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SOIL AND NUTRIENT MANAGEMENT FOR INCREASING SOIL FERTILITY TOWARDS INCREASED RICE PRODUCTIVITY IN SRI LANKA

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INTRODUCTION

Rice is the staple food of 18.6 million people and livelihood of more than 1.8 million farmers in Sri Lanka. More than 30 % of the total labour force is directly or indirectly involved in the rice sector. Annual per capita consumption of rice fluctuates around 93 $\pm$ 3 kg at present and is dependent on the paddy production in the country and the price of imported wheat flour. At present the paddy production is about 2.6 million mt per year, which is about 90% of the total requirement of the country. With the present population growth rate of 1.2%, slightly increasing per capita rice consumption, requirements for seed paddy and for wastage in handling, Sri Lanka would need 3.4 million mt of paddy by the year 2005. The national average yield should therefore be increased from present level of 3.5 t ha^{-1} to 4.14 t ha^{-1} in 2005 to satisfy this requirement.

With the introduction of modern improved varieties in 1968, the national average yield of rice in Sri Lanka increased from about 2 t ha^{-1} in 1970's to about 3.5 t ha^{-1} in early 1980s. Since then it remained stagnant despite 95% of the rice extent being cultivated with improved cultivars (figure 1). The present national average (3.7 t ha^{-1}) is around 37% of the genetic potential (10 t ha^{-1}) of improved cultivars used in Sri Lanka.

THE YIELD GAP BETWEEN RESEARCHER AND FARMER

There is always a yield gap between researcher and the farmer and the difference can be measured by taking the yield ratio of these two. The ratio between researcher and farmers yield vary with crops and even within a crop. Rice has a lower yield ratio compared to other food crops grown in Sri Lanka (table 1). Rice grown in Red Yellow Podzolic soil (RYP), Reddish Brown Latasol (RBL) and Reddish Brown Earth (RBE) has a higher yield ratio (1.66) than that of Low Humic Gley (LHG), Mineral and Organic soil (Kendaragama, 2000). This data suggest that there is a possibility to improve farmer yield in RYP, RBL and RBE soils with existing technologies. But, further research is needed to increase the researcher yields in LHG, mineral and organic soils.

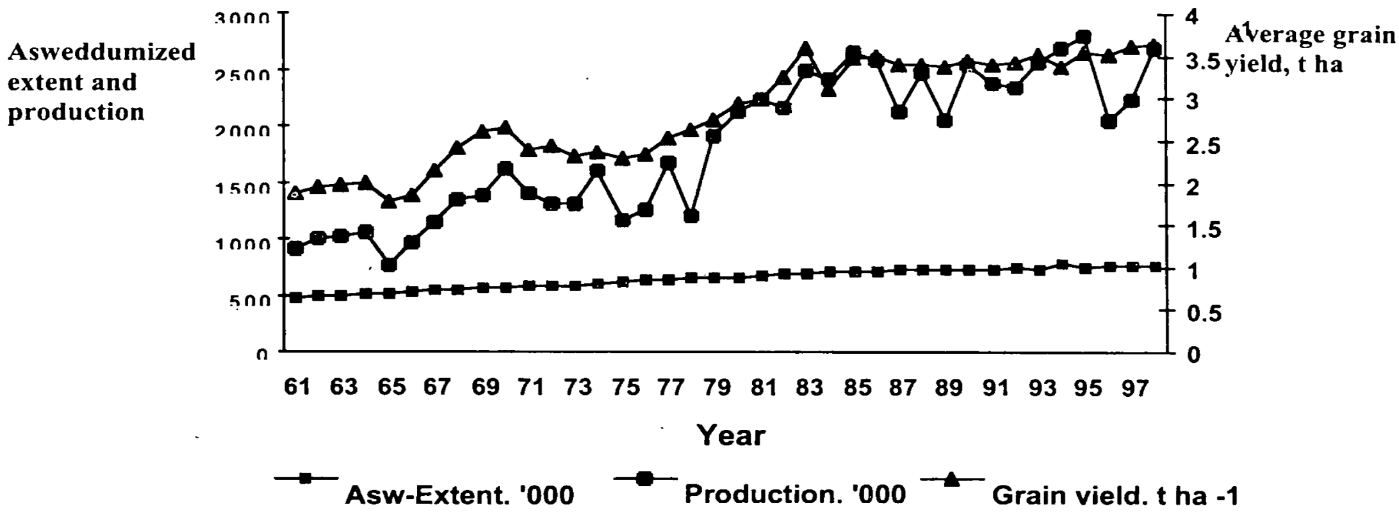

Figure 1. Asweddumized Extent, National Production and Average grain yield of rice in Sri Lanka

Table1. Researcher / Farmer yield ratio of selected food crops in Sri Lanaka

Crop	*Soil*	*Yield ratio*
Onion	RBE	2.18
Potato	RYP	2.04
Chilli	RBE	1.77
Rice	RYP, RBL, RBE	1.66
Rice	LHG, Min., Org.	1.28

The LHG soils in Polonnaruwa, Kalawewa, and Mineral soils in Colombo district has the lowest yield ratio. But this ratio is particularly high in RBL, RYP soils in Kegalla, RBL soils in Kegalla, Kandy and Matale and RBE soils in Anuradhapura (table 2). In these areas, researcher had a yield range of 6.37 – 8.45 t ha^{-1} compared to 3.39 – 6.56 t ha^{-1} yield obtained by the farmer (Kendaragama, 2000). Many factors could be attributed to this yield gap, of those inefficient nutrient management and declining soil fertility and productivity are the key factors.

Table 2. Researcher / Farmer yield ratio in rice in different soils in different district

Soil	*District*	*Yield Ratio*
RBE	Anuradhapura	1.61
RBE	Kalawewa	1.48
RBL	Matale	1.64
RBL	Kandy	1.61
RBL	Kegalla	1.79
RYP	Kegalla	1.69
LHG	Anuradhapura	1.38
LHG	Kalawewa	1.14
LHG	Polonnaruwa	1.06
Min.	Colombo	1.20
Min.	Galla	1.37
Min.	Gampaha	1.33
Min.	Kalutara	1.23
Org.	Colombo	1.38
Org.	Galla	1.46
Org.	Kalutara	1.44

Kendaragama, 2000.

MAJOR SOIL PROBLEMS ASSOCIATED WITH RICE CULTIVATION

Decreased response to fertilizer

Analysis of the yield data of long-term experiments in several regional research stations showed declining average yields. This trend was also observed in long term N studies (Wickramasinghe, 1995). Long-term experiments on the N response of elite breeding lines conducted on the same field at the Rice Research and Development Institute (RRDI), Batalagoda, Sri Lanka, over a period of 10 years have shown a definite declining trend in rice yields of experimental plots where N was applied (figure 2). The rate of decline in grain yield with time was greatest with the highest amount of N applied. The grain yield declined from about 7 t ha^{-1} in early 1970's to about 4-5 t ha^{-1} over the time in the higher N treatments. The treatment, which received no N, showed no yield decline and remained around 3.5 t ha^{-1}. This shows that N is not the only limiting factor to increase rice yields. Increased grain yield necessarily removes an equivalent amount of nutrients from the rhizosphere depleting nutrient supplying capacity of soil at a greater rate in the high yielding treatments than that of low yielding treatments. In long term studies (36 seasons) at RRDI, Batalagoda, Sri Lanka, in an experimental plot without any form of added fertilizer or organic manure, yields around 2.5-3 t ha^{-1} were observed on persistence of inherent soil fertility under maximum cropping intensity. This suggests that the inherent soil nutrient supply is sufficient only for a grain yield of about 2.5 – 3.0 t ha^{-1} in these fields.

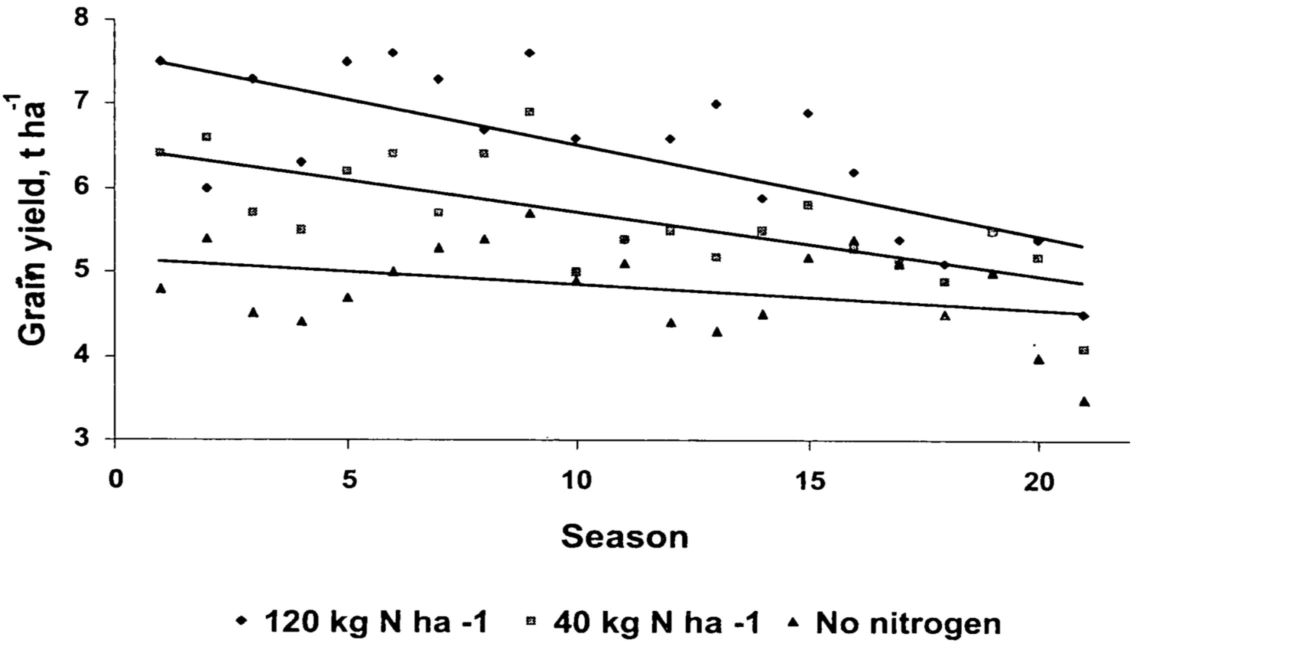

Figure 2. Yield trend of rice varieties to added nitrogen at RRDI, Batalagoda , Sri Lanka.

Imbalance fertilizer use in rice

The nitrogen source for rice in Sri Lanka is Urea. About 63%, 36% and 70% of the total imports of Urea, Muriate of Potash (MOP) and Triple Super Phosphate (TSP) respectively are used for rice cultivation. Although fertilizer recommendations have been made and revised regularly, farmers do not adopt those as there are other factors that influence fertilizer use. N fertilizer use in the paddy sector fluctuates widely with the price of urea, which is subsidized at present. The urea consumption for rice in Sri Lanka suggests that farmers on the average apply 91% of the recommended N level. However, MOP and TSP are not subsided since 1998, thus the uses of these fertilizers has not increased with increased use of urea (figure 3). The increased use of urea by farmers is also attributed to the reduction in crop response to applied N. Farmers apply N fertilizer when crop shows reduction in leaf greenness caused by reduced crop response which in turn stimulates farmers to apply higher amount of urea which is cheap. Farmers use 54% of the recommended amount of TSP while the use of MOP was 104% of the recommended level. This fertilizer usage pattern has created a nutrient imbalance in the rice crop. Therefore the farmer does not achieve the full benefit of applied N. In most of the irrigation schemes, water issues are rotational, making paddy fields dry between water issues. This leads to loss of nutrients by various ways. In most instances, N deficiency was observed even with the present fertilizer recommendation. Thus it is important to develop a fertilizer recommendation for the rice crop based on the crop performances while considering the target yield, yield potential of the system and farmers economy.

Depletion of nutritional status of rice soils

The major rice growing areas are situated in the Low Country Dry Zone (LCDZ) and in Low Country Intermediate Zone (LCIZ). The cropping intensity and the average yields in these areas are higher than the national average. Normally farmers do not recycle the rice straw but burn it in the threshing floors. Therefore, a considerable amount of nutrients are being removed from the soil in these areas. Hence, depletion of nutritional status of soil has been observed. Soil analytical data of rice soils in Sri Lanka support this conclusion (tables 3, 4, 5 and 6). Deb, (1992) reported that most of the rice soils in Sri Lanka are low in secondary and micronutrients, particularly S, Zn and Cu. It is widely accepted that most of the rice growing soils in Sri Lanka are depleted chemically, physically and biologically.

Soils in the LCDZ and LCIZ are slightly acidic to acidic and majority of the soils in Low Country Wet Zone (LCWZ), Up Country Intermediate Zone (UCIZ) and Mid Country Intermediate Zone (MCIZ) are acidic (table.3). Therefore, unavailability of certain nutrients can be expected in most of these soils.

Table. 3. Distribution (%) of pH in different agro-ecological zones in Sri Lanka.

AEZ	*Soil pH*			
	<5.5	*5.5 - 6.5*	*6.5 - 7.2*	*>7.2*
LCDZ	20.3	41.4	23.0	15.2
LCIZ	47.0	40.3	8.9	3.7
LCWZ	81.4	16.7	1.5	0.3
MCWZ	78.0	21.0	0.5	0.5
MCIZ	70.9	26.7	1.3	1.6
UCIZ	66.9	32.3	0.8	

Source: Soil Testing Service, Department of Agriculture

Textural changes in the plough layer

Rice fields in Sri Lanka have continuously been utilized over thousands of years. But negligence by the farmers in the recent past, a considerable amount of finer soil particles (silt and clay) from the plough layer have been washed off during land preparation with the draining water. In addition a fair amount of these particles migrate to the plough pan. Therefore, soil in the plough layer contains less fine particles than the original content (figure 4). Finer particles are the most important fraction of the soil for retaining applied nutrients and thus reduced finer particles may be a reasons for yield not responding to added fertilizer.

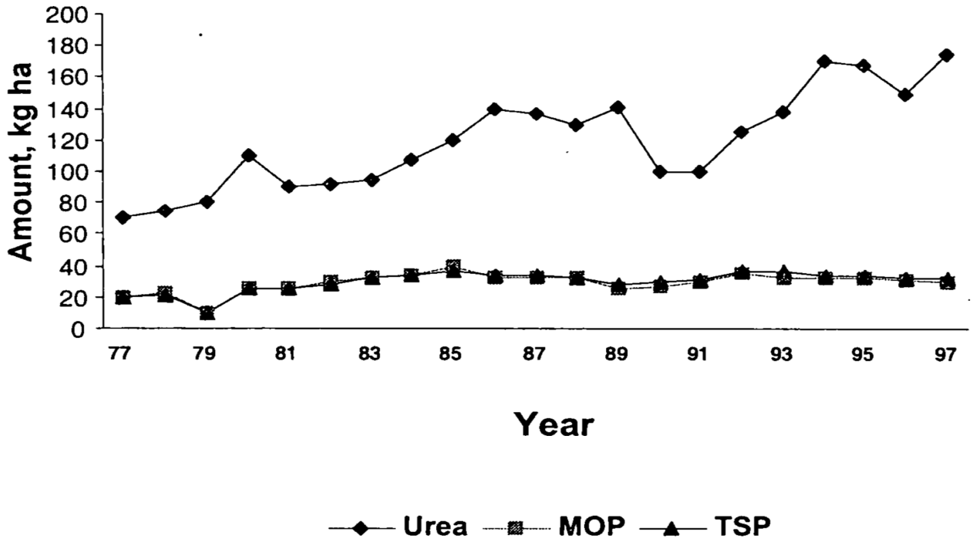

Figure 3. Fertilizer consumption for rice in Sri Lanka.

Development of a shallow plough pan

A change in the land preparation pattern in paddy cultivation during the last two decades appears to be one of the major reasons for the development of shallow plough pan in the field. Since the introduction of two wheel tractors in early 1970s, most of the farmers used only a rotovator instead of a mould board plough at the initial stage of land preparation. The ultimate result of this process has been the development of a plough pan closer to the surface of the soil (figure 5). Investigations at RRDI and Polonnaruwa have shown that a development of a shallow plough layer in certain soil types and the depth of the plough layer in these soils varied between 10-25 cm (Wickramasinghe, 1995 and G.D.I. Amarasinghe, 1996 personal communication). The thickness of the plough pan varies from place to place, probably due to soil type and the instruments used for land preparation. Therefore, the depth of the plough layer is not up to the required level for a better root growth of the rice plant.

MITIGATION OPTIONS ADOPTED TO OVER COME THE PROBLEMS

Nutrient management in rice

A number of studies have been carried out during the past decade on the use of chemical fertilizers. Findings of studies carried out during latter part of 1980s and early part of 1990s lead to the revision of the 1980 fertilizer recommendation for rice and formation of a new fertilizer recommendation for rice in 1990. However, there were complains from the extension workers and farmers that yellowing of leaves occurred when this recommendation was used. Therefore, it is vital to study the merits and demerits of the 1990 fertilizer recommendation.

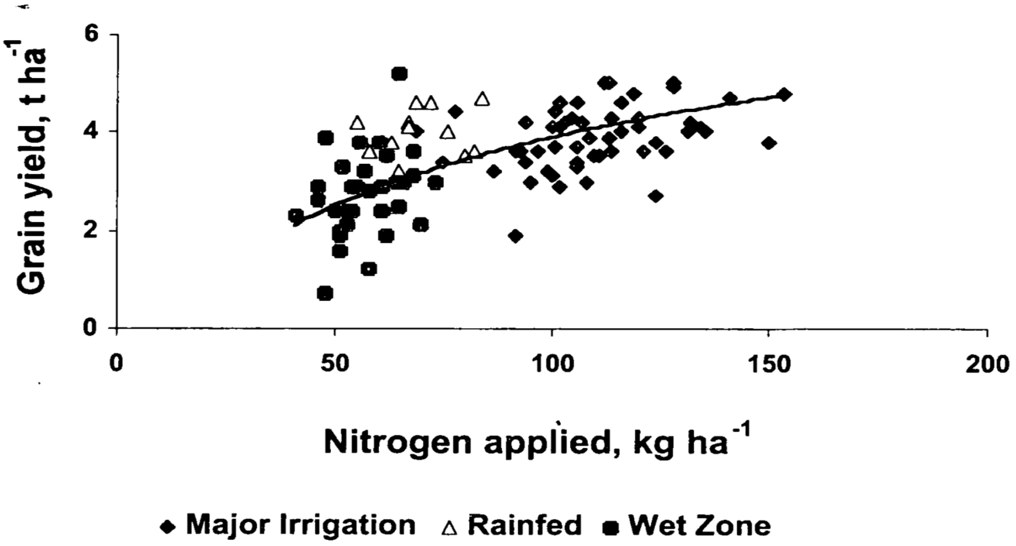

Figure 4. Use of urea in different systems of rice cultivation in Sri Lanka.

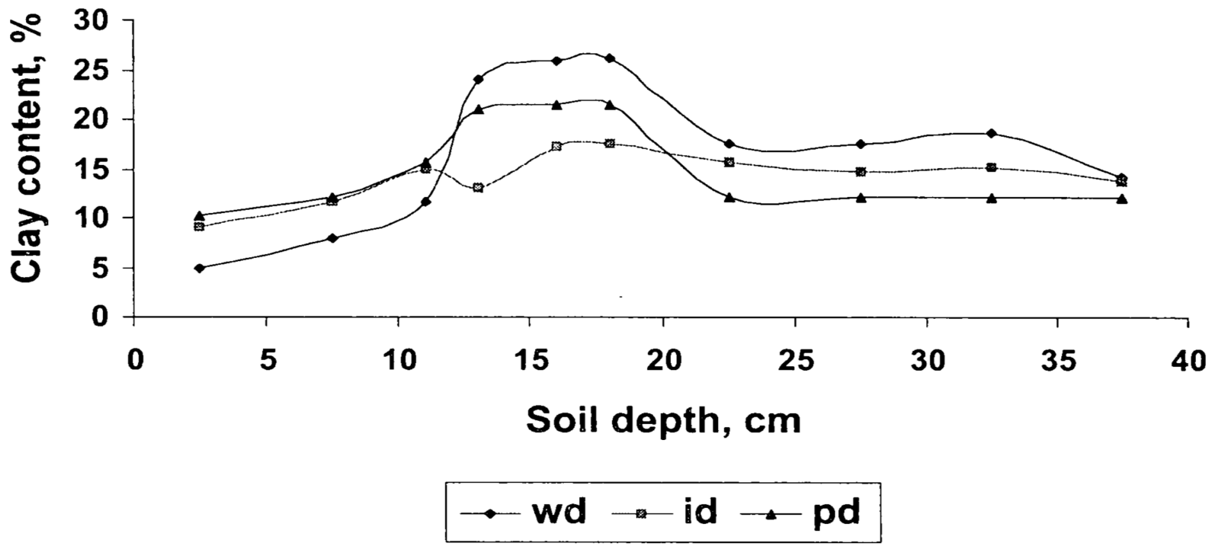

Figure 5. Clay content at different depths of different drainagerial classes of rice soils.

Response to nitrogen and split application

Large number of experiments have been conducted covering all the soil types in different Agro Ecological Regions (AER) to find the optimum nitrogen levels and their split applications. The conclusions of these studies were that the number of splits have to be reduced to three (basal and two top dressings) and 60 increase the basal N application from 7-10% to 25-30%. The first top dressing should delayed from 2-3 to 5-6 weeks after sowing or planting. There was no remarkable difference between different split application methods tested in the LCWZ, MCWZ and MCIZ and the response pattern reflected the heterogeneity in soil moisture regime, which was influenced by the location of fields and flow of upstream water. The 1980 DOA recommendation regarding the proportion of N application as basal proved to be suitable as 20-50% basal application in these zones.

There has been no response to added N in majority of the experiments conducted (77% of 38 trials conducted in LCWZ and 78% of 45 trials conducted in MCWZ, MCIZ and LCWZ). A reason for this may be the lack of attention given to the site selection and probably the selected sites were not representing the locality. It is erroneous to use data from non-responsive experiments to derive conclusions and these non-responsive sites should have been omitted when analyzing the results.

Table 4. Distribution of available P (Olsen's) content of rice soil in different agro-ecological zones in Sri Lanka

AEZ	*Available P, mg kg^{-1}*			
	0 -10	*10 – 20*	*20 – 30*	*>30*
LCDZ	62.9	16.4	10.0	10.6
LCIZ	79.6	13.4	2.4	4.6
LCWZ	67.9	19.5	6.0	6.6
MCWZ	75.1	14.6	3.9	6.3
MCIZ	74.4	16.3	3.2	6.1
UCIZ	30.8	16.9	6.1	46.2

Source: Soil Testing Service, Department of Agriculture

Table. 5 Distribution of exchangeable K content of rice soils in different agro-ecological zones in Sri Lanka,

AEZ	*Exchangeable K, mg kg^{-1}*			
	0 - 75	*75 – 150*	*150 – 400*	*>400*
LCDZ	67.8	24.8	6.9	0.4
LCIZ	80.3	14.0	4.6	1.1
LCWZ	75.5	17.9	5.9	0.7
MCWZ	75.1	17.6	6.3	1.0
MCIZ	68.4	19.5	9.9	2.2
UCIZ	33.1	30.0	30.8	6.2

Source: Soil Testing Service, Department of Agriculture

Table. 6 Influence of varietial duration, establishment method on total N uptake (kg of N ha^{-1}).

Variety	*Direct seeded*	*Transplanted*
	70	60
Bg 379-2	144	103
	154	125
	55	63
Bg 300	95	87
	96	120

Weerakoon and Wickramasinghe, 1998

The yield levels in most of the experiments, conducted in LCWZ, LCIZ and MCIZ except in few locations are as low as 1-2 t ha^{-1} and the co-efficient of variance (CV) of the experiments range from 3-62% with 17-18% in most of the sites. It is very difficult to obtain a significant difference in experiments with low yields and high CV as the standard errors are high. Although several experiments have been conducted in the LCDZ, experimental data in RBE and LHG soils have not been separated in analysis. A proper varietial selection have not been made as check varieties and 3-3.5

month (short duration) varieties had been used as check varieties in many occasions and the results had been extrapolated to 4-4.5 month (medium duration) varieties. Since there is a difference in yield potential and response to Nitrogen between 3 month and 4 - 4.5 month varieties, results obtained for the 3 month varieties should not have been used to extrapolate for 4 – 4.5 month varieties.

The direct seeded rice always uptake a higher amount of N than that a transplanted crop (table 7). This may be mainly due to higher biomas production in direct seeded crops. Also, medium duration rice varieties remove higher amount of N than short duration rice varieties. The reason for this could be that medium duration varieties has a longer growth period, which result to uptake of more nutrients than short duration varieties. Recent investigations show that it is important to apply N fertilizers to keep the leaf N in the top most erected leaf above 2.5% in the dry matter. This level of leaf N content in the flag leaf is also important after flowering of the plants. Experimental evidence have shown that application of a dose of N at heading significantly increased the grain yield, if there was a reduction of leaf N content below 2.5% in the dry matter.

Phosphorus response studies

Phosphorus removal by rice is as low as 9-10 kg ha^{-1}. Therefore response to added P for rice is low in most of the AER other than LCWZ and MCWZ, where leaching is very high and the active iron content is high. In these soils probably the fixation of P may also be high. Despite the high mount of P included in the 1971 fertilizer recommendation, the use of P fertilizer was very low resulting poor P status in the soils. Rezania (1992) reported that deficiency of P is not a common or extensive in Sri Lanka. Long term experiments shows that there is adequate P release from organic and inorganic sources. Therefore, management of P would be to maintain soil P level at around 10 ppm (Olsen's) level and application of 15-20 kg P_2O_5 is suggested (Rezania, 1992). However, this level is now questionable as experiments produced low yields and recent analytical data collected from the soil testing service of the DOA show that majority (63-80%) of rice growing soils are low in available P (Olsen's) in all the AER except in some soils where vegetables are grown in rotation with rice in the UCIZ (table. 4). Investigation shows that in places with high yields farmers have applied high amounts of P. Further, application of P at higher rate in the LCDZ show a residual effect in the subsequent crop without a yield reduction (Senavirathna Banda, personal communication). Phosphorus response studies showed that application of P up to about 30-45 kg P_2O_5 ha^{-1} significantly increased the grain yield of rice, especially in the soils where Olsen's P content is <10 mg kg^{-1}. There is a significant response to added P (30 –100% yield increase) in the LCWZ and the average P requirement is approximately 70 Kg P_2O_5 ha^{-1}.

Table. 7 Grain yields of rice under deep ploughing and shallow land preparation at different sites in Polonnaruwa from Maha 96/97 to Maha 98/99 in Sri Lanka

Location	*Site*	*Soil Type*	*Treat- -ment*	*Season*					
				Grain yield (t/ha)					
				M 96/97	*Y 97*	*M 97/98*	*Y 98*	*M 98/99*	*Mean*
Thopawewa			DP	6.70	6.08	5.28	4.98	4.32	5.47
	1	RBE	SLP	6.60	5.25	4.30	4.07	4.07	4.86
	2	RBE	DP	5.49	5.64	6.52	4.33	4.33	5.26
			SLP	5.16	4.57	5.02	3.46	3.46	4.33
	3	ALLUVIAL	DP	5.40	4.56	5.69	3.94	3.94	4.71
			SLP	4.10	3.60	5.48	3.42	3.42	4.00
Jayanthipura									
	1	RBE	DP	6.02	5.55	-	5.86	5.24	5.67
			SLP	5.26	4.93	-	5.62	4.27	5.02
	2	RBE	DP	6.30	5.03	-	4.31	4.15	4.95
			SLP	5.84	3.93	-	3.00	2.72	3.87
	3	LHG	DP	4.95	7.36	-	5.17	4.46	5.48
Hingurakgod a			SLP	5.57	7.73	-	4.62	3.15	5.27
	1	RBE	DP	6.	-	3.27	5.77	4.32	4.87
			SLP	5.60	-	3.44	4.95	4.18	4.54
	2	RBE	DP	5.95	-	4.59	4.43	4.51	4.89
			SLP	5.03	-	3.90	3.76	4.87	4.40
	3	LHG	DP	5.11	-	4.37	4.99	4.81	4.81
			SLP	5.27	-	3.48	5.06	4.66	4.62

RBE – Reddish Brown Earth, LHG – Low Hmic Gley soil; Sourse: Wickramasinghe, (1998)

The price of TSP in the world market has continuously escalated. Therefore cheaper sources of P fertilizers have been studied. It has been found that Eppavala Rock Phosphate ERP could be used in the acidic LCWZ soils, particularly during *yala* season (Rezania, 1992). However, ERP cannot be used in the LCDZ due to its low solubility. FMP is also a good source of P, Si and Mg and therefore the possibility of using this fertilizer has also been studied and had found that its only effective in the LCWZ, but not in the LCIZ and LCDZ (C.S. Wijesundara and W.M.A.D.B. Wickramasinghe, unpublished). Investigations have showed that DAP is as good as TSP in the LCDZ (W.M.A.D.B. Wickramasinghe, unpublished).

Potassium response studies

Potassium is a nutrient that is absorbed efficiently by the rice plant. An average of 5 t ha^{-1} yield, remove about 100 Kg of K. But the fertilizer recommendation for rice provide only 20 kg K_2O ha^{-1} causing a negative balance in the K status in the soil. Panabokke (1996) has shown that most of the Sri Lankan rice soils are low in exchangeable K (<2 meq / 100 g). This finding has been confirmed by the data collected by the Soil Analytical Service of the Department of Agriculture. About 68 – 80% of the rice soils are low in exchangeable K except soils in the UCIZ (table 5). A number of experiments have been carried out to study the response to added K in different soil types. A clear response to added K has between found in most of the experiments except in few locations in the LCWZ Absence of long-term experiment would be one of the reasons for lack of response to K in Sri Lanka.

The low yield levels (<4 t ha^{-1}) and high CV in most of the experiments conducted except in the experiments conducted in LCDZ may be another reason. The natural supply of K would be sufficient for the yield level achieved in those experiments. Also, it is very difficult to obtain a significant difference with high CV of the experiments as indicated in the previous occasion. Also, a higher amount of exchangeable K (>2 meq/100g) was present in the soils in most of the locations and/or the soils had high CEC values compared to the sites where a response have shown. Response to added K was seen in the LCWZ where mineral soils had a exchange. K content < 0.1 meq/100 g and pH below 4.5. In addition CEC of those soils are low.

Another reason would be the limitation of micronutrients and low soil organic matter (SOM) content of the soil (table 5). A significant yield response to added K was observed when K was applied in combination with organic manure (figure 6). Wanasundara *et. al.*, (1989) showed that application of organic manure increased the K uptake and grain yield of rice. This conclusion was further supported by the analytical data where majority of rice growing soils is low in total C % except soils in LCWZ and UCIZ.

Earlier experiments have suggested that application of rice straw more than 3.5 t ha^{-1} supplements the total K requirement of rice, and based on this data the total K application as fertilizer was withdrawn from rice when more than 3.5 t ha^{-1} rice straw was added. However, recent research has suggested that applications of K with rice straw significantly increased the grain yield of rice (figure 6) and the total K uptake (W.M.A.D.B. Wickramasinghe, unpublished). The K concentration in the flag leaf decreased with increasing N application. The reason for this would be due to dilution of K in the plant with higher biomass production (Weerakoon and Wickramasinghe, 1999). Another important aspect is that though there was no significant yield difference among different levels of K application (0-60 Kg K_2O ha^{-1} there was an increase in the 1000 grain weight and decrease in the hull weight. This clearly reflects the importance of K on grain filling.

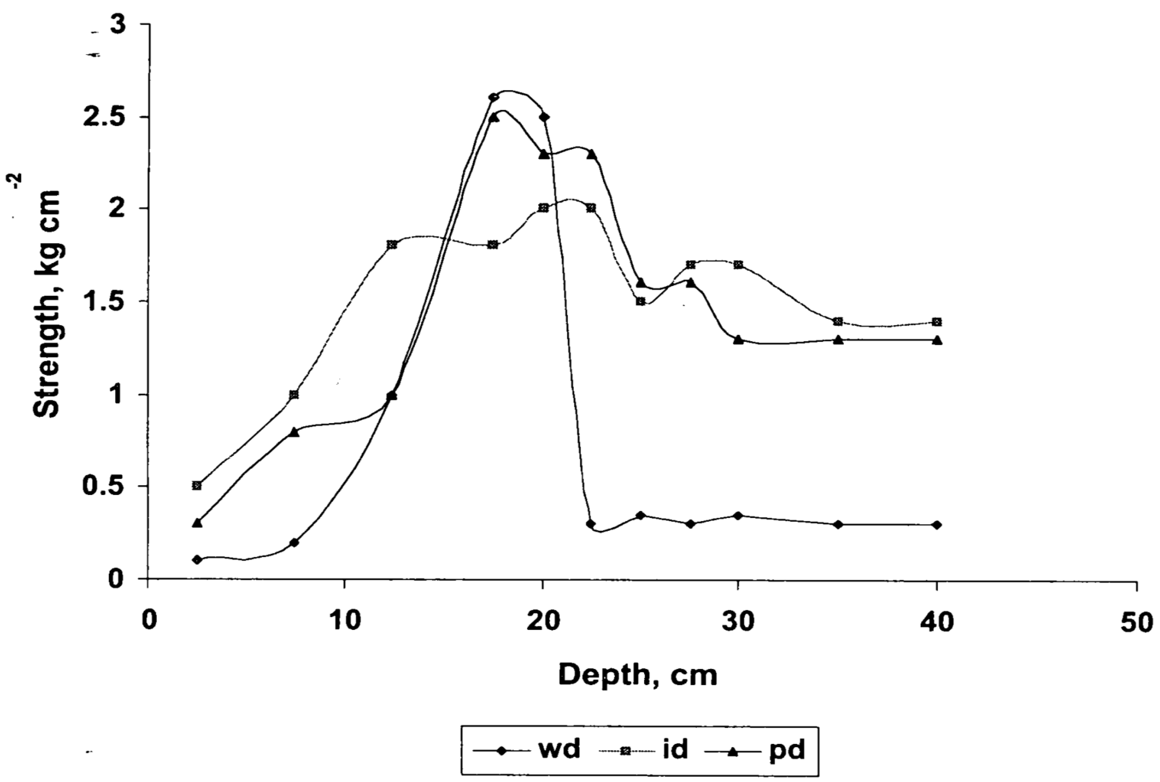

Figure 6. Soil strength at different depths of different drainagerial classes of rice soils

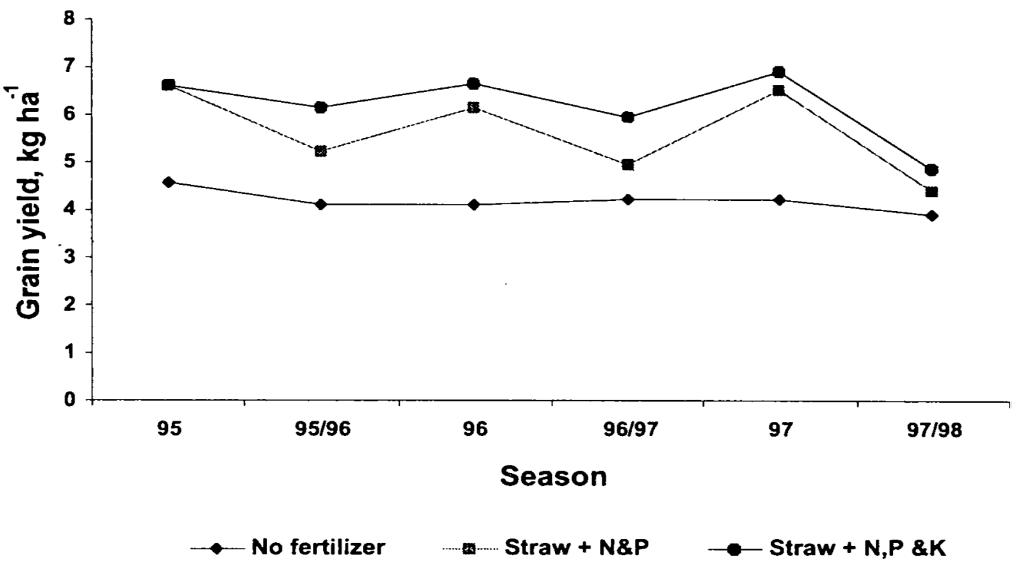

Figure 7. Effect of additional K with rice straw application on grain yield of rice.

Soil testing and fertilizer recommendation

The soil testing and fertilizer recommendation programme was introduced to provide a site specific fertilizer recommendations, which provide greater efficiency in managing nutrients for higher productivity. The main objectives of the soil testing programme are:

i. Management of resources to optimize production and cater to requirements of commercial farmers.
ii. Improvement of the soil fertility of arable lands by managing plant nutrients efficiently and avoiding pollution
iii. Promoting organic recycling to improve the fertility of the soil.
iv. Evaluation of the soil fertility in different AER.
v. Mapping of soil test values based on soil fertility and yield capability.
vi. Provide recommendation to the farmers to improve soil fertility and increase the income of the farmers.
vii. Generate research information for different soils.

Although the programme was initiated to achieve above objectives success has been limited due to various reasons. The most important observation was the generation of a database on soil fertility in different cropping systems and AER (tables 3, 4, 5 and 6). The data suggest that attention should be given in managing those soils for higher productivity assuring sustainability of soil fertilizer otherwise these soils will be further depleted hindering productivity in near future.

Status of secondary and micronutrients in rice.

Pavanasasivam and Kalpage (1973) reported that a little attention has been paid for secondary and micronutrients in Sri Lanka compared to major nutrients This trend continued until the recent past. However, there was an attempt to highlight the importance of secondary and micronutrients in early 1990's and an expert from FAO reviewed the micronutrient status in Sri Lanka. He made several recommendations, but sufficient attention has not been paid to those recommendations.

Dep (1992) analyzed more than 500 soil and plants samples from various part of the country and found that Zn and Cu are deficient in those soil and plant samples and the deficiencies are widely spread all over the country. Sulfur deficiency is also prevalent in most parts of the country except in the LCWZ. The iron content is low in southern LCDZ and this was excessive in the LCWZ. The LCWZ soils are deficient in available Mn, but adequate in the other regions. Recent studies show that Zn, Cu and S are deficient in rice soils in the LCIZ and LCDZ and significant yield increase have been obtained by application of these nutrients (Bandara, 1999). Zn application can be done adopting several methods viz, soil incorporation as $ZnSO_4$ at the rate of 10 kg of $ZnSO_4$ ha^{-1}, root dipping in a solution of 3% ZnO, seed coition with ZnO before sowing and application of 2-3% $ZnSO_4$ s as fouler application. When incorporated $ZnSO_4$ with soil at the rate of 10 kg ha^{-1}, a residual effect is sufficient for 2 crops. Foliar application is effective in curing an affected crop.

However, sufficient data were not available on all the micronutrients and sulfur for high yielding rice crops, their removal and thresh hold levels. Therefore, more emphasis must be given to this aspect in future.

Increasing plough layer depth by proper ploughing

Wickramasinghe (1999) reported that increasing the plough layer depth to about 20-25 cm increased the root growth of the rice plant. As a result, the above ground biomass, and the grain yield of rice where the shallow plough pan was present. This was observed in RYP, RBE and Alluvial soils, but not in LHG where plough layer was comparatively deep (table. 7). In general, most rice roots penetrate to a depth of about 20-25 cm (Sharma *et al.*, 1994). Since root:shoot ratio from a crop variety is a constant, any restriction of root growth will eventually reduce the above ground plant growth. Increasing ploughing depth also increase the nutrient uptake than that of shallow land preparation (Wickramasinghe, unpublished). Increasing the depth of the plough layer would bring the finer particles and nutrients from the plough pan to the plough layer helping plant growth.

Integrated Plant Nutrient System (IPNS) practices in rice cultivation

The present yield cannot be increased even with the excessive application of chemical fertilizers. Application of organic manure is one of the key aspects in increasing soil fertility and productivity. But this process is difficult as the country is located in the tropics and therefore the mineralization rate of organic matter is very high. Analysis shows that the majority of soils in major rice growing areas (LCDZ and LCIZ) are low in total carbon content. Amarasiri and Wickramasinghe (1988) and Wickramasighe, (Unpublished) showed that there was no build up of organic carbon in soil in spite of application of rice straw at the rate of 5 t ha^{-1} continuously for 7 seasons. Even though the organic carbon content was not increased, a significant yield increase was observed when organic manure or bio fertilizers were applied with recommended levels of chemical fertilizer than chemical fertilizer application alone (Amarasiri and Wickramasinghe, 1988; Nagarajah, 1990; Wickramasinghe, 2000). The main sources of organic manures are rice straw, cow dung and poultry manure. Application of paddy husk and charcoaled paddy husk is also helpful in increasing yield. Especially application of these materials in the wet zone reduced the iron toxicity of rice (Wijesundara, unpublished).

SUGGESTION FOR FUTURE RESEARCH.

Future research should give more emphasis to increasing the fertility and productivity of soil to increase yield per unit area in a sustanable manner. Given below are several major areas of research that need to be undertaken.

i. Identifying effecient nutrient management systems.
ii. Developing an efficient integrated plant nutrient management system.
iii. Identification of in situ green manure crops which produce higher biomass within shorter growth duration (3-4 weeks) under dry conditions.
iv. Developing location specific fertilizer recommendation based on target yield.
v. Developing new techniques under present soil testing service to use under field conditions.
vi. Developing an efficient and cheaper analytical techniques.
vii. Developing of critical levels of P, K, and OM for higher yields for different soils.
viii. Budgeting of nutrients in different rice growing systems
ix. Identifying limitations of secondary and micronutrients in different soils and cultivating systems.

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