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Optimizing the Methods and Schedule of Fertilization Escalated Nutrient Uptake, Nutrient Use Efficiency and Dry Matter Yield of Sugarcane (*Saccharum officinarum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field study was performed at Regional Research Station, Uchani (Karnal) of CCS Haryana Agricultural University, Hisar, India during 2020-21 to ascertain the role of precision nutrient management in enhancing nutrient availability to plants by amending the schedule and method of N and K fertilization in spring planted sugarcane (*Saccharum officinarum* L.) crop under wide spacing (120 cm). The experiment was devised under split plot design with three replications. The main plot treatments consisted of two methods of fertilizer placement (B1-broadcasting and B2-band placement) while sub plot treatments included four schedules of application of recommended dose of N and K (RDN+RDK) in five splits (T1), six splits (T2), seven splits (T3) and T4 (RDN in three splits, full dose of P and K at planting). All the main and sub plot treatments showed a remarkable influence on nutrient uptake (kg ha^{-1}), partial factor (kg kg^{-1}) productivity, dry matter accumulation (t ha^{-1}) and plant macro-nutrient content. B1 and T1 among main and sub plot treatments respectively lead to greater nutrient uptake, partial factor productivitie of NPK and highest dry matter yield.

Keywords: Sugarcane, fertilizer schedule; nitrogen; potassium; band placement; nutrient uptake; dry matter; partial factor productivity.

1. INTRODUCTION

Nutrient use efficiency (NUE) is a centrally focused concept for the evaluation of efficiency of crop production systems. It can be highly impacted by fertilizer management. In the recent years, partial factor productivities (yield obtained per unit of nutrient applied) for N, P and K are exhibiting a downward trend in India suggesting a lack of efficient nutrient management [1]. Nutrient management must be both coherent and effective to enhance productivity. As there has been an unprecedented surge in the cost of fertilizers in recent years due to expanding gap in demand and supply [2], there has been increased emphasis on improving nutrient use efficiency to maintain a proper supply of nutrients to crops during the active growth stage. This led to the development efficient nutrient management strategies such as 4R Nutrient Stewardship, which emphasizes on delivering nutrient from right source, in the right place, at the right rate, and at the right time [3]. The nutrient uptake and dry matter accumulation patterns of sugarcane crop follow a sigmoid or “S” shaped curve which denotes slow early uptake, reaches maximum during the active growth phase, and then declines as the crop proceeds towards maturity. Rate of plant nutrient uptake is therefore is not uniform throughout the crop life period. Timed and targeted applications of fertilizer N and K at specific growth stages are instrumental to an extreme extent in improving the yield of exhaustive crops such as sugarcane. Timed and targeted applications may also be beneficial to reduce environmental impacts of nutrient loss from soil [4]. Positioning the desirable nutrients strategically where they can be easily acquired by growing roots enables a plant to develop properly and realize its maximum potential yield, under the environmental conditions available for the growth. Concentrating the macro-nutrients in proximity of plant roots in the bands near crop rows can lead to their enhance availability [5]. The acquisition of nutrients is one of the principal functions of plant roots. Nutrients enter inside the roots from the soil solution and when the concentration of nutrients in the soil solution increases their absorption by plant roots also increases. A plant’s root architecture modifies during the different growth stages and responds to its local environment such as nutrient concentration [6]. Root proliferation takes place when plant roots comes in contact with concentrated zones of either N or P and results in increased nutrient uptake. Fertilizer applications under band placement either at the soil surface or at some depth below increases the nutrients concentration into a smaller soil volume. This higher soil solution concentrations accelerates the nutrient diffusion rates along with greater quantities of nutrients moving through mass flow which improves the replenishment rate of nutrients to plant roots [7]. Band applications are probably the most efficient placement method under lower soil fertility conditions. Placing nutrients below the soil surface can reduce nutrient losses occurring through runoff, volatilization and leaching especially in case of Nitrogen [8,9]. The present study aims to optimize suitable schedules and methods of fertilizer application to maximize their use under long term exhaustive crop like sugarcane.

2. MATERIALS AND METHODOLOGY

2.1. Experimental Site and Climate

Field experiment was performed at Regional Research Station (Uchani), Karnal of CCS Haryana Agricultural University, located at latitude of 29°43'42.19" N and longitude of 76°58'49.88" E and at an altitude of 253 meters above mean sea level. It is more or less equidistant falling almost midway between New Delhi and Chandigarh.

The climate of the experimental site is sub-tropical with mean maximum temperature ranging between 34-39°C in summer while mean minimum temperature falls in the range of 6-7°C in winter. Most of the precipitation is received in the form of rainfall during the months of July to September with few showers experienced during December to late spring.

2.2 Soil of Experimental Plot

The field at Regional Research Station (Uchani), Karnal of CCSHAU exhibited uniformity in fertility gradient. To determine the Initial soil fertility status of experimental field before the planting of crop, soil sampling was performed and four representative soil samples were collected randomly from the entire field at a depth of 0-30 cm before the final layout of experiment was implemented. The analysis was carried out by strictly following established protocols and standard procedures. From the interpretation of results. Chemical analysis of soil revealed that it had clay loam texture, alkaline nature, medium organic carbon content, low available N and medium P and K content.

2.3 Treatments and Layout of the Experiment

The experiment was devised under Split Plot Design with three replications. The experiment included two main plot treatments (Methods of fertilizer application) and four sub-plot treatments (Fertilizer application). Area of each plot was 57 m^2.

Basal dose was applied in furrows. Broadcasting and band application were initiated after basal application. Banding was done through plough sole.

Recommended dose of N,P and K in sugarcane is150 kg N/ha, 50kg P_2O_5/ha and 50 kg K_2O/ha respectively.

Table 1. Initial physio-chemical properties of the soil under experiment

S. No.	Parameter	Value/ Category	Analytical Method Used
1.	Soil Texture	Clay loam	International pipette method [10]
2.	pH $_{(1:2)}$	8.28	pH was determined using digital pH meter
3.	EC $_{(1:2)}$ (dS m^{-1})	0.25	EC was determined using digital EC meter
4.	OC (%)	0.48	Wet digestion method [11]
5.	Av. N (kg ha^{-1})	111.55	Alkaline Potassium Permanganate Method [12]
6.	Av. P (kg ha^{-1})	18.88	Sodium Bicarbonate Extractable P method [13]
7.	Av. K (kg ha^{-1})	201.40	Ammonium Acetate Extractable K method [14]

__pH__-power of hydrogen, __EC__-electrical conductivity, __SOC__-soil organic carbon, __N__-nitrogen, __P__-phosphorus, K-potassium

Table 2. Treatment details

Main plot treatments (two): Methods of fertilizer application	
B1	Broadcasting
B2	Band placement- 3 inches away from cane clump and 3 inches below soil surface
Sub Plot treatments (four): Number of splits of recommended dose of nitrogen and potassium (RDN+RDK):	
T1	RDN+RDK in five splits (Basal 10% and remaining dose at 45, 75, 90 and 120 DAP)
T2	RDN+RDK in six splits (Basal 10% and remaining dose at 45, 75, 90, 120 and 150 DAP)
T3	RDN+RDK in seven splits (Basal 10% and remaining dose at 45, 75, 90, 120, 150 and 180 DAP)
T4	Recommended dose and schedule of nutrient applications (Half of total N and full dose of P and K at planting and rest of the N at 45 and 90 DAP)

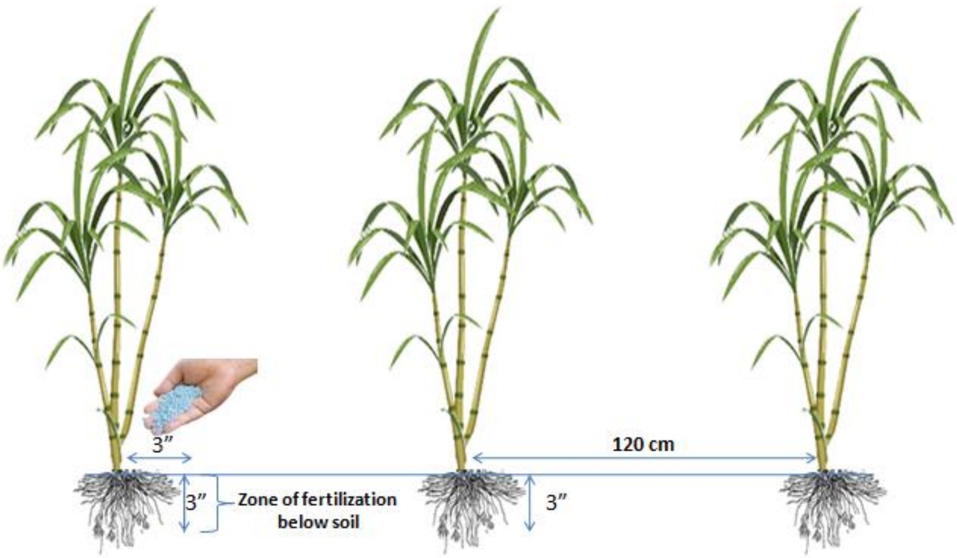

Fig. 1. Application of fertilizer in band at a distance of 3 inch away from cane clump and three inch below soil surface at one side of plant row

Table 3. Amount of fertilizer source of nutrient N, P and K applied at the time of sowing and at different time intervals after sowing as per recommendation of CCS Haryana Agricultural University

	Fertilizer applied at the time of sowing		
	Urea (g/plot)	**Muriate of potash (MOP) in g/plot**	**Diammonium phosphate (DAP) in Kg/plot**
T1	190	50	6.2
T2	190	50	6.2
T3	190	50	6.2
T4	630	480	6.2
	Fertilizer applied after basal dose at different time intervals		
	Urea (g/plot) per split	**MOP(g/plot) per split**	**Time of application**
T1	367	179	45, 75,90 and 120days after planting(DAP)
T2	294	143	45, 75,90, 120 and 150 DAP
T3	245	119	45, 75,90, 120,150 and 180 DAP
T4	545	0	45 and 90 DAP

2.4 Plant analysis

2.4.1 Total nitrogen (%)

Total Nitrogen was determined calorimetrically by using Nessler's reagent method (Lindner, 1944). The intensity of orange color thus developed is measured on spectrophotometer at 440 nm wavelength.

2.4.2 Total phosphorus (%)

Total Phosphorus was determined by Ammonium-vanado-molybdate yellow color method (Koenig and Johnson, 1942). The intensity of yellow color thus developed is measured on spectrophotometer at 440 nm wavelength.

2.4.3 Total potassium (%)

Total Potassium was determined by Flame photometry method (Isaac and Kerber,1971)using flame photometer.

2.5 Dry Matter Yield (t ha^{-1})

Dry matter was calculated by taking the average dry weight of five canes from the plot and then multiplying the average dry matter of one plant with total number of millable canes.

2.6 Nutrient Uptake (kg ha^{-1})

The uptake of macronutrients (N,P and K) was calculated by the following formula:

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{N\%/P\%/K\% X dry matter (kg ha}^{-1}\text{)}}{100}$$

2.7 Partial Factor Productivity (kg ha^{-1})

Partial factor productivity (kg ha^{-1}) was calculated from the following formula:

$$\text{Partial factor productivity of N/P/K(kg kg}^{-1}\text{)} = \frac{\text{Cane Yield (kg)}}{\text{Amount of nutrient N/P/K added (kg)}}$$

2.8 Statistical Analysis

Statistical analysis was carried out by employing OPSTAT software tool developed by Dept. of Statistics, CCS Haryana Agricultural University. Critical Difference (CD) at 5% level of significance was worked out through two-way Analysis of Variance (ANOVA) as described by Sheoran et al. [15].

3. RESULTS AND DISCUSSION

3.1 Effects of Different Treatments of Fertilizer Application on Plant Nutrient Content of Sugarcane Crop

3.1.1 Nitrogen content in plant (%)

Plant samples were analyzed for N content in plants at 45, 90, 150 and 210 DAP (Table 4) showed that both main (methods) and sub plot treatments (application schedule) significantly influenced the N content in plant at all the growth stages N content of the plant. Significantly higher N content was noticed in B2 than B1 at all the active crop growth stages upto maturity. Band placement of N under soil surface might have lowered N_2O emissions [16] and surged the availability of N in soil solution which was readily acquired and transported to leaves and stem raising the N level in the plant. Oliveira et al. [17] found the similar results from their investigation.

Among the sub plot treatments, T4 registered significantly higher N content in plant than others at 45 DAP (1.664 %) and at 90 DAP (1.759 %) which might be due to application of whole

Table 4. Effect of different methods of fertilizer application and numbers of splits of N and K on nitrogen content in plant of sugarcane crop

Methods of fertilizer application	Nitrogen Content (%)			
	45 DAP	90 DAP	150 DAP	210 DAP
B1 Broadcasting	1.483	1.551	1.244	0.647
B2 Band placement	1.544	1.685	1.335	0.664
SEm±	**0.002**	**0.001**	**0.001**	**0.001**
CD (P=0.05)	**0.014**	**0.008**	**0.005**	**0.004**
Number of splits of N and K				
T1 5 splits	1.559	1.550	1.360	0.685
T2 6 splits	1.442	1.556	1.314	0.665
T3 7 splits	1.410	1.551	1.306	0.650
T4 3 splits	1.644	1.759	1.179	0.622
SEm±	**0.002**	**0.002**	**0.002**	**0.001**
CD (P=0.05)	**0.007**	**0.007**	**0.007**	**0.003**
CD of Factor (B) at same level of A	0.015	0.011	0.011	0.005
CD of Factor (A) at same level of B	0.016	0.011	0.010	0.005

***SEm±** represents standard error, **CD (P=0.05)** represents critical difference between treatments at 5% level of significance, **NS** represents that treatments are not significant at at 5% level of significance, **DAP** represents number of days after planting*

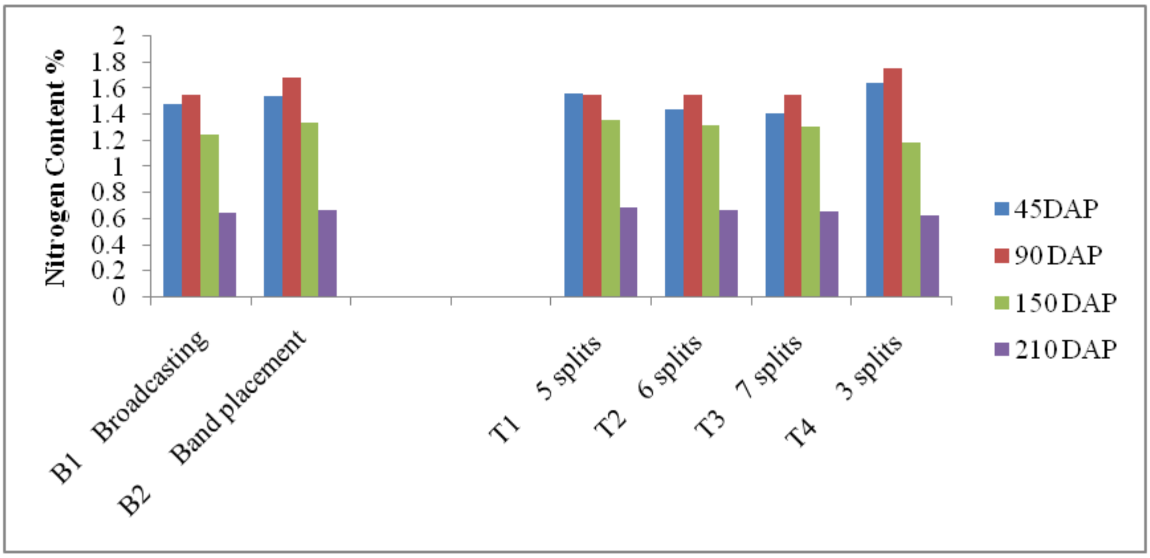

Fig. 2. Effect of different methods of fertilizer application and numbers of splits of N and K on nitrogen content in plant percentage of sugarcane crop

amount of fertilizer N upto 90 DAP in this sub plot treatment leading to higher uptake in early growth stages which was further c reflected in raised N content in Plants [18] (Prasertsak et al., 2002). However, maximum plant N at 150 (1.360%) and 210 (0.685%) DAP was observed under T1 which was significantly more than others treatments which might be a consequence of little response of crop to fertilizer N application at grand growth stage in other treatments. These findings resonates to those of Wiedenfeld [19] who also reported similar trend in his investigation. His work clearly showed that N content in plants in all treatments was highly reduced from 150 to 210 DAP because of initiation of grand growth period in sugarcane after 150 days.

It is evident from the data (Table 4) that under both main plot treatments the N content in plant registered a hike from 45 to 90 DAP during the most active period of crop growth but then gradually came down at 150 and 210 DAP as the plant advanced towards maturity. N content in plants was highly reduced in sub plot treatments from 150 to 210 DAP. Interaction between methods of fertilizer application and application of RDF in different number of splits was significant in influencing N content in plant.

3.1.2 Phosphorus content in plant (%)

Plant samples were analyzed for P content in plants at 45, 90, 150 and 210 DAP and statistical analysis of data disclosed that P content in plant was significantly affected under main plot treatments (Table 5). P content recorded at different growth stages was found significantly higher under B2 P content recorded in plant sample in case of band placement is 0.156, 0.233, 0.145 and 0.094% at 45(0.156%), 90(0.233), 150(0.145%) and 210(0.094%) DAP, respectively. The trend observed was identical to that observed in case of plant N content. Band application of fertilizer resulted in proper placement of P in the vicinity of roots concreting the availability of P to roots and at the same time minimizing contact with soil thereby reducing its fixation [20,21]. Intimate root and fertilizer association enhanced P uptake which increased P concentration in plant. This notion is supported by findings of Linkohr et al. [22] and Ticconi et al. [23]. P content in plant samples increased from 0.156% (45 DAP) to 0.233% (90 DAP). Then it was decreased to 0.145% at 150 DAP and further a drastic reduction was observed at 210 DAP (0.081%).

Among the sub plot treatments, different number of splits failed to exert any remarkable influence at any of the growth stages which might be due application of whole P at planting time in all the sub treatments causing similar response in all the treatments. A large reduction in P content was observed from 45 to 90 DAP and from 150 to 210 DAP in sub plot treatments too which might be related to physiology of plant as concentration of primary macronutrients generally drops at the end of active growth period [18].

Table 5. Effect of different methods of fertilizer application and numbers of splits of N and K on phosphorus content in plant of sugarcane crop

Treatments	Phosphorus Content in Plant (%)			
Methods of fertilizer application	**45DAP**	**90 DAP**	**150 DAP**	**210 DAP**
B1-Broadcasting	0.146	0.219	0.136	0.081
B2 -Band placement	0.156	0.233	0.145	0.094
SEm±	0.000	0.000	0.000	0.003
CD (P=0.05)	0.001	0.001	0.001	NS
Number of splits of N and K				
T1 -5 splits	0.155	0.229	0.145	0.093
T2 -6 splits	0.151	0.224	0.143	0.090
T3 -7 splits	0.150	0.223	0.138	0.085
T4-3 splits	0.149	0.227	0.135	0.082
SEm±	0.000	0.000	0.000	0.000
CD (P=0.05)	NS	NS	NS	NS
CD of Factor (B) at same level of A	NS	0.001	NS	NS
CD of Factor (A) at same level of B	0.001	0.001	0.001	NS

***SEm±** represents standard error, **CD (P=0.05)** represents critical difference between treatments at 5% level of significance, **NS** represents that treatments are not significant at at 5% level of significance, **DAP** represents number of days after planting*

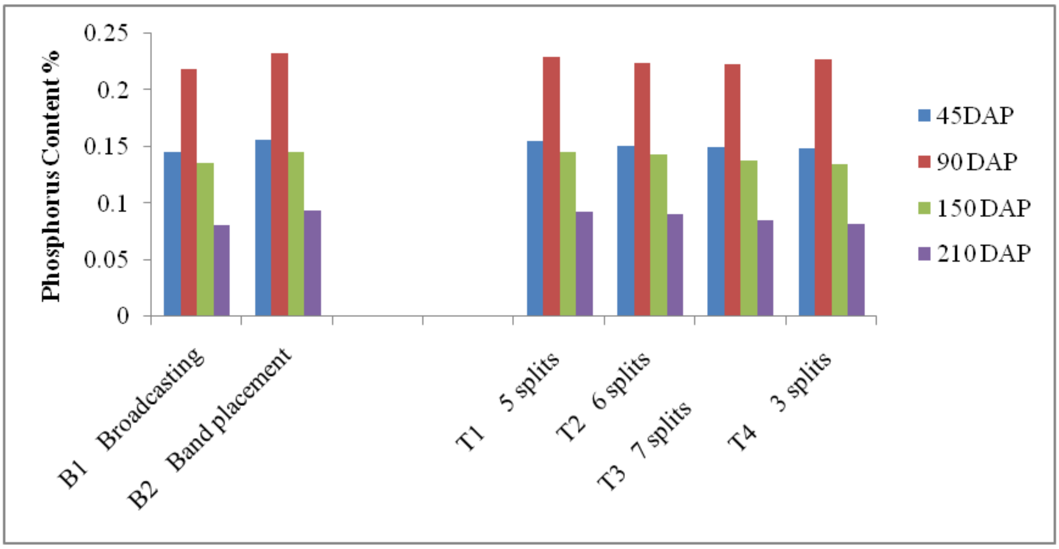

Fig. 3. Effect of different methods of fertilizer application and numbers of splits of N and K on Phosphorus content in plant percentage of sugarcane crop

Interaction between methods of fertilizer application and application of RDF in different number of splits was significant in influencing N content in plant.

3.1.3 Potassium content in plant (%)

Plant samples were analyzed for their K content at 45, 90, 150 and 210 DAP and perusal of data (Table 6) confirms that K content in plant was significantly influenced under main and sub plot treatments at all the growth stages except at 210 DAP and more accumulation K occurred in the plants under B2 than B1. Treatment B1 accumulated 2.498, 2.266, 1.980 and 0.764% K as compared to 2.648, 2.342, 2.034 and 0.773% plant K under B2 at 45, 90, 150 and 210 DAP, respectively. More adequate supply of N to roots in band placement might have synergistic effect of nitrate on potassium cation uptake (Whitehead, 2000) which has ultimately lead to higher plant K content.

Among the sub plot treatments, T4 reported slightly higher K content (2.770%) in plant compared to all other treatments at 45 DAP which can be ascribed to application of whole fertilizer K at sowing under this treatment. These findings are supported by Wubale and Girma [24] who suggested that increasing the application of a particular nutrient improves its concentration in plant. T1 reported slightly higher K content in plants compared to other treatments at 90 (2.325%), 150 (2.140%) and 210 (0.776%) DAP which might be due to the continuous application of higher amount of fertilizer K applied in five splits than other treatments at optimum growth stages upto 120 DAP.

However, in case of K content in plants altogether a different trend was observed. In both main plot and sub plot treatment K content observed at 45 DAP kept on decreasing upto 210 DAP which might be due to transition of crop from active growth stage to maturity causing a fall in nutrient uptake. During the later growth stages, uptake is suppressed as a result of low rate of diffusion process owing to fall in soil temperature during the months of October to December. These findings are corroborated with those of Stranack and Miles [18]. Interaction between methods of fertilizer application and application of RDF in different number of splits was significant in influencing the K content in plant at all the growth stages except at 210 DAP.

Table 6. Effect of different methods of fertilizer application and numbers of splits of N and K on potassium content in plant of sugarcane crop

Treatments	Potassium Content in Plant (%)			
Methods of fertilizer application	**45 DAP**	**90 DAP**	**150 DAP**	**210 DAP**
B1-Broadcasting	2.498	2.266	1.980	0.764
B2-Band placement	2.648	2.342	2.034	0.773
SEm±	0.003	0.002	0.001	0.003
CD (P=0.05)	0.019	0.010	0.007	NS
Number of splits of N and K				
T1 -5 splits	2.649	2.325	2.140	0.776
T2 -6 splits	2.512	2.326	2.042	0.770
T3 -7 splits	2.359	2.306	1.812	0.767
T4-3 splits	2.770	2.261	2.035	0.763
SEm±	0.003	0.002	0.003	0.004
CD (P=0.05)	0.010	0.007	0.009	NS
CD of Factor (B) at same level of A	0.020	0.013	0.014	NS
CD of Factor (A) at same level of B	0.022	0.013	0.013	NS

***SEm±** represents standard error, **CD (P=0.05)** represents critical difference between treatments at 5% level of significance, **NS** represents that treatments are not significant at at 5% level of significance, **DAP** represents number of days after planting*

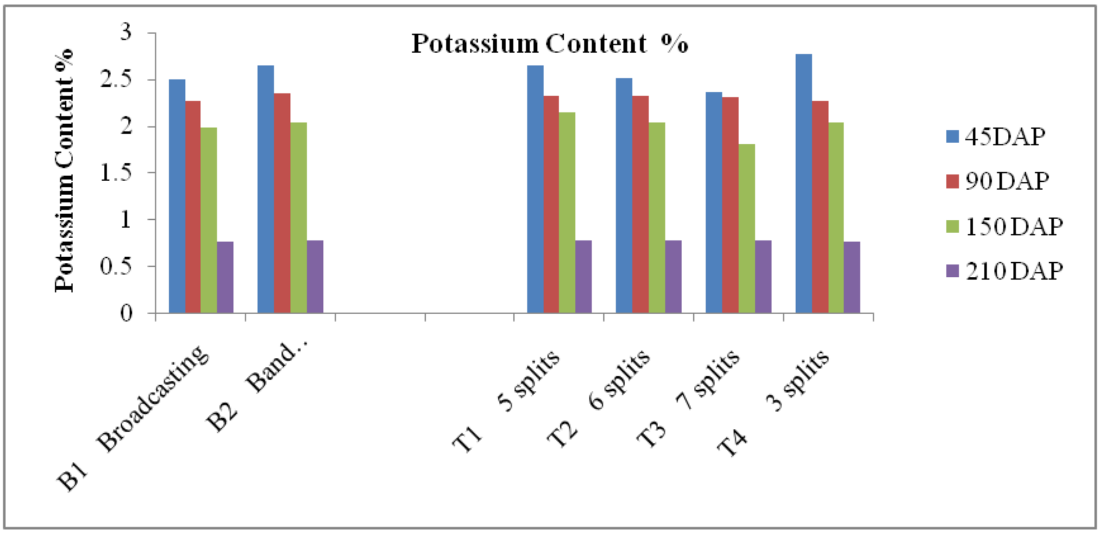

Fig. 4. Effect of different methods of fertilizer application and numbers of splits of N and K on potassium content in plant percentage of sugarcane crop

3.2 Dry matter Accumulation (t ha^{-1})

Dry matter accumulation by plants was heavily influenced under both main plot and sub plot treatments. Careful interpretation of data (Table 7) elucidates the significant effectiveness of B2 over B1 in accumulation of dry matter at 150 DAP (12.407 t ha^{-1}) and at harvest (29.191 t ha^{-1}). This superiority of B2 can be accredited to more absorbance of nutrients from the nearby placement zone which recharges the soil with nutrient influx from time to time and as a result plant is able to assimilated more biomass by utilizing a large pool of available nutrients. The reduction in volatilization losses due to banding maintained optimum concentration of N in soil for enhanced nutrient uptake and consequently increased dry matter yield [25].

Among the sub plot treatments, T1 produced maximum amount of dry matter at 150 DAP (16.547 t ha^{-1}) and (33.703 t ha^{-1}) which was significantly greater than those produced by all the other treatments. The better performance of T1 over others may be due to timely application of nutrients during the most active growth period (after seedling and before maturity) of sugarcane fulfilling its nutritional requirements and enabling it to attain its maximum biomass assimilation potential under prevailing conditions [17] Treatments T2 and T3 were statistically at par with each other at both 150DAP (14.215 and 13.478 t ha^{-1} respectively) and at harvesting (31.382 and 30.632 t ha^{-1} respectively). Interactions between the main and sub plot treatment was not significant in influencing the dry matter accumulation.

3.3 Nutrient Uptake (kg ha^{-1})

Nutrient uptake (kg ha^{-1}) under both main and sub plot treatments was assessed for N, P and K at harvesting and it was perceived that uptake of all the nutrients was heavily influenced by these treatments (Table 8).

3.3.1 N uptake (kg ha^{-1})

N uptake was maximum in B2 (219.60 kg ha^{-1}) which was significantly higher than B1 (189.22 kg ha^{-1}) under main plot treatments. Localized supply of N in the root vicinity may have led to more availability and uptake in band placement [26]. According to Ju et al. [27], reduced levels of ammonia volatilization of urea due to its deep placement in soil under banding had a synergistic effect on N availability to plants while broadcasting led to enormous loss of N through volatilization [4]. Out of all the sub plot treatments, T1(231.03 kg ha^{-1}) registered substantially higher N uptake. The outstanding performance of T1 compared to fellow treatments might be due to targeted and timely delivery of fertilizer N throughout the most critical growth periods which enhanced the N uptake [5].

T2 (209.00kg ha^{-1}) and T3 (199.35kg ha^{-1}) were found to be statistically at par with each other Interaction between sub and main plot treatment was not significant in affecting N uptake.

Table 7. Effect of main and sub plot treatments on dry matter accumulation

	Dry matter accumulation (t ha^{-1})	
Method of fertilizer application	**150 DAP**	**At Harvest**
B1-Broadcasting	12.407	29.191
B2- Band Placement	15.493	33.008
SEm±	0.466	0.324
CD (P=0.05)	3.051	2.122
Number of splits of N and K		
T1-5splits	16.547	33.703
T2-6 splits	14.215	31.382
T3-7splits	13.478	30.632
T4-3splits	11.560	28.680
SEm±	0.476	0.606
CD (P=0.05)	1.483	1.888

SEm± *represents standard error,* ***CD (P=0.05)*** *represents critical difference between treatments at 5% level of significance,* ***NS*** *represents that treatments are not significant at at 5% level of significance,* ***DAP*** *represents number of days after planting*

3.3.2 P uptake (kg ha^{-1})

Nutrient uptake pattern of P exhibited similarity with that of N uptake. B2 (23.74 kg ha^{-1}) and T1 (31.35 kg ha^{-1}) emerged out to be best treatments under main and sub plot treatments respectively with significantly higher P uptake than other treatments. This might be due to synergistic effect of N and K fertilization along with P. Plant roots proliferate in response to abundance of mineral nutrients in its vicinity leading to enhanced P uptake this zone [28]. Ma et al. [5] also observed 86-150% more plant density in banding treatments as compared to broadcasting. Application of RDN and RDK at required active growth period in optimum number of splits improves the P uptake [5].

Treatments T2 (28.41 kg ha^{-1}) and T3 (26.18 kg ha^{-1}) were statistically at par with each other. Interaction between sub and main plot treatment was not significant in affecting dry matter accumulation.

3.3.3 K uptake (kg ha^{-1})

Nutrient uptake pattern of P showed identical trend with that of N uptake. B2 (255.24 kg ha^{-1}) and T1 (261.72 kg ha^{-1}) emerged out to be best treatments under main and sub plot treatments respectively with significantly higher K uptake than other treatments. Lower uptake of K in B1 (223.25 kg ha^{-1}) might be due to stratification of K as suggested by Borges and Mallarino [29] while reduced K fixation in B2 might have increased its availability and thus uptake [28]. Coinciding the K fertilizer splits with the most aggressive growth stages could have led to higher uptake under T1 compared to other treatments where a mismatch of nutrient demand and supply resulted in lower uptake [30]. Treatments T2 (241.60kg ha^{-1}) and T3 (234.95 kg ha^{-1}) were statistically at par with each other. Interaction between sub and main plot treatment was not significant in affecting K uptake.

3.4 Partial Factor Productivity (PNP)

Partial factor productivity serves as a long-term indicator of trends and to ascertain the productivity of a cropping system in comparison to its nutrient input [31].

3.4.1 Partial factor productivity of N (PNP_N)

Among the main plot treatments, PNP_N achieved through B2 (579.23 kg ha^{-1}) was significantly higher than B1 (626.33 kg ha^{-1}) at the time of harvesting. The delivery of N in bands enriched the soil and created nutrient rich patches in the proximity of roots which caused lateral root proliferation and granted more access of added N to plants as compared to broadcasting increasing PNP_N [32] (Chassot et al., 2005).

Among the sub plots treatments, T1 attained significantly higher (634.68 kg ha^{-1}) PNP_N compared to other treatments. The application of N in optimum no. of splits throughout the active growth stages of crop coupled with reduction in volatilization losses led to better utilization of applied fertilizer which increased its efficiency to absorb and assimilate more nutrients which manifested in higher PNP_N [33]. The PNP_N of N ranged from (634.68 kg ha^{-1}) in T1 to (565.82 kg ha^{-1}) in T4. The PNP_N of T2 (1836.16 kg ha^{-1}) and T3 (1795.74 kg ha^{-1}) were statistically similar.

Table 8. N, P and K uptake (kg ha^{-1}) under main and sub plot treatments

	Nutrient uptake (Kg ha^{-1}) at the end of harvesting		
Method of fertilizer application	**N uptake**	**P uptake**	**K uptake**
B1-Broadcasting	189.22	23.74	223.25
B2- Band Placement	219.60	31.04	255.24
SEm±	4.07	0.93	3.23
CD (P=0.05)	26.68	6.11	21.19
Number of splits of N and K			
T1-5 splits	231.03	31.35	261.72
T2-6 splits	209.00	28.41	241.60
T3-7 splits	199.35	26.18	234.95
T4-3 splits	178.27	23.61	218.73
SEm±	5.91	10.92	4.76
CD (P=0.05)	18.42	2.88	14.84

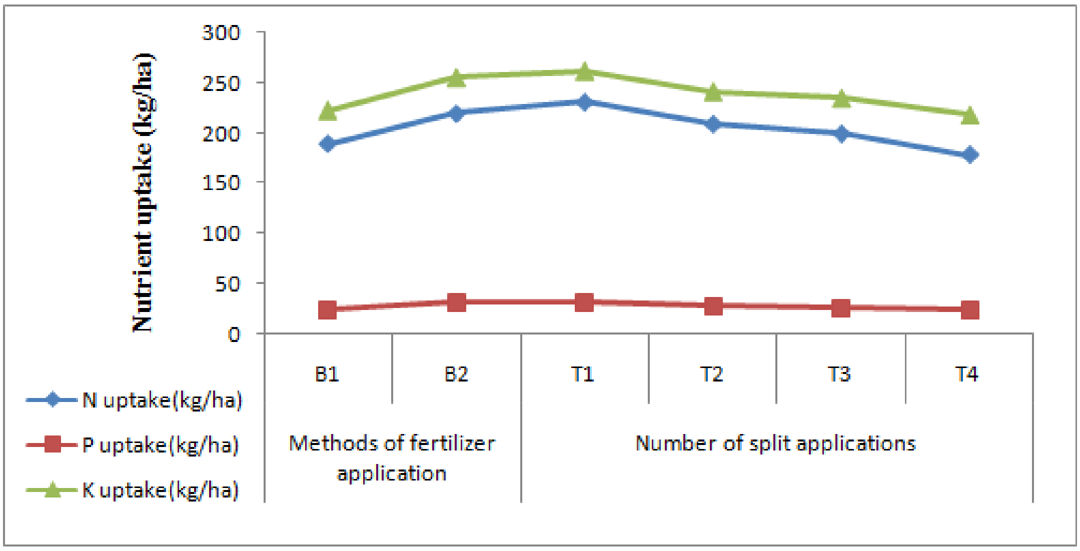

Fig. 5. Effect of different methods of fertilizer application and numbers of splits of N and K on Nutrient uptake

3.4.2 Partial factor productivity of P (PNP_P)

Among the main plot treatments, partial factor productivity attained through B2 (1879.00kg ha^{-1}) was significantly higher than B1 (1737.70kg ha^{-1}) at the time of harvesting. Similar observations were recorded by Ma et al. [5]. The higher PNP_P under B2 than B1 might be attributed to reduced fixation and adsorption of added N by soil particles under banding and improvement in movement of immobile P to plant roots through diffusion [7]. Among the sub plots treatments, T1 attained significantly higher (634.68 kg ha^{-1}) PNP compared to other treatments. Application of N and K The PNP of P ranged from (1904.04kg ha^{-1}) in T1 to (1697.46 kg ha^{-1}) in T4. The application of RDN and RDK by dividing them in optimum no. of splits during the most active growth stages of crop also promoted the continuous supply P due to synergistic effect [5]. PNP_N observed under T2 (1836.16 kg ha^{-1}) was statistically at par with T3 (1795.74 kg ha^{-1}).

3.4.3 Partial factor productivity of K (PNP_K)

Among the main plot treatments, partial factor productivity attained through B2 (1879.00kg ha^{-1}) was significantly higher than B1 (1737.70kg ha^{-1}) at the time of harvesting. Application through broadcasting could have led to stratification of K in soil which decreased its PNP (Borges and Mallarino, 2001). Maintaining a zone of high concentration of K near root zone in row crops by banding where applied K is in contact with less soil volume improves PNP_K [34].

Table 9. Effect of main and sub plot treatments on partial factor productivity (PFP)

Method of fertilizer application	Partial factor productivity (PFP) (kg kg^{-1}) at the end of harvesting		
	(PNP_N)	**(PNP_P)**	**(PNP_K)**
B1-Broadcasting	579.23	1737.70	1737.70
B2- Band Placement	626.33	1879.00	1879.00
SEm±	4.59	13.77	13.77
CD (P=0.05)	30.11	90.25	90.25
Number of splits of N and K			
T1-5splits	634.68	1904.04	1904.04
T2-6 splits	612.05	1836.16	1836.16
T3-7splits	598.58	1795.74	1795.74
T4-3splits	565.82	1697.46	1697.46
SEm±	4.33	12.99	12.99
CD (P=0.05)	13.49	44.48	44.48

Among the sub plots treatments, T1 attained significantly higher (634.68 kg ha^{-1}) PNP compared to other treatments. Superiority of T1 over other sub plot treatments can be ascribed to regular and optimum supply nutrients during the most active growth stages [30] of sugarcane which falls within a range of 45 to 135 DAP [35] The (PNP_K) ranged from (1904.04kg ha^{-1}) in T1 to (1697.46 kg ha^{-1}) in T4 and. The PNP_K of T2 (1836.16 kg ha^{-1}) and T3 (1795.74 kg ha^{-1}) were statistically similar.

4. CONCLUSION

From the above results and discussion it can be concluded that applying the fertilizers at specified zones during the active growth period of the sugarcane positively impacted the nitrogen and potassium uptake and dry matter accumulation of the plant. Nutrient content in plant tissue reduces as the crop life cycle shifts from active growth period towards maturity. Banding of fertilizer gave better results for almost all the physiological parameters. It is also suggested that fertilizer doses should be kept low for application in basal and early growth stages. Too many or less splits of fertilizer N and K are not instrumental in increasing the partial factor productivity of the crop and thus number of splits should be decided carefully. B1 X T1 emerged out as best combination for targeted and timely fertilization.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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