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Effect of Real Time N Management on Biomass Production, Nutrient Uptake and Soil Nutrient Status of Direct Seeded Rice (*Oryza sativa* L.)

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Abstract: A field experiment was conducted at Tamil Nadu Agricultural University, Coimbatore, in deep clay soil (*Vertic ustochrept*) to study the effect of real time N management using Leaf Color Chart (LCC) on biomass production, nutrient uptake and soil available nutrient status in short duration rice (Var. CO 47) under direct wet (drum) seeded condition. The study was conducted in factorial randomized block design with three replications. The treatments included maintaining three LCC critical values (cv.) viz., LCC 3, 4 and 5 with different rates of N application (20, 25, 30 and 35 kg N ha^{-1} each time, besides absolute control (Zero-N), Blanket N (120 kg N ha^{-1}in four equal splits from 21 Days After Sowing (DAS) and Manage N practices (120 kg N ha^{-1} in four unequal splits). The results of the experiment suggest that rate of biomass production and NPK uptake were highest during panicle initiation to first flowering stages for the tested variety CO 47 and LCC based N management have effectively saved the N fertilizer. The lack of difference in soil available nutrient between LCC based treatments and conventional blanket N treatment suggest that LCC based N management could be best option for farmers to save fertilizer N besides maintaining soil fertility. The results suggest further scope to standardise the LCC based N management for different intensively cultivated cultivars at specific location and season.

Key words: Rice, LCC, biomass, nutrient uptake, soil nutrient status

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INTRODUCTION

India's food supply has kept pace with rapid population growth during recent decades; primarily because of wide spread use of modern rice varieties with high yield potential. Long term fertilizer experiment at IRRI indicated that after several consecutive years of intensified cropping with constant and high fertilizer inputs, grain yield begin declining in modern varieties (Cassman and Pingali, 1995). Rice crop usually take half of the applied N to yield above ground biomass. The other half of the N is dissipated in the wider environment causing environmental and ecological problems (Balasubramanian, 2004). The efficient N use is critical to produce sufficient food for feeding the burgeoning population and avoid large scale degradation caused by excess N (Tilman *et al*., 2001). Adoption of blanket dose of N fertilizer recommendation alone causes improper usage in some cases leading to wastage through leaching, volatilization, run off and denitrification and in other cases it may prove insufficient if the soils are poor in N fertility (Balasubramanian *et al*., 1999). In this connection, nitrogen fertilizer has received due attention in order to obtain the required yield targets through rational fertilizer use with the aid of portable diagnostic tools such as chlorophyll meter (SPAD 502) and Leaf Colour Chart (LCC) that can measure crop N *in situ* (Alam *et al*., 2005).

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Optimal nitrogen management strategies seek to match crop N demand with fertilizer N supply, thus reducing losses and maximizing crop N utilization. Adequate leaf N should be maintained throughout the growing period of rice, which is critical for achieving high yield (Olfs *et al*., 2005). Assessing the leaf N concentration is one of the techniques to decide this and maintaining particular N concentration of different physiological stages is one way of increasing the rice yield. This is because N concentration in leaves is highly correlated with the concentration of CO_2 fixing enzyme in photosynthesis and hence, the potential maximum rate of photosynthesis could be linearly related to the N concentration in the leaf (Black, 1993). Since the plant growth reflects the total N supply from all sources, plant N status will be a good indicator of N availability to crops at any given time. LCC is a simple, easy-to-use and inexpensive tool to monitor the crop N status in the field and to determine the timing of N top dressing to rice.

Rice plant take up nutrients from the soil environment (native and applied) and the ratio of nutrients taken up by the rice plant from either source is affected by soil properties, cropping seasons, time and amount of fertilizer application. Native N supply in intensive irrigated rice systems is not sufficient for higher yields; additional N supply through fertilizers is inevitable. Matching seasonal crop demand with supply from soil would be the ideal N management and this requires an understanding of the dynamics of crop requirement and native N supply. The LCC based N management forms an integral part of the Site Specific Nutrient Management (SSNM) strategy. Some soils of South India were able to supply N equal to the demand of a sufficiently fertilized crop during initial crop growth and in such cases, basal N can be skipped (Thiyagarajan *et al*., 1997). Exploring nutrient availability in soil forms an important tool for assessing the demand and supply of nutrients for the growing crop.

A considerable increase in the yield of the economic product is usually dependent on an increase in total dry matter produced, though this is not an absolute relationship and always true. Some amount of carbohydrates formed before flowering are stored in culms and leaf sheaths and later retranslocated to the grain. The response of a crop to an imposed treatment will be reflected by the biomass production. Though nutrient uptake depends on the plant's need and soils ability to supply them, uptake of the nutrients by plants need not be in the same ratio as they occur in soil. Consumption of the harvested produce by domesticated animals and human beings results in the continuous removal of nutrients from the soil. Result of exploitative intensive agriculture has been the progressive occurrence of nutrient deficiencies in soils and crops. For efficient nutrient management, complete knowledge of the nutrient uptake by crops is necessary (Rattan and Goswami, 2002).

This study describes the changes in soil N, P and K, variation in biomass production and N, P and K uptake by rice crop at various stages under real time N management in rice.

MATERIALS AND METHODS

A field experiment was conducted at Tamil Nadu Agricultural University, Coimbatore, India in vertisol belonging to Noyyal series (*Vertic ustochrept*) during 2002 to study the effect of real time N management using LCC on soil available nutrient status, biomass production and nutrient uptake in short duration rice (Var. CO 47) under direct wet (drum) seeded condition. The experimental design was Factorial Randomized Block Design (FRBD) with three replications. The treatments include maintaining three LCC critical values (cv.) viz., LCC 3, 4 and 5 with different rates of N application viz., 20, 25, 30 and 35 kg N ha^{-1} each time, besides absolute control (Zero-N), Blanket N (120 kg N ha^{-1} in four equal splits at 21 Days After Sowing (DAS), Active Tillering (AT), Panicle Initiation (PI) and First Flowering (FF) stages respectively) and Manage N practices (120 kg N ha^{-1} in four unequal splits of 1/6th, 1/3rd, 1/3rd and 1/6th at 21 DAS, AT, PI and FF stages, respectively) (Table 1). Nitrogen was applied as per treatment schedule based on the LCC critical value assessed at

Table 1: Treatment details of the field experiment

Tr. No.	Notation	Treatment details	N dose (kg ha^{-1})	No. of splits
T_1	C	Control (zero-N)	0	0
T_2	BN	Blanket N (120 kg N ha^{-1} in four equal splits from 21 DAS)	120	4
T_3	MN	Manage N practice (120 kg N ha^{-1} in four splits-1/6, 1/3, 1/3 and 1/6 from 21 DAS)	120	4
T_4	L_3N_{20}	LCC cv. 3 with 20 kg N ha^{-1} each time	40	2
T_5	L_3N_{25}	LCC cv. 3 with 25 kg N ha^{-1} each time	25	1
T_6	L_3N_{30}	LCC cv. 3 with 30 kg N ha^{-1} each time	30	1
T_7	L_3N_{35}	LCC cv. 3 with 35 kg N ha^{-1} each time	35	1
T_8	L_4N_{20}	LCC cv. 4 with 20 kg N ha^{-1} each time	60	3
T_9	L_4N_{25}	LCC cv. 4 with 25 kg N ha^{-1} each time	50	2
T_{10}	L_4N_{30}	LCC cv. 4 with 30 kg N ha^{-1} each time	60	2
T_{11}	L_4N_{35}	LCC cv. 4 with 35 kg N ha^{-1} each time	70	2
T_{12}	L_5N_{20}	LCC cv. 5 with 20 kg N ha^{-1} each time	120	6
T_{13}	L_5N_{25}	LCC cv. 5 with 25 kg N ha^{-1} each time	150	6
T_{14}	L_5N_{30}	LCC cv. 5 with 30 kg N ha^{-1} each time	150	5
T_{15}	L_5N_{35}	LCC cv. 5 with 35 kg N ha^{-1} each time	210	6

weekly intervals from 21 DAS. A uniform dose of 38 kg P_2O_5 ha^{-1} (all basal) and 38 kg K_2O ha^{-1} (in two splits at 21 DAS and panicle initiation stage), 25 kg $ZnSO_4$ ha^{-1} (all basal) and 500 kg gypsum ha^{-1} (all basal) were applied to all the treatments. The initial analysis of the soil of the experimental site revealed that soil was neutral (pH = 7.87) with low soluble salts (EC = 0.79 dS m^{-1}), medium organic carbon content (0.72%), medium in $KmnO_4$-N (290 kg N ha^{-1}), high in Olsen-P (41 kg ha^{-1}) and high in NH_4OAc-K (796 kg ha^{-1}). Soil samples collected during panicle initiation and post harvest stages (PH) were processed and analysed for available N (Subbiah and Asija, 1956), P (Olsen *et al*., 1954) and K (Stanford and English, 1949). Separate area was demarked for plant sampling at different growth stages. Whole shoot samples were collected during AT, PI, FF and HT stages and analysed for total content of N (Piper, 1966), P (Pemberton, 1945) and K (Toth and Prince, 1949).

The observations collected from the field experiment and the data on the results of analysis of soil and plant samples were subjected to statistical scrutiny as per the procedure of Gomez and Gomez (1984). The treatments T_4 to T_{15} were treated as FRBD along with three checks (control, blanket N and manage N) and statistically analysed.

RESULTS AND DISCUSSION

Biomass Production

Highest biomass production at FF and HT associated with 210 kg N ha^{-1} was an evidence for a judicious supply of N for reducing vegetative growth. The mean biomass yield of 561, 1525, 8858 and 11316 kg ha^{-1} as recorded at AT, PI, FF and HT stages indicated that the increase in biomass was very slow (16 kg day^{-1} ha^{-1}), slow (46 kg day^{-1} ha^{-1}), rapid (261 kg day^{-1} ha^{-1}) and moderate (79 kg day^{-1} ha^{-1}) during sowing to AT, AT to PI, PI to FF and FF to HT stages respectively. Mir Zaman Hussain (1999) and Sudhalakshmi (2002) observed a steady increase in biomass between PI to FF stage, whereas Bindhu (2002) observed a vigorous dry matter production during active tillering to panicle initiation. Blanket N and manage N recorded almost comparable biomass at all crop growth stages indicating that the differential rate of split N application have no influence on biomass production. The comparable biomass under different LCC levels at AT was due to the uniform dose of N applied in all LCC levels upto AT. While at the latter stages of crop growth viz., PI, FF and HT, LCC cv. 5 recorded markedly higher biomass yield over LCC cv. 3 and 4 (Table 2) which was due to higher N dose applied to maintain LCC cv. 5 (Table 1).

The failure of different rates of N application to create any appreciable variation in the biomass yield at AT, FF and HT stages was due to similar cumulative dose over weeks among the treatments

Table 2: Soil available nutrient (kg ha^{-1}) and biomass production (kg ha^{-1}) at various growth stages of rice as influenced by different N regimes

Tr. No.	Tr.	Soil available N		Soil available P		Soil available K		Shoot biomass production			
		PI*	PH*	PI*	PH*	PI*	PH*	AT*	PI*	FF*	HT*
T_1	C	275	214	33.7	23.5	795	743	322	764	4054	6641
T_2	BN	298	273	23.3	16.3	840	724	593	1403	9442	12539
T_3	MN	294	256	21.3	15.0	795	735	605	1456	8415	12805
T_4	L_3N_{20}	299	251	31.6	24.2	784	735	561	1401	8842	10624
T_5	L_3N_{25}	296	268	34.0	25.2	806	769	683	1660	7786	9987
T_6	L_3N_{30}	295	244	32.9	25.5	833	754	564	1574	8364	10711
T_7	L_3N_{35}	285	254	28.0	20.9	791	732	546	1550	8674	10251
T_8	L_4N_{20}	295	272	31.5	23.4	799	739	467	1235	8723	11781
T_9	L_4N_{25}	283	257	23.1	17.6	799	758	508	1264	8560	10820
T_{10}	L_4N_{30}	275	252	27.8	22.1	810	732	630	1260	8090	10146
T_{11}	L_4N_{35}	280	245	26.6	22.2	717	717	526	1637	9044	11178
T_{12}	L_5N_{20}	278	257	27.5	19.9	799	728	587	1808	9508	11854
T_{13}	L_5N_{25}	280	245	22.7	17.9	758	717	554	1860	10913	13393
T_{14}	L_5N_{30}	271	255	20.8	17.2	769	713	594	1706	10507	12712
T_{15}	L_5N_{35}	291	252	23.5	18.4	777	732	669	2295	11948	14298
LSD (Treatment)		19	24	5.4	3.8	54	35	155	456	1717	1109
LSD (LCC)		10	NS	2.7	1.9	NS	17	NS	228	859	554
LSD (N)		NS	NS	3.1	NS	NS	NS	NS	263	NS	NS
LSD (LCC x N)		NS	NS	NS	3.8	NS	NS	NS	NS	NS	1109

*PI: Panicle Initiation stage, PH: Post harvest stage, AT: Active tillering stage, FF: First flowering stage, HT: Harvesting stage, NS: Non significant at $p<0.05$

under the LCC levels (viz., 25-40 kg for LCC3, 50-70 for LCC 4 and 120-210 for LCC cv.5) (Table 1). The biomass yield of 120 and 210 kg N ha^{-1} applied treatments were comparable. Bindhu (2002) also observed comparable biomass yield in hybrid rice for N application from 135-200 kg ha^{-1} which confirm that N application beyond optimum dose not increase the biomass yield.

Biomass production at harvest was positively correlated with soil available N at harvest ($r = 0.532^*$). The over all result on the biomass production at different stages and its relationship with soil available N urge for an optimal N was an management technique to meet the crop demand at appropriate stages. The results of the present investigation emphasize the possibility of keeping the biomass production at considerably higher level by resorting to the latest N management techniques involving LCC for achieving a higher yield with out wasting fertilizer N.

Nutrient Uptake

The rate of N, P and K uptake followed a similar trend as that of biomass production over crop growth stages (Table 3). The mean N uptake of 11.5, 34.2, 81.2 and 94.2, mean P uptake of 1.90, 8.58, 18.4 and 22.1, mean K uptake of 8.66, 31.2, 90.8 and 96.0 kg ha^{-1} at AT, PI, FF and HT stages respectively, indicated the increase in the rate of N P and K uptake was low between sowing to active tillering (0.33 kg N day^{-1}, 0.05 kg P day^{-1} and 0.25 kg K day^{-1}) and also between first flowering to harvest (0.44 kg N day^{-1}, 0.12 kg P day^{-1}, 0.17 kg K day^{-1}) and moderate between active tillering to PI (1.08 kg N day^{-1}, 0.32 kg P day^{-1}, 1.07 kg K day^{-1}) and high between PI to FF stages (1.67 kg N day^{-1}), 0.35 kg P day^{-1}, 2.13 kg K day^{-1}). Nutrient uptake is a function of biomass production at the respective stages. The rapid increase in biomass between PI and FF has demanded more nutrients, thus resulting in a higher rate of uptake during this growth phase. The result draws buttress from Sivasamy *et al.* (1994), Aruna Geetha (1998), Mir Zaman Hussain (1999) and Sudhalakshmi (2002). Mir Zaman Hussain (1999) contradicted the above results and reported a lower N uptake rate between PI to FF than AT to PI due to seasonal influence on ASD 19 variety. The comparable nutrient uptake under different LCC levels at AT was due to the uniform dose of N

Table 3: Nutrient uptake (kg ha^{-1}) at various growth stages of rice as influenced by different N regimes

Tr. No.	Tr.	N uptake AT	N uptake PI	N uptake FF	N uptake HT	P uptake AT	P uptake PI	P uptake FF	P uptake HT	K uptake AT	K uptake PI	K uptake FF	K uptake HT
T_1	C	6.1	13.5	30.1	50.1	1.20	3.47	10.5	15.5	4.78	14.2	43.6	52.9
T_2	BN	11.5	30.0	76.0	105.7	2.08	6.76	19.5	26.2	9.31	25.6	92.5	103.9
T_3	MN	12.2	29.9	78.1	100.8	1.98	8.27	19.6	25.8	8.77	28.0	91.4	100.2
T_4	L_3N_{20}	11.4	25.7	75.6	84.8	1.83	6.37	16.3	18.7	7.76	28.3	93.9	95.1
T_5	L_3N_{25}	13.1	26.9	61.5	80.3	2.12	6.34	15.0	19.3	10.88	32.2	79.8	82.3
T_6	L_3N_{30}	11.3	27.3	64.4	80.7	1.86	6.62	16.3	19.6	10.20	31.6	78.8	89.0
T_7	L_3N_{35}	11.7	28.4	72.8	78.2	1.84	7.18	16.9	20.0	8.50	28.6	87.9	89.1
T_8	L_4N_{20}	10.4	27.5	78.8	95.9	1.64	7.87	17.7	20.3	7.12	25.4	94.5	95.8
T_9	L_4N_{25}	11.4	26.5	77.8	84.4	1.87	9.01	15.8	19.6	7.15	25.5	78.0	81.9
T_{10}	L_4N_{30}	12.7	28.2	71.0	80.4	2.00	8.37	17.3	20.9	8.96	26.9	89.9	90.4
T_{11}	L_4N_{35}	10.9	42.2	79.4	91.9	1.79	10.32	18.9	21.6	8.63	34.1	83.8	92.3
T_{12}	L_5N_{20}	11.9	42.5	83.4	106.7	2.03	11.73	20.8	23.6	8.53	38.3	87.0	96.5
T_{13}	L_5N_{25}	12.1	43.4	117.6	119.2	1.84	12.14	23.1	25.7	8.26	40.3	116.6	120.2
T_{14}	L_5N_{30}	12.6	56.7	120.0	121.4	2.05	11.21	24.7	27.3	9.78	38.9	109.4	110.6
T_{15}	L_5N_{35}	13.8	64.7	132.0	139.6	2.43	13.07	23.4	26.9	11.25	50.1	134.8	140.4
LSD (Treatment)		2.8	7.2	8.1	7.2	0.61	1.95	2.2	2.3	3.01	9.8	13.3	17.4
LSD (LCC)		NS	3.6	4.1	3.6	NS	0.97	1.1	1.2	NS	4.9	6.7	8.7
LSD (N)		NS	4.2	4.7	4.2	NS	1.13	1.3	1.4	NS	NS	7.7	NS
LSD (LCC×N)		NS	7.2	8.1	7.2	NS	NS	NS	NS	NS	NS	13.3	17.4

*AT: Active tillering stage, PI: Panicle Initiation stage, FF: First flowering stage, HT: Harvesting stage, NS: Non significant at $p<0.05$

applied in all LCC levels upto AT. The concomitant increase in NPK uptake with increasing LCC levels at PI, FF and HT stages was due to differential N dose applied. The N uptake results of this experiment in comparison with earlier studies suggest that LCC could be an indirect tool to measure the N demand of rice varieties in specific season and location.

Increase in P and K uptake with increased dose of N added evidence to the fact that N application has synergistic effect on the uptake of other nutrients besides N which was due to increase in biomass of the crop with increased N application. From the nutrient uptake rate it could be concluded that crop requires higher nitrogen between PI and FF. The increase in N uptake of different rates of N applied under LCC cv. 5 over blanket and manage N has proven that the rice crop required lower N at the early stages; more N during its grand growth period (PI to FF) and a comparatively lower N during the later stages of crop growth. Thus LCC could help in promoting need based nitrogen application for increased nutrient uptake and yield in rice.

Soil Nutrient Status

In the present study there was a marked decline in the available NPK status of the soil from PI to HT stage (Table 2). The decline was due to the removal of nutrients by growing rice crop, various losses in the soil-water-plant-atmosphere system and to certain extent by fixation. A marked decline in the soil available N with the advancement of crop growth was reported by Velu (1989) and Bindhu (2002). Although the crop N uptake in control plot was only 50.1 kg ha^{-1}, the decline of soil available N at HT was maximum in control plot (76 kg over the initial N level) indicating the higher magnitude of losses of nitrogen in paddy field. Similarly the overall mean value of available N status of the soil at the end of the experiment showed a decline of 37 kg N ha^{-1} over the initial N status.

Though the crop N uptake was increasing at decreasing rate, the soil available N was still found to decline with increasing rate of N application indicating higher loss of applied N at higher rate of N application as reported by Velu (1989) and Bindhu (2002). The marked depletion in the available nitrogen status of the soil with increasing LCC critical values at PI stage indicated that more nitrogen is demanded by the rice crop to maintain high chlorophyll content viz a higher LCC values and biomass production. However at post harvest stage, there was no significant variation in available N status of soil with the different levels of LCC or different rates of applied N indicating that application of excessive N does not add soil N fertility and again revealing the benefits of N fertilizer saving under LCC based N management. Mahajan and Tripathi (1992) observed that available N content determined after harvesting rice crop did not show any variation due to levels as well as sources of N suggesting the possibility of loss of excessive N.

The available phosphorus in soil also faced a similar decline as that of nitrogen. Inspite of the application of P_2O_5 at the rate of 38 kg ha^{-1} as SSP, the overall decline was around 50% from initial status of the soil (41 kg ha^{-1}) which could be due to the fixation of the applied phosphorus in submerged soil. Application of N in increments decreased the available P considerably. As the applied N being the primary nutrient factor, the rice biomass and P uptake in rice got increased considerably with increasing rate of N application and LCC levels, ultimately leading to a proportional decline in soil available P. This confirms the findings of Bindhu (2002) and Selviprabha (2002). Apart from the release of P from Fe and Al phosphates, P is also released from occluded forms under anaerobic conditions. Under such circumstances the added P_2O_5 at the rate of 38 kg ha^{-1} could not be expected to create a marked variation in the P availability.

There was only a marginal decline observed in available K status of soil at PI and post harvest stages compared to the initial K. Neither LCC levels nor the different rates of applied N influenced the available K at PI stage. However, there was a marked depletion in available K with increasing levels of LCC at harvest. Higher N application at higher level of LCC enhanced biomass and K uptake of rice there by resulting in a decline in the soil available K. The rates of applied N had little impact on the soil available K at harvest due to the insignificant variations observed in the yield and K uptake in rice under the different rates of applied N. This is due to higher initial K availability (796 kg ha^{-1}) of the experimental field and addition of 38 kg K_2O ha^{-1} have little or no influence on the K availability in soil at PH. Among the three major nutrients, K is always in a dynamic equilibrium with different forms. Once the available K starts depleted, it is automatically replenished from the reserves (De Datta, 1981).

CONCLUSIONS

The results of the experiment suggest that rate of biomass production and NPK uptake were highest during PI to FF stage for the tested variety CO 47 and LCC based N management have effectively saved the N fertiliser. The lack of difference in soil available nutrient between LCC based treatments and conventional blanket N treatment suggest that LCC based N management could be best option for farmers to save fertilizer N besides maintaining soil fertility.

REFERENCES

Alam, M.M., J.K. Ladha, S.R. Khan, Foyjunnessa, Harun-ur-Rashida, A.H. Khana and R.J. Buresh, 2005. Leaf color chart for managing nitrogen fertilizer in lowland rice in Bangladesh. Agron. J., 97: 949-959.

Aruna Geetha, S., 1998. Genotype nitrogen interactions in short duration transplanted rice. M.Sc. Thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Balasubramanian, V., A.C. Morales, R.T. Cruz and S. Abdulrachman, 1999. On-farm adaptation of knowledge-intensive nitrogen management technologies for rice systems. Nutr. Cycl. Agroecosyst., 53: 59-69.

Balasubramanian, V.T., 2004. Efficient N management technologies for irrigated rice in Asia New directions for a diverse planet: In: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia

Bindhu, C.J., 2002. Nitrogen Management for Hybrid rice based on chlorophyll meter and leaf colour chart. M.Sc Thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Black, C.A., 1993. Soil Fertility Evaluation and Control Lewis Publishers, Boca Raton.

Cassman, K.G. and P.L. Pingali, 1995. Extrapolating Trends from Long-term Experiments to Farmers' Fields: The Case of Irrigated Rice Systems in Asia. In: Agricultural Sustainability: Economic, Environmental and Statistical Considerations. Barnett, V. *et al*. (Ed.), John Wiley and Sons, London, pp: 63-84.

De Datta, S.K., 1981. Principles and Practices of Rice Production Wiley Inter Science, New York.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., J. Wiley and Sons, New York.

Mahajan, K.K. and B.R. Tripathi, 1992. Effect of increasing levels of different urea based fertilizers on yield and nitrogen nutrition of rice in an alfisol. Oryza, 29: 101-106.

Mir Zaman Hussain, 1999. Improving Nitrogen Management for transplanted rice: Use of chlorophyll meter (SPAD 502), leaf colour chart (LCC) and controlled release nitrogen fertilizer, M.Sc. Thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Olfs, H.W., K. Blankenau, F. Brentrup, J. Jasper, A. Link and J. Lammel, 2005. Soil-and plant-based nitrogen-fertilizer recommendations in arable farming. J. Plant Nutr. Soil Sci., 168: 414-431.

Olsen, S.R., C.V. Cole, F.S. Watanabe and L.A. Dean, 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture Circular, 939: 19.

Pemberton, A., 1945. Cited in official and tentative methods of analysis of the Association of Official Agricultural chemists. Washington, 4.D.C. 1945. J. Am. Chem. Soc., 15: 383-395.

Piper, C.S., 1966. Soil and plant analysis. Hans Publisher, Bombay.

Rattan, R.K. and N.N. Goswami, 2002. Essential Nutrients and Their Uptake by Plants. In: Fundamentals of Soil Sciences. Indian Society of Soil Sciences Publications, New Delhi, pp: 309-332.

Selviprabha, R., 2002. Assessment of Nitrogen contribution in Rice-Azolla space sharing methods using 15N technique. M.Sc (Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Sivasamy, R., T.M. Thiyagarajan and H.F.M. Ten Berge, 1994. Nitrogen and rice uptake and recovery of applied nitrogen SARP Proceedings, South Korea, pp: 31-55.

Stanford, G. and L. English, 1949. Use of Flame Photometer in rapid soil tests for K and Ca. Agron. J., 41: 466.

Subbiah, B.V. and G.L. Asija, 1956. A rapid procedure for the estimation of available nitrogen in soils. Curr. Sci., 25: 259-260.

Sudhalakshmi, 2002. Crop management options on nutrient dynamics in rice ecosystem. M.Sc. (Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Thiyagarajan, T.M., P. Stalin, A. Dobermann, K.G. Cassmann and H.F.M. Ten Berge, 1997. Soil N supply and plant N uptake by irrigated rice in Tamil Nadu. Field Crops Res., 51: 55-64.

Tilman, D., J. Fargione, B. Wolff, C. D'Antonio, A. Dobson, D. Howarth, W.H. Schindler, D. Simberloff and D. Swackhamer, 2001. Forecasting agriculturally driven global environmental change. Science, 292: 281-284.

Toth, S.J. and A.L. Prince, 1949. Estimation of cation exchange capacity and exchangeable calcium, potassium and sodium contents of soils by flame photometer technique. Soil Sci., 67: 439-445.

Velu, V., 1989. Studies on nitrogen balance in rice soils of Thanjavur. Ph.D Thesis, Tamil Nadu Agricultural University, Coimbatore, India.