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Effect of Nutrient Management and Planting Geometry on Productivity of Hybrid Rice (*Oryza sativa* L.) Cultivars

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ABSTRACT

Field experiments were conducted during the wet seasons of 2006 *and* 2007 *at the Agricultural Experimental Farm of the Indian Statistical Institute, Giridih, a part of eastern plateau region of India. The study was designed to investigate the effect of planting geometry and nutrient management practices on productivity of two hybrid rice cultivars. Split-plot design with three replications was adopted to carry out the experiment by allocating combinations of treatments of planting geometry and rice cultivar in main-plots and nutrient management treatments in sub-plots. "CNRH-*3*" rice proved its efficiency in terms of grain yield that was also reflected in yield attributing characters such as number of productive tillers, number of grains per panicle, length of panicle, panicle weight, test weight and harvest index. Higher rice grain yield was registered when the cultivars grown in* 20 *cm* × 20 *cm planting geometry. Rice cultivars grown with the application of inorganic fertilizers alone produced maximum grain yield and also recorded higher values of ancillary characters. The maximum amount of N, P and K was taken up by the "CNRH-*3*" rice, whereas maximum residual soil fertility was recorded in "Pro Agro* 6201*" rice. Maximum N, P and K uptake values were recorded in* 20 *cm* × 20 *cm crop geometry and inorganic fertilizers treatment.*

Keywords: *Hybrid Rice Cultivars, Planting Geometry, Vermicompost, Nutrient Uptake, Soil Fertility*

1. Introduction

One of every three peoples depends on rice for more than half of their daily food and one in nine (approximately 700 million) depends on rainfed rice. Ninety percent of the world's rice is grown and consumed in Asia. Rice is also an important staple food in some countries of Latin America and Africa. Asian rice production has increased by 24% during 1965 to 1980 and that was attributed to the use of higher rate of fertilizers, mainly N-fertilizer. Rice productivity is now at stagnant situation or declining in areas where N-fertilizer application is very high; it has also raised the concerns about sustainability of monoculture rice [1]. Food security in India (1.6 billion by 2050 that will require 450 Mt of food grain production) is a challenge [2]. To achieve food security, hybrid rice can be one of the most feasible options to increase 15% to 20% of food production [3,4]. The hybrid cultivars are more responsive to higher doses of nutrients [5,6] and thereby the yield potentiality is all high.

It is a big concern that whether the agronomic practices, especially planting geometry for hybrid rice are same as for conventional rice. Thus, there is a need to optimize the planting geometry for hybrid rice [7]. Proper planting geometry have more advantages such as, to maximize light utilization efficiency, improves aeration within crop canopy, enhances soil respiration and provides better weed control thereby higher crop yields [8].

Of late, there has been serious concern about long-term adverse effect of continuous and indiscriminate use of inorganic fertilizers on soil health, biodiversity and environment [9]. The organic matter in sub-tropics soils is low because of high temperature and intense microbial activity. Soil organic matter is the key attribute of soil quality [10] therefore organic matter has to be replenished to maintain the soil health. Apart from nutritional effects [11], application of organic manure influences plant physiologically. It also provides growth regulating substances to plants and modifies soil physical behaviour [12]. Vermicompost is a good source of organic manure that can be used as an alternative to chemical fertilizers in rice cultivation [13]. Organic matter dynamics is similar in different cropping systems but its significance for specific soil properties or crop productivity varies considerably with soil type [14,15]. With the above back drop the experiments have been undertaken to measure the effect of crop geometry and the usefulness of organic materials on yield of low land hybrid rice and soil fertility.

2. Materials and Methods

2.1. Study Site

A study was carried out at the Agricultural Experimental Farm of the Indian Statistical Institute, Giridih (at 24˚1'N, 86˚3'E and altitude 920'), India during the wet seasons of 2006 and 2007. The average annual rainfall of the study area is 1343 mm but the distribution is highly seasonal (about 86% of total rainfall occurs in between June to September). The average maximum and minimum temperatures are 23.8˚C and 12.6˚C respectively. Average annual potential evapotranspiration is 1293 mm with the relative humidity ranges from 78% to 95%. The soil was moderately well drained lateritic sandy loam (30.0% coarse sand, 26.8% fine sand, 25.0% silt and 18.2% clay). Soil was slightly acidic in reaction (6.4) with low in organic carbon (0.52%), available N (132 kg N ha^{-1}) and P (12 kg P ha^{-1}) but medium in K (156 kg K ha^{-1}).

2.2. Experimental Setup

The experiment was laid out in split-plot design and replicated thrice. Combinations of rice cultivars (V_1: CNRH 3 and V_2: Pro Agro-6201) and crop geometry (G_1: 15 cm × 15 cm, G_2: 20 cm × 20 cm and G_3: 25 cm × 25 cm) were allocated in the main-plots and nutrient management practices such as F_0: absolute control, F_1: recommended dose (RD, 140:60:60 kg N, P_2O_5, K_2O ha^{-1}) through inorganic sources, F_2: RD of N through vermicompost, F_3: 50% RD of NPK through inorganic +50% RD of N through vermicompost and F_4: 75% RD of NPK through inorganic +25% through vermicompost were assigned in sub-plots. The recommended dose of NPK was applied in the form of urea (46-0-0), single super phosphate (0-16-0) and muriate of potash (0-0-60). Vermicompost (1.25-0.8-0.65) was incorporated in soil as per the treatment at the time of final ploughing. Rice cultivars were transplanted on 15^{th} July and 18^{th} July and were harvested on 9^{th} December and 11^{th} December in 2006 and 2007, respectively. Agronomic management practices and plant protection measures were followed as per the recommendation.

2.3. Soil Sampling and Analysis

Soil samples were collected from each plot at the depth of 0 - 20 cm just after harvest of rice in both the years. These soil samples were sieved (2 mm) and analyzed for available N by alkaline potassium permanganate method [16] and organic carbon by wet oxidation method [17]. Mineralizable P and exchangeable K were estimated by Olsen's method [18] and neutral normal ammonium acetate method [19], respectively. Concentrations of N, P and K in rice grain and straw were estimated by using the standard methods as advocated by Jackson [19].

2.4. Statistical Analysis

The data obtained during the study were subjected to statistical analysis using the IRRISTAT (software developed by International Rice Research Institute, Philippines).

3. Results

3.1. Plant Height

Plant height of rice cultivars was significantly influenced by the crop geometry and nutrient management practices (**Table 1**). Plant height of "CNRH 3" rice was higher (88.66 cm) over the Pro Agro 6201 (85.88 cm). Rice grown at 15 cm × 15 cm apart recorded higher plant height (88.42 cm) whereas 25 cm × 25 cm spacing recorded shortest ones (86.16 cm). Rice grown with 100% RD of NPK supplied through inorganic sources (F_1) produced tallest plants but it was statistically at par with that of the F_4 treatment.

3.2. Productive Tillers

"CNRH 3" rice produced maximum numbers of reproductive tillers (349 m^{-2}) (**Table 1**). Rice grown at 20 cm × 20 cm spacing, irrespective of cultivars and fertilizer treatments, produced highest reproductive tillers per unit area (395 m^{-2}) and which was followed by 25 cm × 25 cm treatment. Among the nutrient management practices, F_1 treatment was recorded 46% higher reproductive tillers over the F_0 treatment.

3.3. Filled Grains per Panicle

"CNRH 3" rice produced 31% higher filled grains per panicle over Pro Agro 6201 (**Table 1**). Rice transplanted in 20 cm × 20 cm spacing produced maximum number of filled grains per panicle (73.13) followed by rice when grown at 25 cm × 25 cm spacing (64.38). Rice had 85% and 63% higher grains per panicle when grown with F_1 and F_4 treatments respectively over the F_0.

3.4. Panicle Length and Weight

Both panicle length (21.65 cm) and weight (2.55 g) were recorded maximum in "CNRH 3" rice (**Table 1**). Irrespective of cultivars, both the values were higher when rice was grown at 20 cm × 20 cm apart followed by at 25 cm × 25 cm spacing. Fertilizer treatment F_1 had 65% higher panicle length over the control (F_0).

3.5. Test Weight

Rice cultivar CNRH 3 (26.24 g) recorded higher test weight (weight of 1000 grains) over the other one (**Table 1**). Significantly highest test weight (26.50 g) of rice was registered when grown in 20 cm × 20 cm crop spacing whereas least test weight was in 15 cm × 15 cm. Test weight was significantly affected by the nutrient management practices. Fertilizer treatment F_1 followed by F_4 recorded the higher test weight over the others.

3.6. Grain Yield

The "CNRH 3" rice produced the highest grain yield (4527 kg·ha^{-1}) and harvest index (HI; 0.47) over Pro Agro-6201 (**Table 2**). Maximum grain yield was recorded when rice cultivars were transplanted in 20 cm × 20 cm crop spacing (4804 kg·ha^{-1}) followed by 25 cm × 25 cm spacing. HI also recorded the similar trend. There was a significant variation in grain yield and HI due to nutrient management practices as well and were registered highest when the cultivars grown with the F_1. Whereas least values of grain yield and HI were recorded in the F_0.

3.7. Nutrient Uptake

Among the rice cultivars, higher N, P and K uptakes were recorded by CNRH3 (**Table 3**). Cultivars grown at 20 cm × 20 cm spacing accumulated higher nutrients while least amount of nutrients uptake was at 15 cm × 15 cm. Rice cultivars recorded maximum nutrients (NPK) uptake when they received 100% nutrients through inorganic fertilizers (F_2) but it was statistically at par with the treatment F_4. However, least amount of nutrients uptake was found when rice grown without any fertilizers (F_0).

3.8. Residual Soil Nutrients

Residual soil nutrients (N, P and K) values were maximum in "Pro Agro 6201" rice (**Table 4**). Crop geometry did not have significant effect on soil fertility. Although the values were maximum in 15 cm × 15 cm crop spacing. The VC treatment (F_2) had maximum residual soil nutrients (NPK) values whereas these were least in F_0 followed by F_1 treatments.

Table 1. Effect of crop geometry and nutrient management practices on plant growth and yield attributes of hybrid rice cultivars (pooled data of 2006 and 2007).

Treatment	Plant height (cm)	Productive Tillers m^{-2}	Filled grains panicle^{-1}	Panicle length (cm)	Panicle weight (g)	Test weight (g)
Cultivars						
V_1: CNRH3	88.66	348.99	74.42	21.65	2.55	26.24
V_2: Pro Agro 6201	85.88	334.31	56.58	20.42	2.14	25.66
SEm±	0.95	5.39	7.28	0.22	0.08	0.16
LSD (*p* = 0.05)	**2.11**	**12.00**	**16.23**	**0.49**	**0.18**	**0.35**
Crop geometry						
G_1: 15 cm × 15 cm	88.42	287.26	59.59	20.85	1.92	25.78
G_2: 20 cm × 20 cm	86.16	394.73	73.13	21.50	2.69	26.50
G_3: 25 cm × 25 cm	87.05	343.33	64.38	20.80	2.38	25.52
SEm±	0.19	7.03	1.93	0.08	0.09	0.23
LSD (*p* = 0.05)	**0.42**	**15.66**	**4.30**	**0.18**	**0.20**	**0.51**
Nutrient						
F_0: Control	80.92	272.09	45.09	15.67	1.90	22.59
F_1: RDF (160:60:60)	92.23	398.69	83.49	25.86	2.85	28.07
F_2: 100% RDF through VC*	84.79	319.90	59.72	19.98	2.10	24.01
F_3: 50% RDF + 50% VC	87.52	342.78	67.52	20.67	2.19	25.12
F_4: 75% RDF + 25% VC	90.63	376.96	73.32	23.03	2.56	26.94
SEm±	1.60	16.46	5.14	0.98	0.16	0.42
LSD (*p* = 0.05)	**3.22**	**33.12**	**10.34**	**1.97**	**0.33**	**0.85**

*Vermicompost.

Table 2. Grain yield, straw yield and harvesting index as influenced by rice cultivars, crop geometry and nutrient management practices.

Treatment	Grain yield (kg·ha^{-1})		Straw yield (kg·ha^{-1})		Harvesting index	
	2006	2007	2006	2007	2006	2007
Cultivars						
V_1: CNRH3	4577	4869	5266	5506	0.47	0.47
V_2: Pro Agro 6201	4415	4683	5440	5695	0.45	0.45
SEm±	55	50	69	60		
LSD (p = 0.05)	**123**	**112**	**153**	**134**		
Crop geometry						
G_1: 15 cm × 15 cm	4195	4485	5339	5482	0.44	0.45
G_2: 20 cm × 20 cm	4804	5091	5446	5741	0.47	0.47
G_3: 25 cm × 25 cm	4493	4756	5274	5583	0.46	0.46
SEm±	87	76	35	57		
LSD (p = 0.05)	**194**	**169**	**77**	**126**		
Nutrient						
F_0: Control	3928	4035	5424	5702	0.42	0.42
F_1: RDF (160:60:60)	4992	5203	5517	5595	0.48	0.48
F_2: 100% RDF through VC*	4298	4637	5127	5314	0.46	0.47
F_3: 50% RDF + 50% VC	4485	4849	5308	5579	0.46	0.47
F_4: 75% RDF + 25% VC	4773	5158	5382	5831	0.47	0.47
SEm±	66	58	46	57		
LSD (p = 0.05)	**132**	**117**	**93**	**114**		

*Vermicompost.

Table 3. Nutrients (NPK) uptake as influenced by rice cultivars, crop geometry and nutrient management practices.

Treatment	Nutrients uptake (kg·ha^{-1})					
	Nitrogen		Phosphorus		Potassium	
Cultivars	2006	2007	2006	2007	2006	2007
V_1: CNRH3	86.52	89.66	18.87	21.08	128.95	133.15
V_2: Pro Agro 6201	84.81	87.35	17.09	20.28	123.91	129.07
SEm±	0.57	0.44	0.55	0.35	1.85	1.44
LSD (p = 0.05)	**1.26**	**0.98**	**1.23**	**0.78**	**4.12**	**3.21**
Crop geometry						
G_1: 15 cm × 15 cm	81.97	83.76	14.98	17.41	116.84	121.15
G_2: 20 cm × 20 cm	92.48	93.99	20.12	23.63	133.89	139.69
G_3: 25 cm × 25 cm	85.21	87.83	18.86	21.03	128.49	132.48
SEm±	1.44	1.21	0.85	0.72	2.03	1.50
LSD (p = 0.05)	**3.20**	**2.70**	**1.90**	**1.60**	**4.53**	**3.35**
Nutrient						
F_0: Control	70.79	71.23	13.53	15.84	109.53	112.35
F_1: RDF (160:60:60)	100.73	104.07	23.59	25.89	151.27	156.24
F_2: 100% RDF through VC*	79.38	81.14	15.47	17.91	117.79	120.47
F_3: 50% RDF + 50% VC	87.81	90.02	17.79	20.83	121.69	127.98
F_4: 75% RDF + 25% VC	93.99	96.21	19.53	23.97	131.85	138.54
SEm±	2.75	2.09	1.16	1.08	3.10	2.80
LSD (p = 0.05)	**5.54**	**4.21**	**2.33**	**2.17**	**6.23**	**5.64**

*Vermicompost.

Table 4. Residual soil nutrients status as influenced by rice cultivars, crop geometry and nutrient management practices.

Treatment	Residual soil nutrients status (kg·ha^{-1})					
	Nitrogen		Phosphorus		Potassium	
Cultivars	2006	2007	2006	2007	2006	2007
V_1: CNRH3	141.08	146.21	12.15	13.53	123.87	129.24
V_2: Pro Agro 6201	145.78	149.52	13.38	14.43	125.57	132.08
SEm±	1.14	0.96	0.30	0.23	0.84	0.80
LSD (*p* = 0.05)	**2.54**	**2.14**	**0.67**	**0.52**	**1.87**	**1.79**
Crop geometry						
G_1: 15 cm × 15 cm	148.23	152.86	13.91	15.12	128.87	134.28
G_2: 20 cm × 20 cm	139.57	143.94	11.87	12.96	121.88	127.95
G_3: 25 cm × 25 cm	142.48	146.87	12.51	13.85	123.42	129.74
SEm±	1.06	0.66	0.50	0.44	1.81	1.50
LSD (*p* = 0.05)	**2.36**	**1.48**	**1.12**	**0.98**	**4.03**	**3.35**
Nutrient						
F_0: Control	136.98	137.97	10.09	10.94	109.56	111.75
F_1: RDF (160:60:60)	141.60	144.53	11.45	12.97	122.32	127.47
F_2: 100% RDF through VC*	151.85	157.92	16.15	19.43	138.28	146.24
F_3: 50% RDF + 50% VC	143.79	151.58	12.01	14.12	128.19	136.54
F_4: 75% RDF + 25% VC	142.99	147.45	14.17	16.83	125.28	131.29
SEm±	1.55	1.27	0.77	0.63	1.51	1.43
LSD (*p* = 0.05)	**3.12**	**2.56**	**1.54**	**1.27**	**3.04**	**2.87**

*Vermicompost.

4. Discussion

Biomass production is a function of genetic character of the crop cultivar and the environmental factors, inputs applied and their management. Many factors are attributed to obtain the higher biomass production and among them, planting geometry plays a vital role in augmenting rice grain yield [7]. Wider spacing facilitates maximum light interception, better inter-culture operations and better soil aeration [8]. This could be reason for obtaining the maximum yield in wider row spacing.

Highest grain yield under inorganic sources of nutrients might be due to immediate release and availability of nutrients when compared with organic nutrients sources. Chemical fertilizers release nutrients instantly resulting higher crop biomass production. On the contrary, organic sources release nutrients slowly for longer period that does not meet the crop demand thus reduces crop biomass production. However, combined application of nutrients, 75% RD through fertilizer and 25% N through VC, produced higher biomass due to synchronized and balanced nutrients supply for a longer period of time [20,21]. The yield advantage on the application of organic sources is due to their capability to supply essential nutrients other than N, P and K. Application of farm yard manure is known to increase concentrations of Fe, Mn, Zn, and Cu in rice. Higher nutrients uptake with the application of inorganic fertilizer might be due to higher nutrient concentration along with higher biomass production [22,23]. Application of organic manure along with chemical fertilizer accelerates the microbial activity [24], increases nutrients use efficiency [25] and enhances the availability of the native nutrients to the plants resulting higher nutrients uptake [26]. Vermicompost applied plots built-up residual soil fertility because of slow release of nutrients and reduction of nutrient losses.

5. Conclusions

Rice cultivar, CNRH 3 produced maximum grain and straw yield. Rice, irrespective of cultivars, grown with inorganic fertilizers alone produced maximum grain and straw yield but it was statistically at par with that of application of 25% nutrient through organic and 75% through inorganic sources. Rice transplanted in 20 cm × 20 cm spacing produced maximum biomass. Pro Agro 6201 rice cultivar, 25 cm × 25 cm crop geometry, and sole organic manure had built-up maximum soil fertility. It may be recommend that rice cultivar CNRH 3, planting geometry 20 cm × 20 cm and INM treatment (25:75

organic: inorganic) can be adopted to obtain the higher biomass production while maintaining the soil fertility.

REFERENCES

[1] A. Jeyabal and G. Kuppuswamy, "Recycling of Organic Wastes for the Production of Vermicompost and Its Response in Rice-Legume Cropping System and Soil Fertility," *European Journal of Agronomy*, Vol. 15, No. 3, 2001, pp. 153-170. doi:10.1016/S1161-0301(00)00100-3

[2] E. A. Siddiq, "Yawning Productivity Gaps," *The Hindu Survey of Indian Agriculture*, 2000, pp. 39-44.

[3] S. Peng, K. G. Cassman, S. S. Virmani, J. Sheehy and G. S. Khush, "Yield Potential Trends of Tropical Rice since Release of IR8 and the Challenge of Increasing Rice Yield Potential," *Crop Science*, Vol. 39, No. 6, 1999, pp. 1552-1559. doi:10.2135/cropsci1999.3961552x

[4] E. A. Siddiq, "Rice Development Opportunities," *The Hinhu Survey of Indian Agriculture*, 1996, pp. 47-55.

[5] L. P. Yuan, "Hybrid Rice Breeding in China," In: S. S. Virmani, *et al.*, Eds., *Advances in Hybrid Rice Technology*, *Proceeding of* 3rd *International Symposium on Hybrid Rice*, Hyderabad, 14-16 November 1996, pp. 27-33.

[6] L. P. Yuan, "Hybrid Rice Breeding for Super High Yield," *Hybrid Rice*, Vol. 12, No. 6, 1999, pp. 1-6.

[7] R. Prasad, "A Textbook of Rice Agronomy," Jain Brothers, New Delhi, 1999.

[8] A. K. Gautam, D. Kumar, Y. S. Shivay and B. N. Mishra, "Influence of Nitrogen Levels and Plant Spacing on Growth, Productivity and Quality of Two Inbred Varieties and a Hybrid of Aromatic Rice," *Archives of Agronomy and Soil Science*, Vol. 54, No. 5, 2008, pp. 515-532. doi:10.1080/03650340802283470

[9] R. B. Singh, "Environmental Consequences of Agricultural Development: A Case Study for the Green Revolution State of Haryana, India," *Agriculture Ecosystem and Environment*, Vol. 82, No. 1-3, 2000, pp. 97-103. doi:10.1016/S0167-8809(00)00219-X

[10] J. K. Friedel, "The Effect of Farming System on Labile Fractions of Organic Matter in Calcari-Epileptic Regosols," *Journal of Plant Nutrition Soil Science*, Vol. 163, No. 1, No. 2000, pp. 41-45. doi:10.1002/(SICI)1522-2624(200002)163:1<41::AID-JPLN41>3.0.CO;2-9

[11] S. K. Reddy, M. Singh, A. K. Tripathi, M. S. Singh and N. Manbendra, "Changes in Amount of Organic and Inorganic Fractions of Nitrogen in an Eutrochrept Soil after Long-Term Cropping with Different Fertilizer and Organic Manure Inputs," *Journal of Plant Nutrient Soil Science*, Vol. 166, No. 2, 2003, pp. 232-238.

[12] W. E. Larson and C. E. Clapp, "Effect of Organic Matter on Soil Physical Properties," In: W. E. Larson and C. E. Clapp, Ed., *Organic Matter and Rice*, International Rice Research Institute, Manila, 1984, pp. 363-385.

[13] P. V. V. Prasad, V. Satyanarayana, V. R. K. Murthy and K. J. Boote, "Maximizing Yields in Rice-Groundnut Cropping Sequence through Integrated Nutrient Management," *Field Crops Research*, Vol. 75, No. 1, 2002, pp. 9-21. doi:10.1016/S0378-4290(01)00214-3

[14] A. Dobarmman and C. Witt, "The Potential Impact of Crop Intensification on Carbon and Nitrogen Cycling in Intensive Rice Systems," In: G. J. D. Kirk and D. C. Olk, Eds., *Carbon and Nitrogen Dynamics in Flooded Soils*, International Rice Research Institute, Manila, 2000, pp. 1-25.

[15] D. S. Powlson and D. C. Olk, "Long-Term Soil Organic Matter Dynamics," In: G. J. D. Kirk and D. C. Olk, Eds., *Carbon and Nitrogen Dynamics in Flooded Soils*, International Rice Research Institute, Manila, 2000, pp. 49-63.

[16] B. V. Subbiah and G. L. Asija, "A Rapid Procedure for Estimation of Available Nitrogen in Soil," *Current Science*, Vol. 25, No. 8, 1956, pp. 259-260.

[17] A. Walkley and I. A. Black, "An Examination of the Degtjareff Method for Determining Soil Organic Matter, and Proposed Modification of the Chromic Acid Titration Method," *Soil Science*, Vol. 37, No. 1, 1934, pp. 29-38. doi:10.1097/00010694-193401000-00003

[18] S. R. Olsen, C. V. Cole, F. S. Watanabe and L. A. Dean, "Estimation of Available Phosphorus in Soil by Extraction with Sodium Bicarbonate," US Department of Agriculture Circular No. 939, 1954.

[19] M. L. Jackson, "Soil Chemical Analysis," Prentice Hall of India Pvt. Ltd, New Delhi, 1973.

[20] P. Pramanik, "Chemical and Biochemical Aspects of Vermicomposts with Reference to Transplanted Rice," PhD Thesis, Visva Bharati University, Shantiniketan, 2007.

[21] M. Mwale, A. Mapiki and L. K. Phiri, "To Synchronize Nutrient Availability with Plant Uptake," In: M. Mwale, A. Mapiki and L. K. Phiri, Ed., *The Biology and Fertility of Tropical Soils*, A TSBF Report 1997-1998, 2000, pp. 40-41.

[22] A. Swarup and N. P. S. Yaduvanshi, "Impact of Ten-Year Rice-Wheat Cropping System and integrated Nutrient Management on Soil Properties and Crop Productivity in a Gypsum Amended Sodic Soil," 18*th World Congress of Soil Science*, Philadelphia, 9-15 July 2006.

[23] P. Banik., P. K. Ghosal, T. K. Sasmal, S. Bhattacharya, B. K. Sarkar and D. K. Bagchi, "Effect of Organic and Inorganic Nutrients for Soil Quality Conservation and Yield of Rainfed Low Land Rice in Sub-Tropical Plateau Region," *Journal of Agronomy and Crop Science*, Vol. 192, No. 5, 2006, pp. 331-343. doi:10.1111/j.1439-037X.2006.00219.x

[24] R. Rani and O. P. Srivastava, "Vermicompost: A Potential Supplement to Nitrogenous Fertilizer in Rice Nutrition," *International Rice Research Notes*, Vol. 22, No. 3, 1997, pp. 30-31.

[25] R. P. Narwal, M. Chaudhary, "Effect of Long-Term Application of FYM and Fertilizer N on Available P, K and S Content of Soil," 18*th World Congress of Soil Science*, Philadelphia, 9-15 July 2006.

[26] A. L. Bhandari, A. Sood, K. N. Sharma and D. S. Rana, "Integrated Nutrient Management in Rice-Wheat System," *Journal of Indian Society of Soil Science*, Vol. 40, 1992, pp. 742-747.

