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Research Paper

Yield, quality, nutrient uptake and economics of spring sugarcane (*Saccharum officinarum*) as influenced by balanced fertilization in clay loam soils of Rajasthan

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ABSTRACT

A field experiment was conducted from 2011–12 to 2013–14 at Agricultural Research Station, Kota, Rajasthan, to find out suitable nutrient-management practices for sugarcane (*Saccharum officinarum* L.). The experiment was consisted of 13 nutrient management practices, viz. control, N_{200}, $N_{200}P_{60}$, $N_{200}P_{60}K_{40}$ (RDF), $N_{200}P_{60}K_{40}+S_{40}$, $N_{200}P_{60}K_{40}+Zn_5$, $N_{200}P_{60}K_{40}+Fe_1$, $N_{200}P_{60}K_{40}+$ Mn_1, $N_{200}P_{60}K_{40}+S_{40}+Zn_5$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1+Mn_1$, $N_{150}P_{50}+$ $S_{25}+Zn_4$ kg/ha as soil-test recommendation (STR) and FYM @ 20 t/ha were laid out in randomized block design with 3 replications. Balanced fertilization of $N_{200}P_{60}K_{40}$ along with $S_{40}+Zn_5$ kg/ha had significant influenced on tillers, number of millable canes (126,060/ha), single cane weight (880 g), cane yield (91.70 t/ha), commercial cane sugar yield (11.96 t/ha) and net profit (₹ 90,974/ha) over rest of the treatments being on a par with treatments of $N_{200}P_{60}K_{40}+S_{40}$, $N_{200}P_{60}K_{40}+Zn_5$, $N_{200}P_{60}K_{40}+Fe_1$, $N_{200}P_{60}K_{40}+Mn_1$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1+Mn_1$, $N_{150}P_{50}+S_{25}+Zn_4$ kg/ha. Maximum nutrient uptake of N, P and K (265.3, 21.3 and 260 kg/ha) was recorded with application of $N_{200}P_{60}K_{40}+S_{40}+Zn_5$ kg/ha over rest of the treatments and it was observed higher positive net gain of N, P, K and S (8.5, 3.4, 16 and 3.7 kg/ha) was recorded over initial status of soil. The result showed that balanced application of $N_{200}P_{60}K_{40}+S_{40}+Zn_5$ kg/ha may be recommended for obtaining higher millable cane yield, net return and sustained soil health in spring planted in clay loam soils of Rajasthan.

Key words **:** Commercial cane sugar, Nutrient management, Nutrient uptake, Net returns, Sugarcane yield

Sugarcane is an important crop of India, which is cultivated in an area of about 5.04 million ha with an average productivity of 71.67 tonnes/ha (FAO, 2013). The average productivity of sugarcane in the state has been around 73.10 t/ha (Commissionerate of Agriculture, Jaipur, 2013). The development of modern agricultural technologies, intensification of cropping system and changed cropping pattern without balanced fertilization has also led to depletion of major as well as micro-nutrients from the soil (Prasad, 2006). Fertilizer use in India is inadequate, imbalanced and is in favour of nitrogen application. Escalating prices of fertilizers in the market has become a cause of concern to sustain the sugarcane productivity. Imbalanced nutrient-use especially NPK and limited micronutrients have created concern in India, as it may affect overall sugarcane productivity. Nitrogen deficiency may decrease cane yield, while excess N availability during the ripening period reduces the juice quality (Tabayoyong and Robeniol, 1962). Response of sugarcane to applied nitrogen and phosphorus was higher than to potassium. In addition to major nutrients, smaller quantities of secondary and micronutrients such as sulphur, zinc, iron and manganese do enhance the yield as well as quality of sugarcane. Sugarcane is an exhaustive crop which removes about 205, 24, 229, 30, 3.5, 1.2, 0.6 and 0.2 kg/ha of N, P, K, S, Fe, Mn, Zn and Cu, respectively, from the soil for the cane yield of 100 t/ha (Singh *et al.,* 2007). Under the present situation application of nutrient elements especially NPKS and Zn is essential for increasing sugarcane yield and maintaining crop production at higher level. Further, combined application of major nutrients along with sulphur and zinc resulted in higher yield and quality of sugarcane (Shukla, 2007). Considering these facts, the present study was, therefore, undertaken to evaluate the effect of different combinations of NPK along with S, Zn, Fe and Mn in spring-planted sugarcane on clay loam soil of south east Rajasthan.

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MATERIALS AND METHODS

A field experiment was conducted on clay loam soil during the spring seasons for three consecutive cropping seasons in 2011–12, 2012–13 and 2013–14 at Agricultural Research Station, Kota, to study the response of balanced fertilization on growth, yield, nutrient uptake, quality, fertility status of soil and economics of sugarcane. The average annual rainfall received during the crop seasons was about 865 mm. The experimental soil was clay loam with a *p*H of 8.10, ECe 0.25 dS/m^2, medium in organic carbon (5.4 g/kg), available nitrogen (362 kg/ha), phosphorus (23.50 kg/ha) and high in potassium (283 kg/ha), iron (13.24 mg/kg), manganese (20.78 mg/kg) and low in sulphur (9.60 mg/kg) and zinc (0.55 mg/kg) contents. Thirteen treatments, viz. control, N_{200}(@200kg/ha), $N_{200}P_{60}$, $N_{200}P_{60}K_{40}$ as recommended dose of fertilizer (RDF), $N_{200}P_{60}K_{40}+S_{40}$, $N_{200}P_{60}K_{40}+Zn_5$, $N_{200}P_{60}K_{40}+Fe_1$, $N_{200}P_{60}K_{40}+Mn_1$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1+Mn_1$, $N_{150}P_{50}+S_{25}+Zn_4$ kg/ha as soil-test-based recommendation (STR) and FYM @ 20 t/ha were tested in a randomized block design with 3 replications. The nutrients especially NPKSZnFe and Mn were supplied through urea, single superphosphate, muriate of potash, elemental sulphur, zinc sulphate, iron sulphate and manganese sulphate fertilizers respectively. Recommended dose of N_{200} P_{60} and K_{40} fertilizers for sugarcane was applied as per treatments; 40 kg/ha elemental sulphur, 25 kg/ha zinc sulphate, 5 kg/ha iron sulphate and 5 kg/ha manganese sulphate were applied at the time of planting as per treatments. Full PK and one-fourth N were applied basal and remaining N was top-dressed in 3 equal splits within 120 days after planting. Sugarcane variety 'CoPK 05191' was planted at 75 cm row distance, keeping 3 budded 4 setts/m row length in the third week of February during all the cropping seasons. All the recommended agronomic practices were done throughout the crop season. Plot size for each treatment was 6.0 m × 4.5 m = 27.0 m^2. Harvesting was done manually during the third week of February. Initial and post-harvest soil samples after 3 years collected from 0–15 cm depth were dried, processed and analyzed for oxidizable organic carbon, N, P, K, S, Zn, Fe and Mn using standard procedures. Growth, yield attributes, cane yield, quality parameters and nutrient uptake were worked out as per standard statistical procedures. Economics was worked out based on pooled yield data and considering market price of input and output.

RESULTS AND DISCUSSION

Growth and yield attributes

Application of $N_{200}P_{60}K_{40}$ (N, P and K @ 200, 60 and 40 kg/ha) along with $S_{40}+Zn_5$ (S + Zn @ 40 and 5 kg/ha) had significant effect on growth and yield attributes, viz. tillers, cane length, cane girth, number of millable canes and single cane weight. However, the application of $N_{200}P_{60}K_{40}$ along with $S_{40}+Zn_5+Fe_1$ kg/ha resulted in significant increase in germination (46.72%) over rest of the treatments and it was on a par with $N_{200}P_{60}K_{40}+Zn_5$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1+Mn_1$ treatments (Table 1). Significantly higher germination with balanced nutrition of N, P, K, S, Zn and Fe was primarily owing to the improved fertility status of soil. Millable canes, cane length, cane girth and single cane weight were significantly higher with the application of $N_{200}P_{60}K_{40}+S_{40}+Zn_5$ kg/ha over the control, N_{200}, N_{200} P_{60} and FYM @ 20 t/ha except cane weight and the treatment was on a par with rest of the treatments ($N_{200}P_{60}K_{40}$, $N_{200}P_{60}K_{40}+S_{40}$, $N_{200}P_{60}K_{40}+Zn_5$, $N_{200}P_{60}K_{40}+Fe_1$, $N_{200}P_{60}K_{40}+Mn_1$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1+Mn_1$, $N_{150}P_{50}+S_{25}+Zn_4$ kg/ha). However, application of $N_{200}P_{60}K_{40}+S_{40}+Zn_5$ along with Fe and Mn did not show any significant effect on growth and yield attributes over $N_{200}P_{60}K_{40}$ along with $S_{40}+Zn_5$ kg/ha. It was observed that Zn and high soil P levels also reduced Fe uptake in treatment combinations of NPKSZnFe and NPKSZnFeMn. Shahi *et al*. (2000) reported also antagonistic relationship between Fe and Mn as well as Zn and P. Tiller population at 90 and 120 days after planting (DAP) was maximum with the application of $N_{200}P_{60}K_{40}$ along with $S_{40}+Zn_5$ kg/ha (Table 1). Significantly higher values were obtained over the remaining treatments and at par with $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1$ and $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1+Mn_1$. Balanced dose of NPK along with $S_{40}+Zn_5$ also reduced the tiller mortality, indicating the besides production of millable canes. Higher nutrition level helped in maintaining retention of tillers. The increase in the rate of physiological processes in the plant system increased tiller formation. Navnit Kumar (2012) also reported similar results. Desired NPK level created better nutritional environment in soil–plant system which resulted in significant improvement in millable canes and individual cane weight. Synergistic relationship between nitrogen and phosphorus and nitrogen with potassium are also well known. Shukla (2007) also found improvement in tiller, millable canes and cane yield with higher doses of NPK.

Yield and quality

All the nutrient-management treatments significantly improved green top and trash yield as well as cane yield over the control (Tables 1 and 2). The maximum top green yield produced under the application of $N_{200}P_{60}K_{40}$ along with $S_{40}+Zn_5$ kg/ha was significantly superior to the control, N_{200}, $N_{200}P_{60}$ and FYM @ 20 t/ha, and at par with rest of the nutrient-management treatments. Higher green top yield in the referred treatment was the result of higher tiller population and leaf area. It produced 69.42% higher shoot population than the control. Our results confirmed the findings of Tyagi *et al*. (2011). The highest trash yield was obtained with $N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1, which was significantly higher than all the treatments except $N_{200}P_{60}K_{40}$, $N_{200}P_{60}K_{40}$+S_{40}, $N_{200}P_{60}K_{40}$+Zn_5, $N_{200}P_{60}K_{40}$+S_{40}+Zn_5, $N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1+ Mn_1 and $N_{150}P_{50}$+S_{25}+Zn_4 kg/ha. The maximum cane yield obtained with of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha, was significantly higher than the control, N_{200}, $N_{200}P_{60}$, $N_{200}P_{60}K_{40}$+Mn_1, $N_{150}P_{50}$+S_{25}+Zn_4 kg/ha and FYM @ 20 t/ha, and was on a par with rest of the treatments. It was noted that cane yield under various nutrient-management treatments was significantly higher than the control. This could be because of continuous and balanced supply of NPK along with S and Zn and thus increased the absorption of plant nutrients. The increase in cane yield attributed to higher number of millable canes, individual cane length and cane weight. However, addition of Fe and Mn nutrient along with NPKSZn did not show any significant response in cane yield over all the treat-

Table 1. Effect of plant nutrient treatments on growth, yield attributes and yield of spring-planted sugarcane (pooled data of 3 years)

Treatment	Germination (%) at 35 DAP	Tillers population ($\times 10^3$/ha) 90 DAP	Tillers population ($\times 10^3$/ha) 120 DAP	Cane length (cm)	NMC ($\times 10^3$/ha)	Cane girth (cm)	Single cane weight (g)	Green top yield (t/ha)	Trash yield (t/ha)
Control	34.9	117.2	133.8	178.7	101.2	7.3	670	12.1	5.8
N_{200}	40.5	137.8	148.7	207.4	114.1	8.6	725	15.6	6.7
$N_{200}P_{60}$	40.9	143.3	154.8	213.8	115.2	8.8	750	17.1	7.8
$N_{200}P_{60}K_{40}$ (RDF)	40.7	145.1	154.9	221.8	117.8	9.6	840	17.7	8.0
$N_{200}P_{60}K_{40}$+S_{40}	42.9	146.3	158.1	224.5	118.7	9.7	855	18.6	8.5
$N_{200}P_{60}K_{40}$+Zn_5	43.2	148.2	162.6	223.8	116.4	9.3	860	18.7	8.6
$N_{200}P_{60}K_{40}$+Fe_1	42.6	150.3	163.5	229.1	118.6	9.9	850	17.8	7.7
$N_{200}P_{60}K_{40}$+Mn_1	42.5	144.6	157.3	225.8	115.3	9.7	845	17.5	7.3
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5	45.9	159.7	174.3	244.2	126.1	10.2	880	20.5	8.9
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1	46.7	158.4	173.0	230.4	117.9	9.5	865	19.4	9.2
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1+Mn_1	45.0	158.8	172.0	238.1	113.0	9.6	870	20.0	9.0
$N_{150}P_{50}$+S_{25}+Zn_4 (STR)	41.8	145.7	158.5	221.1	110.3	9.6	845	17.7	7.9
FYM @ 20 t/ha	36.7	137.5	156.1	188.7	101.7	7.7	800	15.8	7.6
SEm±	1.33	4.92	4.10	8.33	3.94	0.32	42	1.08	0.51
CD (P=0.05)	3.70	14.82	9.39	12.30	10.92	0.86	120	3.05	1.45

RDF, Recommended dose of fertilizer; STR, soil test recommendation; FYM, farm yard manure; NMC, number of millable canes; DAP, days after planting

Table 2. Yield, quality and economics of spring-planted sugarcane as influenced by plant nutrient treatments (pooled data of 3 years)

Treatment	Cane yield (t/ha)	°Brix	Sucrose (%)	Purity	CCS (%)	CCS yield (t/ha)	Cost of cultivation ($\times 10^3$₹/ha)	Net returns ($\times 10^3$₹/ha)	Benefit: cost ratio
Control	58.1	20.1	17.6	87.3	12.0	6.99	93.5	37.0	1.40
N_{200}	74.1	21.2	18.7	88.2	12.9	9.55	96.1	64.5	1.67
$N_{200}P_{60}$	77.8	20.5	17.9	87.6	12.3	9.59	99.1	64.1	1.65
$N_{200}P_{60}K_{40}$ (RDF)	80.4	21.0	18.5	88.0	12.8	10.24	100.3	65.7	1.66
$N_{200}P_{60}K_{40}$+S_{40}	84.7	21.6	19.1	88.5	13.2	11.19	101.7	75.5	1.74
$N_{200}P_{60}K_{40}$+Zn_5	85.7	21.8	19.3	88.5	13.4	10.91	101.3	77.8	1.77
$N_{200}P_{60}K_{40}$+Fe_1	84.9	21.2	18.7	88.3	12.9	10.94	101.3	76.6	1.76
$N_{200}P_{60}K_{40}$+Mn_1	79.5	21.6	19.1	88.4	13.2	10.48	101.1	67.7	1.67
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5	91.7	21.3	18.8	88.2	13.0	11.96	103.7	91.0	1.88
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1	88.2	20.9	18.4	87.9	12.7	11.15	104.7	84.3	1.81
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1+Mn_1	88.7	20.7	18.1	87.5	12.5	11.13	105.6	80.8	1.77
$N_{150}P_{50}$+S_{25}+Zn_4 (STR)	78.9	21.1	18.6	88.1	12.8	10.12	99.6	64.9	1.65
FYM @ 20 t/ha	75.2	21.0	18.5	88.0	12.8	9.59	109.5	41.6	1.38
SEm±	4.31	0.56	0.57	1.25	0.31	0.73	-	2.86	0.13
CD (P=0.05)	11.96	1.68	1.72	NS	0.87	2.02	-	8.06	0.37

RDF, Recommended dose of fertilizer; STR, soil test recommendation; FYM, farm yard manure; CCS, commercial cane sugar ments except control, N_{200}, $N_{200}P_{60}$ and FYM @ 20 t/ha. Combination of NPK along with S and Zn increased the cane yield because of better nutrient-supplying capacity of the soil. Hence higher number of tillers converted into number of millable canes, which lead to higher cane yield. The results are in agreement with the findings of Khan *et al.* (2005), Thakur *et al*. (2007) and Navnit Kumar (2012).

Application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha brought significant variation in °brix and sucrose, but did not significantly influence juice purity. Application of $N_{200}P_{60}K_{40}$ along with S_{40} kg/ha significantly increased °brix and sucrose over the control and was on a par with rest of the treatments. The effect of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha on sugar yield was significantly higher over the control, N_{200}, $N_{200}P_{60}$ and FYM @ 20 t/ha. The percentage increase in the sugar yields by the application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha was 71.10, 25.24 and 24.71 during first, second and third cropping seasons respectively. The minimum sugar yield was recorded when sugarcane was grown without fertilizer. The highest CCS (13.22%) was obtained with the application of $N_{200}P_{60}K_{40}$+Zn_5 which was significantly higher over the control and $N_{200}P_{60}$ and at par with rest of the treatments. Thus, cane yield and commercial cane sugar yield (CCS) were also higher at this level. The higher cane yield contributed larger share in improving CCS than cane-quality parameters. The higher dry-matter accumulation in N, P, K, S and Zn added plots was primarily responsible for higher sugar yield. Vijaya *et al.* (2007) and Navnit Kumar (2012) also reported positive effect of nutrients on sugar yield.

Economics

The economic analysis of different treatments indicated that net returns and benefit: cost ratio were influenced by nutrient-management treatments. There were differences in cost of cultivation and net returns owing to different variable costs. Application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha fetched significantly higher net returns over remaining treatments except $N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1. Benefit: cost ratio of 1.88 was significantly superior under the application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha over the control and FYM @ 20 t/ha, however rest of fertility levels were statistically at par with each others. It showed increase of 145.61% in net returns and 34.29% in benefit: cost ratio over the control, indicating the response of NPK along with S and Zn was found positive response to N, P, and K along with S and Zn. However, the rate of increase in net returns was very less with $N_{200}P_{60}K_{40}$+Fe_1, $N_{200}P_{60}K_{40}$+Mn_1, $N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1 and $N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1+Mn_1 kg/ha, indicating the non-responsiveness and the non suitability of these treatments for increasing sugarcane production. Maximum cane production cost recorded with FYM @ 20 t/ha was due to higher cost of FYM and less addition of nutrients, whereas minimum production cost and net returns recorded in the control

Table 3. Balance sheet of soil N and P as influenced by different nutrient management in spring-planted sugarcane (pooled data of 3 years)

Treatment	Nitrogen (kg/ha)						Phosphorus (kg/ha)					
	Initial soil N status	N added	N uptake	Expected balance (a+b)-c	Soil N status after harvest	Net gain over initial status	Initial soil P status	P added	P uptake	Expected balance (a+b)-c	Soil P status after harvest	Net gain over initial status
	a	b	c	d	e	(e-a)	a	b	c	d	e	(e-a)
Control	362	-	150.2	211.8	302.3	–59.7	23.5	-	12.4	11.1	20.5	-3.0
N_{200}	362	200	230.4	331.6	355.5	–6.5	23.5	-	14.7	8.8	21.4	-2.1
$N_{200}P_{60}$	362	200	255.1	306.0	357.4	–4.6	23.5	60	17.4	66.1	24.7	-1.2
$N_{200}P_{60}K_{40}$ (RDF)	362	200	257.5	304.5	360.2	–1.8	23.5	60	18.5	65.0	26.5	+3.0
$N_{200}P_{60}K_{40}$+S_{40}	362	200	260.7	301.3	365.5	+3..5	23.5	60	19.2	64.3	26.8	+3.3
$N_{200}P_{60}K_{40}$+Zn_5	362	200	262.5	299.5	367.4	+5.4	23.5	60	19.8	63.7	26.5	+3.0
$N_{200}P_{60}K_{40}$+Fe_1	362	200	258.9	303.2	360.6	–1.4	23.5	60	17.9	65.6	21.4	- 2.1
$N_{200}P_{60}K_{40}$+Mn_1	362	200	250.7	311.3	358.4	–3.6	23.5	60	17.2	66.3	21.7	- 1.8
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5	362	200	265.3	296.7	370.5	+8.5	23.5	60	21.3	62.2	26.9	+3.4
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1	362	200	250.4	311.6	365.2	+3.2	23.5	60	20.1	63.4	22.4	+1.1
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5 +Fe_1+Mn_1	362	200	253.0	309.0	362.8	+0.8	23.5	60	20.2	63.3	22.8	- 0.8
$N_{150}P_{50}$+S_{25}+Zn_4 (STR)	362	150	248.2	264.0	325.4	–36.5	23.5	50	20.5	53.0	23.6	+0.1
FYM @ 20 t/ha	362	100	217.5	244.5	320.6	–41.4	23.5	40	20.7	42.8	24.8	+1.3
SEm±	-	-	3.4	-	16.2	-	-	-	0.9	-	2.08	-
CD (P=0.05)	-	-	9.6	-	49.3	-	-	-	2.4	-	5.25	-

RDF, Recommended dose of fertilizer; STR, soil test recommendation; FYM, farm yard manure

plot. The combined effect of plant nutrients played very significant role owing to their synergistic effect and enhanced the partitioning of photosynthates in vegetative and reproductive parts that go simultaneously in the later growth phases. The increase in yield attributes and yield fetched higher net returns and benefit: cost ratio. The results confirm the findings of Tyagi *et al.* (2011), Navnit Kumar (2012) and Kumar *et al.* (2014).

Nutrient uptake and balance in soil

Sugarcane is a highly nutrient-exhaustive crop, as evident from nutrient removal data presented in Table 3, 4 and 5. Significantly higher nutrients uptake under various nutrient-management treatments over the control indicated availability of these nutrients in labile pool to support the crop growth and yield. Of the nutrient-management treatments, $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 showed significantly higher N uptake over all the remaining treatments except $N_{200}P_{60}K_{40}$, $N_{200}P_{60}K_{40}$+S_{40}, $N_{200}P_{60}K_{40}$+Zn_5 and $N_{200}P_{60}K_{40}$+Fe_1. The net N balance was found to be more negative under no-fertilizer treatment (-59.7 kg/ha), whereas it was more positive under the application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 (+8.5 kg/ha) except all other treatments. The uptake of P was significantly more with $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha than the control, N_{200}, $N_{200}P_{60}$, $N_{200}P_{60}K_{40}$, $N_{200}P_{60}K_{40}$+Fe_1 and $N_{200}P_{60}K_{40}$+Mn_1. The net gain over initial P status was slightly higher (+0.1 to 3.4 kg/ha) under the treatment receiving P nutrient except no use of P fertilizer treatment as well as use of P along with Fe and Mn nutrients treatments, indicating balanced amount of nutrients essential for soil health sustainability. A net gain of +3.4 kg P/ha was found with $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha, whereas it was the most negative in no-fertilization treatment (–3.0 kg/ha). The increase in uptake of phosphorus was due to the complexing properties of organic material which prevented the precipitation and fixation of nutrient and kept them in soluble form. These results are in accordance with those of Thakur *et al.* (2013).

Maximum uptake of K was observed with $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha which was significantly higher over the control, N_{200}, $N_{200}P_{60}$, $N_{200}P_{60}K_{40}$+Mn_1 and FYM @ 20 t/ha and at par with rest of treatments. The highest net gain of + 16 kg K/ha over initial soil K status (283 kg/ha) was recorded with $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha treatment and other potassium applied treatments except use of Fe and Mn nutrients along with NPK. While more negative net gain –56 kg K/ha was observed in the soil under no fertilization. The magnitude of increase in net gain was the maximum under the application of potassium fertilizer each year. Soil K balance had also negative values in all the treatments receiving no-potassium application and K application along with Fe and Mn nutrients. This results showed that K uptake exceeded the initial and without added amount of K leaved higher negative K balance (–39 to –56 kg/ha). The depletion of nutrient reserves

Table 4. Balance sheet of soil K and S as influenced by nutrient-management practices in spring-planted sugarcane (pooled data of 3 years)

Treatment	Potassium (kg/ha)						Sulphur (kg/ha)					
	Initial soil K status a	K added b	K uptake c	Expected balance (a+b)-c d	Soil K status after harvest e	Net gain over initial status (e-a)	Initial soil S status a	S added b	S uptake c	Expected balance (a+b)-c d	Soil S status after harvest e	Net gain over initial status (e-a)
Control	283	-	190	93	227	–56	9.6	-	5.1	4.5	7.5	–2.1
N_{200}	283	-	210	73	237	–46	9.6	-	5.5	4.1	8.4	–1.2
$N_{200}P_{60}$	283	-	218	65	244	–39	9.6	-	6.2	3.4	7.7	–1.9
$N_{200}P_{60}K_{40}$ (RDF)	283	40	250	73	298	+15	9.6	-	7.5	2.1	8.8	–0.8
$N_{200}P_{60}K_{40}$+S_{40}	283	40	247	76	292	+9	9.6	40	14.7	34.7	12.5	+2.9
$N_{200}P_{60}K_{40}$+Zn_5	283	40	246	77	295	+12	9.6	-	7.3	2.3	10.5	–0.4
$N_{200}P_{60}K_{40}$+Fe_1	283	40	248	75	297	+14	9.6	-	8.5	1.1	8.4	–1.2
$N_{200}P_{60}K_{40}$+Mn_1	283	40	240	83	282	–1	9.6	-	7.8	1.8	8.5	–1.1
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5	283	40	260	63	299	+16	9.6	40	16.3	33.3	13.3	+3.7
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1	283	40	251	72	274	–9	9.6	40	15.2	34.0	11.2	+1.60
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1+Mn_1	283	40	249	74	270	–13	9.6	40	15.6	35.2	11.3	+1.70
$N_{150}P_{50}$+S_{25}+Zn_4 (STR)	283	-	245	38	260	–23	9.6	25	14.4	20.2	10.2	+ 0.6
FYM @ 20 t/ha	283	40	220	103	288	+5	9.6	-	8.6	1.4	11.2	+1.6
SEm±	-	-	5.64	-	8.12	-	-	-	0.80	-	1.55	-
CD (P=0.05)	-	-	15.91	-	24.44	-	-	-	2.26	-	4.68	-

RDF, Recommended dose of fertilizer; STR, soil test recommendation; FYM, farm yard manure

from the soil is often a hidden form of land degradations and it was significantly influenced by the application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha over all the remaining treatments except $N_{200}P_{60}K_{40}$+S_{40}, $N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1, $N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1 +Mn_1 and $N_{150}P_{50}$+S_{25}+Zn_4 (STR). Sulphur loss was recorded under the no-sulphur application with NPK. Maximum negative gain of S was noted in the control treatment. However, the maximum positive net gain of S (+ 3.7 kg/ha) over initial S status (9.6 kg S/ha) was also recorded under the application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha.

The positive soil NPK and S balance were observed in the plots receiving NPK and S fertilization in plant crop each year. The results further indicated that among the major nutrients, relatively higher uptake of N was recorded followed by K and P irrespective of treatments. The results are in close agreement with the findings of Thakur *et al.* (2012) and Kumar *et al.* (2014). It was due to fact that added nutrients increased the N, P, K and S concentration in sugarcane by providing balanced nutritional environment inside the plant and higher photosynthetic efficiency which favoured higher dry-matter accumulation resulted in more uptakes of N, P, K and S by sugarcane.

Available nutrients status in soil

Available status of NPK and S at the end of crop cycle revealed that a positive effect of nutrient-management strategies was observed. The soil organic carbon, soil pH and ECe values recorded in the different treatments did not vary significantly among them. However, the highest organic carbon content (0.50%) and lowest soil pH and ECe were observed under the treatment of application of FYM @ 20 t/ha. This was owing to improvement in soil health with the application of FYM. Available Zn, Fe and Mn were found the highest in treatment of $N_{200}P_{60}K_{40}$+Zn_5, $N_{200}P_{60}K_{40}$+Fe_1 and $N_{200}P_{60}K_{40}$+Mn_1, respectively, which were significantly higher over the control except rest of the treatments. However, Zn value of the best treatment was at par with $N_{200}P_{60}$ K_{40}+Fe_1 and $N_{200}P_{60}K_{40}$+Mn_1, Fe value with $N_{200}P_{60}K_{40}$+Zn_5, $N_{200}P_{60}$ and $N_{200}P_{60}K_{40}$+Mn_1 and Mn value with $N_{200}P_{60}$. Non-significant variation in residual soil-nutrient status statistically varies, whereas all the treatments received same amount of NPK (Table 5). Application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha showed significantly improvement in available of nitrogen, phosphorus, potassium and sulphur in the soil over the control and was at par with rest of the treatments. The highest available N was recorded with $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha, which was significantly higher than the control except rest of the treatments. It was declined in N-deficient treatment as well as in use of N with Fe and Mn. The available soil phosphorus content increased with all P-containing treatments and declined to critical level in all phosphorus-deficient treatments as well as use of phosphorus in combination of Fe and Mn containing treatments. The highest available phosphorus was recorded with the application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha which was significantly higher over the control and N_{200} treatment and statistically at par with rest of the treatments. The post-harvest available P content of the soil indicated a significant and progressive increase with corre-

Table 5. Effect of nutrients management treatments on soil properties and available soil nutrients after harvest of spring-planted sugarcane (pooled data of 3 years)

Treatment	Organic carbon (%)	Soil *p*H	ECe (dS/m²)	Available soil nutrients (mg/kg)		
				Zn	Fe	Mn
Control	0.47	8.00	0.30	0.40	14.15	20.70
N_{200}	0.46	8.07	0.32	0.42	15.10	22.32
$N_{200}P_{60}$	0.47	8.05	0.29	0.47	16.20	23.27
$N_{200}P_{60}K_{40}$ (RDF)	0.48	8.10	0.35	0.49	17.34	27.50
$N_{200}P_{60}K_{40}$+S_{40}	0.48	8.09	0.31	0.50	17.10	23.40
$N_{200}P_{60}K_{40}$+Zn_5	0.48	8.10	0.30	0.60	16.15	24.50
$N_{200}P_{60}K_{40}$+Fe_1	0.47	7.98	0.36	0.46	20.16	24.30
$N_{200}P_{60}K_{40}$+Mn_1	0.46	8.15	0.35	0.45	16.40	28.15
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5	0.49	8.12	0.32	0.57	18.70	23.35
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1	0.47	8.14	0.33	0.52	19.50	27.20
$N_{200}P_{60}K_{40}$+S_{40}+Zn_5+Fe_1+Mn_1	0.46	8.23	0.32	0.55	18.20	28.05
$N_{150}P_{50}$+S_{25}+Zn_4 (STR)	0.48	8.15	0.31	0.46	16.50	25.20
FYM @ 20 t/ha	0.50	7.95	0.27	0.47	16.75	25.80
SEm±	0.07	0.15	0.06	0.06	1.25	1.60
CD (P=0.05)	NS	NS	NS	0.14	3.76	4.82

RDF, Recommended dose of fertilizer; STR, soil test recommendation; FYM, farm yard manure

sponding P-applied treatments. It was owing to addition of adequate amount of P through fertilizer. Besides supplying proportionate balance amount to sugarcane, considerable amount of unutilized P was left in the soil. It was found that the available soil potassium content was in medium to high range. The higher available potassium and sulphur in post-harvest soil was recorded significantly under the application of $N_{200}P_{60}K_{40}$ along with S_{40}+Zn_5 kg/ha over the control, N_{200}, $N_{200}P_{60}$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1$, $N_{200}P_{60}K_{40}+S_{40}+Zn_5+Fe_1+Mn_1$ and $N_{150}P_{50}+S_{25}+Zn_4$ for potassium and the control, N_{200}, $N_{200}P_{60}$, $N_{200}P_{60}K_{40}+Fe_1$ and $N_{200}P_{60}K_{40}+ Mn_1$ treatment for sulphur and at par with rest of the treatments. It must be assumed that either K was released from the reserves held in the clay inter-layers, or some other form of K has been taken up by sugarcane. The highest improvement in the soil-fertility status with 100% NPK along with S and Zn had positive interaction of applied nutrients in balanced amount which solubilize the soil-nutrient reserve and make it available to crop. Positive balance of major nutrients (N, P and K) in soil at the end of crop cycle revealed soil fertility enriching effect of the nutrient-management treatments, indicating adequate availability of N, P and K nutrients to ensure remunerative crop production.

It was concluded that application of NPK (200:60:40 kg/ha) along with 40 kg S and 5 kg Zn/ha may be recommended to obtain higher values of yield attributes, millable canes and top green, trash and cane yields of sugarcane, with maximum net returns with benefit: cost ratio. Similarly, sustained soil fertility was also observed in higher nutrient uptake and gains (N, P and K) and more available nutrient status of N, P, K and S. Hence this treatment showed better economic output, improved soil health in terms of positive nutrient balance under clay loam soils of humid south- east plain zone of Rajasthan.

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