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Seed yield, nutrient absorption and soil health as influenced by the sowing time, nutrient levels and genotypes of the garden pea (*Pisum sativum* L.)

Anamika Chandel[1,4], Akhilesh Sharma[1], Parveen Sharma[1], Surinder Singh Rana[2], Ranbir Singh Rana[3], Shilpa[1]*

[1]*Department of Vegetable Science & Floriculture, Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh, India*
[2]*Department of Agronomy, Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh, India*
[3]*Centre for Geo Informatics Research and Training, Chaudhary Sarwan Kumar Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh, India*
[4]*Division of Vegetable Science, Indian Agricultural Research Institute, New Delhi, India*

**Corresponding author: assharmaakhil1@gmail.com*

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Abstract: The choice of variety, sowing time and optimum nutrition are important management options to optimise the seed yield. Accordingly, an experiment comprising of 18 treatments was conducted during the winter 2017–2018 and 2018–2019 in a factorial randomized block design, replicated three times to assess the response of pea genotypes (DPP-SP-6, Him Palam Matar-1 and Pb-89) to the seeding time (26th October and 10th November) and nutrient levels (0, 100 and 125% of the recommended NPK). The individual treatment effects revealed that early sowing, application of 125% NPK and DPP-SP-6 were significantly superior for the seed yield and related traits. The interaction effects indicated a significant response of the 125% NPK on the early sown crop for the seed yield, harvest index and NPK uptake. Significantly highest soil available NPK were obtained at 125% NPK with a respective increase of 41.54, 5.90 and 30.82 kg/ha, respectively, over the initial status. Early sowing of DPP-SP-6 with an application of 125% NPK is a better preposition for enhancing the productivity of peas.

Keywords: fertility; interaction effects; NPK uptake; productivity; soil nutrients

The garden pea is the second most important food legume after *Phaseolus*, and is a principal vegetable crop of temperate and sub-tropical areas of the world. It is considered one of the most nutritious vegetables, being rich in health promoting phytonutrients, minerals, vitamins, and antioxidants (Sharma et al. 2020). It is an important off-season vegetable in the north-western Himalayas of India (Sharma et al. 2023) comprising the states of Himachal Pradesh, Jammu and Kashmir and Uttarakhand which provides lucrative returns to the growers (Sharma et al. 2013).

The sowing time is an important factor affecting the pea growth and development, seed yield and seed quality. The optimum planting time is effective in enhancing the growth and develop-

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ment and has an impact on the yield as it allows synchronisation between the vegetative and reproductive phases on the one hand and the climatic cycle on the other (Sharma et al. 2014). Recently, new mid-season garden pea genotypes have been developed through hybridisation followed by the pedigree method of selection those that possess desirable pod characteristics (lush green, long, well filled pods and high shelling) and improved yield. It would, therefore, be imperative to study the optimum time of their sowing, otherwise the crop may suffer due to morphological, physiological, and biochemical changes and against attacks from pests. Sowing time also positively controls the soil biological properties and nutrients available to the growing crop (Christensen, Christensen 2007).

The growth of plants depends on the availability of nutrients in the soil which must be regulated by the appropriate use of fertilisers. The excessive use of fertilisers by the farmers does not always contribute to a high yield, but over-fertilisation unfortunately decreases the nutrient use efficiency and causes a series of economic and environmental complications (Yousaf et al. 2017). Incessant and long-term nutrient mining from the soil leads to the dilapidation of cultivated land, while the intensive use of fertilisers also leads to soil degradation due to build-up of salts in the rhizosphere. However, the balanced use of mineral fertiliser inputs has played an important role in increasing the yields. Also, a potential way to alleviate negative impacts from the imprudent use of synthetic fertilisers is to follow the integrated use of manures and fertilisers (Sharma et al. 2014; Sharma, Sharma 2016). Applications of organic manures with chemical fertilisers enhance the labile microbial biomass and nutrient availability, and improve the soil properties (Meena et al. 2020). This will, in turn, help to meet the nutrient requirements of the crops as well as maintaining sustainability in terms of the productivity and soil fertility. A crop absorbing enough plant nutrients is expected to produce a higher yield than a crop absorbing smaller amount of nutrients. Therefore, it is imperative to access the response of newly developed garden pea genotypes to the sowing dates and nutrient levels for the yield, nutrient uptake and soil available nutrients status after the harvest of a crop. The main aim of the present investigation is to identify the optimum sowing time and nutrient levels to obtain a high yield of garden peas.

MATERIAL AND METHODS

Basic information. A field experiment was conducted for two consecutive years during the winter season of 2017–2018 and 2018–2019 at the Vegetable Research Farm of CSK Himachal Pradesh Agricultural University, Palampur. The site is located at 32°6'N longitude and 76°3'E latitude at 1 290 m a.s.l. The soil of the experimental site was moderately acidic in reaction (pH 5.6), having a silty clay loam in texture, and a medium level of organic carbon, available nitrogen (243.4 kg/ha), phosphorus (20.2 kg/ha) and potassium (208.4 kg/ha).

Experimental design, treatments, and field management. Eighteen treatment combinations comprised of three varieties [DPP-SP-6 (V_1), Him Palam Matar-1/DPP-SP-22 (V_2) and Pb-89 (check) (V_3)], two sowing dates [26^{th} of October (D_1) and 10^{th} of November (D_2)] and three fertilisation levels *viz.*, 0 NPK, the recommended dose of NPK (50 : 60 : 60 kg $N : P_2O_5 : K_2O$/ha, respectively) (100% NPK) and 125% of the recommended dose of NPK (62.5 : 75 : 75 kg $N : P_2O_5 : K_2O$/ha, respectively) were tested in a factorial randomised block design with three replications. A uniform dose of 20 t/ha of farmyard manure was applied in all the treatments. The experimental field was prepared five days prior to sowing with the help of a tractor drawing a disc plough followed by a rotavator. The seeds of each genotype were treated before sowing with 3 g of Bavistin per kg of seed. After treatment, the seeds of the respective genotypes were sown manually on the respective dates of sowing *i.e.*, on the 26^{th} of October and 10^{th} of November of both years with an inter and intra row spacing of 45 cm and 7.5 cm, respectively. The whole amount of the NPK fertiliser was applied at the sowing time using urea (46% N), single super phosphate (SSP containing 16% P_2O_5) and muriate of potash (MOP containing 60% K_2O) as per the treatments, i.e., the recommended dose of 100% NPK (109 kg urea, 375 kg SSP and 100 kg MOP per ha) and 125% of the recommended NPK (136.25 kg urea, 468.75 kg SSP and 125 kg MOP per ha). The pre-emergence application of pendimethalin at the rate of 1.5 kg active ingredient/ha was performed immediately after sowing followed by three hand weeding events to keep the field weed free. Irrigation was provided prior to sowing after the field preparation. Thereafter, the crop was irrigated at 15-day intervals. In all, eight irrigations were provided during the whole cropping season us-

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Table 1. Methods used for estimation of N, P and K of soil samples

Parameter	Method employed	Reference
Available nitrogen	alkaline potassium permanganate method	Subbiah and Asija (1956)
Available phosphorus	colourimetric method	Olsen et al. (1954)
Available potassium	flame-photometric method	Jackson (1973)

ing a sprinkler in the initial stages of growth and the basin method of irrigation during the flowering and pod formation/development stages.

Observations recorded. The seed and straw yields were recorded on a plot basis and converted to tonnes per hectare (t/ha). The whole plants of each treatment were weighed in kg to get the biological yield and were then threshed manually to separate the seeds which were cleaned and weighed to get the seed yield in kg. The straw yield was estimated by subtracting the seed yield from the whole plant weight. The harvest index was obtained by dividing the economic yield (seed yield) with the total biological yield and expressed as (%).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

One-hundred (100) seeds were counted from each treatment and weighed to estimate the test weight in grams.

Soil health analysis. Representative soil samples (0–15 cm depth) were collected from each plot after completion of the experiment. The samples were dried in the shade, ground in a pestle mortar, passed through a 2 mm sieve and subjected to a laboratory analysis. The processed soil samples were analysed for changes in the available N, P and K using the methods listed in Table 1.

Nutrient uptake. The seed and straw samples were collected at the time of the crop harvest and were dried in an oven at 60 °C. The dried grain samples were then ground in a mixer grinder, passed through a 1 mm sieve, and were stored in air-tight plastic bags. The stover samples were ground in a Wiley mill fitted with stainless steel parts and were then kept in paper bags for the subsequent analysis. The analytical methods used for the plant analysis are listed in Table 2.

The nutrient uptake was calculated by multiplying the percent concentration of a particular nutrient with the seed and straw yield. The uptake of the nutrients obtained with respect to the seed and straw was summed up in order to compute the amount of total nutrients removed by the crop.

Nutrient uptake (kg/ha) = Concentration of nutrients (%) × Yield of the crop (kg/ha) (oven dry weight basis)

Total uptake (kg/ha) = Uptake in seed + Uptake in straw

Statistical analysis. The data obtained from various aspects in the present study were subjected to statistical analysis using a factorial randomised block design as per the procedure suggested by Gomez and Gomez (1982) using CPCS software (CPCS-1; Cheema, Singh 1991)) for both individual years and for the pooled data *i.e.,* the average of two years. The treatment effects were compared at a 5% level of significance. With the effects that exhibited significance at 5% of probability, the critical difference (CD) was calculated to compare the performance of the treatments.

RESULTS AND DISCUSSION

Effect of sowing dates. The days to flowering, seed and straw yields were significantly affected due to the sowing dates during 2018–2019 and the

Table 2. Methods used for estimation of N, P and K of plant samples

Parameter	Method employed
Nitrogen	Digestion with concentrated H_2SO_4 in the presence of a digestion mixture (K_2SO_4, $CuSO_4$ and Selenium powder in 10 : 1 : 0.1 ratio) and further determination by the micro-Kjeldahl method (Jackson 1973).
Phosphorus	Digestion in a diacid mixture (9 : 4 HNO_3 and $HClO_4$) and further determination following the vanadomolybdate yellow colour method (Jackson 1973).
Potassium	Digestion in a diacid mixture (9 : 4 HNO_3 and $HClO_4$) and estimation by Flame photometer (Black 1965).

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pooled years (Table 3). Significantly, a minimum number of days to flowering were taken on the 26th of October sown crop than on the 10th of November sown crop over the years (Table 3). The late sown crop took a greater number of days to flowering which might be due to the low temperature and short-day length during December and January. A higher seed yield (12.52 and 19.33 q/ha) and straw yield (36.92 and 25.3 q/ha) were observed in the early sown crop, i.e., 26th of October as compared to the late sown crop (10th November) during 2018–2019 and the pooled years. The most likely cause is that the early seeded crop had a longer time duration for the varied growth and development phases, whereas the later sown crop had a shorter time duration for better vegetative growth and various developmental stages due to the persisting low temperature circumstances. Therefore, an increase in the temperature from February onwards forced the maturity simultaneously with the early sown crop and, hence, resulted in a reduced seed and straw yield. Early seeded crops had a higher harvest index due to adequate growth, development, and a longer time span for seed maturation than late sown crops. Sirwaiya et al. (2018) also reported a reduction in the harvest index with a delay in sowing. In general, the sowing dates could not influence N, P and K uptake in the seed and total plant except for the N uptake by the straw in the late sown crop (Table 4). The available soil N and P were not influenced by the sowing dates, though the available K was significantly influenced with the maximum available K in the early sown crop.

Effect of fertilisation levels. The fertilisation levels gave significant variation in the seed yield and related traits. Significantly, a minimum number of days to flowering was observed in the control treatment in 2017–2018 and the pooled years. Significantly, the highest seed yield and harvest index was recorded at 125% NPK followed by 100% NPK during both years as well as the pooled analysis data compared to no fertiliser application. The higher straw yield was recorded in 100% NPK over 125% NPK during 2017–2018 and the pooled years. Nutrients are crucial elements of nucleotides, proteins, chlorophyll, and enzymes, and hence facilitate numerous metabolic processes in plants, resulting in enhanced output (Sharma et al. 2023). Furthermore, the uniform application of farmyard manure improved the rhizosphere's physiochemical and microbial environment, resulting in a better expression of the response to the applied chemical

Table 3. Effect of the sowing dates, nutrient levels and varieties on the days to flowering, seed and straw yield, harvest index and 100-seed weight of the garden pea

Treatment	Days to flowering			Seed yield (t/ha)			Straw yield (t/ha)			Harvest index (%)			100 seed weight (g)		
	2017 to 2018	2018 to 2019	pool	2017 to 2018	2018 to 2019	pool	2017 to 2018	2018 to 2019	pool	2017 to 2018	2018 to 2019	pool	2017 to 2018	2018 to 2019	pool
Date of sowing															
26th October	76.3	83.3	79.8	2.61	1.25	1.93	2.62	2.44	2.53	49.80	33.96	42.00	17.00	14.96	15.98
10th November	82.1	98.5	90.2	2.58	0.91	1.74	2.70	1.88	2.29	47.43	32.72	40.00	16.63	15.04	15.83
CD (P = 0.05)	0.7	1.0	0.6	NS	0.03	0.04	NS	0.05	0.05	1.25	0.75	0.70	NS	NS	NS
Nutrient levels															
Control	76.8	91.6	84.1	1.56	0.72	1.14	1.88	1.39	1.63	44.86	34.05	39.00	18.11	15.22	16.67
100% NPK	80.1	90.6	85.3	2.97	1.20	2.09	3.14	2.53	2.84	48.58	32.06	40.00	16.28	14.89	15.58
125% NPK	80.8	90.6	85.6	3.26	1.32	2.29	2.96	2.56	2.76	52.42	33.91	43.00	16.06	14.89	15.47
CD (P = 0.05)	0.9	NS	0.7	0.10	0.03	0.05	0.11	0.06	0.06	1.53	0.92	0.87	0.6	NS	0.64
Cultivar															
DPP-SP-6	80.4	92.5	86.4	2.77	1.19	1.98	2.82	2.27	2.55	48.96	34.70	42.00	17.33	15.67	16.50
Him Palam Matar-1	78.2	89.6	83.8	2.58	1.06	1.82	2.59	2.08	2.33	49.34	33.70	42.00	16.83	15.00	15.92
Pb-89 (Check)	78.9	90.7	84.8	2.44	0.99	1.71	2.58	2.12	2.35	47.56	31.62	40.00	16.28	14.33	15.31
CD (P = 0.05)	0.9	1.3	0.7	0.10	0.30	0.05	0.11	0.06	0.06	NS	0.92	0.9	0.6	1.03	0.64

CD – critical difference; NS – non-significant differences among treatments

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Table 4. Effect of the date of sowing, nutrient levels and varieties on the NPK uptake of the garden pea and soil health (available nutrients) after completion of the experiment (in kg/ha)

Treatment	N uptake			P uptake			K uptake			Available nutrients		
	seed	straw	total	seed	straw	total	seed	straw	total	N	P	K
Date of sowing												
26th October	90.38	19.35	109.73	10.87	5.60	16.47	11.05	20.70	31.75	271.09	23.48	227.76
10th November	93.67	20.72	114.39	10.20	5.48	15.70	11.25	20.62	31.87	268.15	23.17	224.14
CD (P = 0.05)	NS	1.21	NS	NS	NS	NS	NS	NS	NS	NS	NS	3.17
Nutrient levels												
Control (no NPK)	53.91	13.23	67.14	6.42	4.21	10.63	6.05	14.04	20.09	245.37	19.61	211.22
100% NPK	104.76	23.94	128.7	12.17	6.53	18.7	12.56	24.99	37.55	278.92	24.31	227.46
125% NPK	117.41	22.93	140.33	13.03	5.89	18.92	14.85	22.94	37.79	284.58	26.06	239.20
CD (P = 0.05)	6.79	1.48	7.60	1.20	0.53	1.29	1.35	1.14	1.79	3.70	1.46	3.88
Cultivar												
DPP-SP-6	100.91	21.62	122.52	11.59	6.03	17.60	11.98	22.13	34.12	268.73	24.22	225.64
Him Palam Matar-1 (DPP-SP-22)	91.06	19.02	110.07	10.57	5.50	16.09	10.91	20.19	31.10	270.30	23.10	226.74
Pb-89 (Check)	84.14	19.47	103.58	9.46	5.10	14.55	10.56	19.65	30.22	269.84	22.64	225.50
CD (P = 0.05)	6.79	1.48	7.60	1.20	0.53	1.29	NS	1.14	1.79	NS	NS	NS

CD – critical difference; NS – non-significant differences among treatments; recommended dose: 50 : 60 : 60 kg N : P_2O_5 : K_2O per ha; initial status of the soil was 243.4 : 20.16 : 208.38 Kg of N : P : K per ha

fertilisers via their beneficial effect on the nutrient uptake, physiological growth, and yield contributing parameters (Sharma et al. 2016). Such a response of the pea crop to higher levels of NPK, i.e., 100 to 125% NPK in a soil having low to medium N and medium P, K and organic matter was obvious.

The harvest index is important in determining the yield and represents the increased physiological capacity to mobilise photosynthates and their translocation to traits of significance. Therefore, the high harvest index through supplementation of NPK might have enhanced the capacity to translocate photosynthates towards an economic sink resulting in a high seed yield.

Among the fertilisation levels, the total N, P and K uptake increased significantly to the extent of 73.19, 78 and 37.79 kg/ha, respectively, with increasing levels of NPK from 0 to 125% of the recommended dose. The application of N may have resulted in rapid vegetative and profuse root development, which may have resulted in greater nutrient absorption from the soil (Sharma et al. 2001). Furthermore, the nutrient uptake is a function of the dry matter yield and content of the respective nutrients. The seed and straw yields obtained in the current study under different treatments provide ample evidence for the nutrient absorption behaviour of peas in the corresponding treatments. Therefore, the N uptake increased consistently up to 73 kg N/ha.

The highest available N, P and K were recorded in the treatment 125% NPK with respective values of 284.58, 26.06 and 239.20 kg/ha, which significantly improved soil health than control by 16, 33 and 13% of the respective nutrients. The increase in available NPK in the 100% NPK treatment was to the extent of 14, 24 and 8%, respectively, more the control. Furthermore, the 125% NPK treatment increased the available N, P and K levels in the soil by 41.54, 5.90 and 30.82 kg/ha over the initial status of the soil, indicating that all the applied NPK levels were not utilised and there was build up owing to the biological fixation for N and mobilisation for P + K. The increase in the available N might be attributed to the direct addition of nitrogen and the multiplication of soil microbes which could convert organically bound N to an inorganic form to the available pool of the soil (Sharma et al. 2023). Similarly, the increase in available P content might be attributed to the direct addition of P as well as to the release of various organic acids on the organic manure decomposition which chelated the Fe

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and Al and helped in the solubilisation of the native P (Urkurkar et al. 2010). The organic materials form a cover on the sesquioxides and, thus, reduce the phosphate fixing capacity of the soil which ultimately helps in the release of an ample quantity of phosphorus (Pawar et al. 2017). The beneficial effect on the available K may be ascribed to the direct potassium addition to the potassium pool of the soil besides the reduction in the potassium fixation and release of potassium due to the interaction of the organic matter with the clay particles (Sharma et al. 2023).

Furthermore, an increase in the available soil nitrogen, phosphorus and potassium with an increase in the NPK levels might be due to the added synthetic fertilisers per each treatment and result in the better growth of garden peas with the NPK application that added more organic matter to the soil, therefore creating better soil health in terms of the NPK status with increasing nutrient levels.

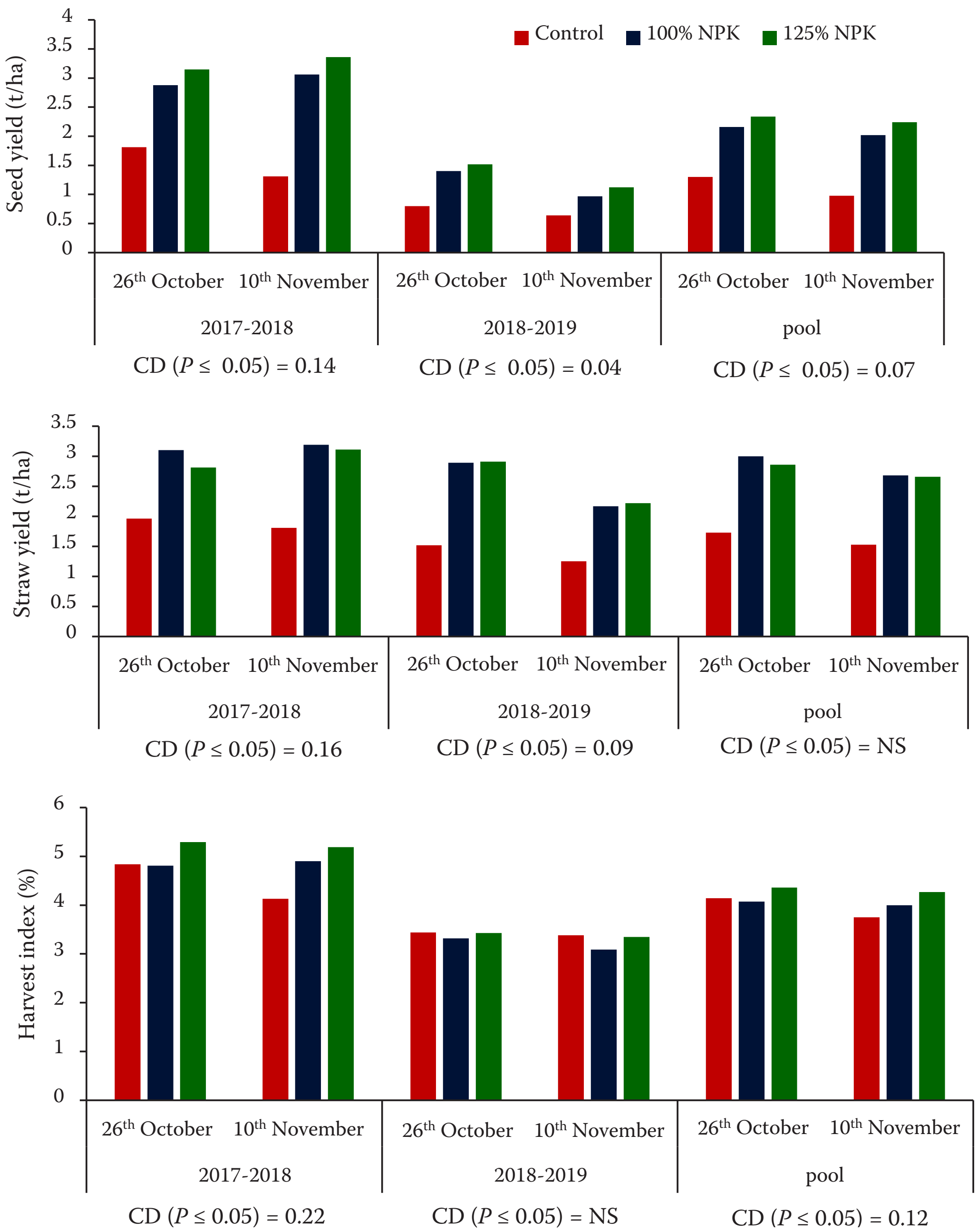

Figure 1. Interaction effect of the sowing dates and nutrient levels on the yield of the garden pea
CD – critical difference

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Effect of cultivars. Genotypes differed significantly for days to 50% flowering, where DPP-SP-22 took a significant minimum number of days to flowering on the pooled basis which was at par with Pb-89 in 2017–2018 and 2018–2019. Of the three genotypes, DPP-SP-6 significantly produced higher seed and straw yields during both years and the pooled years followed by Him Palam Matar-1 then Pb-89. However, DPP-SP-22 and Pb-89 were at par for the straw yield during both years and on the pooled basis. The maximum 100 seed weight was recorded in DPP-SP-6 which was at par with Him Palam Matar-1, but significantly better than the recommended variety Pb-89 during both years and the pooled years. The highest total N, P and K uptake was estimated in the genotype DPP-SP-6 to the extent of 122.52 kg N, 17.6 kg P and 34.12 kg K/ha. The increased N uptake by DPP-SP-6 may be ascribed to the better growth of the yield contributing traits, higher yield and improvement in the nutrient contents due to the increased availability of nutrients owing to the higher production of photosynthates (Ukai et al. 2016) and, thereby, a higher seed yield.

Interaction effects. The maximum seed yield (33.60 q/ha) was recorded in the10^{th} of November sown crop supplemented with 125% synthetic fertilisers followed by the 26^{th} October sown crop along with the 125% NPK fertilisers (Figure 1), significantly better than the control during 2017–2018. Contrary, significantly, the highest seed yield was recorded in the early sown crop augmented with the 125% fertilisation levels in 2018–2019 and the pooled years followed by the 100% NPK which was significantly higher than the control in both sowing dates over the years. The early sown crop on the 26^{th} of October supplemented with 125% NPK significantly revealed a better harvest index followed by the 10^{th} of November sowing in conjunction with the 125% NPK levels in 2017–2018 and the pooled years.

The date of sowing and nutrient levels interact significantly for the N and K uptake by the seeds and total plants in the garden pea (Figure 2). The highest total N uptake was recorded in the treatments supplemented with 125% NPK synthetic fertilisers on the 2^{nd} date of sowing (149.26 kg/ha).

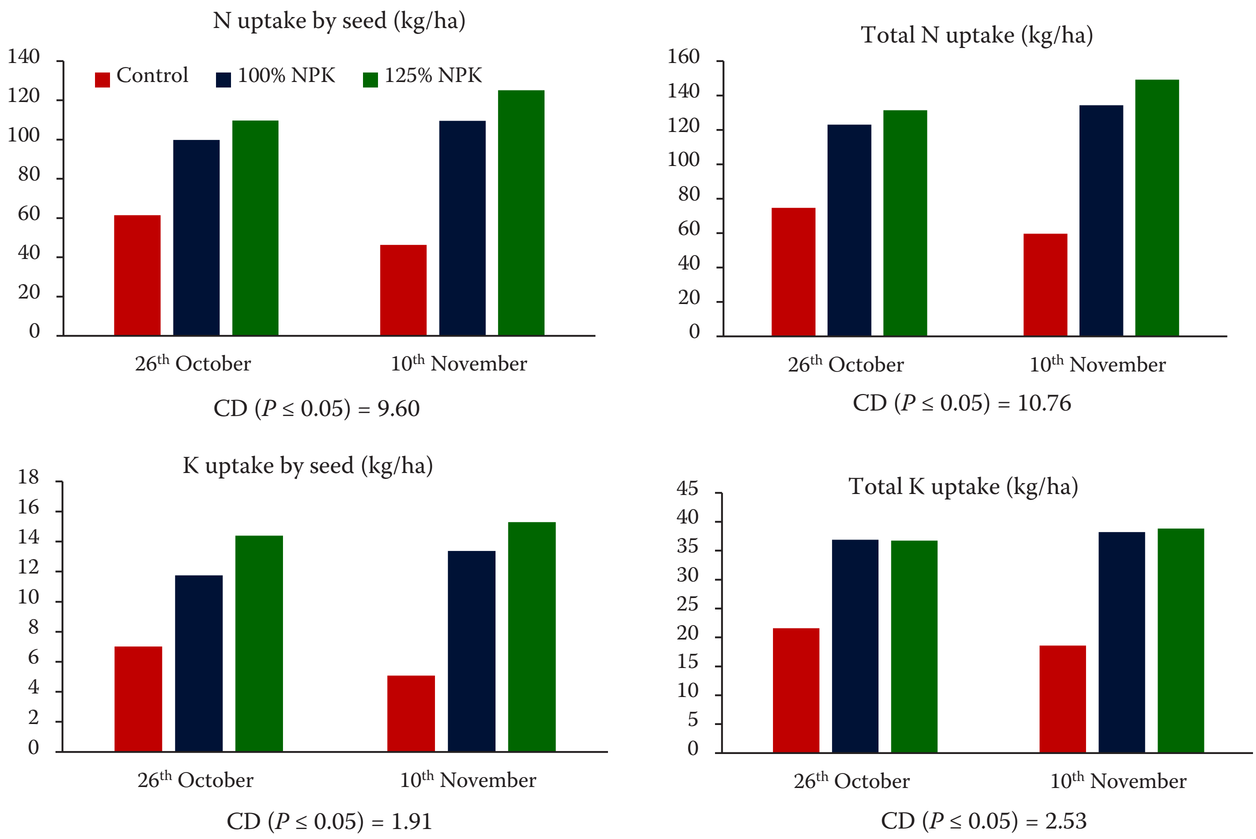

Figure 2. Interaction effects of the date of sowing and nutrient levels on the N and K uptake (kg/ha) in the garden pea
CD – critical difference

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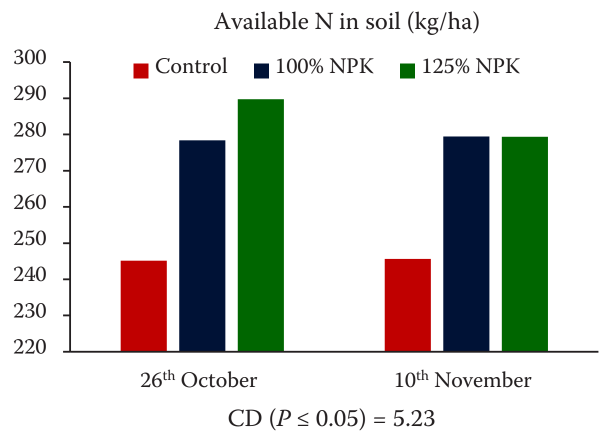

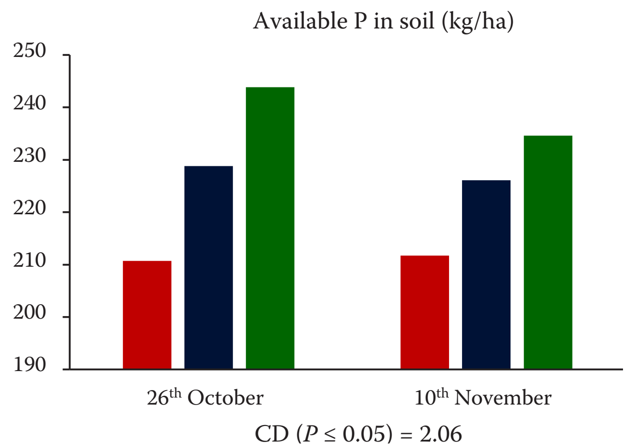

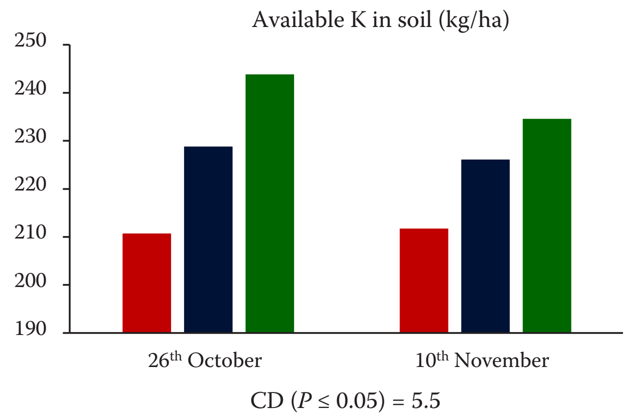

Figure 3. Interaction effect of the date of sowing and nutrient levels on the available N, P and K (kg/ha) in the soil after the completion of the experiment
CD – critical difference

The 100 and 125% NPK treatments, irrespective of the date of sowings, were at par with each other for the total K uptake, but were significantly better than the control. The added fertiliser enhanced the availability of these nutrients and thereby the absorption by the plants which might have resulted in profuse shoot and root growth, yield attributes and finally seed yield (Gaud, Kale 2010). The increased rate of photosynthetic activity following the balanced application of nutrients stimulated better vegetative and reproductive growth of the crop (Yi et al. 2020). The interaction between the sowing dates and fertilisation levels significantly influenced the available N and available K in the soil (Figure 3). The highest available N (289.75 kg/ha) and K (243.83 kg/ha) in the soil was recorded in the first sowing date with the 125% NPK fertilisation level which was 19 and 17% higher than that of the initial N and K status of the soil, respectively. However, the rest of the treatments supplemented with 100 and 125% synthetic fertilisers, irrespective of the sowing dates, were at par with each other for the available N and K in the soil, but were significantly better than no fertilizer application.

The interaction effects between the dates of sowings and varieties for the yield (Figure 4) revealed that the early sown DPP-SP-6 on the 26th of October produced the highest seed and straw yields during 2018–2019 and the pooled years, and a higher harvest index in the pooled years while DPP-SP-6 sown on the 10th of November significantly outperformed the other varieties, irrespective of the date of sowings, for the seed yield and harvest index during 2017–2018.

CONCLUSION

It can be concluded that the appropriate sowing time along with the fertilisation levels and superior genotypes/varieties are the important factors responsible in enhancing the production and productivity of garden peas. Early sowing on the 26th of October along with the application of 125% of the recommended dose of NPK provided promising results to harness high yields under mid hill conditions of Himachal Pradesh. DPP-SP-6 was the most promising genotype followed by Him Palam

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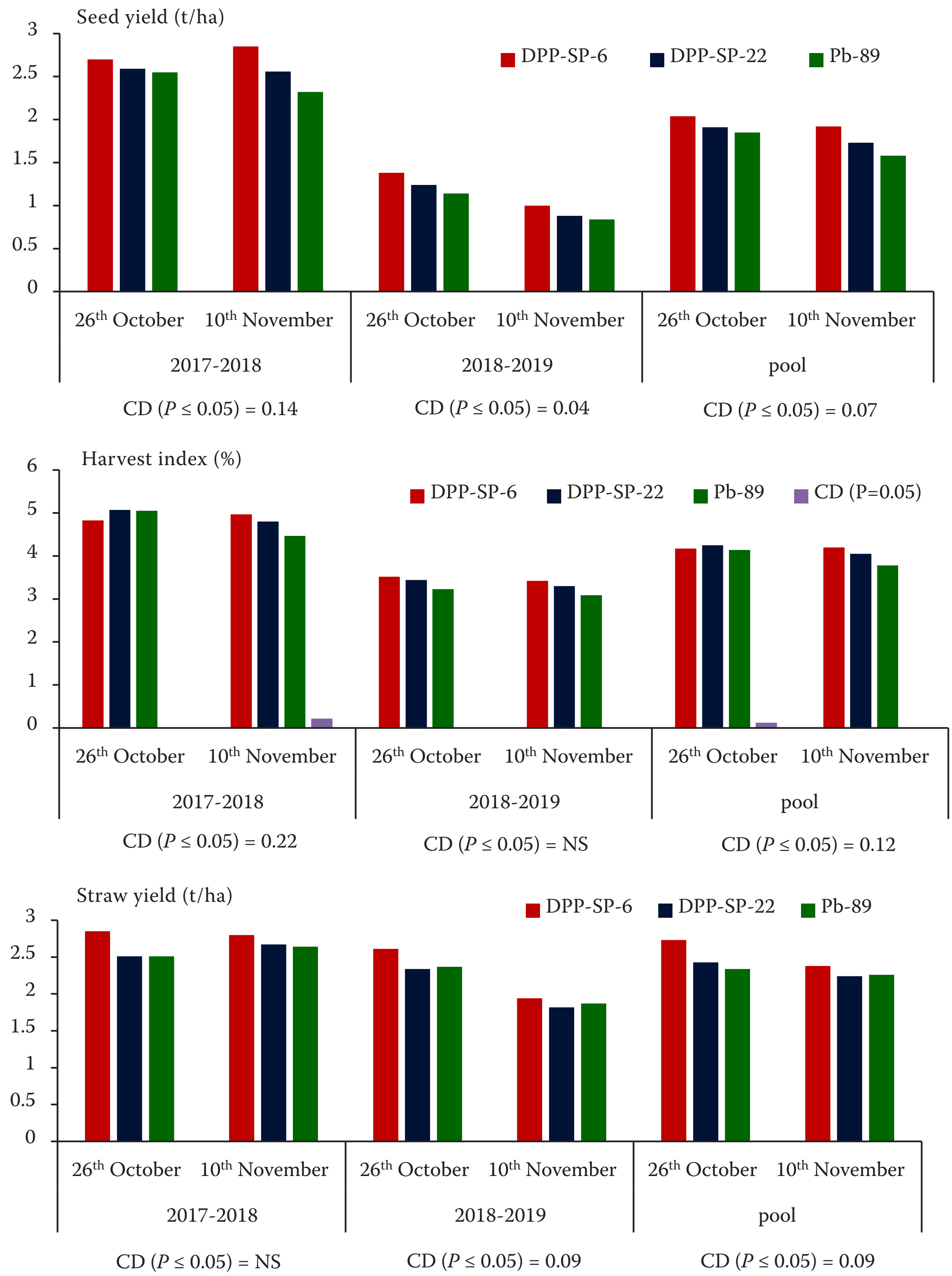

Figure 4. Interaction effect of the sowing dates and varieties on the yield and its attributes in the garden pea
CD – critical difference

Matar-1, which significantly outperformed Pb-89. Furthermore, it was observed that the total uptake of nutrients by the plants in general increased with an increase in the rate of the NPK fertiliser application. It may be recommended that the garden pea variety DPP-SP-6 is the most suitable for cultivation and should be sown in the last week of October with an application of 62.5:75:75 kg

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of $N:P_2O_5:K_2O$/ha, respectively, to harness the maximum yield potential.

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