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Sustainable fertilizer practices for upland rice (*Oryza sativa*) from permanent manurial trials under subhumid alfisols

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ABSTRACT

Twelve permanent manurial trials were conducted from 1994 to 2005 to develop a sustainable fertilizer application schedule for upland rice (*Oryza sativa* L.) and find out optimal fertilizer requirement for attaining maximum productivity in a moist subhumid alfisol. Nine treatments of organic N (glyricidia, cassia and farmyard manure) and inorganic N, P and K fertilizers together with a contol, were tested. The treatments differed significantly from each other in all seasons. Application of 50% N (FYM) + 50% PK of recommended dose proved superior, as evident from lowest yield decrease of 86.4 kg/year compared with a maximum of 170.9 kg/year with application of 100% NPK (inorganic). Regression analysis revealed that the treatment comprising 50% N (FYM) + 50% NPK was superior with a maximum yield predictability of 0.85 with a prediction error of 511 kg/ha, and a maximum sustainability yield index (0.47), maximum mean yield (1,811 kg/ha) and lowest variation (29%) in the study. The study indicated that an optimum application of 32, 22, 17 and 14 kg/ha organic N together with 28, 33, 39 and 47 kg/ha inorganic N could be made respectively under 500–750, 750–1,000, 1,000–1,250 and 1,500–1,750 mm of crop seasonal rainfall for attaining sustainable productivity of upland rice under rainfed conditions in moist subhumid alfisols.

Key words : Optimization, Permanent manurial trial, Predictability, Regression, Seasonal rainfall, Sustainability yield index, Upland rice

Upland rice (*Oryza sativa* L.) is an important cereal grown purely rainfed in different states of India during rainy season (June to October). In Orissa, out of a total rice area of 45 lakh ha, 42.5 lakh ha are used for cropping in rainy season (*kharif*) compared with 2.5 lakh ha in winter season (*rabi*). Its low productivity of 1,000 kg/ha in Orissa is due to light soil texture, rapid leaching of nutrients, low organic matter content, low nutrient content, low cation-exchange capacity of the soil and occurrence of intermittent dry spells during the growing season. Continuous use of chemical fertilizers in rice adversely affects its sustainability (Singh *et al.*, 1999). Sustainable rice productivity can be achieved through integrated nutrient management practices, comprising various sources, viz. chemical fertilizer, farmyard manure (FYM) and green-leaf. Performance of integrated nutrient-management practices in rice depends on the quality and distribution of rainfall during the crop-growing period. Research work on optimizing the fertilizer requirement for rainfed crops was reported by different workers. Venkateswarlu and Singh (1982) reviewed the soil research in India and described the responses of rainfed crops to applied nutrients under limited water conditions. Prihar and Gajri (1988) examined the usefulness of fertilization of crops under dryland conditions. They described strategies for rationalizing fertilizer application in relation to seasonal water supply and innate soil fertility. Senapati *et al.* (2001, 2002) and Pal *et al.* (2006) discussed the long-term effects of manuring practices on upland rice in an alfisol under rainfed conditions in Orissa. Based on multivariate regression models, the long-term effects of crop-seasonal rainfall and fertilizer nutrients on yield could be efficiently assessed and the models could be used for optimization of nutrient application (Draper and Smith, 1998). In the present study an attempt was made to assess the integrated nutrient management practices and select an appropriate nutrient management strategy for upland rice in moist subhumid alfisol.

MATERIALS AND METHODS

Twelve field experiments were conducted on upland

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rice (*Oryza sativa* L.) in a fixed plot in the rainy season (June to October) during 1994 to 2005 in a moist subhumid alfisol at Phulbani under All India Co-ordinated Research Project for Dryland Agriculture. The trials were conducted to assess the performance of organic and inorganic N in combination with P and K fertilizer treatments for rainfed rice under different crop-seasonal rainfall situations and select a superior treatment for attaining maximum and sustainable yield under dryland conditions. The earliest date of sowing of rice was 11 June 2001 and the farthest was 10 July 1997, depending on onset of monsoon. Similarly, the earliest date of harvest was 11 September 2001 and the farthest was 28 October 1995, based on rainfall distribution and withdrawal of monsoon. The crop had a minimum duration of 84 days in 1997 and a maximum duration of 120 days in 1994, with a mean of 99 days and variation of 12%. The different varieties of rice, dates of sowing and harvest and the crop-growing periods in different years are given in Table 1.

Rainfall and its distribution

The crop-seasonal rainfall occurring during the 12 years was in a range of 586 mm (43 rainy days) in 1998 to 1,762 mm (59 rainy days) in 1994, with a mean of 948 mm (43 rainy days) and variation of 40 per cent. Rainfall was received for a minimum of 36 days in 2000 compared with a maximum of 59 in 1994, with a mean of 43 and variation of 18 per cent. A wide variation was observed in the monthly rainfall received in June, July, August, September and October in different years, being 57 (in 1995) to 505 mm (in 2001) in June, 129 (2002) to 798 mm (2001) in July, 134 (1999) to 645 mm (1994) in August, 125 (2000 and 2001) to 572 mm (2005) in September, and 11 mm (2002) to 251 mm (2005) in October in different seasons.The distribution of rainfall had a mean of 178 mm (variation of 67%) in June, 356 mm (54%) in July, 319 mm (52%) in August, 247 mm (54%) in September and 121 mm (70%) in October. The details of monthly rainfall received in crop-growing season are given in Table 2.

Table 1. Variety, duration, date of seeding and harvest of rice at Phulbani

Year	Variety	Duration	Date of seeding	Date of harvest
1994	'Pathara'	120	28 Jun	25 Oct
1995	'Kandagiri'	116	5 Jul	28 Oct
1996	'Pathara'	105	1 Jul	13 Oct
1997	'Heera'	84	10 Jul	1 Oct
1998	'Heera'	85	25 Jun	17 Sep
1999	'ZHU 11-26'	96	20 Jun	23 Sep
2000	'ZHU 11-26'	96	19 Jun	22 Sep
2001	'ZHU 11-26'	93	11 Jun	11 Sep
2002	'Vandana'	106	20 Jun	3 Oct
2003	'Vandana'	94	28 Jun	29 Sep
2004	'ZHU 11-26'	91	24 Jun	22 Sep
2005	'ZHU 11-26'	107	1 Jul	15 Oct

Organic and inorganic fertilizer combinations

A fertilizer dose of 60, 40 and 40 kg/ha of N, P and K is recommended for rice under rainfed conditions in Orissa. To identify an efficient combinaton of N, P and K that would provide a sustainable crop yield under rainfed conditions, nine fertilizer treatments, which are combinations of inorganic and organic sources, were tested in the study. Apart from inorganic N through urea, P through single superphosphate and K through muriate of potash, and organic N through glyricidia, cassia and farmyard manure (FYM) were tested in different treatment combinations. The trials were conducted in randomized block design with three replications. All agronomic practices were adopted while conducting the experiments. The fertilizer N, P and K, and organic N treatments and the corresponding doses tested were:

T_1, Control (0–0–0–0); T_2, 100% inorganic NPK (60–40–40–0); T_3, 50% inorganic NPK (30–20–20–0); T_4, 50% N (glyricidia) + 50% PK (0–20–20–30); T_5, 50% N (cassia) + 50% PK (0–20–20–30); T_6, 50% N (FYM) + 50% PK (0–20–20–30); T_7, 50% N (inorganic) + 50% N (glyricidia) + 100% PK (30–40–40–30); T_8, 50% N (inorganic) + 50% N (cassia) + 100% PK (30–40–40–30); and T_9, 50% N (inorganic) + 50% N (FYM) + 100% PK (30–40–40–30).

Superiority of fertilizer treatments

The change in yield during the 12 years was assessed

Table 2. Monthly rainfall (mm) received during different years at Phulbani

Month	Long-term mean	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Jun	192	220	57	119	250	84	206	144	505	149	117	188	94
Jul	354	608	273	185	304	226	368	279	798	129	237	364	500
Aug	379	645	312	267	640	192	134	273	300	329	358	242	140
Sep	219	378	134	244	171	227	269	125	125	135	350	229	572
Oct	89	130	57	21	80	121	202	31	112	11	216	218	251
Total	1,233	1,981	833	836	1,445	850	1,179	852	1,840	753	1,278	1,241	1,557

by calibrating treatment-wise regression model of yield as a function of time period as:

$$Y = \pm \alpha \pm \beta \text{ (years)} \quad .... (1)$$

A more rigorous evaluation of the effect of organic and inorganic fertilizer treatments is made by calibrating treatment-wise regression model of yield as a function of crop-seasonal rainfall received in June, July, August, September and October as:

$$Y = \pm \alpha \pm \beta_1 \text{ (RF Jun)} \pm \beta_2 \text{ (RF Jul)} \pm \beta_3 \text{ (RF Aug)} \pm \beta_4 \text{ (RF Sep)} \pm \beta_5 \text{ (RF Oct)} \quad ... (2)$$

Sustainability yield index

The organic and inorganic fertilizer treatments were evaluated for superiority, based on sustainability yield index 'η' discussed by Vittal *et al.* (2003). Using mean yield of treatment 'i' ($\bar{A}i$) over 12 years, minimum prediction error (Φ_{min}) based on treatment-wise regression models; and maximum rice-yield potential (Y_{max}) out of 108 observations (9 treatments tested for 12 years), sustainable yield index of each treatment is derived as:

$$\eta = [(\bar{A} - \Phi_{min}) / (Y_{max})] * 100 \quad ..... (3)$$

A treatment with maximum sustainable yield index is selected for attaining a maximum and sustainable crop yield under any rainfall situation.

Optimization of fertilizer requirement based on pooled regression models

Using pooled data of yield attained with nine treatments in 12 years, a combined regression model of yield as a function of fertilizer N, P and K doses with a crop seasonal rainfall varying from 500 to 1,750 mm could be calibrated as:

$$Y = \pm \alpha \pm \beta_1 \text{ (FN)} \pm \beta_2 \text{ (FN)}^2 \pm \beta_3 \text{ (FP)} \pm \beta_4 \text{(FP)}^2 \pm \beta_5 \text{ (FK)} \pm \beta_6 \text{ (FK)}^2 \pm \beta_7 \text{ (ON)} \quad .... (4)$$

In eq. (4), α is intercept and β's are slopes of fertilizer variables. The model (4) is also calibrated for different rainfall situations occurring in the study, i.e. 500 to 750 mm in 6 years (1995, 1996, 1998, 1999, 2000, 2002); 750 to 1,000 mm in 2 years (2003 and 2004); 1,000 to 1,250 mm in 2 years (1997 and 2005); and 1,500 to 1,750 mm in 2 years (1994 and 2001). The optimal fertilizer doses could be derived based on the procedure discussed by Maruthi Sankar (1986) for attaining sustainable productivity of rice.

RESULTS AND DISCUSSION

The yield attained by different treatments ranged from 323 kg/ha under the control in 2005 to 3,403 kg/ha with 100% NPK (inorganic) application in 1996 (Table 3). The year-wise mean yield ranged from 811 kg/ha with a variation of 41% in 2005 to 2,718 kg/ha with a variation of 23% in 1996. The treatment-wise mean yield over 12 years ranged from 692 kg/ha with a variation of 46% under the control to 1,811 kg/ha with a variation of 29% under 50% N (FYM) + 50% PK application. The data given in table 3 show that 100% NPK (inorganic) provided a maximum yield decrease of 170.9 kg/year with a predictability of 0.56, whereas the control provided a minimum decrease of 63.7 kg/year with a predictability of 0.51 during 12 years. Among different fertilizer treatments, 50% N (FYM) +

Table 3. Mean and variation of rice yield (t/ha) attained by fertilizer treatments at Phulbani

Year	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	Mean	CV (%)	CD (P=0.05)
1994	1.38	2.82	1.97	2.04	2.37	2.47	2.50	2.59	2.69	2.31	19	0.40
1995	0.61	1.50	1.14	1.10	1.29	1.30	1.27	1.45	1.33	1.22	22	0.12
1996	1.19	3.40	2.66	2.62	2.83	2.83	2.92	3.00	3.02	2.72	23	0.41
1997	0.73	2.32	1.69	1.49	1.47	1.81	2.01	1.95	2.10	1.73	27	0.11
1998	0.46	1.29	0.81	0.73	0.68	1.61	1.06	1.10	1.24	1.00	36	0.59
1999	0.56	1.54	1.30	0.86	0.69	2.10	1.44	1.51	1.83	1.31	39	0.49
2000	0.91	1.90	1.15	0.98	1.09	2.25	1.04	1.30	2.02	1.40	36	0.56
2001	0.67	1.34	0.93	1.07	1.08	1.75	1.11	1.03	1.44	1.16	27	0.51
2002	0.58	1.61	0.99	0.71	0.74	1.86	1.07	1.01	1.87	1.16	43	0.62
2003	0.51	0.56	0.74	0.79	0.75	1.44	0.95	0.90	1.18	0.87	34	0.21
2004	0.38	1.01	0.84	0.72	0.62	1.24	1.21	1.09	1.51	0.96	37	0.14
2005	0.32	0.85	0.68	0.56	0.46	1.08	1.05	0.93	1.37	0.81	41	0.13
Mean	0.69	1.68	1.24	1.14	1.17	1.81	1.47	1.49	1.80	1.39	26	
CV(%)	46	49	48	54	63	29	44	46	32	42		
β	–0.06	–0.17	–0.12	–0.12	–0.15	–0.09	–0.12	–0.14	–0.09			
R^2	0.51	0.56	0.51	0.52	0.56	0.35	0.47	0.58	0.32			

β = rate of change in yield (t/year); R^2 = coefficient of determination; T_1, control; T_2, 100% NPK (inorganic); T_3, 50% NPK (inorganic); T_4, 50% N (glyricidia) + 50% PK; T_5, 50% N (cassia) + 50% PK; T_6, 50% N (FYM) + 50% PK; T_7, 50% N (inorganic) + 50% N (glyricidia) + 100% PK; T_8, 50% N (inorganic) + 50% N (cassia) + 100% PK; T_9, 50% N (inorganic) + 50% N (FYM) + 100% PK; N content (%) in green biomass : glyricidia = 0.4%, cassia = 0.35%, and FYM = 0.5%

50% NK provided a minimum yield reduction of 86.4 kg/ year in the 12-year study.

Superiority of fertilizer treatments

Based on the values of least significant difference (LSD), the treatments 100% NPK (inorganic), 50% N (FYM) + 50% PK, 50% N (inorganic) + 50% N (FYM) + 100% PK and 50% N (inorganic) + 50% N (cassia) + 100% PK were found to be superior to other treatments under a low crop-seasonal rainfall of 500-750 mm received during 1995, 1996, 1998, 1999, 2000 and 2002. With a better crop-seasonal rainfall of 7500–1000 mm received during 2003 and 2004, 50% N (inorganic) + 50% N (FYM) + 100% PK and 50% N (FYM) + 50% PK were found superior to other treatments.

Relationship between yield and seasonal rainfall

A significant negative correlation in the range of –0.57 for 50% N (inorganic) + 50% N (FYM) + 100% PK to –0.76 for 50% N (inorganic) + 50% N (cassia) + 100% PK was observed between yield and time period (years), indicating a significant reduction in yield during different yeras. The rainfall received in October had a negative correlation with yield attained under all the treatments.

However, the correlation was significant in the control, 100% NPK (inorganic), 50% NPK (inorganic), 50% N (cassia) + 50% PK, 50% N (FYM) + 50% PK, and 50% N (inorganic) + 50% N (FYM) + 100% PK. The August rainfall had a significant positive correlation with yield attained in the control, 100% NPK (inorganic), 50% N (glyricidia) + 50% PK, 50% N (cassia) + 50% PK, 50% N (inorganic) + 50% N (glyricidia) + 100% PK and 50% N (inorganic) + 50% N (cassia) + 100% PK. The crop-growing period had a positive correlation with yield in the range of 0.20 attained by 50% N (FYM) + 50% PK to 0.45 attained in the control.

Prediction of rice yield through seasonal rainfall

The predictability (R^2) of yield was found to range from 0.69 in the control to 0.85 under 50% N (FYM) + 50% PK application (Table 4). The predictability was significant at 1% level of significance (P=0.01) in 100% NPK (inorganic) with a R^2 of 0.75, 50% N (FYM) + 50% PK with 0.85, 50% N (inorganic) + 50% N (FYM) + 100% PK with 0.81, and 50% N (glyricidia) + 50% PK with 0.79 predictability; whereas it was significant at 5% level of significance (P=0.05) in the remaining treatments. The estimate of prediction error (Φ) based on regression models was in a range of 197 kg/ha for 50% N (glyricidia) + 50% PK to 512 kg/ha with 100% NPK (inorganic) application. June and September rainfall had a negative influence, whereas July rainfall had a positive influence on the yield attained in the all treatments except 50% N (FYM) + 50% PK, and 50% N (inorganic) + 50% N (FYM) + 100% PK. August rainfall had a positive influence, whereas October rainfall had a negative influence on the rice yield attained under all the treatments tested in the study.

June rainfall had a significant influence on the rice yield attained by 50% N (cassia) + 50% PK, 50% N (FYM) + 50% PK, and 50% N (inorganic) + 50% N (FYM)_ + 100% PK; whereas July rainall had a significant influence on the yield attained under 50% N

Table 4. Regression models of rice yield during different crop-seasonal rainfall at Phulbani

Treatment	Regression model	R^2	Mean	Φ	η
Control	Y = 323–0.996 (RF Jun) + 1.03 (RF Jul) + 0.993* (RF Aug) – 0.009 (RF Sep) – 1.544 (RF Oct)	0.69*	692	225	0.15
100% NPK (inorganic)	Y = 1047 – 1.153 (RF Jun) + 1.296 (RF Jul) + 2.066* (RF Aug) – 0.29 (RF Sep) – 4.138 (RF Oct)	0.75**	1,678	512	0.44
50% NPK (inorganic)	Y = 571–0.935 (RF Jun) + 0.749 (RF Jul) + 1.795* (RF Aug) – 0.393 (RF Sep) – 0.38 (RF Oct)	0.71*	1,242	339	0.31
50% N (glyricidia) + 50% PK	Y = 271–1.983 (RF Jun) + 1.707* (RF Jul) + 2.165** (RF Aug) – 1.036 (RF Sep) – 0.138 (RF Oct)	0.79*	1,140	197	0.28
50% N (cassia) + 50% PK	Y = 260–3.369* (RF Jun) + 2.61** (RF Jul) + 2.613** (RF Aug) – 1.401 (RF Sep) – 0.717 (RF Oct)	0.72*	1,172	215	0.29
50% N (FYM) + 50% PK	Y = 1664* + 2.933* (RF Jun) – 1.076 (RF Jul) + 0.482* (RF Aug) + 2.936* (RF Sep) – 5.923 (RF Oct)	0.85**	1,811	511	0.47
50% N (inorganic) + 50% N (glyricidia) + 100% PK	Y = 366–1.432 (RF Jun) + 1.126 (RF Jul) + 2.433* (RF Aug) – 0.396 (RF Sep) – 0.948 (RF Oct)	0.71*	1,468	357	0.37
50% N (inorganic) + 50% N (cassia) + 100% PK	Y = 593– 2.783 (RF Jun) + 1.791 (RF Jul) + 2.466* (RF Aug) – 1.089 (RF Sep) – 0.547 (RF Oct)	0.73*	1,488	409	0.38
50% N (inorganic) + 50% N (FYM)+100% PK	Y = 1324* + 2.669* (RF Jun)– 1.083 (RF Jul) + 0.658* (RF Aug) + 3.934* (RF Sep) – 6.582 (RF Oct)	0.81**	1,798	478	0.47

*P = 0.05; **P = 0.01; R^2 = coefficient of determination; Φ= prediction error (kg/ha); RF = rainfall (mm); η = sustainability yield index

Table 5. Pooled regression models of yield under varying rainfall situations at Phulbani

Rainfall (mm)	Pooled regression model	R^2	Mean	CV	Φ	η
500–750	Y = 718* + 22.28* (FN)–0.397 (FN^2) + 48.19* (FP) – 0.857 (FP^2) + 48.19* (FK) – 0.857 (FK^2) + 32.13* (ON)	0.47*	1,469	28	693	0.23
750–1,000	Y= 442* + 928* (FN) – 0.141 (FN^2) + 27.74* (FP) – 0.46 (FP^2) + 27.74* (FK) – 0.46 (FK^2) + 22.12* (ON)	0.58*	913	33	263	0.19
1,000–1,250	Y = 616* + 1.87* (FN) – 0.024 (FN^2) + 36.89* (FP)– 0.57 (FP^2) + 36.89* (FK) – 0.57 (FK^2) + 16.6* (ON)	0.60*	1,270	30	568	0.21
1,500–1,750	Y = 1,150* + 20.51* (FN) – 0.22 (FN^2) + 46.49* (FP) – 0.7 (FP^2) + 46.49* (FK) – 0.7 (FK^2) + 14.20* (ON)	0.59*	1,735	20	703	0.30
Overall	Y = 819** + 9.84* (FN) – 0.13 (FN^2) + 30.34** (FP) – 0.46 (FP^2) + 30.34** (FK) – 0.46 (FK^2) + 17.09** (ON)	0.55**	1,388	26	650	0.22

*P = 0.05, **P=0.01; Y= grain yield (kg/ha); FN = fertilizer N (kg/ha); FP = fertilizer P (kg/ha); FK = fertilizer K (kg/ha); ON = organic N (kg/ha); CV = coefficient of variation (%); Φ = prediction error (kg/ha); R^2 = coefficient of determination; η = sustainability yield index

(glyricidia) + 50% PK, and 50% N (cassia) + 50% PK. September rainfall significantly influenced the yield attained under 50% N (FYM) + 50% PK, and 50% N (inorganic) + 50% N (FYM) + 100% PK. August rainfall had a significant influence on the yield attained under all the treatments, whereas October rainfall had no significant influence on the yield attained under any treatment in the study.

Sustainable yield index

Using the mean yield of each treatment during the 12 years, minimum prediction error (Φ_{min}) of 197 kg/ha derived under regression model of 50% N (glyricidia) + 50% PK, and maximum rice yield potential (Y_{max}) of 3,403 kg/ha attained with an application of 100% NPK (inorganic) in 1996, sustainability yield indices (η) of fertilizer treatments were derived and are given in Table 4. Application of 50% N (FYM) + 50% PK was superior with a maximum N of 0.47 for attaining a mean yield of 1,811 kg/ha with a prediction error of 511 kg/ha in 12 seasons. Application of 50% N (inorganic) + 50% N (FYM) + 100% PK was the second best with a η value of 0.47 for attaining a mean yield of 1,798 kg/ha with a prediction error of 478 kg/ha.

Optimization of fertilizers

Pooled regression models of yield through fertilizer N, P and K were calibrated as described in eq. (4) for 500–750 mm, 750–1,000 mm, 1,000–1,250 mm and 1,500–1,750 mm rainfall groups. Estimates of regression coefficients of N, P and K, coefficient of determination (R^2), prediction error (Φ) and sustainable yield index (η) of treatments in different rainfall situations and the optimal fertilizer doses for attaining a maximum and sustainable rice yield are given in Table 5. The predictability of yield ranged from 0.47 under 500–750 mm to 0.60 under 1,000–1,250 mm rainfall situation, while prediction error ranged from 263 kg/ha under 750-1,250 mm to 703 kg/ha under 1,500-1,750 mm rainfall. The sustainability yield index of treatment ranged from 0.19 under 750-1,000 mm to 0.3 under 1,500-1,750 mm rainfall situation.

The optimal N, P, K and organic carbon was 28, 28 28 and 32 kg/ha under 500-750 mm rainfall compared to 33, 30, 30 and 22 kg/ha under 750-1,000 rainfall situation. Similarly, the optimal dose was 39, 32, 32 and 17 kg/ha under 1,000-1,250 mm rainfall situation, while prediction error ranged from 263 kg/ha under 750-1,250 mm to 703 kg/ha under 1,500-1,750 mm rainfall. The sustainability yield index of treatments ranged from 0.19 under 750-1,000 mm to 0.3 under 1,500-1,750 mm rainfall situation.

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