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Changes in soil available NPK in multiple cropping systems based on short duration sugarcane crops relative to a conventional sugarcane cropping system

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Abstract

Changes in soil available NPK were studied in four intensive crop rotations based on short duration (8 months) sugarcane crops (1. short duration plant cane/1st ratoon/2nd ratoon; 2. short duration plant cane/1st ratoon/finger millet/cotton; 3. finger millet/short duration plant cane/1st ratoon/wheat; and 4. finger millet/maize/short duration plant cane/1st ratoon). These rotations were compared with the conventional duration (12 months) sugarcane crop sequence (one plant + one ratoon) in a cycle of 24 months.

Soil available nitrogen (SAN) declined when 100 or 150 kg N ha^{-1} was applied in the short duration sugarcane based systems, but was either maintained or improved at a higher N application rates (200 or 250 kg ha^{-1}). The conventional system showed a sharp decline in SAN of about 14% from its original status at the end of the sequence. Close row spacing (60 cm) of sugarcane improved the soil N level over that in the conventionally spaced rows (90 cm) probably through greater rhizosphere biomass additions.

Available P declined sharply from its original level in the soil in sequence 2, the decline being marked after cotton. In all the other short duration based sequences it was maintained. The conventional system also showed reduced soil available P at the end of the sequence. Soil available K declined in all crop sequences.

Nitrogen uptake was far less than additions made by fertilizer. The actual soil N balance was much lower than the expected balance thus indicating large losses of N from the soil. Phosphorus removal was also less than the additions made and thus there were improvements in the soil available P status at the end of the crop cycle. In all the sequences, there was a negative potassium balance due to greater removal by the various crops when compared to K additions. However, in the system as a whole there were net gains of K as larger amounts were recovered than had been added.

Introduction

Though crop rotations are common in India, fertilizer recommendations are mostly based on individual crop requirements. However, in recent years several cropping system studies have revealed substantial residual effects on the succeeding crops. Hence there is emphasis on the 'cropping system' approach to nutrient management [4]. To practice this approach, a knowledge of the changes in the soil nutrient status under different component crops of a cropping system is essential. This is particularly important when new cropping systems are introduced.

In India presently, short duration sugarcane (*Saccharum officinarum* L.) varieties ripening in about 8 months as opposed to the normal 12 months, are being bred to improve productivity through intensive crop rotations [1, 10]. With such varieties, three crops of sugarcane (one plant + two ratoons) can be grown in 24 months compared to only two crops (one plant + one ratoon) with conventional varieties. Multiple cropping systems involving other rotational crops are also possible. At the Sugarcane Breeding Institute, Coimbatore, various cropping systems were evaluated for their production potential, economics [11], input productivities and effect on soil fertility. In this paper, we report on the available nutrient changes under different cropping systems.

Materials and methods

Field experiments were conducted during 1982–84 at the Sugarcane Breeding Institute, Coimbatore (11°N) on an alfisol. The crop sequences evaluated are listed below:

1. SEQ1 Short duration plant cane – 1st ratoon – 2nd ratoon
2. SEQ2 Short duration plant cane – 1st ratoon – finger millet (*Eleucine coracana* Gaertn.) – cotton (*Gossypium hirsutum* L.)

Table 1. Quantities of fertilizer nutrients (kg ha^{-1}) applied to different cropping systems at different N rates to sugarcane

Crop sequence	Nutrient element	Component crop of the sequence and nutrient dosage				Total
SEQ 1		Plant cane	1st ratoon		2nd ratoon	
	N	100	100		100	300
		150	150		150	450
		200	200		200	600
		250	250		250	750
	P	33	33		33	99
	K	100	100		100	300
SEQ 2		Plant cane	1st ratoon	Finger millet	Cotton	
	N	100	100	100	75	375
		150	150	100	75	475
		200	200	100	75	575
		250	250	100	75	675
	P	33	33	22	16	104
	K	100	100	42	42	284
SEQ 3		Finger millet	Plant cane	1st ratoon	Wheat	
	N	100	100	100	120	420
		100	150	150	120	520
		100	200	200	120	620
		100	250	250	120	720
	P	22	33	33	26	114
	K	42	100	100	33	275
SEQ 4		Finger millet	Maize	Plant cane	1st ratoon	
	N	100	150	100	100	450
		100	150	150	150	550
		100	150	200	200	650
		100	150	250	250	750
	P	22	33	33	33	121
	K	42	31	100	100	273
SEQ 5		Plant Cane			1st ratoon	
	N	225			225	450
	P	33			33	66
	K	100			100	200

3. SEQ3 Finger millet – short duration plant cane – 1st ratoon – wheat (*Triticum aestivum* L.)
4. SEQ4 Finger millet – maize (*Zea mays* L.) – short duration plant cane – 1st ratoon
5. SEQ5 Normal duration plant cane – 1st ratoon

The short duration sugarcane crops in each sequence were grown at 90 and 60 cm row spacings and at rates of 100, 150, 200 and 250 kg N ha^{-1}. All the other crops were grown and fertilized according to normal practice. The quantities of nutrients applied by fertilizers to the various crops are shown in Table 1. The crop sequences were arranged in a randomised block design with three replications. The short duration sugarcane in each sequence was arranged in a split-plot layout to facilitate spacing (main plot) and nitrogen (sub-plot) treatments. The plot size was 7.2 × 6.1 m. The crop cycles were run from February 1982 to February 1984.

Soil samples were collected from the top 0–20 cm layer before the commencement of the experiment from 15 blocks (5 sequences × 3 replications) to determine the initial soil nutrient status. Later, soil samples were collected from each plot after each crop in each sequence. The samples were air dried and crushed to pass through a 2 mm seive. Available N was determined by the alkaline permanganate method [9], available P, colorimetrically by Olsen's method [3] and available K by the ammonium acetate extract-flame photometer method [8]. Plant samples (5 canes at random, 5 plants in other crops) were collected at harvest, separated into component parts (eg. leaf, sheath and stalk in sugarcane), oven dried at 70°C to constant weight, ground in a Wiley mill and analysed for NPK content following standard procedures [5]. The NPK uptake of each crop was calculated based on the total above ground biomass produced. Data were statistically analysed for each crop. Available nutrient balances were worked out as follows:

Nutrient balance = Y – (x – a) – N, where Y = total amount of nutrient removed by the crops in the sequence, x = initial soil status of the available nutrient element, a = final soil status of the nutrient element and N = total quantity of nutrient added [6, 12].

Results and discussion

In various crop sequences, the highest cane yields of short duration sugarcane plant and ratoon crops were generally attained from the 60 cm row spacing and 200 or 250 kg N ha^{-1} treatment combinations (Table 2). The succeeding crop yields were influenced by the treatments applied to sugarcane. The varying crop yields influenced available NPK in the soil and *vice versa*.

Soil available nitrogen (SAN)

The mean soil available N content (Table 3), declined after the sugarcane plant crop in SEQ 1, but increased slightly after the first ratoon. The SAN level was maintained at N rates of 200 and 250 kg ha^{-1} but declined at the 150 and 100 kg ha^{-1} rates after each crop. These differences were less marked after the second ratoon. The different row spacings did not influence SAN status. Spacing and nitrogen interactions were not significant.

In SEQ 2, the mean SAN status was similar to SEQ 1 up to the end of the first ratoon. A further increase in mean SAN was observed after finger millet followed by a decline after cotton. After finger millet, where 150 or 200 kg N ha^{-1} had been applied to the preceding sugarcane crop, a higher SAN level was observed while there was slight decline in SAN at the 100 kg N ha^{-1} application rate. A higher SAN value was observed where the preceding sugarcane crop had been closely spaced (60 cm). This was possibly because of the large amount of crop residue left behind by the closely spaced sugarcane. The SAN level further declined after cotton where the lower rates of N fertilizer were applied to the preceding cane crop, while at the 250 kg N ha^{-1} rate, SAN improved slightly.

In SEQ 3, after the first crop of finger millet, the mean SAN level improved from that obtained originally. After the succeeding plant cane crop, a further increase was observed in mean SAN level. This increase was due to the increase in SAN at N application rates of 150–250 kg ha^{-1} and close spacing (60 cm) of plant cane. After the first ratoon, the mean SAN declined from the level observed after the plant crop, but was

Table 2. Crop yields (t ha^{-1}) in the cropping systems based on short duration sugarcane

Sequence	Treatment to sugarcane[a]	Component crops and their yields			
SEQ 1			Plant cane	1st ratoon	2nd ratoon
	S_1N_1		65.5	60.7	41.4
	S_1N_2		80.4	76.5	55.0
	S_1N_3		89.4	85.4	51.2
	S_1N_4		84.4	77.9	42.7
	S_2N_1		70.4	70.7	38.6
	S_2N_2		86.5	83.5	52.2
	S_2N_3		101.5	96.4	56.8
	S_2N_4		100.1	93.7	51.8
SEQ 2		Plant cane	1st ratoon	Finger millet (Grain)	Cotton (Kapas)
	S_1N_1	63.5	63.1	3.2	3.7
	S_1N_2	80.4	76.6	3.6	3.8
	S_1N_3	88.3	88.9	3.7	3.8
	S_1N_4	85.4	83.3	3.6	4.0
	S_2N_1	71.4	70.8	3.7	3.7
	S_2N_2	86.1	76.7	3.8	3.9
	S_2N_3	102.5	93.1	3.8	4.1
	S_2N_4	100.0	92.4	3.7	3.9
SEQ 3		Finger millet[b] (Grain)	Plant cane	1st ratoon	Wheat (Grain)
	S_1N_1	4.0	70.4	61.7	1.2
	S_1N_2	4.0	86.1	78.5	1.3
	S_1N_3	4.0	85.4	86.7	1.5
	S_1N_4	4.0	93.1	78.3	1.7
	S_2N_1	4.0	74.1	65.0	1.4
	S_2N_2	4.0	102.3	79.0	1.6
	S_2N_3	4.0	104.5	92.0	1.7
	S_2N_4	4.0	100.2	90.3	1.6
SEQ 4		Finger millet[b] (Grain)	Maize[b] (Grain)	Plant cane	1st ratoon
	S_1N_1	4.0	3.8	62.8	51.9
	S_1N_2	4.0	3.8	68.9	75.5
	S_1N_3	4.0	3.8	82.4	81.7
	S_1N_4	4.0	3.8	98.0	87.3
	S_2N_1	4.0	3.8	62.4	74.0
	S_2N_2	4.0	3.8	73.8	86.0
	S_2N_3	4.0	3.8	95.5	90.4
	S_2N_4	4.0	3.8	102.2	87.5
SEQ 5		Plant cane		1st ratoon	
		103.1		100.5	

[a] Row spacing (cm): S_1-90, S_2-60
N rates (kg ha^{-1}): N_1-100, N_2-150, N_3-200, N_4-250
[b] Finger millet in SEQ 3 and 4, and maize in SEQ 4 were bulk crops; mean yields are given.

still higher than the original mean level. A further decline in SAN occurred after wheat, but at the 200 kg N ha^{-1} rate, there was slight improvement over the original status.

There was an increase in mean SAN after finger millet in SEQ 4, which then declined after maize to below the original soil value. Maize thus appeared to have caused SAN depletion. Following maize, when short duration sugarcane was grown with different rates of N, marked improvement occurred in SAN after the plant crop at the high rates of N, while a pronounced

Table 3. Changes in soil available N in crop sequences based on short duration sugarcane

Sequence and stage	N status (mg kg^{-1})								Mean
	N rates (kg ha^{-1}) to sugarcane					Spacing of sugarcane (cm)			
	100	150	200	250	LSD (0.05)	90	60	LSD (0.05)	
At the beginning[c]									81
SEQ 1									
After plant cane	72	76	78	78	6	77	76	NS	76
After 1st ratoon	74	78	80	82	6	78	79	NS	79
After 2nd ratoon (Final)	76	78	79	79	NS	79	78	NS	78
SEQ 2									
After plant cane	71	76	78	79	5	76	75	NS	76
After 1st ratoon	74	77	80	83	6	77	79	NS	78
After finger millet	73	79	84	82	4	77	82	5	79
After cotton (Final)	70	75	83	82	6	75	79	4	77
SEQ 3									
After finger millet[d]									85
After plant cane	85	91	88	85	5	86	89	NS	87
After 1st ratoon	80	82	84	86	5	80	86	6	83
After wheat (Final)	79	79	85	84	4	80	83	NS	82
SEQ 4									
After finger millet[d]									85
After maize									77
After plant cane	70	80	81	87	4	75	84	6	80
After 1st ratoon (Final)	73	78	86	83	5	79	81	NS	80
SEQ 5									
After plant cane[d]									82
After 1st ratoon (Final)[d]									70

[c] mean of 15 samples (5 sequences × 3 replications)
[d] mean of 3 replications each with 8 samples
NS = Not Significant

decline occurred at the low rate (100 kg ha^{-1}). A significant improvement in SAN was obtained under close spacing, despite greater removal of N by the closely spaced cane. This improvement may have been due to larger amounts of residue present in the soil under close spacing. After the first ratoon crop, with further N addition, mean SAN remained more or less unchanged, but SAN improved markedly at 200 kg N ha^{-1} and slightly at 250 kg N ha^{-1} over the initial status.

In the conventional system (SEQ 5) practically no change from the original SAN value occurred after the plant crop, but after the first ratoon, there was a sharp decline in SAN.

From the above results, it is clear that generally SAN declined under the lower rates of N applied to sugarcane in the different cropping systems; it was maintained at higher N rates in SEQ 1, and improved in other sequences, but declined sharply in the conventional system. With optimum rates of N fertilizer application, all the short duration sugarcane based cropping systems either maintained or improved SAN, while the conventional two-crop sequence depleted SAN. In the short duration sugarcane based multiple cropping systems more N fertilizer was added and more crop residues went into the soil. This is why there was little or no depletion of SAN in these systems.

Soil available P (SAP)

After the plant cane crop in SEQ 1, there was a marked decline in the mean SAP value (Table 4). The SAP status apparently did not vary due to different rates of N or different row spacings. After the first ratoon crop in the sequence, a further decline in the SAP was observed, reductions being greater where high N application rates (200–250 kg N ha^{-1}) produced higher cane

Table 4. Changes in soil available P in crop sequences based on short duration sugarcane

Sequence and stage	Available P ($mg\,kg^{-1}$) status								Mean
	N rates ($kg\,ha^{-1}$) to sugarcane					Spacing of sugarcane (cm)			
	100	150	200	250	LSD (0.05)	90	60	LSD (0.05)	
At the beginning[c]									16
SEQ 1									
After plant cane	12	13	13	12	NS	12	13	NS	13
After 1st ratoon	11	11	9	9	1	10	11	1	10
After 2nd ratoon	15	16	18	18	2	15	18	2	17
SEQ 2									
After plant cane	12	12	12	13	NS	12	12	NS	12
After 1st ratoon	12	11	10	10	1	10	12	1	11
After finger millet	7	10	10	10	1	9	9	NS	9
After cotton	4	6	7	7	1	6	6	NS	6
SEQ 3									
After finger millet[d]									15
After plant cane	14	15	14	15	NS	15	14	NS	14
After 1st ratoon	14	15	14	14	NS	13	15	2	14
After wheat	13	18	20	20	2	17	19	1	18
SEQ 4									
After finger millet[d]									15
After maize[d]									11
After plant cane	12	12	9	9	1	9	11	1	10
After 1st ratoon	14	16	16	14	1	13	16	2	15
SEQ 5									
After plant cane[d]									11
After 1st ratoon[d]									12

[c] mean of 15 samples (5 sequences × 3 replications;
[d] mean of 3 replications each with 8 samples
NS = Not Significant

yields. After the second ratoon, there was upward trend in available P to a level higher than that originally present, with a greater increase under close spacing and higher N application rates. The second ratoon yields were about 40 per cent lower than those of the first two crops and thus P removal was much less.

In SEQ 2, up to the end of the first ratoon crop, the trend was similar to that in SEQ 1. Another decline in P occurred after finger millet, and after cotton, there was a further sharp decline in the SAP level. Uptake of P from this system was greater than that from other systems. Both cotton and the preceding finger millet removed substantial amounts of P. The decline in the SAP might also have been due to greater fixation of applied phosphorus in the top soil (the soils are known to be P fixing) as cotton being a deep rooted crop may have derived its P requirement from the deeper soil layer.

In SEQ 3, SAP declined slightly after finger millet and little change was observed after the succeeding sugarcane plant crop. After the first ratoon crop, there was reduction under wider spacing (90 cm) and after wheat, SAP again increased to a level greater than that present originally, particularly where high rates of N had been applied to the sugarcane crops. Improvement in SAP after wheat may have been due to lower P uptake by the crop, as the yield was less (Table 2).

A decline in SAP was observed in SEQ 4 until the end of the plant cane crop. But after the first ratoon crop, SAP status was restored. Since P has a considerable residual effect, the ratoon might have been benefitted from additions made to the preceding crops. In sequence 5, SAP declined sharply after the plant crop, but improved a little after the first ratoon crop.

Generally, the results indicated significant changes in SAP from season to season. Such changes in P status may be associated with changes in organic matter, soil reaction, etc. Improvement in the SAP status after most ratoon crops suggests that P status in the soil was being maintained in the soil during the cropping cycles. This could be due to a higher requirement for P during establishment of plant cane while ratoon cane has lower P requirement, or the P supplied to the plant crop may have been sufficient for several crops.

Soil available K (SAK)

In general SAK had declined by the end of all sequences. After the plant crop in SEQ 1, there was a slight reduction, and after the first ratoon, a further reduction occurred. This trend continued and at the end of the sequence, a 28% decline in mean SAK had occurred. A larger decline was observed where higher rates of N were applied to sugarcane. After the plant crop and the first ratoon, differences due to different row spacings were not significant, but after the second ratoon a greater decline in K had occurred where the cane was closely spaced. A similar decline in SAK was observed in SEQ 2 also. Higher N rates and close row spacing which resulted in higher yields were associated with greater K removal.

In SEQ 3 the mean SAK declined after finger millet and again after the plant cane crop, followed by an upward trend after the first ratoon. This trend however did not continue and there was a further decline in SAK after the wheat crop. The reduction in SAK was about 40% at the close spacing and 200 kg N ha^{-1} combination. In SEQ 3, significant effects of N and spacing treatments on SAK were found. Increasing N applications up to optimum yield decreased the SAK status. Depletion was even greater under close spacing. An almost similar pattern was

Table 5. Changes in soil available K in crop sequences based on short duration sugarcane

Sequence and stage	Available K status (mg kg^{-1})								Mean
	N rates (kg ha^{-1}) to sugarcane					Spacing of sugarcane (cm)			
	100	150	200	250	LSD (0.05)	90	60	LSD (0.05)	
At the beginning[c]									232
SEQ 1									
After plant cane	230	224	219	224	10	225	223	NS	224
After 1st ratoon	202	199	185	194	10	198	192	NS	195
After 2nd ratoon	179	172	155	161	8	173	160	9	167
SEQ 2									
After plant cane	225	216	210	210	10	218	213	NS	215
After 1st ratoon	210	207	202	199	6	209	201	7	205
After finger millet	194	196	190	184	11	192	190	NS	191
After cotton	163	163	161	144	10	166	149	12	158
SEQ 3									
After finger millet[d]									169
After plant cane	147	140	137	138	8	145	136	10	141
After 1st ratoon	163	155	148	158	10	161	151	6	156
After wheat	149	144	141	141	5	151	137	7	144
SEQ 4									
After finger millet[d]									169
After maize[d]									162
After plant cane	177	168	167	159	8	172	163	9	168
After 1st ratoon	141	139	134	129	4	140	132	6	136
SEQ 5									
After plant cane[d]									184
After 1st ratoon[d]									152

[c] mean of 15 samples (5 sequences × 3 replications);
[d] mean of 3 replications each with 8 samples
NS = Not Significant

observed in SEQ 4. In the conventional system (SEQ 5), SAK status was reduced by about 35% at the end of the crop sequence.

Thus all the sugarcane based cropping systems depleted the SAK status, the decline being greatest in sequences 3 and 4. Greater depletion was noticed under high N rates. Although spacing effects were inconsistent, in sequences 3 and 4, there was evidence of a greater decline in SAK at close spacing.

The results indicated that SAK status was greatly influenced by the crop yields. In all the cropping systems removal of K by the crop exceeded the total addition of K by fertilizer resulting in a decline in SAK. In intensive cropping systems stable levels of K have been reported despite larger removals [2], but this was not evident in the present study.

Nutrient balance

The cropping systems based on short duration sugarcane gave best total productivity when the sugarcane was grown at the 60 cm row spacing and 200 kg N ha^{-1} combination (Table 2). Therefore, an assessment of nutrient uptake and application has been made at this level and the data are presented in Tables 6, 7 and 8.

Nitrogen removal was less than the total additions made by N fertilizer (Table 6). The total N removal was higher in the short duration cropping systems because of the greater number of crops. Since total N removal in all these sequences was far less than that applied, the expected N balance in the soil should have been high, but this was not reflected in the actual SAN status at the end of the cropping sequences which indicated a slight improvement in sequences 2, 3 and 4, while the continuous sugarcane cropping systems (SEQ 1 and SEQ 5) showed a decrease from the original SAN status. Thus in all the systems, there was a net loss of N which may be due to leaching, volatalization, immobilization, etc. These cropping cycles were of two year duration and passed through two rainy seasons each year. Volatilization losses have been reported to be high under heavy applications of urea [7]. Thus these intensive

Table 6. Nitrogen balance in the cropping systems[e]

Sequence	Total N applied (kg ha^{-1})	Total N removed (kg ha^{-1})	Available N at the beginning (kg ha^{-1})	Available N at the end (kg ha^{-1})	Increase (+) or decrease (−) in available N status (kg ha^{-1})	Net gain (+) or loss (−) in the system (kg ha^{-1})
SEQ 1	600	274	182	177	−5	−331
SEQ 2	575	353	182	200	+18	−204
SEQ 3	620	328	182	194	+12	−280
SEQ 4	650	325	182	194	+12	−313
SEQ 5	450	214	182	157	−25	−261

[e] At 200 kg N ha^{-1} at 60 cm row spacing to the short duration sugarcane

Table 7. Phosphorus balance in the cropping systems[e]

Sequence	Total P applied (kg ha^{-1})	Total P removed (kg ha^{-1})	Available P at the beginning (kg ha^{-1})	Available P at the end (kg ha^{-1})	Increase (+) or decrease (−) in the available P status (kg ha^{-1})	Net gain (+) or loss (−) in the system (kg ha^{-1})
SEQ 1	99	73	35	42	+7	−19
SEQ 2	104	93	35	16	−19	−30
SEQ 3	114	83	35	47	+12	−19
SEQ 4	121	86	35	39	+4	−31
SEQ 5	66	58	35	32	−3	−11

[e] At 200 kg N ha^{-1} and 60 cm row spacing to the short duration sugarcane

Table 8. Potassium balance in the cropping systems[e]

Sequence	Total K applied (kg ha^{-1})	Total K removed (kg ha^{-1})	Available K at the beginning (kg ha^{-1})	Available K at the end (kg ha^{-1})	Increase (+) or decrease (−) in the available K status (kg ha^{-1})	Net gain (+) or loss (−) in the system (kg ha^{-1})
SEQ 1	300	605	521	335	−186	+119
SEQ 2	284	670	521	323	−198	+188
SEQ 3	275	616	521	298	−223	+118
SEQ 4	273	596	521	299	−222	+101
SEQ 5	200	474	521	341	−180	+94

[e] At 200 kg N ha^{-1} and 60 cm row spacing to the short duration sugarcane

cropping systems involving heavy applications of N appear to have caused considerable N losses.

In the case of P (Table 7), crop removal was less than the P applied, but differences were smaller when compared to N. Except in sequences 2 and 5, there was increase in SAP status at the end of the crop cycle. The net balance in the system was again negative which might have been due to P fixation as the soils are known to be P fixing.

In contrast to the N and P balances, the total crop removal of K was far higher than the K additions by fertilizer in all the cropping systems (Table 8). Thus there was a significant depletion in SAK status. However, considering the system as a whole, there were net gains, which may have come from the soil reserves and crop residues. All the new cropping sequences (1–4) showed greater gains, as there were larger amounts of residue added in these systems (Table 9).

Table 9. Crop residue addition (t ha^{-1}) by the cropping systems[f]

Sequence	Residue added[g]
SEQ 1	10.8
SEQ 2	13.0
SEQ 3	9.9
SEQ 4	8.9
SEQ 5	7.4
LSD (0.05)	1.6

[f] Total oven dry weight of residue added in the top 30 cm soil layer, estimated by collecting residues in 50 × 50 × 30 cm soil after each crop in each sequence

[g] at 200 kg N ha^{-1} at 60 cm row spacing of the short duration sugarcane

Conclusion

Growing of multiple cropping systems based on short duration sugarcane was more productive than the conventional cropping system. Such systems are able to maintain soil available N status through greater residue additions, particularly when the sugarcane is grown at an optimum N rate of 200 kg N ha^{-1} and close row spacing (60 cm). Available P status was also maintained except when cotton was a component crop in the sequence. In contrast to N and P, there was a large decline in available K level in the soil in all crop sequences. In these cropping systems, uptake of N and P was less than additions made by fertilizers, while K removal was more than that added. Thus there is scope for improving N and P use efficiencies and checking N losses, whereas there appears to be a need to restore K balance in the soil.

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