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Research Paper

Zinc and sulphur nutrition in sugarcane (*Sachharum officinarum*) and potato (*Solanum tuberosum*) intercropping system affecting soil microbial biomass carbon, respiration and crop growth in subtropical India

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ABSTRACT

A field experiment was conducted during 2 cropping seasons of 2015–2017 at experimental field Lucknow, Uttar Pradesh to evaluate the sulphur- and zinc-containing complex fertilizers in sugarcane (*Sachharum officinarum* L.)–potato (*Solanum tuberosum* L.)-based cropping systems. The experiment was laid out in a split-plot design under 3 replications. The treatments of cropping system (CS) and nutrient management (NM) were kept in main and subplots, respectively. Results revealed that soil organic carbon did not differ significantly with the cropping systems. Higher values of soil organic carbon, soil respiration and soil microbial biomass nitrogen (SMBN) were obtained after harvesting of potato as compared to sugarcane crop in both the cropping systems. Balanced application of NPSZn compound fertilizer improved the SMBC, soil organic carbon (SOC), soil respiration and SMBN. The extent of increase in SMBC and SMBN owing to application of NPSZn was higher at harvesting of potato (component crop) compared to sugarcane. Application of farmyard manure (FYM) with recommended fertilizer (NPK) significantly increased SOC (0.92%) after harvesting of potato. After harvesting of sugarcane, SOC declined and reached the level of 0.76%. Recommended dose of NPK and FYM significantly left the highest status of residual level of nutrients (199.45 kg N, 23. 81 kg P_2O_5 and 348.15 kg K_2O/ha) after harvesting of sugarcane crop in both the systems. The statistically at par yield (32.98 t/ha) of potato was harvested in potato–sugarcane system as compared to potato + sugarcane (31.48 t/ha) system. Recommended NPK (T_2)/ recommended NPKS (T_3) were found superior to the absolute control (T_1) and produced significantly higher yield of potato (30.67 to 31.33 t/ha). The highest individual cane weight (1,015 g) was recorded with application of recommended NPK + FYM. Commercial cane sugar was influenced greatly by different levels of nutrients. The highest sugar yield (11.60 t/ha) was obtained with application of recommended dose of NPK along with S and Zn application equivalent to compound fertilizer (NPSZn).

Key words: Intercropping; Nitrogen-use efficiency; Soil microbial biomass carbon; Soil respiration

In India, sugarcane is grown in an area of 5.042 million ha with a production of 411 million tonnes cane at 81.5 t/ha average cane yield (Pathak, 2019). Autumn sugarcane crop provides ample scope for intercropping/ companion cropping. In autumn sugarcane, in subtropical India, tillering is almost ceased during winter season (November to January) and it favours growth of any other component crop/ intercrop. Although through several experiments, it has been proved that autumn crop could increase sugarcane yield by 20–25% over spring crop besides increase in sugar recovery by 0.5–1.0 unit (Shukla *et al*., 2016). However, autumn planting could not be adopted at larger extent because of loss of 1 winter (*rabi*) season crop. In subtropical India, duration of autumn crop (15–16 months) *vis-a-vis* spring crop (12 months) focused much attention of farmers.

Sugarcane being a long-duration crop, removes huge amount of nutrient from soil. A 100 tonnes of sugarcane crop removes 205 kg N, 55 kg P_2O_5, and 275 kg K_2O besides 30 kg S, 3.5 kg Fe, 1.2 kg Mn and 0.6 kg Zn (Lal and Shukla, 2000). Micronutrient status of potato-growing areas indicated that zinc is the most deficient micronutrient in potato-growing soils. Out of 121 field experiments conducted in alluvial soils of Jalandhar (Punjab), potato re-

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sponded to zinc in 57% (Kumar *et al*., 2015). Nowadays, in subtropical India, deficiencies of S and Zn are being observed due to adoption of straight fertilizers and lower use of bulky organic manures. Thus, scope of complex fertilizers and micronutrients containing fertilizers is increasing particularly in high-density cropping systems. Two crop rotations, rice–wheat in eastern part of Uttar Pradesh and sugarcane-ratoon–wheat in western part of Utttar Pradesh are predominant. Potato crop is grown in an area of 2.142 million ha in India, having 51.31 m tonnes production at an average yield of 23.96 t/ha at national level (DAC, 2018). It can be profitably grown as an intercrop with autumn sugarcane. Farmers are not leaving their fields fallow even though productivity and profitability can be increased due to selection of potato as vegetable crop in sugarcane-based system.

Soil-quality parameters viz., soil organic carbon, soil microbial biomass carbon, soil microbial biomass nitrogen and soil respiration are affected through biological activities. Imbalanced use of nutrients besides affecting crop growth and yields also influence soil physical, chemical and biological properties adversely. New fertilizer compounds consisting of NPKSZn have also been developed. Sulphur is increasingly being recognized as the fourth major plant nutrient after nitrogen, phosphorus and potassium. The importance of S in agriculture is being increasingly emphasized and its role in crop production is well recognized (Shukla and Lal, 2004; Shukla and Lal, 2007). A shortage in the S supply to the crops lowers the utilization of the available soil nitrogen, thereby increasing nitrate leaching (Likkineni and Abrol, 1994).

Keeping above points in view, the present investigation was aimed to assess the effect of balanced fertilization on growth and yield of potato and sugarcane in intercropping/ sequential cropping system and to determine the effect of new Zn- and S-containing fertilizer compounds on soil quality parameters and sustaining the productivity of sugarcane and potato.

MATERIALS AND METHODS

A field experiment was conducted for 2 cropping seasons during October 2015–December 2017 at ICAR-Indian Institute of Sugarcane Research, Lucknow, (26%.56‘ N, 26%.52‘ E and 111 m above mean sea–level), Uttar Pradesh, with semi-arid subtropical climate having dry hot summer and cold winter. The soil was sandy loam (16.2 clay, 25.6% silt and 58.2% sand) of Indo-Gangetic alluvial origin very deep (>2 m), well drained, flat and classified as non-calcareous mixed hyperthermic *‘Udic Ustochrept’*. The initial soil *p*H (7.32) was determined by 1:2.5 soil water suspension by a glass electrode pH meter before experimentation.

Before planting the crop, surface (0 to 15 cm depth) soil was sampled by core sampler (8 cm diameter) from 5 different sites in the field. These samples were pooled together, and the representative homogenous sample was analyzed for organic carbon (Walkley and Black method 0.66%), available N ($KMNO_4$ method), 0.5 M sodium bicarbonate ($NaHCO_3$, *p*H 8.5) extractable P and 1 N NH_4OAC-extractable K, as reported by Jackson (1973). The initial available N, P_2O_5 and K_2O of the experimental soil were 260.29, 27.61, 400.79 kg/ha respectively. Initial values of hot- water-soluble sulphur and DTPA-extractable zinc in soil were determined as 67.47 and 3.70 mg/kg soil. Planting of sugarcane early-maturing variety ‘CoPk05191’ was done using 38,000 three-bud cane sett/ha was done on 20 October 2015 and 22 October 2016 in sugarcane + potato intercropping system during the first and second cropping season, respectively. Potato variety ‘Kufri Anand’ was intercropped in 1 : 1 row arrangement with autumn sugarcane. However, sole potato was planted at 60 cm × 15 cm spacing in potato–sugarcane sequential system. After harvesting of potato, sugarcane planting was done at 75 cm row spacing in these plots on 25 February 2016 and 22 February 2017 in both the cropping seasons. The recommended doses of N, P and K for sugarcane (150, 26.2 and 49.8 kg/ha) and potato (175, 34.93 and 83 kg/ha) were followed. Besides, sulphur @ 40 kg /ha and Zn @ 5 kg/ha were also applied as per treatment. Total N in both the crops were split 3 times during tillering stage in sugarcane and up to 70 days after planting in potato. However, phosphorus, potassium, sulphur and zinc were applied basal during planting of both the crops. The recommended package of practices for both the crops was followed. The potato and sugarcane crops were harvested on 15 February 2016 and 15 January 2017, respectively, during the first season. Corresponding dates of harvesting during 2 cropping season were 18 February 2017 and 25 December 2017, respectively. Nine treatments, viz. T_1, Absolute control (No NPK); T_2, recommended dose of NPK; T_3, recommended dose of NPKS; T_4, recommended dose of NPKSZn; T_5, recommended dose of NPK+ FYM; T_6, recommended dose of P through NPS1 (additional N and K through conventional sources); T_7, recommended dose of P through NPS 2 (additional N and K through conventional sources); T_8, recommended dose of P through NPSZn (additional N and K through conventional sources); T_9, recommended dose NPK + sulphur and Zn equivalent to NPSZn supplied in T_8 were allocated in 2 cropping systems (C_1, potato-sugarcane and C_2, sugarcane + potato) under 3 replications in split-plot design. Experimental plot size was kept to 8 m × 6 m. The nutrient composition of three products, viz. NPS-1, NPS-2 and NPSZn tested in given below.

Evaluation material	Composition	Nutrients	Products
Grade I	19:38:00:07	(N:P:K:S)	NPS-1
Grade II	12:46:00:07	(N:P:K:S)	NPS-2
Grade III	12:45:00:05:01	(N:P:K:S:Zn)	NPSZn

Soil microbial biomass C (SMBC) and soil microbial biomass N (SMBN) were determined using the chloroform fumigation-incubation method (Jenkinson and Powlson, 1976). Soil respiration (mineralizable C) was determined by the cumulative CO_2-C evolved after 30 days at 28 ± 2°C and it was considered the basal respiration. Unfumigated soil (50 g) was incubated in 1-litre air-tight sealed jars along with a small flask containing 10 ml 1 M NaOH. Evolved CO_2-C trapped in NaOH was measured after 7 days by titrating it with 1 M HCl. At harvesting of sugarcane crop, 5 plants were randomly selected from each plot for estimation of growth attributes and juice quality parameters. Juice purity and sugar yield were calculated by the following formulae:

$$\text{Juice purity (\%)} = \frac{\text{Sucrose percent in juice} \times 100}{\text{Corrected brix}}$$

CCS (%) = {S–(B–S) × 0.4} × 0.73

CCS (t/ha) = CCS (%) × cane yield (t/ha)/100

Where S is the sucrose per cent in juice, B is the corrected brix and CCS is commercial cane sugar.

Sucrose (%) in juice was determined as per the method described by Meady and Chen (1977). Sugar yield was calculated after multiplying CCS (%) and cane yield. Observations on growth and yield attributes of potato were also recorded at the harvesting stage. Whole plot of potato was harvested and tuber yield was determined. Mean tuber weight was determined by harvesting of 1 m row length in each plot.

Nitrogen us efficiency (NUE) was calculated as:

$$\text{NUE (\%)} = \frac{\text{N uptake by plant with N application–N uptake by plant without N application)}}{\text{The amount of N applied}} \times 100$$

where NUE is nitrogen-use efficiency

The mean data of 2 cropping seasons for sugarcane and potato crops were pooled and statistically analyzed through online authenticated SAS software available at the ICAR-Indian Agricultural Statistics Research Institute:

RESULTS AND DISCUSSION

Soil microbial biomass carbon and nitrogen, soil respiration rate and organic carbon

Soil microbial biomass carbon (SMBC), Soil microbial biomass carbon nitrogen (SMBN), soil respiration rate and organic carbon were determined at the harvesting of potato and sugarcane crops in both the cropping systems (Tables 1, 2). Potato–sugarcane cropping system proved better in increasing soil microbial biomass carbon and soil respiration rate after harvesting of potato and sugarcane crops. Cropping system could not affect soil organic carbon (SOC) significantly. Higher, soil microbial biomass nitrogen was obtained after harvesting of potato and sugarcane crops in potato–sugarcane sequential system. Thus, sequential cropping improved SMBC and SMBN, whereas reverse trend was obtained for soil respiration rate. Soil organic carbon did not differ significantly with the cropping system. Higher values of SMBC, soil respiration and SMBN were determined after harvesting of potato as compared to sugarcane crop in the system. Thus, potato–sugarcane sequential system proved its superiority to potato + sugarcane intercropping system.

Nutrient management played an important role in sustaining soil fertility. Balanced application of NPSZn compound fertilizer improved the SMBC, SOC, soil respiration and SMBN. The plots received no fertilizer showed lowered values of all these soil parameters. The higher SMBC was observed after harvesting of potato than harvesting of sugarcane (Table 1). Mean soil organic carbon (0.87%) was also reduced by 17.24% after harvesting of sugarcane (Table 1) as compared to harvesting of potato. Integrated application of NPK and FYM increased the soil quality parameters as compared to other compounds of fertilizer. The highest soil microbial biomass carbon (140.8 mg C/kg soil/ day) was determined through application of recommended dose of P through NPSZn after harvesting of potato, whereas after harvesting of sugarcane, application of NPKSZn (T_4) was found the best (136.9 mg C/ kg soil/ day) among all the treatments. In general, SMBC rate declined after harvesting of sugarcane (in December) as compared to harvesting of potato in February. In both the cropping systems, higher mean soil organic carbon (0.87 %) was found after harvesting of potato than sugarcane (0.72%). Application of FYM with recommended fertilizer (NPK) significantly increased SOC (0.92%, Table 1) after harvesting of potato. Although in similar treatment, after harvesting of sugarcane, SOC declined and reached the level of 0.76%. Soil respiration rate also increased with increasing application of various kinds of nutrients. Balanced fertilization through NPK + FYM increased soil respiration rate up to 63.35 (mg Co_2-C/ kg soil/day). Soil respiration rate and SMBN decreased after harvesting of sugarcane. Improved microbial activity during crop growth also improved all the soil quality parameters after harvesting of potato in both the cropping systems. Incorporation of potato crop residue and application of fertilizers for potato crop along with optimum temperature regime during spring season (February) favoured the soil microbial activities

Table 1. Soil microbial biomass carbon and soil carbon at different stages in sugarcane and potato-based cropping system

Treatment	Soil microbial biomass carbon (mg C/kg soil/day)		Soil organic carbon (%)	
	After harvesting of potato (February)	At harvesting of sugarcane (December)	After harvesting of potato (February)	At harvesting of sugarcane (December)
Cropping system				
C_1, Potato–sugarcane	122.5	124.9	0.87	0.71
C_2, Potato + sugarcane	109.5	116.2	0.87	0.73
SEm±	1.36	2.82	0.013	0.012
CD (P=0.05)	4.06	NS	NS	NS
*Nutrient management**				
T_1, Absolute control (No N, P, K)	93.85	107.6	0.86	0.69
T_2, Recommended dose of N, P, K	99.75	112.4	0.87	0.72
T_3, Recommended dose of N,P,K,S	99.75	117.3	0.89	0.72
T_4, Recommended dose of N, P, K, S, Zn	117.3	136.9	0.83	0.76
T_5, Recommended dose of NPK + FYM	131.9	141.7	0.92	0.74
T_6, Recommended dose of P through NPS-1	99.75	112.4	0.86	0.75
T_7, Recommended dose of P through NPS-2	102.7	117.3	0.87	0.71
T_8, Recommended dose of P through NPSZn	140.8	117.3	0.87	0.73
T_9, Recommended dose of NPK + sulphur and Zn equivalent to NPSZn supplied in T_8	134.9	122.2	0.86	0.73
SEm±	0.84	2.92	0.014	0.012
CD (P=0.05)	2.37	8.84	0.042	0.036

*The recommended doses of N, P and K for sugarcane (150, 26.2 and 49.8 kg/ha) and potato (175, 34.93 and 83 kg/ha). Besides, sulphur @ 40 kg /ha and Zn @ 5 kg/ha as per treatments; NPS, 1 contains19 : 38 : 00 : 07 N : P : K : S; NPS 2 contains 12 : 46 : 00 : 07 (N : P : K: S) and NPSZn contains 12 : 45 : 00 : 05 : 01 N : P : K : S : Zn

Table 2. Soil respiration and microbial biomass nitrogen in sugarcane-and potato-based cropping system

Treatment	Soil respiration (CO_2-C/g soil/day)		Soil microbial biomass nitrogen (NH_4-N/g soil/day)	
	After harvesting of potato (December)	At harvesting of sugarcane (February)	After harvesting of potato (December)	At harvesting of sugarcane (February)
Cropping system				
C_1, Potato–sugarcane	50.46	22.98	11.14	7.64
C_2, Potato + sugarcane	55.13	25.91	10.35	6.88
SEm±	1.30	0.081	0.23	0.084
CD (P=0.05)	3.83	0.24	0.68	0.27
*Nutrient management**				
T_1, Absolute control (No N, P, K)	47.5	19.8	8.44	6.38
T_2, Recommended dose of N, P, K	50.15	19.8	9.89	6.79
T_3, Recommended dose of N, P, K, S	52.8	24.2	10.98	6.94
T_4, Recommended dose of N, P, K, S, Zn	52.8	24.2	11.79	7.43
T_5, Recommended dose of NPK + FYM	63.35	28.6	12.73	8.75
T_6, Recommended dose of P through NPS-1	47.5	24.2	10.06	7.48
T_7, Recommended dose of P through NPS-2	50.15	24.2	10.84	8.55
T_8, Recommended dose of P through NPSZn	58.10	26.4	10.73	6.41
T_9, Recommended dose of NPK + sulphur and Zn equivalent to NPSZn supplied in T_8	52.8	28.6	11.26	6.61
SEm±	1.10	0.47	0.15	0.13
CD (P=0.05)	3.02	1.4	0.46	0.36

after harvesting of potato, thus making higher nutrient availability to further succeeding/ intercropped sugarcane crop (Shukla *et al.,* 2008)**.**

Potato–sugarcane sequential cropping system increased soil microbial biomass carbon and respiration rate after harvesting of both the crops. Soil microbial biomass is the main driving force in the decomposition of organic materials and is frequently used as an early indicator of changes in soil properties resulting from soil management and environment stresses in agricultural ecosystems.

After harvesting of component crop, potato haulm was incorporated in the sugarcane field. Potato–sugarcane system improved soil physical environment. The chemical and microbiological activities in sequential cropping system superseded intercropping system. Declined soil respiration rate in sequential cropping resulted in increased soil microbial biomass carbon and nitrogen. However, soil organic carbon could not be significantly affected by cropping systems. Balanced application of NPSZn in compound fertilizer improved the soil microbial biomass carbon, SOC, respiration and SMBN. These nutrients are required to improve the growth and yield crop. Better nutrient availability improved root growth resultantly growth and yield of potato and sugarcane crops. Improvement in availability of nutrients and soil organic carbon during grand growth and reduction at the harvesting stage of sugarcane were observed. Although potato is heavy feeder of nutrients, higher residual fertility improved the nutrients level in soil. Integrated application of NPK and FYM improved the soil quality parameters. Application FYM improved the soil physical conditions besides supplying slow release of nutrients for longer period. Farmyard Manure is a good source of nutrients and contributed towards build up of organic matter in soil. It helps improve and conserve the fertility of soil (Pratap *et al*., 2016) Integration with organic and inorganic fertilizer provided C for growth of microbes. Improved physical and biological conditions made higher availability of nutrients to crop plants. Higher SOC after harvesting of potato as compared to sugarcane led higher nutrients availability. After harvesting of sugarcane, SOC was almost stabilized. Application of FYM provided congenial environment to microbes and also increased soil respiration rate (Shukla *et al*., 2008).

Available nutrients in soil

Available N, P_2O_5, K_2O, S and Zn were determined after harvesting of sugarcane in both the cropping systems (Table 3). Cropping Systems affected the nutrient status of soil significantly. Available nitrogen and Zn in 0–15 cm soil depth were slightly higher in potato + sugarcane intercropping system than potato-sugarcane system. However, potato–sugarcane sequential system was found superior to intercropping system with respect to available P_2O_5, K_2O and S. Nutrient management caused significant effect on available nutrients status of soil. Among all the treatments, recommended dose of NPK and FYM significantly left the

Table 3. Available nutrients status after harvesting of sugarcane in sugarcane- and potato-based cropping system

Treatment	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	Available S (mg/kg soil)	Available Zn (mg/kg soil)
Cropping system					
C_1, Potato–sugarcane	178.3	22.48	309.2	61.79	3.06
C_2, Potato + sugarcane	185.4	22.3	253.2	50.64	3.15
SEm±	2.48	0.41	7.56	1.72	0.021
CD (P=0.05)	7.28	1.20	22.76	5.38	0.06
Nutrient management					
T_1, Absolute control (No N, P, K)	163.4	20.66	319.6	44.43	2.16
T_2, Recommended dose of N, P, K	179.6	20.83	314.9	48.47	3.01
T_3, Recommended dose of N, P, K, S	179.0	21.88	300.7	55.39	2.87
T_4, Recommended dose of N, P, K, S, Zn	185.0	22.50	317.3	63.26	2.96
T_5, Recommended dose of NPK + FYM	199.4	23.81	348.1	58.52	2.42
T_6, Recommended dose of P through NPS-1	168.6	23.03	305.4	55.45	2.51
T_7, Recommended dose of P through NPS-2	184.7	23.02	354.4	52.69	2.60
T_8, Recommended dose of P through NPSZn	187.1	23.03	345.4	62.36	3.45
T_9, Recommended dose of NPK + sulphur and Zn equivalent to NPSZn supplied in T_8	189.1	23.19	374.6	65.38	2.96
SEm±	2.28	0.36	6.33	1.56	0.014
CD (P=0.05)	6.82	1.10	18.97	4.51	0.04

*The recommended doses of N, P and K for sugarcane (150, 26.2 and 49.8 kg/ha) and potato (175, 34.93 and 83 kg/ha). Besides, sulphur @ 40 kg /ha and Zn @ 5 kg/ha as per treatments; NPS, 1 contains19 : 38 : 00 : 07 N : P : K : S; NPS 2 contains 12 : 46 : 00 : 07 (N : P : K : S) and NPSZn contains 12 : 45 : 00 : 05 : 01 N : P : K : S : Zn higher status of residual level of nutrients (199.4 kg N, 23. 81 kg P_2O_5 and 348.1 kg K_2O/ha) after harvesting of sugarcane crop in both the systems. Sulphur application along with recommended dose of P (T_8)/recommended dose of NPK (T_9)/ recommended dose of NPK Zn (T_4) exhibited higher status of available S after harvesting of crop. Available Zn in soil was the highest where Zn was applied with NPS (T_8).

Available nitrogen and zinc in soil under intercropping system were higher than sequential cropping system. This was owing to improved nutrient-use efficiency in potato + sugarcane intercropping system. Higher amounts of P, K and S in soil under potato–sugarcane sequential cropping system was recorded owing to higher amounts of potato crop residues produced and incorporated in to the soil. Thus, soil fertility in potato–sugarcane system improved as compared to potato + sugarcane system. Balanced fertilization through NPKSZn improved the crop growth as well as soil fertility.

Yield and yield attributes of potato and sugarcane

The statistically at par yield (32.98 t/ha: Table 4) of potato was harvested in potato–sugarcane sequential cropping system as compared to potato + sugarcane (31.48 t/ha) system. Nutrient management played an important role in increasing potato yield ranged from 21.75 to 36.22 t/ha in different treatments. The lowest potato yield (21.75 t/ha) was harvested in absolute control (T_1). Recommended NPK (T_2)/ recommended NPKS (T_3) were found superior to the absolute control (T_1) and resulted in significantly higher yields in the range of 30.67–31.33 t/ha. All other treatments in enhancing potato yield were at par except T_1, T_2 and T_3. Mean tuber weight was not adversely affected by the cropping systems. Nutrient management significantly influenced tuber size/ weight. The lowest mean tuber weight (39.96 g) was recorded with the absolute control (No NPK). Application of recommended NPK significantly improved the individual tuber weight (52.93 g). The highest mean tuber weight (56.93 g) was recorded with the application of recommended NPK + S and Zn equivalent to NPSZn applied in T_8. The recommended NPK + FYM (T_5) were found at par with T_9.

The highest potato yield (Table 4) in potato–sugarcane system was obtained owing to zero competition with sugarcane crop. Potato and sugarcane intercropping did not affect the potato yield significantly. Nutrient management involving balanced fertilization improved the potato yield significantly. Individual tuber weight was significantly influenced by balanced fertilization. Application of NPK + S and Zn and NPK + FYM improved the individual tuber weight and potato yield. The highest sugarcane yield was obtained in potato + sugarcane system. Intercropping in autumn (October) planted sugarcane increased tillering and growth period as compared to sequential cropped cane. However, during November to January, because of winter months ($t_{max.}$ 26.2°C and t_{min} 6.4° C), sugarcane crop remained dormant and potato crop attained the maximum growth. Thus, competition for nutrients and moisture between sugarcane and potato was minimized. This resulted in higher sugarcane and sugar yields (Verma *et al.,* 1996; Shukla, 2005). Higher nitrogen-use efficiency in potato + sugarcane was owing to effective utilization of N in intercropping system and higher cane yield produced.

Balanced fertilization in the system improved the yield

Table 4. Mean potato yield (t/ha) and average tuber weight (g)

Cropping system (CS)	Nutrient management*									CS (Means)
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	
	Potato yield (t/ha)									
C_1, P–S	22.50	31.33	32.83	34.83	33.83	33.67	34.17	35.83	37.83	32.98
C_2, P + S	21.00	30.00	29.83	33.93	35.50	32.23	33.03	33.17	34.60	31.48
Subplot Mean	21.75	30.67	31.33	34.38	34.67	32.95	33.60	34.50	36.27	GM=32.23
SEm± (CS): 0.63 CD(CS) : NS; SEm± (NM) : 1.0 CD(NM) : 3.35 ; SEm± (CS × NM) : 1.50 CD: (CS × M) : 4.62										
	Average tuber weight (g)									
C_1, P–S	42.87	53.87	56.00	56.17	58.00	54.83	54.33	55.00	56.33	54.16
C_2, P + S	37.05	52.00	53.67	53.00	54.83	54.00	54.67	55.33	56.73	52.37
Subplot Mean	39.96	52.93	53.83	54.58	56.42	54.42	54.50	55.17	56.53	GM: 53.26
SEm± (CS): 0.81 CD(CS) : NS; SEm± (NM) : 0.74 CD(NM) : 2.45 ; SEm± (CS × NM) : 1.28 CD: (CS × M) : 4.75										

T_1, Absolute control (No NPK); T_2, recommended NPK; T_3, recommended NPKS; T_4, recommended NPKSZn; T_5, recommended NPK + FYM; T_6, recommended P through NPS 1 (compensate N and K through conventional sources); T_7, recommended P through NPS 2 (compensate N and K through conventional sources); T_8, Recommended P through NPSZn (compensate N and K through conventional sources); T_9, recommended NPK + Sulphur and Zn equivalent to NPSZn supplied in T_8

and yield attributes (Table 5). Sugarcane yield was the results of higher number of millable canes and individual cane weight. Higher number of millable canes with balanced fertilization was recorded owing to synchronous tillering and greater contribution of primary and secondary tillers to millable canes. Primary and secondary tillers in sugarcane get longer duration for growth and food from stubble. Thus, they turn into millable canes of higher length, diameter and weight (Verma *et al.,* 1996). Sugarcane yield and commercial cane sugar improved with increasing levels of nutrients and uptake by crop plants (Shukla *et al*., 2012).

Significantly higher number of millable canes (119.9 thousand/ha: Table 5) were counted with potato intercropped autumn-planted sugarcane. Autumn-planted cane in potato + sugarcane system was significantly superior to sequential cropped cane in potato–sugarcane system in attaining cane length, diameter, weight, number of internodes per cane and ultimately sugarcane yield. Thus potato + sugarcane system gave higher sugarcane and sugar yields (Table 5). Nitrogen-use efficiency was also higher (45.1%) in potato + sugarcane cropping system as compared to potato - sugarcane system (38.4%).

Nutrient management greatly influenced the growth, yield attributes, sugarcane and sugar yields. Yield attributes and cane yield were decreased in the absolute control (T_1). However, recommended dose of NPK influenced different growth attributes significantly. Application of S and Zn fertilizers increased the number of millable canes. New compounds NPS_2 and NPSZn also improved the production of millable canes significantly. The highest individual cane weight (1,015 g) was recorded with application of recommended NPK + FYM (T_5). The highest individual cane length was recorded in with T_9 (recommended dose of NPK + S and Zn equivalent to NPSZn) treatment, but it was at par with T_8, T_7, T_6, T_5, T_4 and T_3 treatments. Application of FYM increased cane diameter (2.19 cm) with recommended dose of NPK. No significant differences were observed on sucrose content (%) in juice. However, commercial cane sugar influenced greatly with different levels of nutrients. The highest sugar yield (11.60 t/ha) was obtained with application of recommended dose of NPK along with S and Zn application equivalent to NPSZn. However, recommended dose of P through NPSZn was found at par with T_9 treatment. No NPK application (T_1) resulted in the lowest sugarcane (61.6 t/ha) and sugar (6.63 t/ha) yields.

Application of NPS_2 and NPSZn supplied S and Zn to both the crops positively influenced yield attributes. Integrated use of NPK+ FYM improved the individual cane weight. Application FYM improved the cane diameter which positively affected cane weight also. Role of S and

Table 5. Effect of cropping system and nutrient-management schedule on sugarcane yield and quality parameters (pooled data of 2 years)

Treatment	Milliable canes ('000/ha)	Cane weight (g)	Cane length (cm)	No. of Internodes	Cane diameter (cm)	Cane yield (t/ha)	Sucrose % juice	Commercial cane sugar (t/ha)	Nutrient-use efficiency (%) (N)
Cropping system									
C_1, Potato–sugarcane	108.9	928	278.9	22.34	2.01	87.3	15.98	9.48	38.4
C_2, Potato + sugarcane	119.9	983	307.3	22.77	2.10	103.5	17.05	11.86	45.1
SEm±	1.10	11.22	2.60	0.36	0.03	1.40	0.032	0.11	0.62
CD (P=0.05)	3.20	30.56	7.58	NS	NS	4.10	0.10	0.32	1.84
Nutrient management									
T_1, Absolute control (No N, P, K)	97.6	718	263.2	20	1.62	61.6	16.39	6.76	0
T_2, Recommended dose of N, P, K	112.0	970	289.0	21	2.02	93.8	16.47	10.45	35.0
T_3, Recommended dose of N, P, K, S	113.3	990	297.5	22	2.05	97.7	16.9	11.18	42.5
T_4, Recommended dose of N, P, K, S, Zn	120.9	973	297.0	23	2.10	101.6	16.29	11.22	44.0
T_5, Recommended dose of NPK + FYM	114.3	1015	300.0	25	2.19	100.8	16.4	11.17	49.5
T_6, Recommended dose of P through NPS-1	117.4	978	291.5	21	2.09	95.9	16.72	10.83	39.0
T_7, Recommended dose of P through NPS-2	117.8	989	297.5	22	2.12	98.9	16.19	10.81	35.0
T_8, Recommended dose of P through NPSZn	119.7	985	300.0	24	2.17	102.6	16.65	11.60	44.0
T_9, Recommended dose of NPK + Sulphur and Zn equivalent to NPSZn supplied in T_8	117.0	980	302.0	25	2.16	105.6	16.66	11.88	45.0
SEm±	1.64	14.56	3.60	0.60	0.09	2.30	0.05	0.15	0.78
CD (P=0.05)	4.85	43	10.5	1.8	0.27	6.7	0.15	0.42	2.25

*The recommended doses of N, P and K for sugarcane (150, 26.2 and 49.8 kg/ha) and potato (175, 34.93 and 83 kg/ha). Besides, sulphur @ 40 kg /ha and Zn @ 5 kg/ha as per treatments; NPS, 1 contains19 : 38 : 00 : 07 N : P : K : S; NPS 2 contains 12 : 46 : 00 : 07 (N : P : K : S) and NPSZn contains 12 : 45 : 00 : 05 : 01 N : P : K : S : Zn

Zn in improving growth and yield attributes significantly influenced the cane yield (Shukla and Lal, 2007; Hafeez *et al*., 2013).

Thus it could be concluded that intercropping of potato with autumn sugarcane is beneficial with respect to improvement in yields of both the crops as well as nutrient-use efficiency. Application of NPK along with FYM increased the availability of nutrients for longer period during crop growth and left higher amount of residual nutrients after harvesting of sugarcane in both the systems. The highest was obtained with application of recommended dose of NPK along with S and Zn application equivalent to NPSZn. Hence, application of Zn and S either through commercially available fertilizers or through compound fertilizers tested is recommended to increase the crop growth and yield besides sustaining soil fertility.

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