

## **EFFECT OF APPLIED Zn ON N USE EFFICIENCY, GROWTH AND GRAIN YIELD OF RICE GROWN IN LOW HUMIC GLEY SOILS OF LOW COUNTRY INTERMEDIATE ZONE**

W. M. J. BANDARA, D. B. WICKRAMASINGHE, D. N. SIRISENA  
and  
L. C. SILVA

*Rice Research and Development Institute, Batalagoda, Ibbagamuwa*

### **ABSTRACT**

Zinc (Zn) is the most important micronutrient that limits the rice yield in Sri Lanka at present. Its deficiency in soils would reduce the use efficiencies and recoveries of other essential nutrients affecting the rice yield. Therefore, a two factor factorial experiment was conducted for two seasons using two levels of Zn (viz. 0 and 2.5 Kg Zn/ha) and 5 levels of nitrogen (viz. 0, 75, 100, 125 and 150 kg N/ha) with recommended levels of P and K to study the effect of Zn on N use efficiency, recovery, growth and grain yield of rice grown in Low Humic Gley (LHG) soil in Low country Intermediate Zone of Sri Lanka. Soil analysis reveals that soil was deficient in Zn and application of Zn at the rate of 2.5kg Zn/ha induced the N use efficiency from 15.6 to 19.4 kg grain yield per kilogram of applied nitrogen and N recovery from 31% to 41% by rice and augmented higher rice yield in LHG soils. A combination of 100 kg N and 2.5 kg Zn gave the same yield as that of 125 kg N/ha alone. The interaction between N and Zn on grain yield was synergistic. Residual effect of Zn on the same was also observed in the second crop of rice.

**KEYWORDS:** LHG soils, Applied Nitrogen, Zinc use efficiency, Rice yield.

### **INTRODUCTION**

Annual extent of rice cultivation in Sri Lanka is 0.89mha (Abey Siriwardana and Sandanayaka, 2000). Ninety eight percent of this area is cultivated using new improved rice varieties, which require high level of fertilizer application to obtain maximum yield while sustaining the soil fertility. Annual estimated requirement of fertilizer is 0.32 million metric tons and this entire requirement is annually imported to Sri Lanka incurring a cost of 2.88 billion rupees (NSF, 2000). On the other hand, fertilizer N use efficiency by the rice plant under the present system of cultivation in Sri Lanka is estimated to be around 25-30% and the rest is lost in the rice ecosystem due to improper soil fertility management in paddy soils (Sirisena *et al.*, 2001a). This situation has led to use of large amount of foreign exchange while potentially polluting the environment as well.

Nutrient imbalance in soils produces low fertilizer use efficiency, low yields and low farmer profit (Tiwari, 2002). It also results in further depletion of the most deficient nutrients in the soil. Once a nutrient is reached to its

critical level, yields fall dramatically even when large amounts of other nutrients are applied (PPIC, 2000). Hence, the importance of balanced fertilization must be realized in increasing crop yields.

Nitrogen is the most important nutrient for growth and yield of rice. It is the most limiting nutrient in rice cultivation in Sri Lanka. Recovery of applied N by rice plants under local conditions is below 33% at present (Sirisena *et al.*, 2001a; 2001b). N is comparatively cheaper and its effects are quickly visible, therefore, farmers give priority to N application, sometimes exceeding the requirement without considering the balanced nutrient management. Balanced fertilizer management practice increases the N use efficiency and therefore is important to achieve higher rice yield as well as to save foreign exchange by reducing the fertilizer wastage.

Zinc deficiency was recognized as a widespread and an important plant nutritional problem throughout the rice growing countries. It is also the major micronutrient deficiency problem in most of the soils of Low country intermediate and dry zones of Sri Lanka. (Deb 1992; Bandara and Silva, 2000a, 2000b) and in some poorly drained soils of mid country wet zone of Sri Lanka (Nagarajah *et al.*, 1983). Bandara and Silva (2000a and 2000b) studied the response of rice crop to micronutrient application in LHG soils at Polonnaruwa and Maha Illuppallama in low country dry zone and in same soils at Batalagoda and Pothuhera in low country intermediate zone. Significant response to Zn was observed in this study. Zn application improved the growth and grain yield of rice, where yield increase ranged from 10-15% (Bandara and Silva, 2000b; Bandara and Silva, 2001). Applied Zn to soil would recover deficiency problem in plants and improve the use efficiencies of other nutrients by rice plants, subsequently giving higher yields.

Antagonistic and synergistic effects between applied nutrients have been observed in many crops (Krisnermurthy, 1979; Abdul Salam and Subramanian, 1988), but the interaction effect between applied Zn and N on N use efficiency, growth and grain yield of rice grown in soils of Sri Lanka has not been studied.

Therefore, present investigation was undertaken to study the effects of applied Zn, N and their interaction on N use efficiency, growth and grain yield of rice grown in low humic gley soil of low country intermediate zone of Sri Lanka.

## MATERIALS AND METHODS

Field experiments were conducted for 2 seasons (1999 *yala* and 1999/2000 *maha*) in imperfectly drained LHG soils (Plinthaquits) which are the lower members of the drainage catena in association with red yellow

podzolic (RYP) soils (Panabokke, 1996) at Batalagoda in IL<sub>1</sub> Agro-climatic region of the Low Country Intermediate Zone (LCIZ).

A two factor factorial experiment which comprised 2 levels of Zn (0.0 and 2.5 kg Zn/ha, applied as ZnSO<sub>4</sub>.7H<sub>2</sub>O) and five levels of N fertilizer (*viz.* 0, 75, 100, 125 and 150 kg of N/ha, applied as urea) were carried out in randomized complete block design with 3 replicates.

Eighteen-day-old seedlings of rice variety BG 403 were transplanted, 3 plants per hill (at the spacing of 15 x 20cm) on ploughed and leveled lowland plots of 6m x 3 m, which were surrounded by 30cm wide bunds.

Phosphorous (P) and potassium (K) fertilizers were applied at the rate of 28.0 kg/ha of P<sub>2</sub>O<sub>5</sub> and 22.5 kg/ha of K<sub>2</sub>O respectively as triple super phosphate and muriate of potash. Elemental Sulfur (S) was added at the rate of 1.35 kg/ha respectively to the plots in which ZnSO<sub>4</sub>.7H<sub>2</sub>O was not received. Elemental S addition was done to compensate the S effect (added with ZnSO<sub>4</sub>.7H<sub>2</sub>O) on growth and grain yield of rice. Phosphorus, K, S and Zn fertilizers were broadcasted and incorporated into soil by puddling just before transplanting. Nitrogen as urea was applied in 4 splits, respectively at basal, 3, 5 and 7 weeks after transplanting. Manual weed control and chemical methods of pest control were practiced.

Plant growth was measured by taking tiller counts, plant height, biomass production and yield components of rice (culm length, panicle length, number of panicles per square meter, number of filled grains per panicle and thousand grain weight). Soils were analysed to determine the fertility level of the experimental fields. Soils were extracted with relevant extracting solutions listed in table 1 for each micronutrient. Concentrations of Zn, Fe and Cu in soil extracts were determined by atomic absorption spectrophotometer. Plant samples taken at maximum tillering stage were dried in an oven at 85°C for 8 hours and ground in a stainless steel mill to 1.0mm size particles. Each sample of 1.0g was digested in diacid mixture (HNO<sub>3</sub>:HClO<sub>4</sub> 1:1) and Zn was determined by atomic absorption spectrophotometry. Tissue N was analyzed using kjeldahl digestion followed by colorimetric determination. Trial was conducted with the variety BG 403 for two seasons on two different sites at Batalagoda research farm. Experiment was repeated in same plots without application of Zn to observe the residual effects of applied Zn on N use efficiency in the second crop. Only N, P and K fertilizers were applied in second season. Experimental procedure and data recording were as same as for the first crop.

**Table 1. Soil extraction and analytical methods of each micronutrient.**

<i>Nutrient</i>	<i>Method of soil extraction</i>
Cu	AAAC-EDTA
Fe	AAAC at pH 4.8
Mn	AAAC-EDTA
Zn	0.05N HCl
AAAC-Acid ammonium acetate    EDTA - Ethylene diamine tetra acetic acid	

## RESULTS AND DISCUSSION

### Soil properties

Soils of the experimental sites were sandy clay loam classified as imperfectly drained low humic gley (LHG) soils of low base status. Soils were low in organic matter (1.7-1.8%) and neutral in reaction (table 2). These soils contained high level of Fe, marginal level of Cu and low extractable P. Cation exchange capacity was also low in the two sites (table 2). 0.05 N HCl extractable Zn in soils were low for rice crop growth (table 2).

### Available Zn in soil, tissue Zn and N at maximum tillering stage of the crop

Soil and plant samples analyzed at maximum tillering stage of the crop showed that available Zn in soils and tissue Zn in plants of Zn -untreated plots were in deficient ranges for healthy growth of rice (table 3). But addition of Zn to the plots treated with different levels of N increased the soil Zn levels and tissue Zn to the sufficient levels (table 3). Application of 2.5 kg Zn ha<sup>-1</sup> in the form of ZnSO<sub>4</sub> 7H<sub>2</sub>O increased the available Zn in soil to a sufficient level ranging from 0.91 to 1.0 mg kg<sup>-1</sup> and also increased the tissue Zn to 18 - 20.5 mg kg<sup>-1</sup> which are sufficient levels for healthy growth of rice crop (table 3).

Zero N plots had N deficient plants at maximum tillering stage of the crop (table 3). However, increased addition of N fertilizer increased the tissue N and it has come to the sufficient level at 125 kg N without Zn and at 100 kg N with Zn application (table 3). Therefore, results show that Zn application enhanced the N uptake by plants showing their synergistic behavior and increase efficiency of N use. It also shows that, with the addition of Zn at the rate of 2.5 kg/ha, N recovery was increased from 31% to 41% at maximum tillering stage of the crop (table 3). The Beneficial effects of Zn on uptake of major and micronutrients have earlier been reported by Tiwari and Pathak (1976). Similarly, Abdul Salam and Balasubramanian (1988) observed that Zn application up to 5.7 kg/ha increased the uptake of Zn and N on a vertisols at Coimbatore, India.

**Table 2. Some chemical properties of the soils of experimental sites at Batalagoda in LCIZ.**

<i>Property</i>	<i>Site 1</i>	<i>Site 2</i>	<i>*Deficient level</i>
pH (1:5 soil: water)	6.2	6.1	-
Total N % (Kjeldahl method)	0.08	0.09	-
Organic matter %, (Walkley and Black method)	1.7	1.8	-
Olsen P (mg kg <sup>-1</sup> )	8.4	9.0	-
CEC (c mol(+) kg <sup>-1</sup> )	8.6	9.1	-
1N NH <sub>4</sub> OAC at pH7.0)			
Exchangeable K (c mol (+) kg <sup>-1</sup> )	0.07	0.08	<0.2
Fe (mg kg <sup>-1</sup> ), (AAAC at pH 4.8)	302	291	<2.0
Mn (mg kg <sup>-1</sup> ), (AAAC-EDTA)	9.8	11.2	<2.0
Cu (mg kg <sup>-1</sup> ), (AAAC-EDTA)	1.2	1.1	<1.0
Zn (mg/kg <sup>-1</sup> ), (0.05N HCl)	0.67	0.60	<1.0

AAAC - Acid ammonium acetate. EDTA - Ethylene diamine tetra acetic acid

\* Adapted from Yoshida (1981)

**Table 3. Zn and N contents in plant tissues at maximum tillering stage of the rice crop grown in LHG soils of LCIZ.**

<i>Zn level (kg/ha)</i>	<i>N level (kg/ha)</i>	<i>Season</i>					
		<i>Yala 1999</i>			<i>Maha 1999/2000</i>		
		<i>Soil Zn (mg/kg)</i>	<i>Tissue Zn (mg/kg)</i>	<i>Tissue N (%)</i>	<i>Soil Zn (mg/kg)</i>	<i>Tissue Zn (mg/kg)</i>	<i>Tissue N (%)</i>
0	0	0.68	8.5	1.5	0.60	8.4	1.3
	75	0.60	8.5	2.0	0.58	8.2	1.8
	100	0.60	8.2	2.5	0.55	8.0	2.2
	125	0.58	8.0	2.7	0.53	7.8	2.6
	150	0.57	8.0	2.9	0.50	7.6	2.8
2.5	0	1.0	20.5	1.9	0.98	19.6	1.4
	75	0.96	19.5	2.2	0.94	19.0	2.0
	100	0.94	18.3	2.7	0.92	18.8	2.6
	125	0.92	18.0	3.0	0.90	18.0	2.8
	150	0.91	18.0	3.1	0.88	18.0	3.0

### Growth, yield components and grain yield

Application of N increased the dry matter production, plant height and number of tillers/m<sup>2</sup> of rice when compared with the no N treatment (table 4). Addition of 2.5 kg Zn/ha further increased these growth parameters at all N levels. The mean increases at all N levels over no - Zn treatment were of 11.4%, 5.4%, and 6.0% respectively. This shows the effect of Zn on the N use efficiency by rice plants (table 4). Above growth parameters given at 125 kg N alone can be obtained at 100 kg N with Zn. table 4 also showed that application of N at higher rates ie. 150 kg N/ha has no effect on these growth

parameters if Zn is not added (table 4). Table 5 shows that the yield components viz. number of panicles/m<sup>2</sup>, culm length and panicle length of rice has affected by Zn application at each level of N.

**Table 4. Effects of applied Zn and N on dry matter production (DMP g/2 tiller), plant height (PH, cm) and number of tiller per square meter (NTM) at maximum tillering stage of the rice crop grown in LHG soils in LCIZ.**

Zn level (kg/ha)	N level (Kg/ha)	Season					
		Yala 1999			Maha 1999/2000		
		DMP	PH	NTM	DMP	PH	NTM
0	0	16.1 e	47.0 c	294 e	20.2 e	50.2 d	285 e
	75	18.2 d	50.5 b	331 d	22.5 d	54.0 c	338 c
	100	19.4 c	50.7 b	354 bc	24.5 c	56.0 b	356 b
	125	19.6 c	54.0 a	360 b	24.8 c	57.3 b	358 b
	150	19.9 c	54.1 a	366 b	25.0 c	58.5 a	360 b
2.5	0	17.4 de	48.5 c	327 d	21.0 e	52.0 d	310 d
	75	20.6 bc	51.9 b	359 b	24.2 c	54.5 c	364 b
	100	21.0 b	54.1 a	370 ab	26.8 b	58.5 a	372 a
	125	21.9 ab	54.8 a	380 a	28.6 a	58.8 a	378 a
	150	22.9 a	54.6 a	377 a	29.0 a	59.0 a	380 a
Zn x N		ns	ns	ns	ns	ns	ns
CV %		8.5	10.1	12.0	7.6	9.6	11.5

CV - Coefficient of variation, ns - not significant at 5% level

Values followed by the same letter in each column are not significantly different at p=0.05

**Table 5. Effects of applied Zn and N on number of tillers per m<sup>2</sup> (NPM) culm length (CL) (cm) and panicle length (PL) (cm) at harvesting stage of the rice crop grown in LHG soils of LCIZ.**

Zn level (kg/ha)	N level (Kg/ha)	Season					
		Yala 1999			Maha 1999/2000		
		NPM	CL	PL	NPM	CL	PL
0	0	226 e	54.0 c	20.6 d	232 e	53.0 cd	21.5 d
	75	260 c	56.0 bc	22.5 c	246 d	56.0 c	22.8 bc
	100	269 bc	58.0 b	23.0 bc	258 c	58.5 bc	23.0 bc
	125	278 b	60.0 a	24.0 b	262 c	59.6 ab	23.5 bc
	150	280 b	61.0 a	24.5 b	266 c	59.4 ab	23.8 bc
2.5	0	252 d	54.0 c	21.0 d	248 d	54.0 cd	22.5cd
	75	278 b	58.0 b	24.0 b	270 c	57.2 bc	23.3 bc
	100	289 b	64.0 ab	25.5 a	292 b	59.6 ab	24.0 ab
	125	296 a	68.0 a	26.0 a	299	64.0 a	24.8 a
	150	310 a	67.0 a	26.4 a	306 a	68.0 a	24.9 a
Zn x N		ns	ns	ns	ns	ns	ns
CV %		8.2	10.2	7.8	9.5	7.5	10.8

CV - Coefficient of variation, ns - not significant at 5% level

Values followed by the same letter in each column are not significantly different at p=0.05

Application of 2.5 kg Zn/ha increased the number of panicles per square meter, culm length and panicle length, respectively by averages of 10.2%, 7.6% and 7.8% at all N levels over no Zn treatment (table 5). Similar results were obtained for the thousand-grain weight and number of filled grains per panicle of rice (table 6). It also showed that application of 2.5 kg Zn/ha increased the thousand grain weight and number of filled grains per panicle respectively by averages of 3.0% and 5.9% over no Zn treatment at all N levels (table 6).

**Table 6. Effects of applied Zn and N on 1000-grain weight (TGW) (g), number of filled grains per panicle (NFG) and grain yield (GY) (t/ha) of rice grown in LHG soils of LCIZ.**

Zn level (kg/ha)	N level (Kg/ha)	Season					
		Yala 1999			Maha 19499/2000		
		TGW	NFG	GY	TGW	NFG	GY
0	0	23.8 c	78 e	3.28 f	24.0 c	80 d	3.14 f
	75	25.0 b	103 c	4.06 e	25.0 b	91 c	3.77 e
	100	25.3 b	112 c	4.82 d	25.2 b	93 c	4.45 c
	125	25.4 a	128 a	5.31 bc	25.4 b	103 ab	4.68 b
	150	25.4 a	126 ab	5.24 c	25.3 b	100 b	4.69 b
2.5	0	24.1 c	90 d	3.78 e	25.0 b	87 cd	3.22 f
	75	25.2 b	106 c	4.62 d	25.4 b	92 c	4.15 cd
	100	25.5 a	120 b	5.52 b	25.8 ab	100 b	4.78 b
	125	25.8 a	128 a	5.79 a	26.1 a	107 a	4.96 a
	150	25.8 a	130 a	5.93 a	26.2 a	107 a	5.06 a
Zn x N		ns	ns	ns	ns	ns	ns
CV %		8.6	9.2	6.5	10.2	8.4	8.2

CV - Coefficient of variation, ns - not significant at 5% level

Values followed by the same letter in each column are not significantly different at p=0.05

Results also shows that the addition of either N or Zn was effective in increasing these growth parameters and yield components, but combined effect of these two nutrients was higher than the effect of N or Zn alone. Application of Zn at the rate of 2.5 kg Zn/ha increased the average grain yield at all N levels and 2 seasons by 12.9% over no Zn treatments (table 6). Addition of N up to 125 kg N increased the grain yield and further addition (*i.e.* 150 kg N/ha) had no effect on grain yield at both with and without Zn (table 6). However, yields at each level of N with Zn were always significantly higher than that of without Zn. For example, 12% yield increase has been obtained by 125 kg N + 2.5 kg Zn over 125 kg N alone. Similarly Abdul Salam and Subramanian (1988) observed that combination of 60 kg N/ha and 5.7 kg Zn/ha gave the same yield as that of 120 kg N/ha alone on a vertisol in India. He also reported that the interaction between N and Zn on grain yield was synergistic and was seen only in southwest monsoon. Therefore, these results show the application of Zn increases the N use efficiency from 15.6 to

19.4 kg grain yield per kilogram of applied N. Results of all 2 sites over 2 seasons showed that application of Zn significantly increased the N use efficiency, N recovery, growth parameters, yield components and grain yield.

**Table 7. Residual effect of applied Zn at different levels of N on number of panicles per m<sup>2</sup> (NPM), thousand grain weight (TGW) (g); number of filled grains per panicle (NFG) and grain yield (GY-t/ha) of 2<sup>nd</sup> crop of rice grown on LHG soils of LCIZ.**

<i>Treatment</i>		<i>Yala 2000</i>			
<i>Zn level</i> (kg/ha)	<i>N level</i> (Kg/ha)	<i>NPM</i>	<i>TGW</i>	<i>NFG</i>	<i>GY</i>
0	0	226 d	23.8 c	86 d	3.04 d
	75	242 c	24.4 b	98 cd	4.03 c
	100	258 b	24.8 b	108 bc	4.08 c
	125	265 b	25.2 ab	112 b	4.79 b
	150	256 b	25.2 ab	109 b	4.75 b
2.5	0	231 cd	23.7 c	88 d	3.12 d
	75	252b	24.8 b	106 bc	4.23 c
	100	276 ab	25.5 a	118 ab	4.68 b
	125	289 a	25.7 a	124 a	5.03 a
	150	292 a	25.8 a	124 a	5.10 a
Zn x N		ns	ns	ns	ns
CV%		6.5	7.2	8.5	7.2

CV - Coefficient of variation, ns - not significant at 5% level

Values followed by the same letter in each column are not significantly different at  $p=0.05$

### Residual effect of applied Zn

Yield data recorded from the trial conducted on same plots in second season using the same variety showed the residual effects of Zn on second crop of rice is occurred (table 7). Application of 2.5 kg Zn/ha in first season increased the number of panicles/m<sup>2</sup>, thousand grain weight, number of filled grains per panicle and grain yield of second crop of rice. They were respectively by averages of 7.5%, 1.8%, 5.3% and 9.1% at all N levels over no Zn treatment. (table 7). It shows that residual amounts of applied Zn present in second season are in sufficient levels to increase the N use efficiency, yield components and grain yield of the second rice crop.

## CONCLUSIONS

Low Humic Gley soils which occur as lower members of the drainage catena in association with red yellow podzolic soils contains comparatively less than critical level of available Zn for rice crop growth. This is further confirmed by the tissue Zn content. N recovery and N use efficiency can be

increased respectively from 31% to 41% and from 15.6 to 19.4 kg grain yield per kilogram of applied N by correcting this Zn deficiency problem through Zn fertilization. One application of Zn at the rate of 2.5 kg Zn/ha is sufficient to sustain two crops of rice. Synergistic effect between applied Zn and N on N use efficiency, growth and grain yield of rice is observed.

### ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance given by Ms. Farooza Sahabdeen to type the manuscript.

### REFERENCES

- Abeysirwardena, D. S. De Z. and C. A. Sandanayake. 2000. Future rice research as directed by trends in cultivated extent and yield of rice during the recent past. Proceeding of the Annual Symposium of the Department of agriculture, Sri Lanka. 2: 371- 380.
- Abdul Salam, M and S. Balasubramanian. 1988. Influence of N, Zn and their interaction on the yield and nutrient uptake of 'IR 20' rice (*Oryza sativa*) in different seasons. Indian Journal of Agricultural Sciences. 58(3): 190-193.
- Bandara, W. M. J. and L. C. Silva 2000a. An assessment of micronutrient requirements for rice grown in Low Humic Gley soils of Low Country Dry Zone. Proceeding of the Annual symposium of the Department of Agriculture, Sri Lanka 2:35-46.
- Bandara, W. M. J and L.C. Silva 2000b. Effects of applied micronutrients on growth and grain yield of rice grown in Low Humic Gley soils of Low Country Intermediate Zone. Journal of the soils science society of Sri Lanka 12: 40-50.
- Bandara, W. M. J and L. C. Silva. 2001. Rice crop response to Zn application in Low Humic Gley soils of Low Country Intermediate Zone. Annals of the Sri Lanka Department of Agriculture. 3: 9-18.
- Deb, D. L. 1992. Development of soil and plant analytical methods for micronutrient and sulfur in Sri Lanka. GCPF/SRI/047/NET field document No. 11. Pp 42-54.
- Krisnamurthy, V. S. 1979. 'Zinc nutrition of rice (*Oryza sativa* L.) with special reference to varieties, soil conditions, sources and methods of applications of Zinc.' Ph.D. Thesis, Tamil Nadu Agricultural University. Coimbatore. India.
- Nagarajah, S., B. M. Nizar, M. M. Jauffar and S. De Silva. 1983. Zinc as a limiting nutrient for rice growth in the mid country wetzone of Sri Lanka. Tropical Agriculturist 139: 67-71.
- NSF. 2000. The Review of Fertilizer Year 2000. National Fertilizer Secretariat, No. 31 Pathiba Road, Narahenpita, Colombo 5. Sri Lanka. Pp 32-36.
- PPIC (Potash and Phosphate Institute of Canada). 2000. Balanced fertilizer use for sustainable agriculture in India. PPIC India program, gurgaon- 122016, Haryana. Pp 4-6.

- Panabokke, C. R. 1996. The Great Soil Groups in Sri Lanka, their Environmental setting, Main Characteristics and Taxonomic Placement. In *Soils and Agro- Ecological Environment of Sri Lanka*, Natural resources Energy and Science Authority, 47/5, Maitland place, Colombo 7, Sri Lanka, 30-40.
- Sirisena, D. N., D. B. Wickramasinghe and L. S. Silva, 2001a. Recovery of fertilizer N applied to wetland paddy soils. *Annals of Srilanka Department of Agriculture* 3:231-236.
- Sirisena, D. N., D. B. Wickramasinghe, W. M. W. Weerekoon, S. T. Bandara and D. Kumaragamage, 2001b. Nitrogen availability in rice soils. *Journal of Soil Science*. 13:46-51.
- Tiwari, K. N. and A. N. Pathak. 1976. Direct, residual and cumulative effects of applied Zn on yield, chemical composition, uptake by rice and wheat crops in a fixed rotation under field condition. *Fertilizer News*. Newdelhi. 21(7):31-37.
- Tiwari, K. N. 2002. Rice production and nutrient management in India. *Better Crop International*. 16:18-22.
- Yoshida, S. 1981. *Fundamental of rice crop Science*. Pp 186. The International Rice Research Institute, Los Banos, Laguna, Philippines.