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Macronutrient Status and Soil Chemical Properties as Influenced by Methods and Schedule of Fertilization in Karnal Alfisols under Sugarcane (*Saccharum officinarum* L.) Cultivation

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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

An experiment was conducted at the Regional Research Station , Uchani (Karnal) of CCS Haryana Agricultural University, Hisar, India during 2020-21 to assess the effect of the method and schedule of fertilizer application on macronutrient status *viz.* available Nitrogen (N), Phosphorus (P) and potassium(K) and soil chemical properties *i.e*. soil pH, electrical conductivity (EC) and soil organic carbon (SOC) at different intervals of the crop growth period. The experiment was laid out in split plot design with two methods of fertilizer application (B1-broadcasting and B2- band placement) as main plot treatments and four sub plot treatments consisting of the application of recommended doses of N and K fertilizer (RDF) in the different number of splits at different number of days after planting (DAP) *i.e.* T1(five splits), T2(six splits), T3(seven splits) and T4(three splits). Results elucidated that the availability of all the macronutrients was significantly affected by both sub and main-plot treatments at different stages of crop growth period. Available N content was found to be significantly higher in B2 compared to B1 at all the time intervals from 75 DAP (131.86 Kg ha^{-1}) to harvest (145.91 Kg ha^{-1}) reaching the maximum at 180 DAP (142.80 Kg ha^{-1}). Among the sub plot treatments, T4 and T1 respectively reported significantly higher values of available N from 75 DAP (134.51 Kg ha^{-1}) to 90 DAP (147.08 Kg ha^{-1}) and 90 DAP(153.10 Kg ha^{-1}) to 150 DAP(162.11 Kg ha^{-1}). At 180 DAP and at the time of harvesting, significantly higher values of available N (159.21 Kg ha^{-1} and 157.01Kg ha^{-1}) were observed in treatments receiving fertilizer in T2 and T3 splits respectively. Available K content was significantly higher in B1 compared to B2 at all the time intervals except at 0, 150, 180 DAP and at harvest where the difference was not significant. Higher values of available K were reported under T4 upto 75 DAP (225.30 Kg ha^{-1}) and thereafter, T1 exhibited significantly higher available K values upto 150 DAP (222.06 Kg ha^{-1}). At 180 DAP and at the time of harvesting, significantly higher values of available K (225.10 Kg ha^{-1} 227.48 Kg ha^{-1}) were observed in T2 and T3 respectively. Available P content was significantly higher (24.63 Kg ha^{-1}) in B1 compared to B2 at the time of harvesting. Soil pH, EC and SOC did not registered any significant change under any treatment. Overall treatment B2 and T1 emerged out be best among main and sub-plot treatments respectively. Availing the suitable methods and schedule of fertilization improved the status of micronutrients in soil during the active growth stage of crop.

Keywords: Split application; band placement; broadcasting; nitrogen; potassium.

1. INTRODUCTION

Chemical fertilizers are the most crucial inputs to satisfy the nutrient requirement of crops for obtaining high yield in modern crop production. Modern agriculture is extensively dependent upon fertilizers and they are regarded as vital tools for global food safety [1]. The price of fertilizers which are already expensive keep on increasing due to a gap in demand and supply of fertilizer minerals [2] which directly adds up a significant portion to the cost of cultivation. Therefore, a reduction in the cost of cultivation demands the adoption of effective nutrient management techniques. The employment of fertilizers also influences soil's physicochemical and biological properties [3]. The imbalanced use or inefficient management of chemical fertilizers may reduce soil fertility and can cause soil, water and air pollution along with a reduction in important nutrients of soil and minerals when applied without following standard agronomic practices [4]. To avoid these harmful effects, innovative approaches like the 4R nutrient stewardship approach may serve as a guide for the effective nutrient management. The concept of this approach emphasizes the application of the right source of the nutrients at right rate and time and in the right place [5].

The adoption of the proper method of fertilizer application is essential to minimize the loss of nutrients from the soil with simultaneous rise in its availability and it is equally important at the time of application to achieve higher nutrient use efficiency [6]. Method and time of fertilizer application are important components of an effective nutrient management program. Band placement of nitrogenous fertilizer in the subsurface portion of soil prevents its loss through volatilization. Nitrogen is mobile in soil whereas fixation of P and K occurs in the soil suggesting their placement in bands along the crop rows to make them easily available [7]. Band Placement of potassium is recommended in soils having low level of K or with a high K fixing capacity. In upland areas, several studies indicates that the band placement is overwhelmingly superior to broadcasting as long as efficiency is concerned. Proper placement carries the same gravity in P management under wide row spacing as split application carries for N management. P and K applied through fertilizers tend to fix into the soil, therefore practicing band placement aids in reducing fixation and increases their availability [8,9] Band placement of fertilizer near the root zone aids the roots to easily draw nutrients from the soil as it minimizes the distance between root hairs and nutrients placed in soil. Less contact with the soil lessens the opportunity for nutrient loss due to leaching or fixation reactions. Placement decisions depend on the crop and soil conditions, which interact to influence nutrient uptake and availability [10].

Nitrogen fertilizers are expensive and crops are able to utilize only 50% of the nitrogen provided by them. Suitable fertilizers application strategies which make some amount of added fertilizer, available for early growth and left-over part in later growth stages of the crop should be encouraged [11]. Precision nutrient application by splitting the recommended dose of fertilizer may be functional in improving the sustainability of available N by preventing leaching or volatilization losses of fertilizers [12]. Split application refers to the application of total dose of fertilizer in fragments for synchronization of supply of applied nutrient with the needs of plants as well as the ability of plants to use these nutrients. If the full dose of nutrients especially N is applied in a single dose as pre planting or at planting, the window for the potential loss of these nutrients through various pathways is always open. By postponing a portion of N treatment until the crop is better able to utilize the nutrient, plants take up the nitrogen more quickly and efficiently. Fixation of K in the soil can be minimized by its split application which facilitates enhanced access and use efficiency by plant [13]. This study aims to determine efficient methods and schedule of fertilizer placement to establish a proper synchronization of nutrient demand of sugarcane crop with adequate supply of macronutrients for higher productivity.

2. MATERIALS AND METHODOLOGY

2.1 Experimental Site and Climate

Field experiment was conducted at the Regional Research Station, CCS Haryana Agricultural University, Karnal located at the 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 (MSL). It is roughly equidistant and almost midway between New Delhi and Chandigarh.

The climate is sub-tropical with mean maximum temperature ranging between 34-39°C in summer and mean minimum temperature ranging between 6-7°C in winter. Most of the rainfall is received during the months of July to September and few showers from December to late spring.

2.2 Soil of Experimental Plot

The field at Regional Research Station, CCSHAU, Karnal selected for conducting the experiment was uniform in fertility gradient. The initial soil fertility status of the experimental field was determined prior to planting of crop, for which four representative soil samples were collected randomly from the entire field at a depth of 0-30 cm before implementing the final layout of the experiment. The analysis was carried out by strictly following established protocols and standard procedures. From the interpretation of results obtained after soil analysis, it was interpreted that soil exhibited clay loam texture, alkaline in reaction, medium in organic carbon content, low in available N and medium in P and K content.

2.3 Treatments and Layout of the Experiment

The experiment was arranged in Split Plot Design with three replications. The experiment was designed with two main plots (Mode of fertilizer application i.e. Broadcasting and Band Placement) and four sub-plots (No. of split application i.e. 5, 6, 7 and 3 splits). The details of the experiment are as follows:

2.3.1 Main plot treatments (two): Methods of fertilizer application

B1: Broadcasting
B2: Band placement

2.4 Soil Analysis

Soil samples were collected at 0, 15, 30, 45, 75, 90, 120, 150, 180 days after planting (DAP) and at harvesting. These collected soil samples were analyzed for available N and K during different crop growth stages. For the determination of pH, EC, Soil organic carbon (SOC) and available P soil samples were analyzed at the time of sowing and at harvesting.

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 [14]
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.	SOC (%)	0.48	Wet digestion method [15]
5.	Available N (kg ha^{-1})	111.55	Alkaline Potassium Permanganate Method [16]
6.	Available P (kg ha^{-1})	18.88	Sodium Bicarbonate Extractable P method [17]
7.	Available K (kg ha^{-1})	201.40	Ammonium Acetate Extractable K method [18]

pH-power of hydrogen, EC-electrical conductivity, SOC-soil organic carbon, N-nitrogen, P-phosphorus, K-potassium

Chart 1. Sub Plot treatments (four): Number of splits of recommended dose of fertilizer:

T1	Recommended dose of N and K in five splits (Basal 10% and remaining dose at 45, 75, 90 and 120 DAP)
T2	Recommended dose of N and K in six splits (Basal 10% and remaining dose at 45, 75, 90, 120 and 150 DAP)
T3	Recommended dose of N and K 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)

2.5 Statistical Analysis

Statistical analysis was carried out by employing OPSTAT software tool developed by deptartment 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. [19].

3. RESULTS AND DISCUSSION

3.1 Effects of Different Treatments on Soil Macronutrient Status

3.1.1 Available nitrogen

The data relating to the effect of different main and sub plot treatments on available N at different time intervals presented in Table 2 indicates an overall appraisal in available N status at harvesting under all the treatments compared to the initial.

This augmentation observed in N status might be directly linked to the addition of N to soil through the applied fertilizer in balanced manner as also reported by Dubey et al. [20]. Further, examination of data elucidated that upto 45 DAP no significant increase was noticed in the available N content of soil under both sub or main plot treatments as at the time of sowing similar amount of basel dose was applied in all the treatments except T4 (3 splits) where half of the total N dose was applied at the time of sowing. This, however did not culminate in the build-up of N in T4 during the initial stage which might be due to volatilization losses owing to high temperature and absence of shade due to negligible crop cover at the time of sowing. As reported by Bouwman and Boumans [21], potential NH_3 emissions are greatest for urea among synthetic fertilizers, for which cumulative losses may account as high as 60% of applied N [22,23]. After 45 DAP available N content in soil was remarkably influenced by both main and sub plot treatments.

Among the methods of fertilizer application, significantly higher values of available N were recorded in band placement (B2) compared to broadcast (B1) at all the stages after 45 DAP upto harvest. Surface broadcasting of urea may have contributed to higher volatilization and leaching losses while emissions were reduced by placement in subsurface band placement which lead to the trapping of majority of the ammonical N in the soil. Similar findings were elucidated by Prasertsak et al. [24] and de Castro et al. [25]. Moreover broadcasting has an additional disadvantage of N leaching in deeper layers as reported by Chen et al. [26]. The amount of available N gradually increased in both main and sub plot treatments with the application of each split dose which is consistent with findings of Everaarts and Willigen [27].

Among the number of splits, T4 reported significantly higher values of available N from 75 DAP (134.51 kg ha^{-1}) upto 90 DAP (147.08 kg ha^{-1}) and thereafter it was significantly highest in T1 from 120 DAP (142.63 kg ha^{-1}) to 150 DAP (162.11 kg ha^{-1}) which corresponds to the higher amount of fertilizer N applied in these time intervals through the respective split applications under these treatments. These findings are in congruence with those of [28]. However, from 180 DAP (153.35 kg ha^{-1}) till the harvest (145.93 kg ha^{-1}) decreasing trend was observed in available N in the soil under T1due to no further fertilizer application. T4 also registered a consistent fall in the available N content in soil after 90 DAP (147.08 kg ha^{-1}) upto harvesting (118.31 kg ha^{-1}). In T2 from 75 DAP (125.63 kg ha^{-1}) upto180 DAP (159.21 kg ha^{-1}) increase in available N was observed which decreased at harvest (151.78 kg ha^{-1}). However, in T3 available N content in soil kept on increasing significantly from 75 DAP (124.46 kg ha^{-1}) upto harvesting (157.01 kg ha^{-1}) both of which can be attributed to retention of unutilized urea applied through later splits in the soil as sugarcane crop utilizes most of the applied nutrient upto 150 DAP [29]. Interaction between different treatments (main and sub-plot treatments) and time intervals was significant in influencing available N status in soil.

3.1.2 Soil available K

The data presented in Table 3 revealed a fair appreciation of available K status at the time of harvesting compared to initial status under both main and sub plot treatments.

The rise in available K might be attributed to the frequent addition of K through a number of split applications of RDF throughout the crop period at different time intervals which enriched the soil in available K as argued by Pandey et al. [11] and Tariq et al. [30]. Moreover, Singh et al. [3] opined that K drawn by roots from the lower layer is deposited in the surface layer which finally leads to enhancement in available K status in alfisols which might be the case here as sugarcane is a deep-rooted crop capable of drawing sizeable amount of K from the subsurface layer.

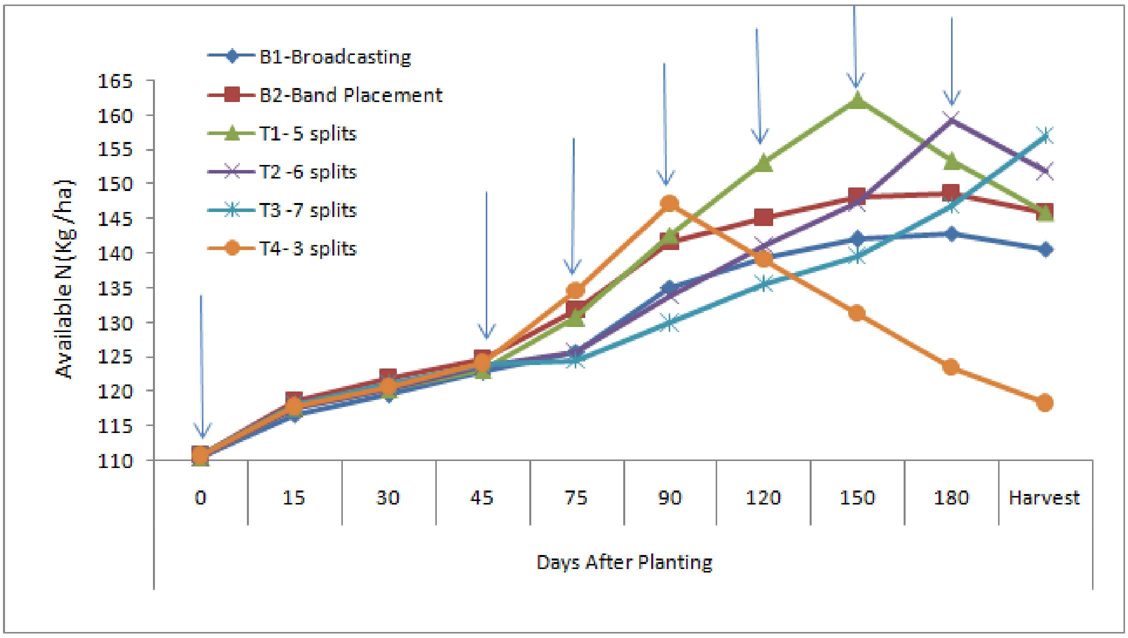

Fig. 1. Effect of different methods of fertilizer application and numbers of splits of N and K on available nitrogen of soil (arrows represent the timing of fertilizer application)

Table 2. Effect of different methods of fertilizer application and numbers of splits of N and K on available nitrogen of soil

	Available N (kg ha^{-1})									
Method of fertilizer application	**0 DAP**	**15 DAP**	**30 DAP**	**45 DAP**	**75 DAP**	**90 DAP**	**120 DAP**	**150 DAP**	**180 DAP**	**Harvest**
B1-Broadcasting	110.44	116.70	119.54	122.80	125.73	135.11	139.21	142.01	142.80	140.60
B2-Band Placement	110.80	118.72	121.79	124.62	131.86	141.55	145.17	148.10	148.66	145.91
SEm±	1.03	0.71	0.69	0.37	0.43	0.50	0.43	0.78	0.68	0.72
CD (P=0.05)	NS	NS	NS	NS	2.82	3.301	2.85	5.14	4.49	4.72
Number of splits of N and K										
T1-5 splits	110.45	117.58	120.30	123.11	130.66	142.63	153.10	162.11	153.35	145.93
T2 -6 splits	110.48	117.50	120.50	123.61	125.63	133.76	141.02	147.26	159.21	151.78
T3 -7 splits	110.84	118.01	121.13	124.00	124.46	129.86	135.60	139.55	146.96	157.01
T4-3 splits	110.72	117.76	120.73	124.13	134.51	147.08	139.06	131.31	123.40	118.31
SEm±	0.66	0.81	0.83	0.64	0.64	0.69	0.67	1.01	0.87	0.87
CD (P=0.05)	NS	NS	NS	NS	2.02	2.15	2.08	3.15	2.71	2.72

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

Table 3. Effect of different methods of fertilizer application and numbers of splits of N and K on available potassium of soil

	Available K_2O (kg ha^{-1})									
Methods of fertilizer application	**0 DAP**	**15 DAP**	**30 DAP**	**45 DAP**	**75 DAP**	**90 DAP**	**120 DAP**	**150 DAP**	**180 DAP**	**Harvest**
B1-Broadcasting	201.40	216.08	218.33	221.19	222.02	216.97	213.37	217.84	220.43	220.50
B2-Band Placement	201.25	213.69	215.82	218.69	217.11	212.59	206.71	209.81	213.37	214.6
SEm±	0.53	0.09	0.39	0.04	0.47	0.60	1.00	1.55	2.44	1.16
CD (P=0.05)	NS	0.63	2.59	0.28	3.12	3.96	6.57	NS	NS	NS
Number of splits of N and K										
T1 -5 splits	201.28	206.66	208.61	210.70	220.83	218.33	215.25	222.06	220.41	218.75
T2 -6 splits	201.50	206.01	207.31	209.40	217.78	215.28	211.16	217.88	225.10	223.76
T3 -7 splits	201.55	205.10	207.11	210.40	214.40	211.73	208.23	212.78	220.50	227.48
T4-3 splits	200.00	241.76	245.26	249.26	225.30	213.78	205.53	202.59	201.59	200.21
SEm±	1.00	0.75	0.82	0.76	0.92	0.90	0.72	0.67	1.06	0.64
CD (P=0.05)	NS	2.33	2.56	2.37	2.88	2.82	2.25	2.57	3.28	1.99

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

Among different methods of fertilizer application, significantly higher values of available K were recorded in band placement (B2) compared to broadcast (B1) at all the time intervals upto harvest. However, the difference noted was non significant at 0, 150, 180 DAP and at harvest. This might be accredited to the slow downward movement of K arising from accelerated adsorption of K on soil colloidal complex as a result of wider soil fertilizer [31] contact in broadcasting. Moreover, K uptake might be higher in band placement leading to more exhaustion of nutrient applied in the vicinity of plant roots. Similar observations were annotated by Kraska et al. [32].

At 0 DAP, available K content observed in all the sub-plot treatments was at par with each other. Among different number of applied splits, treatment receiving fertilizer in three splits (T4) reported the highest values of available K upto 75 DAP (225.30 kg ha^{-1}) as it received the whole amount of RDF to be applied before 90 DAP which was higher than other treatments. Thereafter treatment T1 exhibited significantly higher available K values upto 150 DAP (222.06 kg ha^{-1}) while at 180 DAP and at the time of harvesting, significantly higher values of available K were observed in treatments T2 (225.10 kg ha^{-1}) and T3 (227.48 kg ha^{-1}) respectively which might be due to higher application of fertilizer K compared to other treatments during these time intervals through the scheduled splits in respective treatments. These findings are in compliance with those of and Pandey et al. [11] who reported an increase in soil available K when applied in splits. Treatment T4 reported a fall in available K content in soil 45 DAP after initial rise at 15 DAP upto harvesting while in T1 and T2 it decreased after 150 and 180 DAP respectively upto harvesting. This drop in soil might be attributed to non-application fertilizers at these intervals as per findings of Nand et al. [31]. Interaction between different treatments (main and sub-plot treatments) and time intervals was significant in influencing available K status in soil.

3.1.3 Available phosphorus

It is clear from the perusal of data in Table 4 that at harvesting, different splits of N and K applied had non- significant effect on P_2O_5 content of the soil. When effect of the broadcasting and band placement were compared it was seen that soil P_2O_5 content recorded was significantly higher in broadcasting (B1) than the band placement (B2) which might be due to fixation and retention of unutilized P as a result of higher soil to fertilizer contact [33]. An increment in available P values was noticed in all the treatments at harvesting which might be associated with the application of mineral fertilizers at the time of sowing [32].

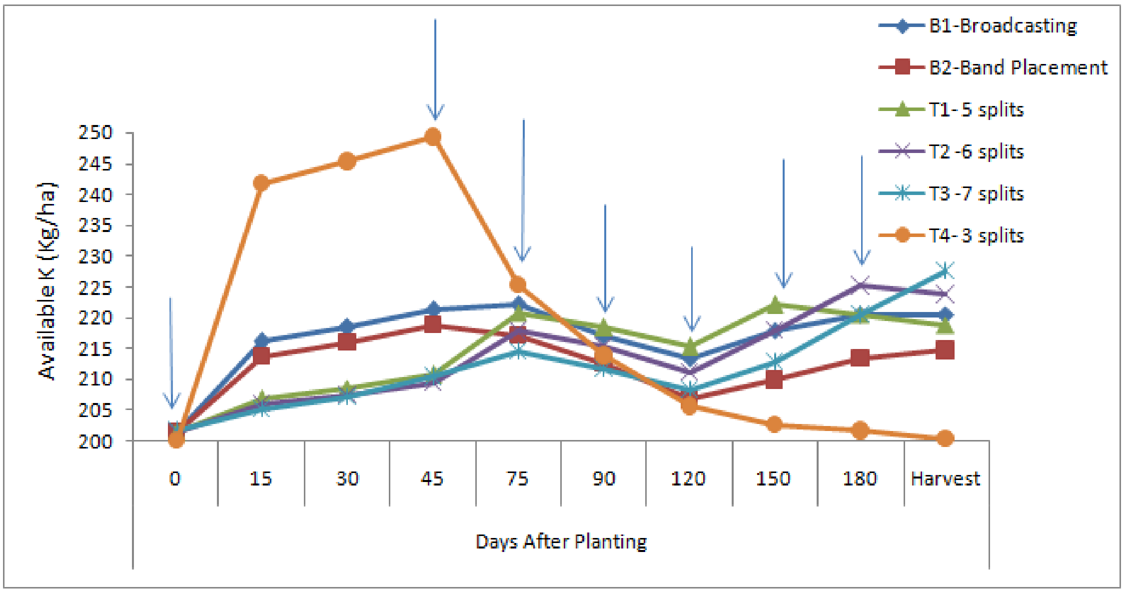

Fig. 2. Effect of different methods of fertilizer application and numbers of splits of N and K on available potassium of soil (arrows represent timing of fertilizer application)

Table 4. Effect of different methods of fertilizer application and numbers of splits of N and K on available phosphorus and soil organic carbon of soil

Method of fertilizer application	P_2O_5 At sowing (kg ha^{-1})	P_2O_5 At harvest (kg ha^{-1})	SOC At sowing (%)	SOC At harvest (%)
B1 -Broadcasting	18.62	24.63	0.48	0.50
B2 - Band placement	19.62	21.68	0.48	0.51
SEm±	0.10	0.38	0.03	0.01
CD (P=0.05)	NS	3.057	NS	NS
Number of splits of N and K				
T1 - 5 splits	18.71	22.36	0.47	0.48
T2 - 6 splits	18.88	22.96	0.47	0.49
T3 - 7 splits	19.36	23.28	0.48	0.50
T4 - 3 splits	18.80	24.01	0.48	0.48
SEm±	0.40	0.58	0.06	0.02
CD (P=0.05)	NS	NS	NS	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

Table 5. Effect of different methods of fertilizer application and numbers of splits of N and K on pH and EC of soil

Method of fertilizer application	Initial pH	pH At Harvest	Initial EC (dSm^{-1})	EC At Harvest (dSm^{-1})
B1-Broadcasting	8.23	8.13	0.25	0.16
B2- Band placement	8.20	8.16	0.26	0.16
SEm±	0.00	0.01	0.01	0.03
CD (P=0.05)	NS	NS	NS	NS
Number of splits of N and K				
T1- 5 splits	8.15	8.12	0.26	0.16
T2 - 6 splits	8.25	8.15	0.26	0.16
T3 - 7 splits	8.21	8.15	0.25	0.17
T4- 3 splits	8.25	8.17	0.25	0.17
SEm±	0.02	0.06	0.02	0.06
CD (P=0.05)	NS	NS	NS	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

3.2 Effects of Different Treatments on Soil Chemical Properties

3.2.1 Soil organic carbon

It is very much clear from the data presented in Table no. 4 that no significant changes were recorded in the organic carbon content of initial soil samples and those collected at harvest. Neither method of fertilizer application nor the number of applied splits had any significant influence on the organic content of the soil. However a slight increase in numerical value was observed at harvesting with respect to organic carbon content at harvesting which might be due to the suppressive effect of N fertilization on microbial mineralization of soil organic matter. Addition of ammonium molecules through urea application in splits throughout the life cycle of crop reduced oxidative enzyme activity [34] by inhibiting the synthesis of ligninolytic enzymes released by ligninolytic fungi [35].

3.2.2 Soil pH and EC (dS m^{-1})

Changes undergone in pH and EC of the soil during the crop growth are presented in Table 5 which shows no remarkable variations in pH and EC of the soil either under the main plot treatments (methods of fertilizer application) or sub plot treatments (application of RDF in different splits). This might be due to the strong buffering capacity of the clay soils of the experimental site. However a slight decrease in soil pH values was observed in all the treatments at harvesting relative to initial values which might be the release of root exudates and accumulation of other decomposition products which are acidic in nature. Moreover application of urea also had an acidic residual effect in the soil causing a fall in pH values [29,32].

4. CONCLUSIONS

Based on the observations recorded and intensive interpretation of the results it can be concluded that band application of N fertilizer is an effective strategy for enhancing the availability of N in the soil while banding of K is effective in enhancing the absorption of nutrient by plant roots. However increasing the number of splits beyond five is not helpful to crop as most of the absorption of required nutrients occur during the vegetative stage and thus fertilizer applied at the latter stages remains unutilized and is lost through various mechanisms. Providing an excessive amount of fertilizer at sowing is also not very productive as plant roots are not developed in the early stages and thus applied N can be lost through volatilization and leaching. Thus it can be said that increasing and decreasing the number of splits before or after the peak nutrient requirement stages of crop are not fruitful and should be adjusted accordingly. In the case of sugarcane dividing the RDF into five splits emerged to be best treatment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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