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Title
RESPONSE OF WETLAND RICE TO LONG TERM FERTILIZATION IN AN ENTISOL

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INTRODUCTION

Rice-rice cropping sequence is the predominant cropping system in Central and South India, especially in the state of Kerala. Many lowland areas where rice-rice cropping is followed have been brought to intensive cultivation during the past decades. Continuous cropping with imbalanced and inadequate fertilization combined with inefficient management of other inputs causes depletion of soil nutrient levels even in the fertile soils in the long run, adversely affecting nutrient uptake and consequently crop yields (Choudhary, 2007) and the yield response to chemical fertilizers.

Efficient and sustainable management of natural resources especially of soil and water is basic to agricultural growth and national economy in India. This led to the establishment of long term fertilizer experiments to study the effects of continuous cropping and fertilizer application on soil fertility and sustenance of crop production. The results of a long-term experiment initiated to monitor the productivity, nutrient dynamics and soil fertility of a rice-rice cropping system in the long run and to determine appropriate soil fertility management strategies is reported in this study.

MATERIALS AND METHODS

The experiment was established in 1977 at the Cropping Systems Research Centre, Karamana, Kerala, to monitor the growth, productivity, nutrient use efficiency (NUE), nutrient dynamics, and soil fertility of a rice-rice cropping system in the long run. The soil of the experimental site was deep riverine alluvial sandy loam, a Typic Tropofluvent, low in available nitrogen (155kg ha^{-1}), and medium in available P, Bray method, (10.9kg ha^{-1}) and K (125kg ha^{-1}) contents. Wetland rice *(Oryza sativa L. cv. Aiswarya*, medium duration) was planted twice each year, once during the 'kharif' season (May-June to August-September), and during the 'rabi' season (September-October to December-January). The treatments consisted of 18 combinations of three levels of N (40, 80 and 120 kg ha^{-1}), 3 levels of P (0, 40 and 80 kg ha^{-1}), and two levels of K (0 and 40 kg ha^{-1}) arranged in a partially confounded factorial block design with one unfertilized control plot in each of the three blocks of every replication. The fertilizers applied were urea for N, rock powdered rock phosphate for P and muriate of potash for K. The effect of continuous depletion of N, P and K for over 30 years on the crop and soil characters is presented in this study.

RESULTS

Plant growth parameters

Plant height, total and productive tillers increased significantly with increasing rates of N and P application (Table 1). Withholding P fertilization for over 30 years resulted in a decrease in these parameters. In contrast to N, consecutive increase in P up to the third level was found to stimulate growth and tiller production significantly.

At harvest, P at 80 kg ha^{-1} produced significantly taller plants during both kharif and rabi (100.49 and 88.06cm respectively) than the different levels of N and K. The growth-enhancing effect of N levels was significant up to 80 kg ha^{-1}, whereas increased application did not give further response. The two levels of K did not significantly affect plant growth.

Table 1. Effect of NPK mineral fertilization on plant growth of rice on a Typic Tropofluvent in Kerala, India.

Treatments	Plant height (cm)		Total tillers		Productive tillers	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
N						
N_{40}	95.081	82.992	11.338	9.567	10.054	8.308
N_{80}	97.829	84.300	12.104	9.988	10.679	8.933
N_{120}	96.735	85.846	12.113	10.467	10.640	9.275
CD (0.05)	1.495**	2.229*	.633*	.694*	NS	.617**
P						
P_0	92.544	81.317	11.225	9.492	10.067	7.829
P_{40}	96.610	83.758	12.158	10.221	10.588	9.121
P_{80}	100.492	88.063	12.171	10.308	10.719	9.567
CD (0.05)	1.495**	2.229**	.633**	.694*	NS	.617**
K						
K_0	96.333	84.228	11.794	9.986	10.536	8.878
K_{40}	96.764	84.531	11.908	10.028	10.379	8.800
CD (0.05)	NS	NS	NS	NS	NS	NS
$N_0P_0K_0$	89.450	76.375	9.933	8.142	9.083	6.800

Yield and dry matter production

Grain and straw yields increased linearly with increasing P during both seasons, whereas for N, increase in grain yield was marked only during rabi (Table 2). Thus long term skipping of P has resulted in a decreased yield response to N. At each level of N, increase in P levels increased grain yield. Hence, grain yield remains low in the treatments depleted of P over the long term but supplied with adequate N (Fig.1). The dry matter production also followed a similar trend with low yields in treatments where long-term P application was low or completely skipped, at each level of N (Table 3). Thus the degree of stimulation of plant growth by N application seems to be decreased in treatments with inadequate P application. Potassium did not show any effect on the total dry matter production or yield.

Table 2. Rice yield and dry matter production as influenced by levels of N, P and K.

Treat-ment	Grain yield (kgha $^{-1}$)		Straw yield (kgha $^{-1}$)		Per cent increase in grain yield over absolute control		Total dry matter production (kgha $^{-1}$)	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
N								
N_{40}	4326	2970	8336	5352	40.23	52.23	12662	8322
N_{80}	4554	3027	8893	5518	47.61	55.13	13447	8544
N_{120}	4432	3310	9369	6153	43.67	69.66	13802	9463
CD(0.05)	NS	224	NS	446	-	-	NS	552
P								
P_0	3498	2330	7006	4229	-	-	10504	6558
P_{40}	4707	3327	9393	5975	52.57	70.53	14100	9302
P_{80}	5107	3649	10200	6820	65.54	87.03	15307	10469
CD(0.05)	302	224	885	446	-	-	945	552

K								
K_0	4499	3118	8891	5632	-	-	13391	8750
K_{40}	4375	3086	8841	5716	41.81	58.18	13216	8802
CD(0.05)	NS	NS	NS	NS	-	-	NS	NS

The percent increase in grain yield over control was significantly higher at higher levels of N and P (Table 2) but the magnitude of increase was more for P levels than for N. The values were also higher during rabi than for kharif season.

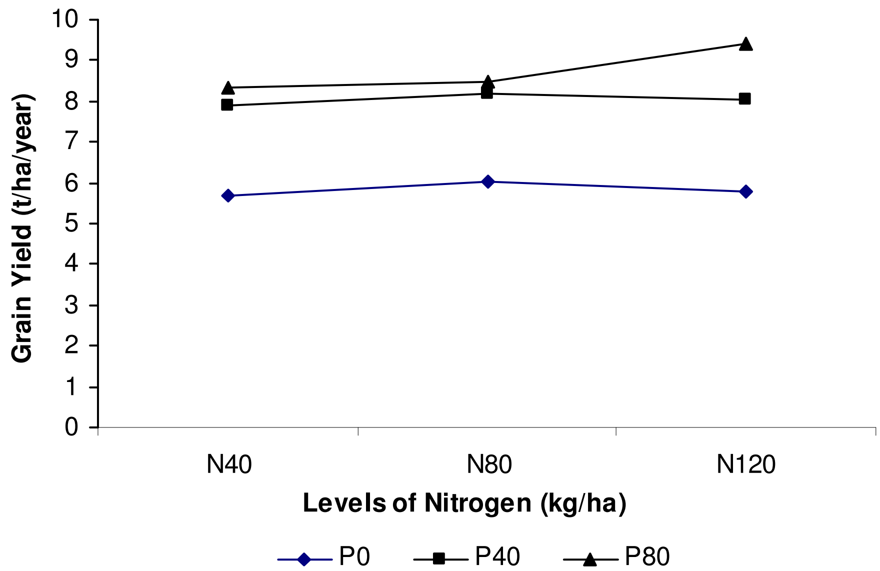

Figure 1. Response of rice to nitrogen and phosphorus levels

Table 3. Total dry matter production (kg ha^{-1}) of rice as affected by levels of N and P.

Treatments	Dry matter production (Kharif)			Dry matter production (Rabi)		
	P_0	P_{40}	P_{80}	P_0	P_{40}	P_{80}
N_{40}*	9673	13922	14390	5944	8936	10085
N_{80}	11335	13883	15121	6715	9027	9889
N_{120}	10501	14495	16407	7015	9941	11431

**CD for NP interaction: Kharif: 1638 Rabi: 957*

Agronomic efficiency

The agronomic efficiency *(kg grain produced per kg nutrient applied)* was higher at lower levels of N and P (Fig. 2), revealing that rice crop responds more to applied nutrients when inherent nutrient availability is low. This indicates a decline in nutrient supplying power of the soil to wetland rice with increasing levels of nutrient addition and that proportionately less amount of applied nutrients are available to the crop at higher levels of fertilization.

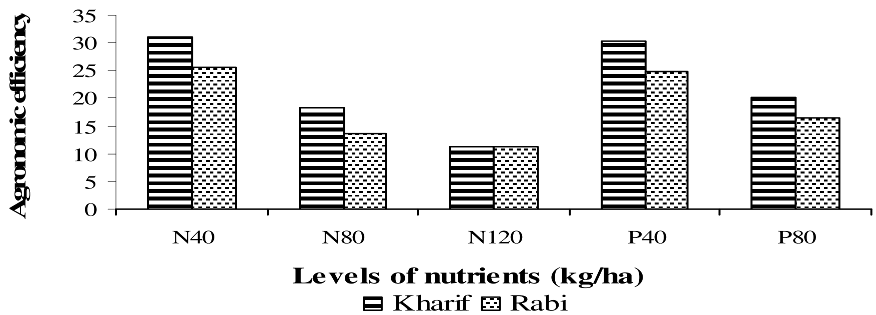

Figure 2. Agronomic efficiency as influenced by levels of nutrients

At equal levels of fertilizer addition the agronomic efficiency was more for P than for N. This is because wet land rice depends more on soil N even when it is adequately supplied with fertilizer nitrogen (Shinde 1991) indicating the loss of soil nutrient supplying capacity.

Table 4. Nutrient uptake (kgha $^{-1}$) by rice as influenced by levels of nutrients.

Treat-ment	Uptake (Kharif)						Uptake (Rabi)					
	N		P		K		N		P		K	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
N												
N_1	54.2	88.3	8.7	12.0	7.0	77.7	37.7	38.5	6.6	6.3	5.2	81.6
N_2	59.5	105.0	8.4	11.8	6.4	87.8	38.6	42.2	6.5	6.3	5.3	89.4
N_3	60.1	113.2	8.2	14.1	6.6	90.1	45.2	54.9	7.3	7.7	5.6	95.9
CD (0.05)	NS	13.44	NS	1.65	NS	9.91	3.33	4.43	NS	NS	NS	9.73
P												
P_0	45.2	79.4	5.7	7.7	5.4	63.1	29.7	32.1	4.3	3.8	3.8	66.3
P_1	62.6	109.1	8.7	12.2	6.9	93.4	43.9	47.6	7.4	7.7	5.7	94.7
P_2	66.0	117.9	10.9	17.9	7.8	99.0	47.9	55.9	8.8	8.9	6.6	106.0
CD (0.05)	6.25	13.43	1.57	1.65	0.92	9.91	3.33	4.43	0.72	1.36	0.53	9.73
K												
K_0	59.2	102.9	8.7	13.0	6.6	82.9	40.8	44.5	6.8	6.7	5.3	85.5
K_1	56.7	101.5	8.2	12.3	6.7	87.4	40.2	46.0	6.9	6.9	5.4	92.5
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
($N_0P_0K_0$)	34.7	65.4	5.1	6.1	4.2	55.4	23.6	22.7	3.8	3.2	3.3	47.3

Since alternate regimes of submergence prevail during the crop growth period due to the sandy loam texture of soil, the unsaturated conditions favor infiltration of soil N, and is more likely to leach with subsequent irrigation or rains resulting in less efficient use of applied nitrogen.

Nutrient uptake and Nutrient use efficiency

Nitrogen uptake by grain and straw generally showed a significant positive response (Table 4) with increasing levels during both seasons but did not influence the uptake of either P or K by grain. But P levels showed remarkable influence on the uptake of N, P and K. For each ton of grain production, the total nutrient uptake increased with increase in application levels for all the three major nutrients showing the less efficient use of fertilizers (Table 5). This is confirmed by the decreasing nutrient use efficiency *(dry matter production per unit nutrient uptake)* with increasing N, P, and K levels. The nutrient use efficiency was found to be highest for P than for N, the least being for K.

Table 5. Influence of NPK levels on nutrient use efficiency.

Treat-ment	Total uptake ($kgha^{-1}$)		Total uptake per year ($kgha^{-1}$)	Total uptake (kg) for the production of one ton grain		Nutrient Use Efficiency	
	Kharif	Rabi		Kharif	Rabi	Kharif	Rabi
N							
N_{40}	142.49	76.20	218.68	32.94	25.66	88.87	109.22
N_{80}	164.48	80.86	245.34	36.12	26.72	81.75	105.67
N_{120}	173.32	100.06	273.38	39.10	30.23	79.63	94.57
CD(0.05)	15.81	6.01	-	-	-	-	-
P							
P_0	13.40	8.17	21.56	3.83	3.50	783.90	803.22
P_{40}	20.93	15.09	36.02	4.45	4.54	673.62	616.42
P_{80}	28.82	17.66	46.48	5.64	4.84	531.07	592.77
CD(0.05)	2.26	1.68	-	-	-	-	-
N							
K_0	89.55	90.86	180.40	19.90	29.14	149.54	96.31
K_{40}	94.18	97.87	192.05	21.52	31.71	140.34	89.94
CD(0.05)	NS	NS	-	-	-	-	-

Nutrient balance and effect on soil fertility

The nutrient balance has been worked out by the balance of annual addition and removal of N, P, and K for their respective treatments (Nambiar and Ghosh, 1984). The balance of N was always negative (Table 6) with the values increasing with each incremental addition of N (-138.68 at N_{40} to -33.38 at N_{120}).

Table 6. Mean annual nutrient balance in rice-rice sequence.

a. **Nitrogen**

Treatment	Annual nutrient addition ($kgha^{-1}$)			N uptake ($kgha^{-1}$)			N balance ($kgha^{-1}$)
	Kharif	Rabi	Total	Kharif	Rabi	Total	
N_{40}	40	40	80.00	142.49	76.20	218.68	-138.68
N_{80}	80	80	160.00	164.48	80.86	245.34	-85.34
N_{120}	120	120	240.00	173.32	100.06	273.38	-33.38
CD	-	-	-	15.81	6.01	-	-

b. Phosphorus

Treatment	Annual nutrient addition (kgha $^{-1}$)			P uptake (kgha $^{-1}$)			P balance (kgha $^{-1}$)
	Kharif	Rabi	Total	Kharif	Rabi	Total	
P_0	0	0	0.00	13.40	8.17	21.56	-21.56
P_{40}	40	40	80.00	20.93	15.09	36.02	43.98
P_{80}	80	80	160.00	28.82	17.66	46.48	113.52
CD	-	-	-	2.26	1.68	-	-

c. Potassium

Treatment	Annual nutrient addition (kgha $^{-1}$)			K uptake (kgha $^{-1}$			K balance (kgha $^{-1}$)
	Kharif	Rabi	Total	Kharif	Rabi	Total	
K_0	0	0	0.00	89.55	90.86	180.40	-180.40
K_{40}	40	40	80.00	94.18	97.87	192.05	-112.05
CD	-	-	-	NS	NS	-	-

Phosphorus balance was negative only in control plots (-21.56 kg ha^{-1}annum^{-1}) and increased at higher levels to give a positive balance reaching 113.52kgha^{-1}annum^{-1} at P_{80}, leaving the soil rich in P which is reflected in the soil available P contents (Table 7).

Table 7. Effect of treatments on soil fertility level during kharif and rabi seasons.

Treat-ments	Kharif			Rabi		
	Organic Carbon (%)	Avail. P (kgha $^{-1}$)	Exch.K (kgha $^{-1}$)	Organic Carbon (%)	Avail. P (kgha $^{-1}$)	Exch.K (kgha $^{-1}$)
N						
N_1	1.032	11.160	72.053	.956	11.075	60.290
N_2	0.993	11.209	77.747	0.963	10.961	63.117
N_3	0.978	11.640	80.197	0.989	11.117	60.647
CD (0.05)	NS	NS	NS	NS	NS	NS
P						
P_0	0.975	9.994	82.390	0.975	9.075	67.573
P_1	0.951	11.356	75.320	0.963	10.921	60.410
P_2	1.076	12.660	72.287	0.970	13.156	56.070
CD (0.05)	.0545**	.729**	7.895*	NS	.633**	4.197**
K						
K_0	1.002	11.282	74.573	0.993	10.939	55.658
K_1	1.000	11.392	78.758	0.946	11.162	67.045
CD (0.05)	NS	NS	NS	NS	NS	3.427**

Potassium balance was negative for both control and K added plots. In spite of such high negative balance for K over the years, the crop is not showing a response to K application due to the probable release from K minerals (Ganeshmurthy *et al.,* 1985). The different levels of N did not affect the soil available nutrient content whereas P availability was significantly increased and soil availability of K markedly decreased with increased application of P.

Implications of the study

- Imbalanced and inadequate fertilization affects yield response of wetland rice to nutrients.
- Each incremental addition of nutrient increases the percentage of increase in grain yield over control showing that where agronomic efficiency decreases due to loss of applied nutrients like leaching, adsorption, etc., higher amounts of fertilizers are to be applied to attain maximum yields.
- Though phosphorus is not generally a limiting nutrient in the acid entisols of India, it is equally important for rice as N and K, and its long term depletion was found to affect the crop response to N and K as well.
- Since nitrogen balance was always negative, to maintain soil health and for long term sustainability, a higher application of the nutrient is required which should be through organics for maintaining production.

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