Site-Specific Nitrogen and Potassium Management for Irrigated Rice in the Cauvery Delta

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A site-specific nutrient management (SSNM) approach was used to formulate and evaluate improved fertiliser management for irrigated rice in farmer fields of the Cauvery Delta in Tamil Nadu for four consecutive seasons during 2001-03. Yield gain and profitability assessment with leaf colour chart (LCC)-guided N management and deciding fertiliser K rates for improved yields with increased profitability in two contrasting soil types of the Delta were the major outcome of this study.

Tamil Nadu accounts for 8.5% of India's total rice production and the Cauvery Delta is the major rice producing zone within the State. Two rice crops are typically grown each year in cropping systems of either rice-rice-fallow or rice-rice-pulses, depending on the availability of irrigation water. The first rice crop, with highest yield potential, is cultivated in Kuruvai, the pre-monsoon dry season (June-September), with predominantly short duration varieties and a plant population of 66 hills/m^2. The second rice crop is grown in Thaladi, the wet season (October-February), with medium duration rice varieties and a planting density of 50 hills/m^2. The entire delta is categorised into "old" and "new" delta with clay loam to clay soils dominating in old delta and sandy loam to clay loam soils with good drainage characteristics existing in new delta.

Improved productivity under irrigated cropping system is vital for meeting the profitability of rice farmers in the State and SSNM offers significant opportunities in this dimension. Nagarajan et al. (2004) used a 'fixed time-adjustable dose approach' of N management and compared the performance of SSNM with that of farmer fertiliser practice (FFP), wherein a yield advantage of 0.49 and 0.63 t/ha of rice was observed in old and new delta soils, respectively. In the SSNM approach, top-dressing of N fertiliser was set at critical growth stages and a chlorophyll meter was used to adjust the N fertiliser doses above or below the pre-set times of N application. This study also used remarkably higher fertiliser K rates than the farmer practice or the existing State recommendations. An alternative approach of 'real-time N management" has evolved where farmers have an option of matching the leaf colour at 7 to 10 day intervals using colour panels of LCC and apply N whenever the leaf colour becomes more yellowish-green than a critical LCC value. There is also a need to optimise the K fertiliser rates before providing valid SSNM recommendations to farmers. Therefore, a study was designed to redefine SSNM recommendations for rice farmers of the Cauvery delta with the use of LCC-guided N management, besides confirming the optimum K fertiliser rates.

Field experiments were conducted in four consecutive rice seasons (Kuruvai 2001; Thaladi 2002; Kuruvai 2002; and Thaladi 2003) during 2001 to 2003. Experiments in the old delta were conducted in 14 farmer fields in two villages – namely Ammanpettai and Therazhandur near Aduthurai (11° 1´N, 79° 29´E) – whereas experiments in the new delta were conducted in 15 farmer fields in two villages (Panchanathikkottai and Vandayariruppu) near Tanjavur (10° 47´N, 79° 10´E). The selected sites represented the major soil types of the delta and had ensured irrigation supply for both rice crops. Three treatments were imposed in farmer fields in all four seasons in a completely randomised block design with one set of treatments in a farmer field considered as a replication **(Table 1)**. An additional fourth treatment was also tested during dry season of 2002 and wet season of 2003.

The P and K fertiliser rates in the SSNM treatments were determined as outlined by Witt et al. (2002). Phosphorus rates were not considered as experimental variables as the soils are moderately high in extractable P and application rates commonly used by farmers are already near the recommended levels. Thus, in any given season and site, the P rate was equal for all SSNM treatments. However, K rates were differentiated within SSNM low K and SSNM high K treatments to help assess crop response and profitability under higher K rates. These K rates were kept similar in both seasons to examine whether differences in crop performance and profitability between K rates were affected by season. All the P fertiliser and 50% of the K fertiliser were incorporated in the soil immediately before transplanting and the remaining K fertiliser was top-dressed at panicle initiation stage.

In the fixed time-adjustable dose approach, N was applied at pre-set days after transplanting (DAT), and the N doses were adjusted upward or downward from tillering phase based on

Abbreviations: N = nitrogen; P = phosphorus; K = potassium; USD = U.S. dollar.

Table 1. Treatment details for field experiments.

Treatment	Details
T_1	Farmer fertiliser practice, where NPK fertiliser management was done by a farmer without involvement of researcher.
T_2	LCC-based N management by fixed time adjustable dose approach, P rate determined by SSNM approach and K applied at less than an estimated SSNM rate (SSNM-LK). Altogether, P was applied at 10 to 15 kg P/ha in the old delta and 15 kg P/ha in the new delta, whereas K was applied at 30 kg K/ha in the old delta and 40 kg K/ha in the new delta.
T_3	Exactly as T_2, except K was applied at an estimated SSNM rate (SSNM HK), which was 50 and 80 kg K/ha in the old and new delta soils, respectively.
T_4	LCC-based N management by real time approach with P and K management as followed in farmer practice.

Table 2. Effect of site-specific nutrient management on grain yield, plant accumulation of NPK, and profitability of rice-growing farmers of Cauvery delta.

Parameter	Site	Season[1]	------ Treatment[2] -----			SSNM LK – FFP		SSNM HK – FFP	
			FFP	SSNM LK	SSNM HK	Δ	$p > \|t\|$[3]	Δ	$p > \|t\|$
Grain yield, t/ha	Old delta	Dry	5.8	6.3	6.4	0.5	0.001	0.6	< 0.001
		Wet	5.9	6.2	6.3	0.3	0.001	0.4	< 0.001
	New delta	Dry	6.0	6.5	7.0	0.5	0.017	0.9	< 0.001
		Wet	5.6	5.9	6.3	0.4	0.058	0.7	< 0.001
Plant N, kg/ha	Old delta	Dry	103	117	120	14	< 0.001	17	< 0.001
		Wet	102	117	117	15	< 0.001	15	< 0.001
	New delta	Dry	99	105	112	6	0.045	13	< 0.001
		Wet	88	95	101	7	0.048	13	0.001
Plant P, kg/ha	Old delta	Dry	21	22	23	1	0.116	2	0.047
		Wet	22	23	23	1	0.334	1	0.142
	New delta	Dry	26	27	28	1	0.432	2	0.031
		Wet	25	26	27	1	0.330	2	0.017
Plant K, kg/ha	Old delta	Dry	85	98	105	13	< 0.001	20	< 0.001
		Wet	89	97	100	8	0.009	11	< 0.001
	New delta	Dry	84	88	94	4	0.118	10	< 0.001
		Wet	81	84	91	3	0.160	10	< 0.001
GRF[4], USD/ha	Old delta	Dry	649	710	720	61	< 0.001	71	< 0.001
		Wet	646	691	695	45	< 0.001	49	< 0.001
	New delta	Dry	674	730	769	56	0.015	95	< 0.001
		Wet	612	658	692	46	0.065	80	0.001

[1]Dry, two dry season crops; Wet, two wet season crops.
[2]FFP, farmer fertiliser practice; SSNM LK, site-specific nutrient management with low K rate; SSNM HK, SSNM with high K rate
[3]Probability of a significant difference between two treatment means.
[4]GRF, gross return above fertiliser cost.

a LCC reading taken for the youngest fully developed leaf immediately before N application. In the dry season, urea was applied at 40, 50, and 30 kg N/ha at about 15, 28 to 32, and 45 to 50 DAT, whereas, in the wet season, urea was applied at 30, 40, 40, and 10 to 15 kg N/ha at about 15, 30, 45-50, and 60 to 70 DAT, respectively. For the real-time N management, LCC readings were taken at 10-day intervals starting from about 14 DAT to heading. Urea was applied at 35 kg N/ha in the dry season and 30 kg N/ha in the wet season whenever the average LCC reading fell below 4.

Crop management at all experimental fields was completely monitored by farmers. Plant samples were collected from 12 hills at physiological maturity and growth parameters were recorded and nutrient concentrations in grain and straw were determined. Grain yields were recorded from a 5 m^2 harvest area in the centre of each plot at harvestable maturity and reported at 14% moisture. The agronomic efficiency (AE_N) and partial factor productivity (PFP_N) for applied N fertiliser were calculated following Cassman et al. (1998).

Grain yield increased significantly across seasons and sites with both SSNM low K (average = 0.43 t/ha) and SSNM high K (average = 0.65 t/ha) as compared to FFP **(Table 2)**, but the difference was more evident within the new delta sites (mean = 0.63 t/ha) than the old delta sites (mean = 0.45 t/ha). The yield increase with SSNM, which corresponded to 7% at low K and up to 12% with high K, was associated with increased panicle number (+5%) over FFP (data not shown) and higher plant accumulation of N, P, and K at maturity **(Table 2)**, which was comparable to the 8 to 13% yield increase with SSNM reported by Nagarajan et al. (2004). Grain yields were higher in the dry season than the wet season in the new delta, but not in the old delta ($p = 0.021$ for site x season interaction).

The relatively higher plant accumulation of N and K in the old versus the new delta across FFP and SSNM treatments did not translate into higher yields in the old delta **(Table 2)** as the internal efficiencies of N and K use were consequently higher in the new delta. This is evident from the fact that in SSNM high K, the average internal N use efficiency (kg grain/kg plant N) was 54 and 62 in the old and new deltas, whereas, the internal K use efficiency (kg grain/kg plant K) was 62 and 72 in the old and new deltas, respectively. Plant accumulation of P was higher with SSNM high K than FFP even though P fertiliser use was lower with SSNM than FFP **(Table 2)**. Further, plant P was significantly lower ($p < 0.001$) in the old versus new delta. However, the low average internal P use efficiency (277 kg grain/kg plant P) in the old delta, relative to other reports of 385 kg grain/kg plant P for balanced nutrition (Witt et al., 1999), suggests that P was not limiting in this region.

The gross return above fertiliser cost (GRF) increased with SSNM over FFP at both sites **(Table 2)** and profit for SSNM was higher with both options in the old delta; however in the new delta, profit was only improved with SSNM high K during the dry season. The increased profit with SSNM as compared to FFP was attributed to additional returns arising from higher yields with SSNM **(Table 2)**. The profit (ΔGRF) with SSNM high K (50 kg K/ha) as compared to SSNM low K (30 kg K/ha) in the old delta was negligible (mean = USD 7/ha) and not significant. In the new delta, however, the use of more K increased grain yield (mean = 0.4 t/ha) and profit (mean = USD 36/ha) in both seasons. Participating

Yields obtained in SSNM plots are compared to results from FFP plots by weigh-scale.

farmers in the new delta used, on average, 37 kg K/ha, which corresponded to SSNM low K treatment (40 kg K/ha). Consequently, our results indicate a clear benefit from greater use of K fertiliser by farmers in the new delta soils. The current recommendation of the extension service, which promotes uniform K fertiliser management throughout the Cauvery delta, should be revised to provide different recommendations for the old and new delta soils.

LCC-Guided N Management

A comparison of the agronomic and economic performance between the LCC-based real-time N management (RTN) and FFP is shown in **Table 3**. Use of LCC-RTN significantly increased grain yield (0.3 to 0.5 t/ha) in both seasons within the old and new delta soils. Further, N management with LCC significantly increased N fertiliser use in the old delta but not in the new delta ($p < 0.001$ for site and treatment), even though fertiliser use under FFP was already higher in the old delta. However, agronomic efficiency of N fertiliser consequently increased in the new delta as a result of increased grain yield without a corresponding increase in N fertiliser use **(Table 3)**.

Table 3. Effect of real-time N management using LCC on grain yield, N fertiliser use, N use efficiency, and economics of rice farmers.

Parameter	Site	Season[1]	Treatment[2] FFP	RTN	RTN – FFP Δ	$p > \|t\|$[3]
Grain yield, t/ha	Old delta	Dry	5.9	6.4	0.5	< 0.001
		Wet	6.0	6.3	0.3	< 0.001
	New delta	Dry	5.8	6.2	0.3	< 0.001
		Wet	5.9	6.2	0.3	< 0.001
N fertiliser, kg/ha	Old delta	Dry	119	140	21.0	< 0.001
		Wet	131	150	19.0	< 0.001
	New delta	Dry	104	105	1.0	0.896
		Wet	101	104	3.0	0.746
AEN[4], kg/kg N	Old delta	Dry	18	19	1.2	0.246
		Wet	20	19	-0.5	0.612
	New delta	Dry	11	15	3.2	0.001
		Wet	15	17	1.2	0.206
GRF[4], USD/ha	Old delta	Dry	654	722	68	< 0.001
		Wet	655	703	48	< 0.001
	New delta	Dry	646	678	32	0.005
		Wet	653	686	33	< 0.001

[1]Dry, one dry season crop; Wet, one wet season crop.
[2]FFP, farmer fertiliser practice; RTN, LCC-based real-time N management with farmer PK fertiliser practice.
[3]Probability of a significant mean difference between RTN and FFP.
[4]AEN, agronomic efficiency of N fertiliser; GRF, gross return above fertiliser cost.

Use of LCC for N management was profitable across all seasons and sites. Profit, as determined from the difference in GRF between RTN and FFP, averaged USD 58/ha in the old delta and USD 33/ha in the new delta. The increased profit was due to an increase in yield rather than a reduction in N fertiliser use **(Table 3)** and yield increase with LCC was further attributed to a change in timing of N fertiliser application to better match the crop needs for additional N (data not shown). Rice crops generally need higher N levels during active tillering (AT) to panicle initiation (PI) stage and LCC based RTN recommends mostly 50% of total N application during this period. However, in FFP, lesser N (20 to 30% of total N) was only applied during this critical period while more N (30 to 35% of total N) was applied as basal before planting of rice, which was nil in the case of LLC-based RTN. In FFP, N fertiliser was applied basally in both seasons. However, with the use of LCC, basal N application was skipped and delayed until 14 DAT and applied during the critical growth stages of AT and PI when crop demand for N was high. Thus, better timing and splitting of N fertiliser applications using LCC-based RTN proved to be beneficial to increase the yield and profitability of rice farmers.

Conclusions

The findings from the above studies suggest that the improved N management with LCC consistently increased yield and profit as compared to FFP, when the supply of K fertiliser was sufficient. This approach should be promoted throughout the Cauvery delta for harnessing higher profits. Existing P fertiliser recommendation of 22 kg P/ha in the dry season and 26 kg P/ha in the wet season may be reduced to about 15 kg P/ha. In the old delta, application of 30 kg K/ha in each season (which was nearer to the common farm practice) was sufficient. Grain yield and profitability were higher with 80 than 40 kg K/ha in the new delta. Thus, it is not possible to determine the optimum K rate from our study, but farmers of new delta should be targeted for promoting additional use of K fertiliser. The SSNM approach used for improving fertiliser recommendations at the experimental villages in this study can now be promoted and used throughout the Cauvery delta and irrigated rice zones in southern India. BC-SA

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