

[1]**Corresponding author**'s **Email**: bsdhillon@pau.edu
[1]P.G. Student, Department of Agronomy, [2]Agronomist, [3]Deputy Director (T_1), [4]Senior Statistician, Department of Plant Breeding and Genetics, [5]Principal Food Technology, Department of Food Science and Technology, Punjab Agricultural University, Ludhiana, Punjab 141 004

which are manipulated to obtain optimal plant stand for yield maximization (Maheshwari and Sharma, 2000). Crop may not be able to express its full genetic potential under one sowing method due to prevalence of unfavourable conditions, limiting the growth. Therefore, increasing seed rate can be one of the options to compensate for reduced individual plant growth. At the same time, the higher seed rate may result in production of thinner roots, which may affect the yield and quality of produce. Keeping in view the points, present investigation was carried out to evaluate the effect of sowing methods and seed rates on growth, photosynthetic parameters, yield and quality of chicory.

MATERIALS AND METHODS

An experiment was conducted at Research Farm, Department of Agronomy, Punjab Agricultural University (PAU), Ludhiana, (30°56' N, 75°52' E; 247 m altitude in the Indo-Gangetic Plains Region) during the winter (*rabi*) seasons of 2016–17 and 2017–18. Climate of Ludhiana is subtropical, semi-arid with annual rainfall of 733 mm out of which about 80% is received during the monsoon period (June to September). Winters prevails from December to January, when the lowest temperature may go as low as 1 or 2°C along with frost and foggy conditions; whereas April to June is characterized as summer season when temperature may go as high as 45°C. The meteorological data recorded at meteorological observatory of the PAU, Ludhiana (situated at 300 m from experimental field) indicate that during the crop season, maximum, minimum and mean air temperature varied from 24.7 to 38.8 and 27.8 to 39.1°C, 11.5 to 25.1 and 12 to 24.1°C and 18.1 to 31.9 and 19.9 to 31.5°C during 2016–17 and 2017–18, respectively. The rainfall of 140.4 and 104.4 mm was received during crop seasons of 2016–17 and 2017–18, respectively. The relative humidity during crop-growing season ranged from 39 to 60% during 2016–17 and from 35 to 70% during 2017–18. The soil of experimental site was sandy-loam in texture. It rated low in available N (225.4 kg/ha) and soil organic carbon (0.29%) status but medium in available P (13.8 kg/ha) and available K (149 kg/ha) status. The soil *p*H (7.7) and electrical conductivity (0.23 dS/m) were normal.

The experiment was laid-out in split-plot design with 6 sowing methods, viz. bed (1 row), bed (2 rows), ridge (1 row), ridge (2 rows), flat (60 cm) and flat (30 cm) in main-plot, and 4 seed rates, i.e. 0.5, 0.75, 1.0 and 1.25 kg/ha, in subplots with 3 replications. Beds were of 67.5 cm (37.5 cm bed + 30.0 cm furrow) and ridges were laid at a spacing of 60 cm (top to top). Chicory (var. 'Orcies') was sown manually in lines as per specified treatments during the 1st week of November during both the years. Crop was fertilized with phosphorus @ 60 kg/ha and nitrogen @ 100 kg/ha in the form of di-ammonium phosphate (18% N and 46% P_2O_5) and urea (46 % N). Full dose of phosphorus was applied basal before sowing, whereas, nitrogen (in addition to that applied through diammonium phosphate (DAP) was applied through urea in 3 equal splits–one-third basal, one-third at 30 DAS and one-third at 60 DAS. Crop was irrigated as per the crop demand. During growing season, 2 hoeings were done to control weeds at 30 and 60 DAS.

Plant height and green leaves/plant were recorded from 5 random plants in middle 3 rows of each experimental unit. Canopy analyser (Model CI-110/CI-120) was used to record leaf-area index (LAI) at 90 and 120 DAS. Portable chlorophyll fluorometer (Model - OS-30p) and portable chlorophyll content meter (Model - CCM-200), respectively, were used to record observations on chlorophyll fluorescence and chlorophyll content index (CCI) at 90 and 120 DAS. The observations were noted from fully expanded apical leaves. Similarly, photosynthetically active radiations interception (PARI) was measured using line-quantum sensor from 3 random spots from each plot at 90 and 120 DAS. The absorption and reflectance of bare ground was measured from each plot along with canopy interception of the crop.

$$\text{PARI} = \frac{\text{PAR (I) - PAR (T) - PAR (R)}}{\text{PAR (I)}} \times 100$$

where PAR (I) is incoming solar radiations, PAR (T) is transmitted solar radiations, PAR (R) is reflected solar radiations.

Five plants were randomly taken from all plots and were partitioned into root and leaf. These plant samples were dried in sun and then in an oven (at temperature of 65 ± 2°C) till constant weight was achieved. The weight obtained was expressed as g/plant. Yield attributes like root diameter, root length, root volume and root weight/plant were recorded from 5 randomly selected roots from each plot using Varnier Calliper, metre scale, Archimedes' principle and electronic balance respectively. The fresh root yield and shoot yield/plot were recorded using electronic balance in kg/net plot. The yield was expressed as tonnes/hectare. Root : shoot ratio was calculated dividing root yield by shoot yield. The cost of cultivation was calculated. It is given as total variable costs which included cost of seed, seed bed preparation, fertilizers, pesticides, irrigation, labour, tractor hours and interest on working capital for half period @ 9%. The selling price of chicory was ₹300/q.

Twenty randomly selected roots from each plot were observed for the physical distortion, i.e. forking and cracking at the time of harvesting and the results are presented as per cent of forked/ cracked roots. The total soluble solids (TSS) of the roots was recorded using the digital refractometer. Inulin was estimated by as per procedure of Ashwell (1957). Crude protein in root was worked out calculating nitrogen (N) content in dried ground root sample followed by multiplying N with the factor 6.25.

For evaluation of differences between treatment means, data were subjected to analysis of variance (ANOVA) using statistical analysis system (SAS 9.3 software). Treatment means were compared at $P < 0.05$ with Tukey's test. The correlation among root yield and shoot yield and their influencing characters was calculated. The estimates of direct and indirect effects of independent variables on root and shoot yield (assumed to be dependent variables) were calculated through path-coefficient analysis.

RESULTS AND DISCUSSION

Growth parameters and dry-matter partitioning

The tallest plants were found in ridge (1 row) during both the years but the shortest plants were noted under bed (2 rows) and ridge (2 rows)-sowing methods. However, the highest number of green leaves/plant were observed under ridge (2 rows), whereas, the least under ridge (1 row) and flat (60 cm)-sowing methods due to varying availability of intra-row spacing under different sowing methods. In spite of significant effect on plant height and numbers of green leaves/plant, leaf-area index (LAI) did not vary under the influence of sowing methods (Table 1). Bed (one row) recorded the highest shoot weight/plant, which being statistically similar to bed (2 rows) and flat (30 and 60 cm), was significantly better than ridge (1 and 2 rows) (Table 1). Ridge (1 row) sowing method exhibited the highest dry-matter partitioning to root which excelled all the other sowing methods.

Data further reveals that plant height and LAI increased, whereas, numbers of green leaves/plant decreased in response to increment in seed rates. The solar-radiation exposure and proximity of plants due to variable plant population were also important factors associated with the interception and utilization of solar radiation. Further, the dry-matter partitioning to root was the highest under the lower seed rates (because more space was available for the root growth at lower seed rate) and it showed decreasing trend with each consecutive higher seed rate. All the interactions were non-significant. Asghari and Farahani (2014) also reported similar findings.

Photosynthetic parameters

The highest interception of photo-synthetically active radiations (PARI) under bed (2 rows) was statistically at par with ridge (2 rows) at 90 and 120 DAS (Table 2). It is further evident that chlorophyll content index (CCI) and chlorophyll fluorescence were also higher under bed (2 rows) and ridge (2 rows)-sowing methods at 90 DAS but as crop age advanced to 120 days, the effect of sowing methods became inconspicuous. It is evident that PARI increased consistently with the increment in seed rate from 0.5 kg/ha to 1.25 kg/ha. Similarly, chlorophyll-content index also showed increasing trend in response to increment in seed rate but differences between consecutive seed rates except 0.75 and 1.0 kg/ha were not significant at both the

Table 1. Effect of sowing methods and seed rates on growth attributes and dry-matter partitioning of chicory (average data of 2 years)

Treatment	Plant height (cm) at harvesting	No. of leaves/ plant at harvesting	Leaf-area index		At harvesting			
			90 DAS	120 DAS	Dry weight (g/plant)		Dry weight (%)	
					Shoot	Root	Shoot	Root
Sowing method								
Bed (1 row)	28.0	17.7	2.22	3.17	118.4	185.3	39.2	60.8
Bed (2 rows)	27.4	19.2	2.38	3.46	124.8	164.7	43.2	56.9
Ridge (1 row)	29.8	17.2	2.29	3.15	111.9	195.7	36.2	63.9
Ridge(2 rows)	25.4	19.6	2.27	3.33	110.1	131.5	45.8	54.3
Flat (60 cm)	28.6	16.9	2.29	3.16	124.9	185.8	41.1	59.0
Flat (30 cm)	27.8	18.3	2.32	3.38	121.8	136.5	47.1	53.0
SEm±	0.7	0.5	0.12	0.12	3.9	5.8	1.1	1.3
CD (P=0.05)	1.8	1.3	NS	NS	10.8	13.4	3.1	3.8
Seed rate (kg/ha)								
0.5	25.8	20.9	2.02	2.84	139.1	199.7	43.9	56.2
0.75	27.7	18.5	2.18	3.17	124.6	173.6	42.5	57.6
1.00	28.5	17.2	2.43	3.50	115.6	152.8	41.8	58.3
1.25	29.6	16.0	2.55	3.59	95.3	140.2	40.2	59.8
SEm±	0.5	0.2	0.05	0.10	4.1	4.0	1.1	1.2
CD (P=0.05)	1.5	0.6	0.13	0.23	10.8	11.1	2.7	3.0

DAS, Days after sowing

stages of observations (90 and 120 DAS). At 90 DAS, chlorophyll fluorescence increased with increment in seed rate but differences were non-significant. The non-significant differences between 1.0 and 1.25 kg/ha in photosynthetic parameters can be ascribed to the fact that increasing seed rate above 1.0 kg/ha imposed a competition/stress and reduced the efficiency of photosynthetic machinery. All the interactions were found to be non-significant.

Yield attributes, yield and economics

The highest root yield was obtained under bed (2 rows) which was statistically similar to all other sowing methods except bed (1 row) and ridge (2 rows), which were statistically at par with each other (Table 3). The high yield under rest of the treatments was due to improvement in one or the other yield attribute under these sowing methods. Yield attributes, viz. root length, root volume and root weight/plant, were significantly better under bed (1 row) and ridge (1 row) but the superiority of yield attributes under bed (1 row) could not be translated into root yield due to comparatively low final plant population (Table 3). The higher root yield under bed (2 rows) and ridge (1 row)

Table 2. Effect of sowing methods and seed rates on photosynthetic parameters of chicory (average data of 2 years)

Treatment	Photosynthetically active radiations interception		Chlorophyll content index		Chlorophyll fluorescence (Fv/Fm)	
	90 DAS	120 DAS	90 DAS	120 DAS	90 DAS	120 DAS
Sowing method						
Bed (1 row)	23.7	52.6	28.5	25.0	0.693	0.708
Bed (2 rows)	27.2	57.5	32.4	25.8	0.712	0.712
Ridge (1 row)	24.8	55.6	29.0	25.5	0.698	0.711
Ridge(2 rows)	27.0	58.5	33.1	26.4	0.717	0.717
Flat (60 cm)	24.4	54.0	26.3	24.3	0.682	0.695
Flat (30 cm)	25.7	56.3	27.7	24.7	0.690	0.699
SEm±	0.5	0.6	0.4	0.7	0.002	0.01
CD (P=0.05)	1.31	1.58	1.31	NS	NS	NS
Seed rate (kg/ha)						
0.5	21.4	50.8	28.6	23.8	0.691	0.702
0.75	24.1	54.8	29.2	24.1	0.698	0.705
1.00	26.9	57.4	30.5	26.6	0.700	0.714
1.25	29.4	59.9	29.7	26.3	0.711	0.707
SEm±	0.3	0.8	0.34	0.29	0.002	0.002
CD (P=0.05)	0.8	1.8	0.9	0.8	NS	NS

DAS, Days after sowing

Table 3. Effect of sowing methods and seed rates on yield and attributes of chicory (average data of 2 years)

Treatment	Root diameter (cm)	Root length (cm)	Root volume (cm^3)	Root weight (g/root)	Final plant population (10^3/ha)	Root yield (t/ha)	Shoot yield (t/ha)	Root : shoot
Sowing method								
Bed (1 row)	5.14	20.6	254.0	308.8	184.0	22.1	15.2	1.45
Bed (2 rows)	4.50	22.5	220.4	266.1	308.6	29.4	19.1	1.54
Ridge (1 row)	5.09	23.3	256.5	326.2	235.1	28.9	17.6	1.64
Ridge (2 rows)	4.15	20.6	220.7	195.0	332.2	24.5	16.9	1.46
Flat (60 cm)	4.79	21.9	236.3	324.6	222.6	29.0	18.6	1.56
Flat (30 cm)	4.47	22.0	222.5	227.6	315.2	28.7	19.1	1.50
SEm±	0.09	0.2	1.8	6.1	11.4	0.66	0.33	0.03
CD (P=0.05)	0.24	0.6	6.0	15.2	30.4	1.4	0.7	0.07
Seed rate (kg/ha)								
0.5	5.37	19.7	255.8	313.0	172.5	25.1	16.2	1.55
0.75	4.82	21.2	242.9	282.8	249.1	26.2	17.4	1.51
1.00	4.40	22.7	224.8	257.1	305.3	28.4	18.3	1.57
1.25	4.18	23.7	216.7	245.9	338.3	28.6	19.2	1.50
SEm±	0.09	0.5	1.3	5.5	7.1	0.31	0.19	0.02
CD (P=0.05)	0.24	1.2	3.7	13.8	18.4	0.9	0.06	NS

was contributed by higher final plant population and better yield attributes, respectively. Data indicate that yield attributes like root diameter, root volume and root weight/plant decreased but root length increased in response to increment in seed rate. Similarly, shoot yield increased linearly but enhancement in root yield was recorded only up to 1.0 kg/ha seed rate. Root shoot and root-quality parameters did not vary due to seed rate. Baert (1992) also reported increase in root yield in response to increment in seed rate. All the interactions were non-significant. Our results corroborate the earlier findings of Seghatoleslami *et al.* (2014).

Sowing 2 rows on bed resulted in the highest gross returns (₹87,997/ha), which were almost similar to ridge (1 row) as well as flat (30 and 60 cm) sowing, whereas, bed (1 row) gave the least gross returns (₹66,390/ha). The highest net returns were registered under ridge (1 row), due to comparatively lower variable cost. The treatments of bed (2 rows) as well as flat (30 and 60 cm) sowing also fetched net returns almost equal to ridge (1 row) but bed (1 row) and ridge (2 rows) gave the least gross returns, which were lesser than ridge (1 row) by a margin of ₹21,062/ha and ₹14,929/ha, respectively. Similarly, the benefit: cost was also markedly higher under ridge (1 row) sowing method followed by flat (60 cm), bed (2 rows) and flat (30 cm). Bed (1 row) recorded the least benefit: cost ratio which was almost similar to ridge (2 rows). It is further evident that increasing seed rate caused consistent increase in gross returns and total variable cost, leading to the highest net returns and benefit: cost under seed rate of 1.0 kg/ha.

Table 4. Effect of sowing methods and seed rates on economics of chicory cultivation (average data of 2 years)

Treatment	Gross returns (₹/ha)	Total variable cost (₹/ha)	Net returns (₹/ha)	Benefit: cost
Sowing method				
Bed (1 row)	66,390	26,840	39,550	2.47
Bed (2 rows)	87,997	27,668	60,329	3.18
Ridge (1 row)	86,808	26,195	60,612	3.31
Ridge (2 rows)	73,627	27,944	45,683	2.63
Flat (60 cm)	87,055	27,208	59,847	3.20
Flat (30 cm)	85,988	27,760	58,228	3.10
Seed rate (kg/ha)				
0.5	75,387	25,337	50,051	2.98
0.75	78,684	26,523	52,161	2.97
1.00	85,338	27,770	57,568	3.07
1.25	85,835	29,447	56,388	2.91

Table 5. Effect of sowing methods and seed rates on physical and biochemical quality parameters of chicory (average data of 2 years)

Treatment	Physical quality parameters		Biochemical quality parameters		
	Forking (%)	Cracking (%)	Protein content (%)	Total soluble solids (TSS %)	Inulin content (g/100 g)
Sowing method					
Bed (1 row)	8.8	6.3	3.37	13.7	21.2
Bed (2 rows)	7.5	6.3	3.38	14.0	21.5
Ridge (1 row)	6.3	6.3	3.41	14.2	21.6
Ridge(2 rows)	8.8	7.5	3.36	13.7	21.2
Flat (60 cm)	16.3	27.5	3.30	13.6	21.3
Flat (30 cm)	17.5	20.0	3.30	13.6	21.3
SEm±	0.5	0.6	0.06	0.1	0.1
CD (P=0.05)	1.7	1.9	NS	NS	NS
Seed rate (kg/ha)					
0.5	6.7	16.7	3.30	13.5	21.4
0.75	8.3	14.2	3.32	13.7	21.4
1.00	11.7	10.0	3.36	13.9	21.4
1.25	16.7	8.3	3.43	14.1	21.3
SEm±	0.2	0.3	0.05	0.10	0.11
CD (P=0.05)	0.6	0.9	NS	NS	NS

Quality

Physical quality parameters: Forking and cracking (per cent) were higher under flat sowing than ridge and bed sowing. Under flat sowing, the crop sown at 60 cm spacing recorded higher cracking as compared to that sown at 30 cm. It is also evident that forking increased consistently with increase in the seed rates from 0.5 to 1.25 kg/ha. However, the effect of seed rate on cracking was reverse to that observed for forking, i.e. it decreased with increase in seed rate (Table 5). All the interactions were non-significant.

Biochemical quality parameters: A perusal of data on protein content, TSS and inulin content of chicory presented in Table 6 indicate that these quality parameters did not vary in response to sowing methods and seed rates during both the years (Table 6). However, there was slight increase in the TSS of the roots with increase in seed rate. These results are in line with that of Sharma *et al.* (2013). All the interactions were non-significant.

Correlation and path analysis

Correlation among various parameters and root yield of chicory presented in Table 6 reveal significant (P<0.05) positive correlation of final emergence count, final plant population, plant height (at harvest), leaf-area index (90 and 120 DAS), root length and shoot yield with root yield. Number of leaves/pant was negatively correlated with the root yield of chicory. The negativity in correlation between this parameter can be explained by the fact that, due to different sowing methods, the effect of this parameter was masked over by plant population in some of the treatments. It was observed that final emergence count had positive correlation with final plant population, plant height at harvesting and leaf-area index (90 and 120 DAS). However,

Table 6. Correlation coefficients between various parameters and root yield (average data of 2 years)

Parameters	FEC	FPP	PHH	LNH	LAI 90	LAI 120	DMSH	DMRH	RD	RL	RW	SY
FPP	0.89**											
PHH	0.57**	0.39										
LNH	–0.63**	–0.38	–0.78**									
LAI 90	0.51**	0.52**	0.41*	–0.45*								
LAI 120	0.82**	0.82**	0.47*	–0.49*	0.71**							
DM SH	–0.79**	–0.56**	–0.62**	0.71**	–0.37	–0.66**						
DM RH	–0.62**	–0.71**	–0.15	0.32	–0.39	–0.74**	0.51**					
RD	–0.80**	–0.84**	–0.31	0.40*	–0.55**	–0.85**	0.66**	0.78**				
RL	–0.58**	–0.53**	0.73**	–0.62**	0.53**	0.62**	–0.59**	–0.27	–0.49*			
RW	–0.56**	–0.72**	0.03	0.11	–0.29	–0.64**	0.38	0.95**	0.73**	–0.09		
SY	0.28	0.37	–0.15	–0.34	0.43*	0.38	0.12	–0.24	–0.32	0.11	–0.24	
RY	0.48*	0.41*	0.50*	–0.46*	0.45*	0.50**	–0.27	–0.22	–0.39	0.65**	0.08	0.51**

*P=0.05; **P=0.01; FEC, Final emergence count; FPP, final plant population; PHH, plant height at harvest; LNH, leaf/plant at harvest; LAI 90, leaf-area index at 90 days after sowing (DAS); LAI 120 DAS; DMSH dry weight of shoot at harvesting; dry weight of root at harvesting; RD, root diameter; RL, root length; RW, root weight; SY, shoot yield

Table 7. Direct and indirect effect of various parameters on root yield of chicory (average data of 2 years)

Parameters	FEC	FPP	PHH	LNH	LAI 90	LAI 120	DMSH	DMRH	RD	RL	RW	SY
FEC	1.11	–1.07	0.31	–0.17	–0.04	–0.17	–0.48	0.08	0.27	0.39	0.10	0.14
FPP	0.99	–1.2	0.21	–0.10	–0.04	–0.17	–0.34	0.09	0.29	0.35	0.13	0.19
PHH	0.53	–0.47	0.59	–0.22	–0.03	–0.10	–0.38	0.02	0.10	0.48	–0.005	–0.08
LNH	–0.70	0.46	–0.43	0.28	0.04	0.10	0.43	–0.04	–0.14	–0.41	–0.02	–0.01
LAI 90	0.57	–0.63	0.22	–0.12	–0.09	–0.15	–0.22	0.05	0.19	0.35	0.05	0.22
LAI 120	0.91	–0.98	0.25	–0.13	–0.06	–0.21	–0.40	0.09	0.29	0.41	0.12	0.20
DM SH	–0.87	0.67	–0.34	0.19	0.03	0.14	0.61	–0.06	–0.23	–0.39	–0.07	0.06
DM RH	–0.69	0.85	–0.08	0.09	0.03	0.15	0.31	–0.13	–0.27	–0.18	–0.18	–0.12
RD	–0.89	1.0	–0.17	0.11	0.05	0.18	0.40	–0.10	–0.34	–0.32	–0.14	–0.16
RL	0.55	–0.63	0.40	–0.17	–0.04	–0.13	–0.36	0.03	0.17	0.68	0.01	0.05
RW	–0.62	0.86	0.01	0.03	0.02	0.13	0.23	–0.12	–0.25	–0.06	–0.19	–0.12
SY	0.31	–0.44	–0.08	–0.09	–0.03	–0.08	0.07	0.03	0.11	0.07	0.04	0.52

FEC, Final emergence count; FPP, final plant population; PHH, plant height at harvest; LNH, leaf/plant at harvest; LAI 90, leaf-area index at 90 days after sowing (DAS); LAI 120 DAS; DMSH dry weight of shoot at harvesting; dry weight of root at harvesting; RD, root diameter; RL, root length; RW, root weight; SY, shoot yield final emergence count was highly but negatively correlated with dry matter of shoot and root (at harvesting), root diameter, root length and root weight/plant.

Of the12 characters, 5, namely final emergence count, plant height (at harvest), dry matter of shoot (at harvest), root length and shoot yield had a positive direct effect towards the root yield (Table 7). Further analysis revealed that final plant population had positive indirect effect on the root yield followed by leaf-area index (90 and 120 DAS) and root length via. final emergence count. Further, dry matter of root at harvesting had positive indirect effect on root yield via final plant population. Number of leaves/plant (at harvesting) although negatively correlated but had a positive indirect effect on root yield through dry matter of shoots (at harvest).

Thus, sowing of 2 rows on bed (67.5 cm) or 1 row on ridge (60 cm) gave higher root yield and net returns owing to better growth, photosynthetic parameters and yield attributes. Although flat-sown crop (30 and 60 cm) gave root yield statistically similar to that obtained under beds (2 rows) or ridge (1 row) but roots obtained from flat sowing were physically distorted, i.e. forked and/or cracked. Yield attributes decreased with increasing seed rate but higher plant population/unit area due to higher seed rate compensated the effect of yield attributes, resulting in consistent improvement in root yield and benefit: cost ratio in response to seed rate up to 1.0 kg/ha.

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