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RESEARCH ARTICLE

Foliar Application of Potassium Salt of Active Phosphorus (PSAP) Mitigates Insect Pests and Improves Yield Along With Sugarcane Quality in Response to Agroclimatic Conditions of Punjab

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Abstract In semiarid tropics, potassium (K) and phosphorus (P) are the major nutrients that enhance the yield and juice quality of the sugarcane plants. The research experiment was carried out at PAU-Regional Research Station, Kapurthala, Punjab, India, on the potential of Potash Salt of Active Phosphorus (PSAP) which contains potassium and phosphorus during the spring season of 2021–2022 concerning insect-pests, yields, and quality parameters. With 50% reduction of P and K fertilizers, treatments compared with control (T_1, treatment frequency @3 times, water spray) with different foliar sprays of PSAP concentrations, such as 12.5, 15.0, and 25 kg ha^{-1} at 60, 90, and 120 days after planting as T_2, T_3, and T_4, respectively. Relative to the control plots, 12.5, 15, and 25 kg ha^{-1} PSAP treatments had significantly higher cane length, diameter, millable canes, yields and sugar recovery (%), which were 2.17, 2.26 and 2.30%; 1.83, 1.47 and 1.47%; 7.69, 8.97 and 9.23%; 12.51, 12.72 and 12.72%; 20.4, 18.6 and 17.8%, respectively. Further, the incidence of early shoot borer (*Chilo infuscatellus*), top borer (*Scirpophaga excerptalis*), and stalk borer (*Chilo auricilius*) was reported to be significantly lower during T_2, T_3 and T_4 to the tune of − 31.3, − 25.0 and − 18.7%; − 27.8, − 19.4 and − 16.7% and − 27.6, − 24.2 and − 20.7%, respectively, as compared to the control (T_1) plots. Better growth, yield, and quality parameters along with lesser insect–pest incidence resulted in higher B: C ratio of 1.40 in T_2 treatment as compared to 1.19 and 0.71 in T_3 and T_4 as compared to T_1 treatment. Our results suggest that PSAP @12.5 kg ha^{-1} may be recommended for reducing insect incidence and for enhancing sugarcane growth, yield, and sugar recovery.

Keywords Millable canes · Insect pests · Brix · Sugar recovery · PSAP · Sugarcane

Introduction

Sugarcane (*Saccharum* spp. Hybrids) is an important industrial crop in India (Bhatt et al. 2022). Sugarcane with biomass accumulation rates as high as 550 kg ha^{-1} day^{-1} is primarily grown in tropical and subtropical regions of the world (Bhatt et al. 2021c, d; Bhatt et al. 2022). Sugarcane stores up to 20% sucrose in stalk tissues. With average productivity of 71 t ha^{-1}, sugarcane is grown over 23.8 mha, yielding 1685 million tonnes of cane. South Asia's rice–wheat cropping system (RWCS) requires a lot of labor, water, money, and energy, and as the supply of these resources has decreased, it has become less lucrative (Bhatt et al. 2021a; b, c, d, f), and thereby majority of the Punjab soils show deficiency of

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major nutrients, viz. N, P, and K. Nitrogen applied rather in excess to cane fields ignoring P and K nutrients. Therefore, now the major concern was to assess the deficiency of these ignored nutrients, mainly sugarcane, for enhanced yields and quality (Verma et al. 2021; Bhatt et al. 2022).

Potassium (K) and phosphorus (P) carry direct or indirect involvement in photosynthesis, protein synthesis, the production of starch and controlling of stomatal openings in drought conditions (Wood and Schroeder 2004; Hasanuzzaman et al. 2018). Additionally, these nutrients are also involved in the transportation of proteins and photosynthates from the leaves to the whole plant (Filho 1985; Kwong 2002; Wood and Schroeder 2004; Bhatt 2020), turning leaves comparatively bitter, and reducing the incidence of insect pests (Hartt 1969; Bhatt et al. 2021c,d; Bhatt et al. 2022; Mengel and Haeder 1977; Verma et al. 2021). At PAU-Regional Research Station, Kapurthala 80 kg K_2O ha^{-1} (Bhatt et al. 2022) while at Indonesia 180 kg K_2O ha^{-1} (Kadarwati 2020) reported as sustainable dose for sustainable sugarcane production. In Australian soils, it varied between 2.1 and 2.4 kg K ton^{-1} of cane yield (Wood and Schroeder 2004). According to Kwong (2002), vegetative sugarcane biomass could have more than 200 kg of K ha^{-1}.

Because of the immobilization, fixation, and leaching of these nutrients, the sugarcane's ability to absorb administered P and K through the soil ranges from 15 to 60 days depending on soil, water, and climate conditions (Kumar et al. 2022). While its foliar application can boost cane production and quality, shortages in phosphorus and potassium can both cause significant yield loss in poor soils (Wood 1990; El-Tilib et al. 2004; Asraf et al. 2008; Bhatt et al. 2021a, b, c, d, f; Bhatt et al. 2022). In general, sugarcane reacts to K fertilizers by boosting cane yield without altering sucrose content (Kwong 2002; Shukla et al. 2009); however, in India Punjab was found to be substantial differences from the control plots both in yield and in quality (Bhatt et al. 2021c, d; Bhatt et al. 2022). Shukla et al. (2009) established a standard K fertigation dosage of 66 kg K ha^{-1}, while Bhatt et al. (2021c; d) claimed 80 kg K ha^{-1} as the sustainable dose for better growth, yield, and quality parameters with reduced incidence of insect pests. Singh et al. (1999) reported that potassium application had no significant effect on cane yield but increased commercial cane sugar content. In some countries, a consistent response in sugar content of cane to K applications is recorded for Punjab, India (Bhatt et al. 2021c; d), Guatemala (Perez and Melgar 1998), and Jamaica (Innes 1959).

Potassium and phosphorus are crucial for the transfer of sugar from leaves to the cane body, but when provided by chemical fertilizers, they become fixed in the soil and only 10 to 13% of them are made available to crop plants. Potash is plenty in our soil, but its availability is poor. Potash salt of active phosphorus (PSAP) is also very effective in C_3 and C_4 crops, seasonal or perennial (https://psap.in/psap_m.php). Hence, the enhanced sugarcane growth, yields, and quality parameters split foliar application of P and K that are required without entering into soil clay fixation mechanism (Bhatt 2020).

The present experiment was carried out at the experimental field of PAU-Regional Research Station, Kapurthala, Punjab, to delineate the response of PSAP (1) on cane growth and yields parameters (2) on cane juice quality parameters at the 10th and 12th months (3) on the incidence of different sugarcane insect pests and (4) on the benefit–cost ratio as compared to the controlled plots.

Materials and Methods

Investigation Site

The experiment was executed from 2021 to 2022 spring season of sugarcane cultivation at C-block, PAU- Regional Research Station, Kapurthala, Punjab, India (31° 23.032' N and 75° 21.647' E) at an altitude of 225 m above mean sea level (Bhatt and Singh 2020). The sugarcane crop cultivar (CoPb 93) was planted in March 2021 and harvested in March 2022.

Different agroclimatic variables were recorded at the agrometeorological center near the experimental site. During the experimental season, viz. 2021–22, the Class A pan evaporation was 1389 mm, the average ambient air temperature was 15.5–37.1 °C, and the average lowest air temperature was 8.4–25.0 °C. The maximum rain (307.5 mm) falls on 42 rainy days in June 2021, while the least (0 mm) falls in November, December 2021, February, and March 2022, respectively. A total of 124.9 mm of rainfall was reported during the dry season (December 2021 to February 2022). The average pan evaporation throughout the experimental period was 1388.5 mm, with an extreme of 209.5 mm in June 2021 and a lowest of 9.5 mm in January 2022 (Fig. 1).

Soil Characteristics

Representative soil samples were taken from the experimental site which further revealed that it was a sandy loam (sand 65–68%, clay 11–3%), neutral to slightly alkaline, non-saline, and the topsoil (0–15 cm depth) had low levels of phosphorus and potassium, calcium, and soil organic carbon (Bhatt and Dwivedi 2022) (Table 1).

Irrigation Water Quality

Groundwater at the experimental site was 35 m. The quality of replicas of the irrigation water applied to the cane was evaluated (Table 2).

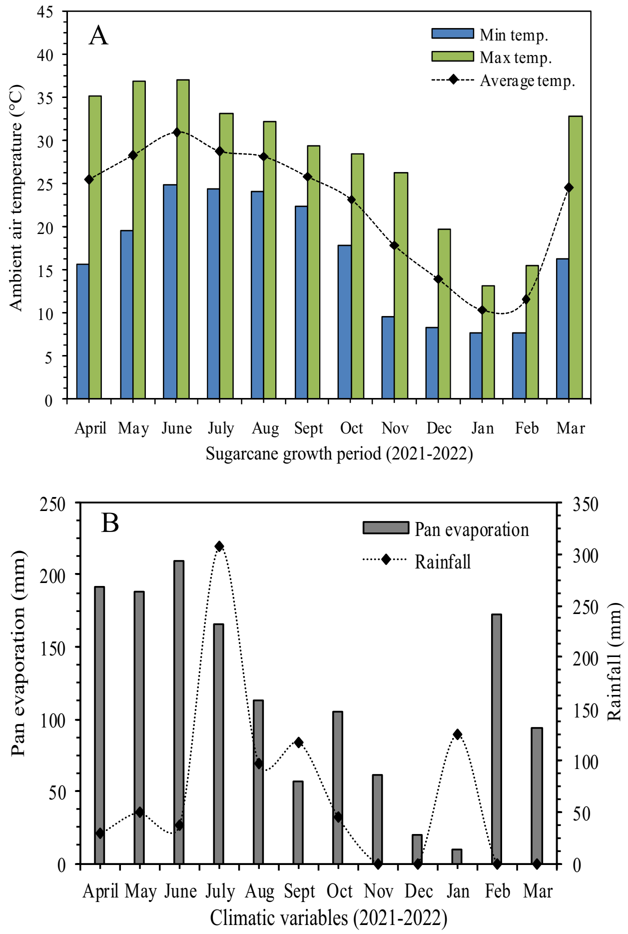

Fig. 1 Ambient air temperature (°C, maximum, minimum, and average), pan evaporation, and rainfall (mm) from the sugarcane growth period, i.e., April 2021 to March 2022

Table 1 Inherent surface soil properties at the experimental site

Soil properties	Values
Sand (%)	66.2
Clay (%)	11.6
pH (2:1)	8.68
EC (ds m^{-1})	0.22
OC (%)	0.38
Available nitrogen (Kg ha^{-1})	34.8
Available phosphorus (Kg ha^{-1})	20.8
Available potassium (Kg ha^{-1})	133.8
Available magnesium (ppm)	553.8
Available calcium (ppm)	140.2
Bulk density (Mg m^{-3})	1.62

Table 2 Parameters of irrigation water quality at the experimental site

Replicates	$Ca^{2+}+Mg^{2+}$ ($meql^{-1}$)	Cl^{-1} ($meql^{-1}$)	EC (ds m^{-1})	HCO3- ($meql^{-1}$)
R_1	3.5	0.5	0.46	3.7
R_2	3.8	0.8	0.52	3.8
R_3	3.6	0.9	0.52	3.6
Average	3.6	0.7	0.5	3.7

*Residual $NaHCO_3$ and CO_3^{-2} reported being zero

Treatments and Experimental Design

Present experiments were carried out in triplicate at the C-block of Regional Research Station (RRS), Kapurthala, during the Spring season (2021–22). The three budded sugarcane 50,000 billets ha^{-1} were established as per the recommendations of Punjab Agricultural University, Ludhiana (PAU 2022). Near to canes maturity, the healthy cane samples consisting of five canes from each plot were harvested and analyzed for different quality parameters such as Brix, Pol, CSS (%), and extraction (%), at the 10th and 12th months after planting. PSAP was sprayed thrice at different cane growth stages (60, 90, and 120 DAP).

T_1: 0 kg PSAP ha^{-1} (spray water, @ 3 times) + 50% reduction in P and K

T_2: 12.5 kg PSAP ha^{-1} (foliar spray, @ 3 times) + 50% reduction in P and K

T_3: 15.0 kg PSAP ha^{-1} (foliar spray, @ 3 times) + 50% reduction in P and K

T_4: 25.0 kg PSAP ha^{-1} (foliar spray, @ 3 times) + 50% reduction in P and K

Sugarcane mid-late moderately stress-tolerant cultivar, viz. CoPb 93, was planted in 27-m^2 experimental plots (6 m × 4.5 m) on March 20, 2021, at a row-to-row spacing of 75 cm. The control plots received only water sprays, while T_2, T_3, and T_4 plots were sprayed with PSAP @ 12.5, 15, and 25 kg ha^{-1} at 60, 90, and 120 DAP as 2.5, 4.0, and 6 kg ha^{-1}; 3, 4.8 and 7.2 kg ha^{-}1 and as 5, 8 and 12 kg ha^{-1} at 60, 90 and 120 DAP, respectively. All the recommended practice packages were followed for planting and cultivating the sugarcane plant crop during the spring season of 2021–22 (PAU 2022).

Data Collection and Calculations

Following the suggested methodology, the germination percentage of the seeded sugarcane setts was measured in each plot (45 days) after the crop was planted (DAP) for each treatment (Bhatt and Singh 2021; Bhatt et al. 2021d). Periodic Brix in the field was measured using a hand refractometer (Optics Technology; Delhi 34) at 112, 211, 251, 286, 303, and 322 DAP. At the same time, the number of tillers was assessed at 69, 125, and 180 DAP during plant season by counting the total number of single plant tillers in randomly selected five plants ($n=5$) within each treatment plot. During plant season, 345 DAP were counted as millable sugarcanes (NMCs). The number of mill-ready canes was determined visually, counted from inside the entire plot, and expressed as thousands per hectare (Bhatt and Singh 2021; Bhatt et al. 2021d).

To measure the root length density (cm cm^{-3}) with a length of 81 cm and a diameter of 5 cm, an iron pipe was used in each plot, followed by washing with streams of water, drying in the oven, and then measuring of total root lengths. In each plot, five randomly chosen sugarcane stalks were marked with tags. During plant season, a ruler was used to measure the shoot length of these stalks between the soil surface and the top growth point at 95, 123, 139, 158, and 180 DAP. Vernier caliper was used to measure the cane diameter at 101, 162, 222, and 255 DAP throughout the plant season on the five sugarcane stalks ($n=5$) that were chosen at random. The cane stalk diameter was represented by the mean value of the stalk diameter at the top, middle, and bottom. In the spring of 2021–2022, leaves per plant were also counted at 200, 250, and 300 DAP. At 96, 128, 149, and 241 DAP throughout plant season, the total number of internodes on each of the five randomly chosen sugarcane stalks was counted and averaged for a value in each treatment plot. Leaf chlorophyll concentration was measured at 72, 110, 160, 216, and 242 DAP during plant season using a SPAD-502 + chlorophyll meter. However, NDVI was measured using green seeker at 87, 118, 148, 287, and 306 DAP. Relative leaf water content (%) was determined at 160, 219, and 250 DAP by collecting 10 g leaf discs (fresh weight) from each plot, which were then submerged in distilled water in test tubes till saturation. After 6 h, the leaf discs were removed from test tubes. The surface water of the discs was blotted off without putting any pressure and then weighed to obtain saturated weight. After drying the discs at 70 °C for 72 h, their dry weight RLWC (%) is determined using an equation:

$$\text{RLWC}(\%) = \text{Fresh weight} - \text{Dry weight/Saturated weight} - \text{Dry weight} \times 100$$

Finally, at the maturity stage, the weight of all sugarcane stalks in each plot was determined after manual harvesting using a weighing balance in the field, representing the cane yields as t ha^{-1} (Bhatt and Singh 2021).

Quality Parameters of Sugarcane Juice

At the 10th and 12th months following planting, randomly chosen sugarcane stalks ($n=5$) were taken from each plot. The juice was extracted using a cane-crusher and then put through a quality check using established procedures (Meade and Chen 1977). Following the method described by Meade and Chen in (1977), a digital refractometer was used to quantify brix and the amount of sucrose in the cane juice. The following equation is used to determine the commercial cane sugar content (%, CCS) (Shukla 1991)

$$\text{CCS}(\%) = [\text{Sucrose}\,\% - (\text{Brix}\,\% - \text{Sucrose}\,\%) \times 0.4] \times 0.74 \tag{1}$$

The multiplication and crushing factors in Eq. (1) are 0.4 and 0.74, respectively. The CCS content in ton per hectare was computed using the cane yield and CCS content (%).

$$\text{CCS}\left(\text{t ha}^{-1}\right) = \left[\text{CCS}(\%) \times \text{Sugarcane yield}\left(\text{t ha}^{-1}\right)\right]/100 \tag{2}$$

Insect-Pests Incidence Monitoring

Incidence of major insect pests of sugarcane, viz. early shoot borer (*Chilo infuscatellus* Snellen), top borer (*Scirpophaga excerptalis* Walker), and stalk borer (*Chilo auricilius* Dudgeon), recorded as per prescribed procedures during experimental periods. To assess the influence of different PSAP doses on the incidence of inset-pest on sugarcane, the top borer population was recorded in June, the early shoot borer counted in May, and the stalk borer counted from 100 plants at harvest

$$\text{Percent incidence of early shoot borer} = \text{Total no. of dead hearts/total no. of shoots} \times 100$$

$$\text{Percent incidence of top borer} = \frac{\text{Total no. of infested canes in 3 m row length}}{\text{Total no. of canes observed in 3 m row length}} \times 100$$

The top borer percent incidence was measured in June, July, and August as:

The percentage incidence of stalk borer was recorded at the time of harvest, as stated below

Percent incidence of stalk borer

$= \text{Total no. of affected canes}/100 \text{ canes} \times 100$

Percent incidence of stalk borer

$= \text{Total no. of affected canes}/100 \text{ canes} \times 100$

Benefit-to-Cost Ratio of Sprayed PSAP

The calculation of the benefit-to-cost (B: C) ratio included the costs of PSAP (as applied) and the minimum support price (MSP) of sugarcane cane during 2021–2022 (Kumar et al. 2019; Bhatt and Singh 2021; Bhatt et al. 2021d). The B: C ratio is calculated using the equation:

B: C ratio (INR ha^{-1}) = Economic benefit from PSAP/ Cost of PSAP × 100

Statistical Analysis

The current study examines the impact of various PSAP dosages on cane growth, development, insect pests, yield, and quality data using the OPSTAT program created by Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India. CD was used to compare the mean differences between the different treatments.

Results and Discussion

Cane Growth and Yield Parameters

The potassium salt of active phosphorus seems to improve the cane growth and yield parameters in deficient soils. Brix and internodes $plant^{-1}$ significantly improved (Table 3) generally after the 3rd PSAP spray at 120 DAP. At 286, 303, and 322 DAP, reported Brix as compared to the control plots varied as + 4.29, + 4.93 and + 3.82%; + 3.37, − 1.94 and − 0.42%; + 2.98, + 0.56 and 0.97% in T_2, T_3 and T_4 treatments, respectively. Similarly, internodes $plant^{-1}$ improved as + 12.9, + 7.6 and + 7.93; + 9.26, + 8.20 and + 10.1%; + 6.93, 5.8 and 5.5% in T_2, T_3 and T_4 treatments, as compared to control T_1 plots. Faster P and K absorption in cane leave further modulates physiological and metabolic processes, improving cane growth, yield, and quality metrics (Singh and Tilak 2001; Singh et al. 2018;

Table 3 Variation of periodic sugarcane Brix and plant nodes in response to different PSAP concentrations

	Brix (°)						Internodes $plant^{-1}$			
	112 DAP	211 DAP	251 DAP	286 DAP	303 DAP	322 DAP	96 DAP	128 DAP	149 DAP	241 DAP
T_1	14.45	18.22	20.54	21.7	23.73	24.86	3.87	8.83	12.63	20.20
T_2	14.67	20.11	20.73	22.63	24.53	25.6	3.60	9.97	13.80	21.60
T_3	14.56	18.16	20.3	22.77	23.27	25.0	3.93	9.50	13.67	21.37
T_4	14.4	18.0	20.0	22.53	23.63	25.1	3.84	9.53	13.9	21.3
CD	NA	NA	NA	0.35	0.4	0.19	NA	0.6	0.81	0.55
SE(m)	0.25	0.59	0.37	0.1	0.11	0.05	0.3	0.17	0.23	0.16
SE(d)	0.35	0.83	0.53	0.14	0.16	0.08	0.43	0.23	0.33	0.22
CV	2.94	5.5	3.18	0.77	0.83	0.36	10.23	3.02	2.94	1.28

*T_1, T_2, T_3, and T_4 indicate PSAP concentrations, i.e., 0, 12.5, 15, and 25 kg ha^{-1} at 60, 90 and 120 days after planting (DAP)

Table 4 Effect of sugarcane length, diameter, and RLWC (%) by different levels of PSAP

	Length (cm)					Diameter (cm)				RLWC (%)		
	95 DAP	123 DAP	139 DAP	158 DAP	180 DAP	101 DAP	162 DAP	222 DAP	255 DAP	160 DAP	219 DAP	250 DAP
T_1	39.7	103	146.8	181.5	230.4	2.51	2.54	2.72	2.73	54.3	52.1	31.1
T_2	47.1	111.8	156.7	184.7	235.4	2.53	2.74	2.77	2.78	59.0	55.4	34.5
T_3	41.3	104.1	155.6	186.2	235.6	2.5	2.62	2.74	2.77	56.9	55.5	34.4
T_4	42.4	107.9	155.8	186.8	235.7	2.51	2.63	2.75	2.77	61.5	54.8	33.5
CD	NA	NA	1.49	3.17	3.46	NA	0.03	0.03	0.03	NS	0.78	0.82
SE(m)	4.38	7.56	0.42	0.89	0.98	0.12	0.01	0.01	0.01	2.20	0.22	0.23
SE(d)	6.2	10.73	0.6	1.27	1.39	0.16	0.01	0.01	0.01	3.11	0.31	0.33
CV	17.8	12.31	0.47	0.84	0.72	8.03	0.57	0.54	0.48	6.58	0.70	1.21

Kumar et al. 2020; Bhatt 2020; Bhatt et al. 2021c,d; Bhatt et al. 2022).

Sugarcane length and diameter were also not affected up to 123 and 101 DAP, respectively, in response to PSAP sprays which differed significantly afterward (Table 4). Recorded data revealed that cane length at 139, 158, and 180 DAP, compared to control plots, increased to the tune of 6.74, 5.99, and 6.13%; 1.76, 2.59, and 2.92%; 2.17, 2.26, and 2.30%, respectively, in T_2, T_3, and T_4 treatments. Cane diameter was observed at 162, 222, and 255 DAP, in T_2, $T_{3,}$ and T_4 treatments, there was an increase of 7.87, 3.15, and 3.54%; 1.84, 0.74 and 1.10%; 1.83, 1.47 and 1.47%, respectively, as compared to the control T_1 plots (Table 4). Relative water contents of cane leave also hold a good relation with photosynthesis and C-assimilation patterns as water restriction in plants is the reduction in growth and development due to the cessation of cell expansion. According to Benesova et al. (2012) and Bhatt (2020), physiological process that is partially or regulated by stomatal closure results in a decrease in water loss. This change in the leaf's water status has a direct impact on the rates of carbon absorption and photosynthetic activity (Table 4). Current experiments revealed that relative leaf water content (%) at 160, 219, and 250 DAP, compared to control plots, increased to the tune of 8.66, 4.85, and 13.2%; 5.92, 5.34 and 4.39%; 10.71, 10.60 and 7.60%, respectively, in T_2, T_3 and T_4 treatments due to the sustained supply of the potash with phosphorus through PSAP intermittent sprays at 60, 90 and 120 DAP (Table 4) as earlier reported by Bhatt et al. (2021a; b, c, d, f) in case of potash applications at deficient soils. Potash of PSAP is responsible for translocation of prepared photosynthates from leaves to rest cane. This higher sugar translocation in stalks resulted in higher cane length and diameter (Singh et al. 2018; Kumar et al. 2020).

Due to the interactive effect of potash with nitrogen, leaf chlorophyll contents are also affected under different PSAP sprays at 60, 90, and 120 DAP. Photosynthetic capacity is the main physiological process for crop growth and productivity (Chaves et al. 2009; Li et al. 2019; Bhatt 2020). Present experiments revealed that leaf chlorophyll concentration and normalized difference vegetation index (NDVI) were not affected by different PSAP treatments at 72, 110, and 160 DAP; 87, 148, and 306 DAP per SPAD and green seeker readings, respectively (Table 5). In comparison with the control plots, SPAD values changed to 7.42, – 2.39, and – 1.91%; 11.51, 6.26, and 9.1% in the T2, T3, and T4

Table 5 Variations of soil and plant analysis development (SPAD) and normalized difference vegetation index (NDVI) as per green seeker by different levels of PSAP

	SPAD							NDVI		
	72 DAP	110 DAP	160 DAP	216 DAP	242 DAP	87 DAP	118 DAP	148 DAP	287 DAP	306 DAP
T_1	39.5	53.3	44.8	41.8	42.67	0.48	0.5	0.5	0.61	0.62
T_2	44.1	53.9	47.9	44.9	47.58	0.52	0.56	0.56	0.67	0.69
T_3	43.3	52.8	46.9	40.8	45.34	0.5	0.52	0.54	0.61	0.63
T_4	49.7	52.2	46.6	41	46.54	0.49	0.53	0.54	0.62	0.64
CD	NA	NA	NA	2.44	1.19	NA	0.05	NA	0.03	0.06
SE(m)	3.89	4.01	1.48	0.69	0.34	0.02	0.02	0.02	0.01	0.03
SE(d)	5.49	5.66	2.1	0.97	0.48	0.03	0.02	0.03	0.01	0.04
CV	15.2	7.8	5.51	2.84	1.35	7.32	5.16	6.14	2.24	6.92

Table 6 Sugarcane leaves, number of millable canes (NMC), root length density (RLD), tillers cane^{-1}, and yields as affected by different levels of PSAP

	Leaves cane^{-1}			NMC (000, ha^{-1})	RLD (cm cm^{-3})	Tiller cane^{-1}			Yield (t ha^{-1})
	200 DAP	250 DAP	300 DAP	345 DAP	300 DAP	69 DAP	125 DAP	180 DAP	
T_1	13.93	9.97	8.33	3.90	0.426	4.93	5.87	5.53	58.27
T_2	14.4	10.57	8.93	4.20	0.439	6.13	8.4	7.2	65.56
T_3	14.33	10.6	8.93	4.25	0.437	6.00	7.4	6.2	65.68
T_4	14.4	10.67	9.03	4.26	0.438	5.87	7.13	6.87	65.68
CD	0.31	0.5	0.44	0.04	0.009	NA	NA	0.54	0.97
SE(m)	0.09	0.49	0.13	0.01	0.002	0.55	0.5	0.15	0.28
SE(d)	0.13	0.19	1.18	0.02	0.003	0.77	0.71	0.22	0.39
CV	1.08	2.33	2.45	0.43	0.965	16.6	11.9	4.1	0.75

treatments. As opposed to the control T1 plots, the normalized difference vegetation index (NDVI) was reported to be higher at plots 118, 287, and 306 DAP, measuring 12.0, 4.0, and 6.0%, 9.84, 0.0, and 1.64%, and 11.3, 1.6, and 3.23%, respectively. This indicates better, healthier canes with a good plant population (Table 5). Further, Verma et al. (2021) revealed that applying PSAP increased the photosynthetic activities by protecting the photosynthetic machinery during unfavorable water-stressed conditions.

Further, sugarcane leaves cane^{-1} at 200, 250, and 300 DAP were significantly affected under different PSAP treatments as compared to the control plots as 3.37, 2.87 and 3.37%; 6.02, 6.32 and 7.02%; 7.20, 7.2 and 8.4%, respectively, in T_2, T_3 and T_4 treatments as compared to the control plots (Table 6). According to Singh et al. (2012), the function of cane yield directly depends on the length, diameter, and number of millable canes (NMC). Our study reported that NMC was significantly higher at 7.69, 8.97, and 9.23% in T_2, T_3, and T_4 treatments than the control at 345 DAP. Further, PSAP sprays also promoted the root length density (RLD) as roots up to the depth of 90 cm reported at 300 DAP, significantly increased to the tune of 3.05, 2.58, and 2.66%, respectively, in T_2, $T_{3,}$ and T_4 treatments as compared to the control plots where only water sprayed at 60, 90, and 120 DAP, respectively. To tillers per cane at 69 and 125 DAP, non-significant improvements were there, but at 180 DAP, T_2, $T_{3,}$ and T_4 treatments had significantly higher tillers as 30.2, 12.12, and 24.23%, respectively, as compared to the control plots (Table 6). All these improved, cane growth and development parameters under PSAP spray finally also reflected in the cane yield as reported to be significantly higher in T_2, T_3, and T_4 treatments to the tune of 12.51, 12.72, and 12.72%, respectively, as compared to the control plots, which might be due to the observed significantly higher insect-pests attack in the control plots (Table 6).

Kumar et al. (2018) reported an enhancement of 36% with PSAP sprays as compared to the control. Sarwar et al. (2009) applied different fertilizers in broadcast and foliar forms and reported significantly higher tillers, NMC, cane yield, and juice quality. Singh et al. (2018) also reported a similar observation, who noted that PSAP @ 15 kg ha^{-1} produces higher cane productivity and improved cane growth parameters. The critical analysis further revealed that the improvements were similar between T_2, T_3, and T_4 treatments (Table 6). Hence, farmers could follow the recommendation of 12.5 kg PSAP ha^{-1} as other higher doses, viz. 15 and 25 kg ha^{-1} reported with similar yields (Table 6).

Incidence of Insect Pests

Sugarcane insect-pest incidence is the most important factor in deciding the development, growth, yields, and quality parameters. In the current investigation, the incidence of three major insects, viz. early shoot borer (*C. infuscatellus*), top borer (*S. excerptalis*), and stalk borer (*C. auricilius*), were recorded in different treatment plots as compared to the control one. In each treatment plot, the top borer and early shoot borer populations were counted after 60 DAS. The number of stem borers in each plot, 100 plants were counted at harvest time. The incidence of early shoot borer (*C. infuscatellus*) was reported to be significantly reduced to the tune of − 31.3, − 25.0, and − 18.7% in T_2, $T_{3,}$ and T_4 treatments, while top borer (*S. excerptalis*) incidence reduction reported to the tune of − 27.8, − 19.4, and − 16.7% in T_2, $T_{3,}$ and T_4 treatments as compared to the control plots (Table 7). However, PSAP effects on stalk borer (*C. auricilius*) incidence in T_2, $T_{3,}$ and T_4 treatments were revealed to be − 27.6, − 24.2, and − 20.7%, respectively, as compared to the control T_1 plots, which were significantly higher (Table 7).

Interestingly in our experiments, all the recorded insects were reported to be significantly reduced in PSAP plots as compared to the control water-sprayed plots (Table 7). It might be due to the sustained supply of potash under PSAP intermittent sprays as potash translocate the photosynthate from leaves to stalks, reducing the sweetness of leaves and hence the incidence of insect pests (Kumar et al. 2018; Bhatt et al. 2021a, b, c, d, e, f). This might be the reason for the observed significantly better yields and CCS (%) in the

Table 7 Sugarcane insect-pest variations under different levels of PSAP

	Early shoot borer	Top borer	Stalk borer
T_1	10.67	12.0	9.67
T_2	7.33	8.67	7.00
T_3	8.00	9.67	7.33
T_4	8.67	10.0	7.67
CD	0.96	1.70	1.40
SE(m)	0.27	0.48	0.40
SE(d)	0.39	0.68	0.56
CV	5.44	8.26	8.68

Table 8 Sugarcane juice quality variations at 10th month as per different levels of PSAP

	Brix (°)	Pol (%)	Purity (%)	CCS (%)	Extraction (%)
T_1	18.25	15.44	84.61	10.46	44.57
T_2	18.82	16.56	87.97	11.42	46.20
T_3	19.02	16.25	85.45	11.05	45.88
T_4	18.68	16.30	87.24	11.2	45.72
CD	0.28	0.47	2.45	0.47	NA
SE(m)	0.06	0.13	0.69	0.13	1.91
SE(d)	0.08	0.128	0.98	0.19	2.70
CV	0.52	1.42	1.39	2.09	7.19

Table 9 Sugarcane juice quality variations at 12th month as per different levels of PSAP

	Brix (°)	Pol (%)	Purity (%)	CCS (%)	Extraction (%)	CCS (t ha^{-1})
T_1	20.38	17.68	86.79	12.12	47.10	7.06
T_2	21.38	18.78	87.82	12.95	47.18	8.50
T_3	21.57	18.33	89.37	12.74	47.15	8.37
T_4	21.38	18.5	86.5	12.66	47.27	8.32
CD	0.83	0.27	NA	0.42	NA	0.27
SE(m)	0.23	0.08	1.18	0.12	1.11	0.08
SE(d)	0.33	0.11	1.68	0.17	1.57	0.11
CV	1.94	0.72	2.34	1.63	4.08	1.64

PSAP plots as compared to the control plots. The critical analysis further revealed that the overall reduction in insect-pest incidence was similar between T_2, T_3, and T_4 treatments (Table 7). Hence farmers could spray 12.5 kg PSAP ha^{-1} as other higher doses, viz. 15 and 25 kg ha^{-1}, were not economical for reducing insect-pest incidence in sugarcane, which further reduces the benefits (Table 7).

Sugarcane Juice Quality Parameters and Their Variations

Present investigations revealed a significant variation in Brix, Pol, Purity, and CCS (%) except extraction (%) at the 10th month after planting of cane under different PSAP spray treatments (Table 8), while purity and extraction (%) showed no variations at 12th month (Table 9). Careful evaluation of the data revealed that after 10th months, Brix, Pol, purity, CCS (%), and extraction (%) in T_2, $T_{3,}$ and T_4 treatments were reported to be significantly higher to the tune of 3.12, 4.22, and 2.36%; 7.25, 5.25 and 5.57%; 3.97, 0.99 and 3.11%; 9.18, 5.64 and 7.07%, respectively, over the control plots (Table 8). An increase in CCS (%) may be primarily due to increased cane yields and, to some extent, improved juice quality. The effect of CCS (%) at different PSAP doses was reported to be significant both at the 10th (Table 8) and at the 12th months (Table 9). The above-recorded results might be because the active phosphorus of PSAP helps produce additional energy in the form of P-bound ATP/ADP in sugarcane. This additional energy pushes all the pathways to the nearest competition much earlier than control plots. Further, the advancement of various syntheses in the presence of active potash of PSAP will produce more sugar in the canes (Kumar et al. 2018). Active potash of PSAP converts reducing sugar, finally into sucrose which reflects as CCS (%) and CCS (t ha^{-1}). Higher sugar translocation in stalks resulted in higher cane length and diameter, as shown in Table 2. However, the variations between T_2, T_3, and T_4 treatments were reported to be non-significant, which showed T_2 treatments as the best one as higher cost occurred on the PSAP higher dose as in T_3 and T_4 treatments with same quality parameters improvements (Table 8).

In the 12th month, different quality parameters, as shown in Table 9, showed an improvement with varying treatments of PSAP, though in purity and extraction, the improvements were statistically non-significant (Table 9). Careful evaluation of the data revealed that at 12th months, Brix, Pol, and CCS (%) in T_2, $T_{3,}$ and T_4 treatments were reported to be significantly higher to the tune of 4.91, 5.84, and 4.91; 6.22, 3.68 and 4.64%; 6.85, 5.12 and 4.46%, respectively, over the control plots (Table 9). Further, CCS (t ha^{-1}) was reported to be significantly higher to the tune of 20.4, 18.6, and 17.8% in T_2, T_3, and T_4 treatments concerning the control T_1 plots, which might be due to overall good plant growth enabling plants to accumulate more photosynthates for the synthesis of sucrose. Further cane yields and insect pest incidence were also reported significantly lower (Table 6) and higher (Table 7), respectively, in control plots as compared to the PSAP treatments. However, differences between T_2, T_3, and T_4 treatments were found to be non-significant, indicating that T_2 treatments were the best option as higher doses in

Table 10 The benefit-to-cost ratio in sugarcane under different PSAP treatments

Treatments	PSAP cost (INR ha^{-1})	Sugarcane yield (t ha^{-1})	Yield change from control	Economic benefit from PSAP (INR ha^{-1})	Benefit-to-cost ratio
T_1	0	58.31	0	0	0
T_2	18,125	65.56	7.25	25,375	1.40
T_3	21,750	65.68	7.37	25,795	1.19
T_4	36,250	65.68	7.37	25,795	0.71

*Cost of PSAP reported as INR 1450 per kg while sugarcane costs INR 3500 per ton

T_3 and T_4 treatments were more expensive but had the same performance (Table 9).

Benefit–Cost Ratio

The cost of PSAP was lowest in T_2 (12.5 kg ha^{-1}) and highest in T_4 (25 kg ha^{-1}), sprayed at 60, 90, and 120 DAP. Sugarcane yields were significantly lower in T_1 (58.31 t ha^{-1}) and considerably higher in T_2 plots (65.56 t ha^{-1}). The economic benefit from sprayed PSAP was 25,375, 25,795, and 25,795 INR ha^{-1} for T_2, T_3, and T_4, respectively. Benefit-to-cost (B: C) ratios were highest in T_2 (1.4) and lower in T_4 (0.71), which is not desired as here incurred costs are higher than yield benefits. Recorded benefit reduced in T_3 and T_4 plots to the tune of PSAP is an effective multi-nutrient fertilizer that must be applied to have good sugarcane yields and sugar recovery. Due to greater insect-pest infestations (Table 7), restricted production, and NMC response (Table 6), as well as higher fertilizer costs when comparing T_2 and T_3, a larger PSAP dosage (25 kg ha^{-1} rather than 12.5 kg K ha^{-1}) did not boost but rather lowered the economic advantages for farmers (Table 10). Prior to this, similar trends of lower benefits at higher doses concerning potash fertilization in sugarcane were reported by Bhatt et al. (Bhatt et al. 2021c; d) and Bhatt et al. (2022).

Conclusion

Present sugarcane plant experiments carried out during 2021–22 at PAU-Regional Research Station, Kapurthala, Punjab, India, revealed that PSAP dose @ 12.5 kg ha^{-1} applied through foliar sprays at 60, 90, and 120 DAP with 50% reduction in P and K fertilizers significantly reduces the insect-pest incidence, improved cane growth, yields, and quality parameters and hence benefits of the cane farmers of the region. However, further studies must be needed to evaluate the performance of PSAP on sugarcane carry out under diverse agroclimatic conditions under texturally divergent soils.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Human and Animal Rights The present research did not involve human participants and/or animals.

Consent for Publication All authors included in this study consent for publication.

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