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Phosphorus Fertilizers under Subsurface Drip Fertigation System for Improving Soil Health, Yield and Quality of Sugarcane (*Saccharum officinarum L.*)

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A B S T R A C T

The present investigation was taken up with an aim to optimize the phosphorus fertigation requirement and to determine correct fertigation schedule of phosphorus source through fertigation so as to maximize cane yield and juice quality in sugarcane crop. The phosphate source of fertilizers viz., Mono ammonium phosphate and 19-19-19 and phosphoric acid under sub surface drip irrigation were standardized at seven levels in randomized block design. The plant crop of sugarcane crop cv CoC (SC) 24 was planted on 23.7.2013 and subsequently ratooned on 12.9.2014 The fertigation was given at fortnight intervals up to 210 days after planting. The tiller and millable cane population was maximum with 217670/ha and 89440/ha in plant crop and 210750 /ha and 89950/ha in ratoon crop with 125 % recommended NPK (300:100:200 kg /ha.) through urea, 19-19-19 and KCl through subsurface drip systems. Application of 125 % recommended NPK as urea, 19-19-19 and KCl (T_6) were significantly superior in increasing the cane yield to 175.48 t/ha and on par with T_5(164.87 t/ha),T_4 (164.44 t/ha) and T_7 (162.46t/ha). In ratoon crop, application of 125 % recommended NPK as urea, 19-19-19 and KCl (T_6) were significantly superior in increasing the cane yield of 180.44t/ha and on par with $T_{4.}$The treatments did not affect the commercial cane sugar significantly in both plant and ratoon crop. The sugar yield followed the same trend as cane yield. The available nitrogen content was found to be maximum at 20 cm depth of soil both plant and ratoon crop. The available phosphorus content was accumulated at 40 cm depth of soil and available potassium content was observed to be higher at 20 cm depth of soil and decreased with increasing depth. Application of 125 % recommended NPK as urea, 19-19-19 and KCl (T_6) were significantly superior in increasing nitrogen, phosphorus and potassium content and uptake of 259.87, 103.19, 415.15 kg/ha respectively. The benefit cost ratio was observed to be maximum in the treatment receiving 100 % recommended NPK as urea, 19-19-19 and KCl (T_4) both in plant and ratoon crops. So application of 100 % recommended NPK as urea and KCl along with 19-19-19 phosphate sources of fertilizers apply as fortnightly intervals upto 210 days after planting under sub surface drip fertigation improved the yield, economics and soil nutrient status.

Keywords

Fertigation, Drip Irrigation, Water Soluble Fertilisers, Uptake, Soil Nutrient Dynamics

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Introduction

Sugarcane, one of the most important commercial crops is being grown in an area of around 3.0 lakhs hectares in Tamil Nadu with a productivity of 102 Mt ha^{-1}. Sugarcane being a giant crop producing huge quantity of biomass generally demands higher amounts of nutrient elements. A large number of research experiments have clearly demonstrated that for producing higher cane and sugar yields on a sustainable basis, application of adequate amounts of fertilizer nutrients viz., nitrogen, phosphorous and potassium are essential. The recent trend on labour availability, particularly for sugarcane cane harvesting shows the urgent need for developing suitable management operations with mechanization. Under the present water scarce conditions, efficient use of irrigation water becomes an important means to increase the cane productivity per unit quantity of applied irrigation water. Those problems can very well be addressed with the introduction of sub surface drip irrigation which not only helps to get higher cane yield but also favours the introduction of mechanization in cane cultivation starting from planting to harvesting. Phosphorus is a key nutrient required for higher and sustained productivity of sugarcane and sugar. Phosphorus promotes tillering, root and shoot development, it also requires for various metabolic activities including photosynthesis, sucrose synthesis and accumulation. Preplant conventional soil application of P has the advantage of providing the initial high P concentration in the soil solution (Papadopoulus, 2000) however, concentration declines during the growing season due to sorption and precipitation reaction (Mohammad and Rawajfih 1997). Therefore, drip-irrigated crops, which are characterized by restricted root volumes, may suffer from P deficiency during and toward the end of the growing season(Anitta fanish *et al.*, 2011).Traditional P fertilizer sources, i.e., ordinary super phosphate (8% water-soluble P) and triple super phosphate (12% water-soluble P) are considered unsuited for use in irrigation systems because of the difficulty of dissolving them, and the fact that they contain some insoluble P and considerable solid residues and is more efficient in terms of uptake, the amount of P taken up by the crop in any one season rarely exceeds 20% due to limited P mobility in the soil

A continuous P supply through fertigation on the other hand, may enhance P uptake later in the season and fertigation maycreate a more favorable soil moisture condition that improves P mobility and availability. In addition, fertigation minimizes leaching ofwater and nutrients from the rhizosphere, thus minimizes groundwater contamination and improves fertilizer and water use efficiency, considered fertigation as an efficient method for providing and supplying available forms of immobile elements such as P, at a desirable level in the root zone. The aim of the present study was to investigate the effect of phosphorus along with nitrogen and potassium combined application on sugarcane in subsurface drip irrigation, and provide a reference to improve the cane and sugar yield, quality and finally to improve the income.

In this context, this study aimed to evaluate sugarcane growth and its agricultural and industrial yields, influenced by P sources, doses and forms of application through subsurface drip irrigation.

Materials and Methods

A field study was conducted in sugarcane plant crop (2013 to 2014) and ratoon crop (2014-2015) at the experimental farm of the Sugarcane Research Station, Cuddalore, Tamil Nadu, India. Mean annual rainfall is approximately 1200 mm and nearly 80% of the total rainfall is received through North-East Monsoon. The soil is characterized as a sandy clay loam, with organic C (0.22%) and low available N (152kg/ha), medium P availability (10.10 kg/ha) and high in available K (333 kg/ha). Soil EC was 0.12 dS/m and its pH was 7.35. Seven treatments were imposed in Randomised block design with four replications in sugarcane cv CoC (SC) 24. Sub surface drip irrigation systems were laid out as per the specification. Urea, muriate of potash and phosphate source of fertilizers viz., Mono Ammonium Phosphate (MAP), 19-19-19 water soluble fertilizers were used for fertigation at fortnight intervals through fertigation up to 210 days in splits. Phosphoric acid was applied as eight equal doses upto three months for T_7 treatment only. The treatment schedule is as follows. One plant and one ratoon crops were grown with same set of treatments.

Growth, Yield and Quality of Sugarcane

The germination percentage was taken on 30 DAP, tiller and millable cane population were taken on 3 rd and 7 th month after planting as per the procedure. At the harvest, six rows exclusively left for yield was harvested. The juice quality was assessed in terms of polarization, brix and purity. Polarization (refers to the sucrose content) was determined as described by Blackburn (1984). The prevailing market price of inputs and outputs were taken into account for economic analysis of different treatments.

Plant Nutrient Content and its Uptake

From eight randomly harvested canes, sub samples for dry leaves, green tops and stem were collected, dried at 80^{o}C in an electric oven and powdered in a powdering machine. Powdered samples were digested with H_2SO_4 and H_2O_2 till the solution was colourless and made up to the known volume. Nitrogen in plant part was estimated colorimetrically using Nessler's reagent for colour development (Jackson, 1967). Phosphorus was determined colorimetrically by vanadomolybdophosphoric yellow colour method (Jackson, 1967). Potassium was determined using flame photometer (Jackson, 1967). Nitrogen, phosphorus and potassium uptake in dry plant parts was computed by multiplying N,P,K per cent with biomass production of plant parts. Values were subjected to statistical analysis and means were separated at the 5 % probability level.

Soil Nutrient Dynamics

Soil samples were collected from 20, 40 and 60 cm depth of soil layers and analysed for its available nutrient content. The available soil nitrogen (Subbiah and Asija,1956), phosphorus (Olsen *et al.,* 1954) and potassium (Standford and English, 1949) were analyzed.

Results and Discussion

Effect of fertigation with phosphorus on growth characters

Germination

The germination was more than 96 % and 89.0 % in plant and ratoon crop respectively. There was no significant difference in germination with respect to fertigation.

Tiller Population

In plant crop, the tiller population was maximum with 217670 tillers/ ha with 125 % recommended NPK through urea, 19-19-19 and KCl under subsurface drip systems followed by T_7,T_3,T_4 and T_5 and on par with each other. The tiller population were increasing in the order of 28.6, 28.58,26.79,26.19 and 25.40 % in T_6,T_7,T_3, T_4 and T_5 respectively over fertigation with 75 % recommended NPK through urea, mono ammonium phosphate and KCl (T_1). In ratoon crop, the tiller population was 210750 / ha at 125 % recommended NPK through urea, 19-19-19 and KCl and on par with T_5, T_7 and T_4. The tiller population was observed to be minimum in 75 % recommended NPK (153700/ha.) through urea, mono ammonium phosphate and KCl (Table.1).

Effect of Fertigation with Phosphorus on Yield Attributes, Yield and Quality of Sugarcane

Millable Cane Population

In plant crop (Table.1), application of 125 % recommended NPK as urea, 19-19-19 and KCl were significantly superior in increasing millable cane population to 89444/ha and 89995/ha plant and ratoon crop respectively. In plant crop, T_6 was on par with T_7,T_4 and T_5.In ratoon crop, T_6 was on par with T_7 and T_4. The shoot population was minimum with T_1 (78220/ha) and T_1 (79360/ha) in plant and ratoon crop respectively.

Commercial Cane Sugar Percentage

The result on CCS is presented in Table.1. The result showed that treatments did not affect the cane sugar significantly in plant and ratoon crops. Better juice quality with 12.33 % CCS was recorded by the application of 125 % recommended NPK as urea, 19-19-19 and KCl. In ratoon crop, application of 100 % NPK through urea, MAP and KCl increasing the CCS to 12.04 % followed by application of urea, phosphoric acid and potassium chloride (T_7)(12.02%), T_5 (11.73 %) and T_6 (11.67 %).

Cane Yield and sugar Yield

Significant variation in cane yield was observed for the different phosphorus treatments evaluated in plant and ratoon crops. In plant crop, application of 125 % recommended NPK as urea, 19-19-19 and KCl (T_6) were significantly superior in increasing the cane yield of 175.48 t/ha and on par with T_5 (164.87t/ha),T_4 (164.44 t/ha) and T_7 (162.46t/ha) which was 4.2%,6.7 % and 8.0 % reduction over T_6. In ratoon crop, application of 125 % recommended NPK as urea, 19-19-19 and KCl (T_6) were significantly superior in increasing the cane yield of 180.44t/ha and on par with T_4 (100 % Rec. NPK (Urea, 19-19-19 and KCl).The lowest yield was recorded by the application of 75 % Rec. NPK through Urea, MAP and KCl (135.75 t/ha and 160.46 t/ha) which was 29 % and 12.45 % reduction over the T_6 treatments in plant and ratoon crops respectively. The treatments T_2 and T_1 were on par with each other in plant crop and in ratoon crop T_3 and T_1 were on par with each other. The higher sugar yield under sub surface drip fertigation with 125 % recommended NPK as urea, 19-19-19 and KCl was mainly due to the availability of higher moisture with better aeration coupled with water soluble nutrients in all the stages of cane growth and water given based on the crop demand and the sugar yield was reported to be 21.63 t/ha and it was 23.76 % increase over T_1 (16.49t/ha) in plant crop. In ratoon crop, 125 % recommended NPK as urea, 19-19-19 and KCl increased the sugar yield to 20.99 t/ha and on par with T_7 (20.34 t/ha) which was 15.05 and 12.34 % increase over T_1 (17.83 t/ha.).The optimized parameters such as moisture movement, nutrient mobility, availability and uptake of applied nutrients due to higher soil moisture content, prevention of losses such as leaching, volatilization and denitrification resulted in increased total cane yield under sub surface drip fertigation. The increase in cane yield and yield components with the continuous injection of the dissolved phosphate fertilizers could be because of a more uniform water distribution during the whole irrigation time resulting in an improved distribution of the fertilizer. These favorable environments resulted in better and earlier conversion of tillers to millable cane and the early vigor was maintained during the crop growth period due to continuous availability of nutrients and resulted in increased cane and sugar yield. The increased sugar yield was mainly due to improved juice quality parameters with the result of uniform millable cane production under this treatment. CCS content was increased with application of water soluable phosphate fertilizers may most probably due to the increase in activities of sucrose synthase and sucrose phosphate synthase. The favourable effect of irrigation in enhancing herb and oil yields of various mint species have been reported by (Behera *et al*., 2014).

Effect of Fertigation with Phosphorus on Soil Nutrient Dynamics Pattern

The soil samples were collected on 270 DAP at 20,40 and 60 cm depth of soil in plant and ratoon crop respectively. The pH of soil distributed evenly among the depth of soil in plant as well as ratoon crop. The soluable salt content was below 1 dSm^{-1} and unevenly distributed from drip point and depth of soil (Figure 1).The available nitrogen content was found to be maximum at 20 cm depth of soil (Figure 2). The highest available nitrogen concentration212.0 and 219.4 kg/ha in the surface layer was for in the 125 % Rec. NPK (Urea, MAP and KCl), followed by 100 % Rec. NPK (Urea, H_3PO_4 and KCl).For all depths, the available nitrogen concentrations for the treatments with water soluable fertilizers showed differences when compared to T_1treatments in plant and ratoon crops. The available N content was confined to maximum at immediately below the emitter and moved vertically up to 60 cm and thereafter dwindled. The seasonal moisture distribution efficiency in drip system was uniform and relatively much higher than surface irrigation and it was higher near the dripper and then decreased consistently with increasing distance in both horizontal and vertical Directions(Sanjit Pramanik *et al.,* 2014).

The available phosphorus content was accumulated at 40 cm depth of soil (Figure 2). The content was observed to be maximum in T_6 treatments in all three depths of soil. Application of 125 % NPK through urea, 19-19-19 and KCl increased the content and the mobility of P was both plant and ratoon crop.

This might be due to readily available water soluble phosphorus in soil through sub surface fertigation with MAP and 19-19-19 fertilizers (Gonge*et al.*,2015). Adhami *et al.,* 2013 stated that the Iran soils showed a high inorganic P content, appeared almost in all of the P fractions, which is probably an effect of the intensive inorganic P fertilizer application.

Table.1 Treatments Schedule

T_{1}-	**Sub Surface Drip Fertigation (SSDF) of 75 % Rec. NPK (Urea, MAP and KCl)**
T_{2}-	**SSDF -75 % Rec. NPK (Urea, 19-19-19 and KCl)**
T_{3}-	**SSDF -100 % Rec. NPK (Urea, MAP and KCl)**
T_{4}-	**SSDF -100 % Rec. NPK (Urea, 19-19-19 and KCl)**
T_{5}-	**SSDF -125 % Rec. NPK (Urea, MAP and KCl)**
T_{6}-	**SSDF -125 % Rec.NPK (Urea, 19-19-19 and KCl)**
T_{7}-	**SSDF -100 %Rec. NPK (Urea, phosphoric acid and KCl)**
(MAP- Mono Ammonium Phosphate ; KCl – Potassium Chloride)	

Table.2 Effect of phosphorus fertilizers fertigation on growth parameters, yield attributes and quality of sugarcane cv CoC (SC)24Plant and I st Ratoon (Mean values)

Treatments	Germination &Establishment percentage		Tiller population ('000/ha)		Millable cane population('000/ha)		CCS (%)		Cane yield (t/ha.)		Sugar yield (t/ha.)	
	Plant crop	I st Ratoon	Plant	I st Ratoon	Plant crop	I st Ratoon	Plant crop	I st Ratoon	Plant	I st Ratoon	Plant	I st Ratoon
T_{1-} 75 %NPK(Urea, MAP &KCl)	96.23	95.04	155.31	153.70	78.22	79.36	12.02	11.11	135.75	160.46	16.49	17.83
T_{2-} 75 %NPK(Urea, 19-19-19 &KCl)	97.96	95.04	154.19	166.53	81.33	82.52	11.93	11.00	150.66	168.81	17.89	18.45
T_{3-}100%NPK(Urea, MAP &KCl)	98.35	95.33	212.13	183.04	84.00	85.52	12.29	12.04	156.34	164.98	19.22	19.88
T_{4-}100%NPK(Urea, 19-19-19 &KCl)	98.62	89.00	210.42	196.13	87.88	87.95	11.60	11.01	164.44	180.04	19.06	19.82
T_{5-}125%NPK(Urea, MAP &KCl)	98.68	94.40	208.18	196.73	86.33	86.52	12.08	11.73	164.87	171.00	19.92	20.06
T_{6-}125%NPK(Urea, 19-19-19 &KCl)	97.21	95.40	217.67	210.75	89.44	89.95	12.33	11.67	175.48	180.44	21.63	20.99
T_7-100 % NPK- Urea, H_3PO_4 and KCl	98.73	93.60	217.48	196.53	88.44	88.30	12.04	12.02	162.46	169.04	19.52	20.34
S.Ed	NS	NS	10.12	9.39	16.90	0.42	NS	NS	6.77	1.32	0.607	0.26
C.D (P=0.05)			22.04	18.74	36.83	1.30			14.75	4.06	1.33	0.86

Table.3 Effect of phosphorus fertilizers fertigation on plant nutrient content (%) and its uptake (kg/ha) under plant- I[st] Ratoon sequences (pooled values)

Treatments	Nitrogen content (%)	Phosphorus Content (%)	Potassium content (%)	Nitrogen uptake (kg/ha.)	Phosphorus uptake (kg/ha.)	Potassium Uptake (kg/ha.)
T_{1-} 75 %NPK(Urea, MAP &KCl)	0.77	0.35	1.92	166.85	55.63	306.13
T_{2-} 75 %NPK(Urea, 19-19-19 &KCl)	1.29	0.39	1.92	216.77	65.85	324.13
T_{3-}100%NPK(Urea, MAP &KCl)	1.27	0.42	2.13	209.54	68.68	352.13
T_{4-}100%NPK(Urea, 19-19-19 &KCl)	1.39	0.44	2.08	251.51	78.67	368.57
T_{5-}125%NPK(Urea, MAP &KCl)	1.43	0.54	2.10	244.58	92.87	359.59
T_{6-}125%NPK(Urea, 19-19-19 &KCl)	1.44	0.57	2.30	259.87	103.19	415.15
T_7-100 % NPK-Urea, H_3PO_4 and KCl	1.32	0.53	2.09	223.19	90.39	353.80
S.Ed	0.13	0.03	0.03	4.88	4.63	6.93
C.D .(P=0.05)	0.40	0.08	0.10	14.50	14.28	21.36

Table.4 Effect of phosphorus fertilizers fertigation on economics of sugarcane under plant crop (2014-2015) and ratoon crop (2015-2016)

Treatments	Yield (t/ha)	Rate per tonne (Rs)	Gross income Rs.)	Cost of cultivation Rs)	Net income (Rs)	BCR
Plant crop (2014-2015)						
T_{1-} 75 %NPK(Urea, MAP &KCl)	135.75	2200	298650	120420	178230	2.45
T_{2-} 75 %NPK(Urea, 19-19-19 &KCl)	150.66		331452	139370	192082	2.38
T_{3-}100%NPK(Urea, MAP &KCl)	156.34		343948	125798	218750	2.75
T_{4-}100%NPK(Urea, 19-19-19 &KCl)	164.44		361768	122470	239298	2.95
T_{5-}125%NPK(Urea, MAP &KCl)	164.87		362714	128219	234495	2.83
T_{6-}125%NPK(Urea, 19-19-19 &KCl)	175.40		386056	156780	229276	2.45
T_7-100 % NPK-Urea, H_3PO_4 and KCl	162.46		357412	117874	239358	2.79
Ratoon crop (2015-2016)						
T_{1-} 75 %NPK(Urea, MAP &KCl)	160.40	2300	368620	132959	235961	2.77
T_{2-} 75 %NPK(Urea, 19-19-19 &KCl)	168.81		388263	130149	258114	2.98
T_{3-}100%NPK(Urea, MAP &KCl)	164.98		379454	125973	253481	3.01
T_{4-}100%NPK(Urea, 19-19-19 &KCl)	180.04		414092	135324	278768	3.06
T_{5-}125%NPK(Urea, MAP &KCl)	171.00		393300	128994	264306	3.04
T_{6-}125%NPK(Urea, 19-19-19 &KCl)	180.44		415012	148218	266794	2.80
T_7-100 % NPK-Urea, H_3PO_4 and KCl	169.04		388792	136800	251992	2.84

Fig.1 Effect of phosphorus fertilizers fertigation on pH and EC (dSm^{-1}) of soil under plant(2013-2014) - I[st] Ratoon (2014-2015)sequences (Mean values)

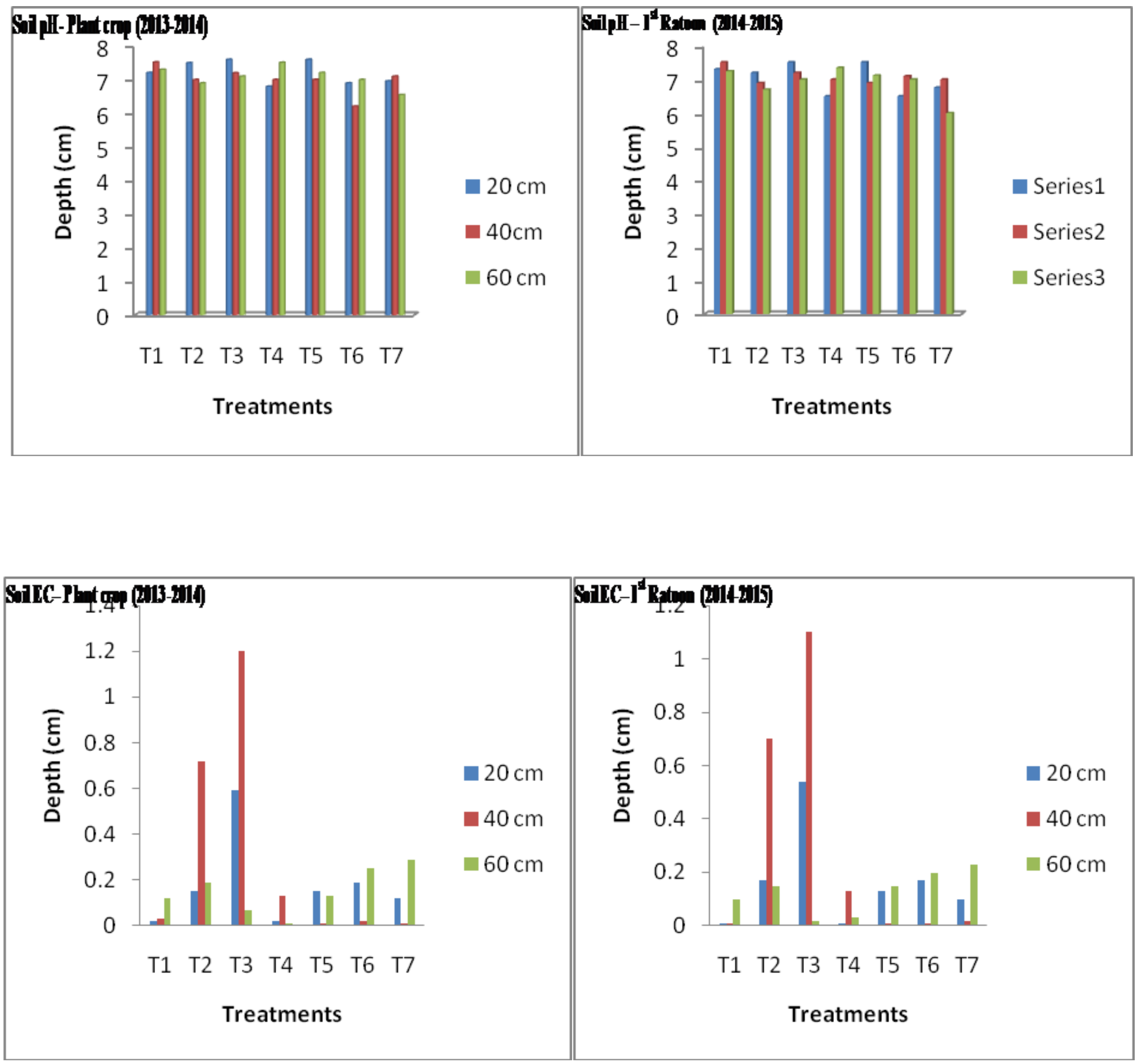
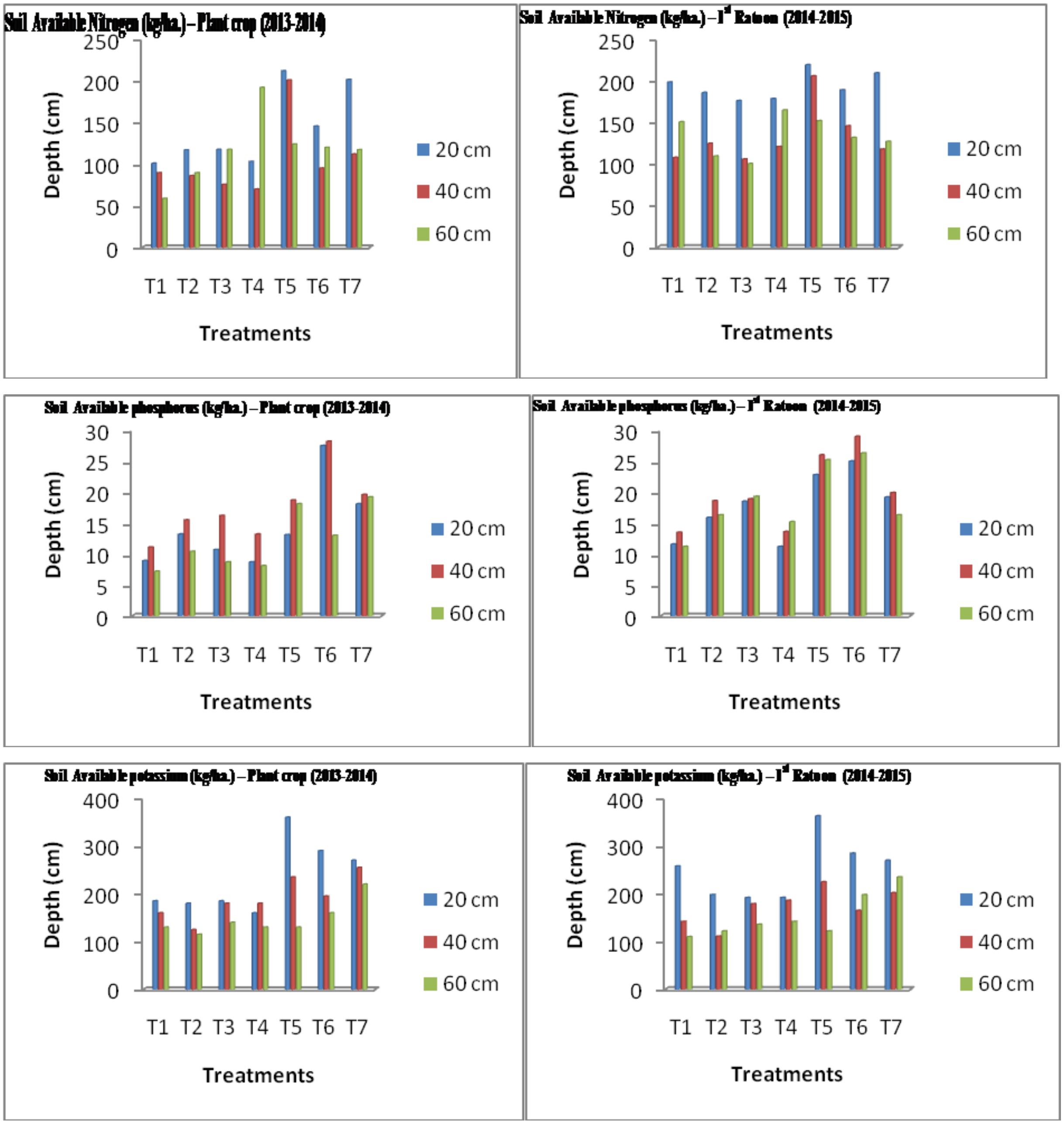


Fig.2 Effect of phosphorus fertilizers fertigation on Available Nitrogen, Phosphorus and Potassium (kg/ha) of soil under plant crop (2013-2014) - Ist Ratoon (2014-2015) sequences (Mean values)



The phosphorus content ranged from 0.35 to 0.57 %. The total potassium content for whole plant ranged from 1.92 to 2.30 % and application of 125 % recommended NPK as urea, 19-19-19 and KCl significantly increased the content to 2.30 % followed by T_3 (2.13 %). The lowest content was observed in T_1(1.92%).The nitrogen, phosphorus and potassium uptake was observed to be significantly higher with 125 % recommended NPK as urea, 19-19-19 and KCl to 259.87, 103.1, 415.15 kg/ha respectively. Increased the fertigation doses also positive effect on nutrient and uptake pattern of nutrients both in plant and ratoon crop. Husameldin *et al.*, (2014) that the applied nutrients at any stage should be properly reflected in terms of available nutrients in soil so that the plant could absorb these nutrients without any hindrance. The N uptake was significantly higher under drip fertigation with 125 per cent recommended NPK compared with other ferigation doses. The P and K uptake values followed more or less the similar trend as that of N uptake. The concentration and availability of various nutrients in the soil for plant uptake depends on the soil solution phase which is mainly determined by soil moisture availability. The higher available soil moisture provided due to continuous water supply under drip fertigation had led to higher availability of nutrients in the soil and thereby increased the nutrient uptake by the crop. The increased nutrient uptake under drip fertigation was the result of increased biomass production due to continuous availability of water and nutrients to the crop. The increased uptake may also be due to split application of N P and K under drip fertigation that resulted in minimal loss of nutrients thereby making them available continuously to the crop.

Economics

Under sub surface drip fertigation system, the highest BC ratio of 2.95 and 3.06 was observed in the treatment receiving 100 % NPK through urea, 19-19-19 and KCl (T_4)in plant and ratoon crop respectively. Application of 125 % recommended NPK as urea, 19-19-19 and KCl recorded the benefit cost ratio of 2.45 and 2.80 in plant and ratoon crop. The lowest BC ratio was in the treatment receiving urea, MAP and KCl with 75 % RDF in plant and ratoon crop respectively. Drip fertigation treatments performed well with respect to net returns and return per rupee investment (Sanjit Pramanik *et al.*, 2014)

Phosphorus need is spread in earlier to mid growth stage. Basal application of phosphorus is fulfilling the earlier growth stage absorption and severe phosphorus deficiencies are observed in mid growth stage. Mid growth stage needs of phosphorus can be fulfilled through soluble fertilizers of phosphorus there is a direct need to educate the farmers for supplementing the phosphorus during mid-growth stage to maturity.

Though 125 % and 100 % recommended NPK through Urea, 19-19-19 and KCl increased the yield, yield attributes and quality of sugarcane, application of 100 % NPK through urea, 19-19-19 and KCl through drip fertigation up to 201 DAP increased yield, quality and plant nutrient uptake and BC ratio.

Hence 100 % recommended dose of urea,19-19-19 and KCl recommended for fertigation up to 210 DAP to enhance sugarcane productivity and soil health. Based on two season's results the author recommends that, regulation of the injection of phophate fertilizer to match the flow of irrigation water is so precise that application rates are substantially lowered. Accordingly, fertilization of the sugarcane crop should be carried out via fertigation strategy mainly through sub surface with dissolved100 % recommended dose of NPK (300:100:200 kg/ha) through urea,19-19-19 and KCl fertilizers enhanced yield and benefit cost ratio due to uniform distribution of added nutrients compared to applied phosphate fertilizer as basal.

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