Int.J.Curr.Microbiol.App.Sci (2017) *6*(8): 1501-1513

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 6 Number 8 (2017) pp. 1501-1513**
Journal homepage: http://www.ijcmas.com

Original Research Article https://doi.org/10.20546/ijcmas.2017.608.181

Integrated Nutrient Management on Sustainable Production of Rice- Maize Cropping System in Bhadra Command area of Karnataka, India

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Keywords

INM, Rice – Maize cropping system, INM in cropping system.

Article Info

Accepted:
17 June 2017
Available Online:
10 August 2017

A B S T R A C T

A long term field study was initiated in 1989 at Agricultural Research Station, Kathalagere, University of Agricultural Sciences, Bangalore in rice – maize cropping system as alternative to existing system with imposing various nutrients combinations of organic and inorganic source of nutrients. The results of 25th year crop rotation cycle indicated that treatment receiving 25 per cent "N" through paddy straw and 75 per cent NPK through inorganic fertilizers during *summer* (T_9) (6.4 t ha^{-1} and 5.0 t ha^{-1}) has increased yields in rice and maize, while yield reduction was noticed in control (3.2 and 2.1 t ha^{-1} in rice and maize, respectively) over period. Similarly, organic carbon content was improved by 0.72 per cent in treatment receiving 25 per cent "N" through paddy straw and 75 per cent NPK through inorganic fertilizers during *summer* (T_9) and 0.70 per cent in plots (T_{10}) 50% N + 50% N Glyricidia and 100 per cent NPK inorganic during *summer*. A reduction of organic carbon was notice in only inorganic source of nutrient. Adoption of integrated nutrient management (INM) practices and inclusion of light irrigated crop like maize after rice in *summer* season as alternative to existing rice -rice cropping system by application of inorganic nutrient source along with locally available organic nutrients source in limited irrigated condition save 25 per cent of recommended dose of nitrogen through incorporation of locally available organic source specially paddy straw/green manure crops as nutrient source for rice-maize cropping system.

Introduction

Rice and maize are the two major crops grown in India contributing more than 50 per cent to the total cereal production in the country. These crops are grown in sequence on the same land in the same year either in double or triple cropping systems to meet the rice demand of a rapidly expanding human population and maize demand for livestock and poultry feeds. These crops are grown in maximum under Bhadra command area of Karnataka. Rice is grown in an area of 10.67 lakh hectares in *kharif* season and 2.85 lakh hectares in the *summer* season with total production of 36.46 lakh tonnes in Karnataka. Similarly, maize is also grown in an area of 9.61 lakh hectares with production of 26.42 lakh tonnes in Karnataka [1].

Major contribution to total rice as well as maize production comes from Bhadra command area. Among the various production constraints, shortage of canal water and development of salinity in some patches are the major considerations for lower productivity in rice-rice system. Hence, there is a need to replace the *summer* rice by certain light irrigated required crops like maize, finger millet and pulses, which are profitable in terms of economic value as well as reducing the development of salinity [2].

In addition to this, deficiency of some of the plant nutrients has been observed in some areas due to imbalanced application of fertilizers and by continuous mono-cropping. In order to overcome this problem, alternative strategies are needed so that soil degradation as well as soil fertility level can be managed for sustainable production and productivity [3].

Integrated nutrient management is one of the most important components of the production techniques to sustain soil fertility and crop productivity through combined use of organic and inorganic sources of plant nutrients. The advantage of combining organic and inorganic sources of nutrients in integrated nutrient management has been proved superior to the use of each component separately [16]. Though, the fertilizers have played a prominent role in increasing the productivity of crops in the country but over a period of time continuous and imbalanced use of chemical fertilizers has resulted in deterioration of soil health [5].

Organic manures improve physical, chemical and biological properties of soil and thus enhance crop productivity and maintain soil health. Organic manures contain plant nutrients though in small quantities in comparison to the chemical fertilizers, the presence of growth hormones and enzymes make them essential for improvement of soil fertility and productivity [6].

In addition to this, the organic manures help in improving the use efficiency of inorganic fertilizers [7]. The supply of essential micronutrients through organic manures also improved plant metabolic activities especially in the early vigorous growth of plant.

Materials and Methods

A twenty five year long term field experiment was conducted (1989-90 to 2014-15) at Agricultural Research Station, Kathalagere ($13^0 2^1$N, $76^0 15^1$E and 561.6 m MSL) in Bhadra command area to study the long term effect of integrated nutrient management on sustainable production of rice-maize cropping sequence under permanent plot experiment in moderately shallow, dark reddish brown, sandy clay soils (Alfisols). The climate is semi-arid with an average annual rainfall of 655 mm which mainly distributed between May to October. Mean maximum and minimum temperatures are 34^0C and 10^0C, respectively during the months of March to January taken as reference. Soil pH was determined in 1:2.5 soils: water suspension using digital pH meter having the glass electrode. Electrical conductivity of soil was measured in 1: 2 soil: water extract using Conductivity Bridge.

Organic carbon in the sample was determined by Walkley and Black's rapid titration method and the available P content was computed and expressed in Kg ha^{-1} and Available K content was extracted using neutral N NH_4OAC as described and outlined by Jackson [8a]. The alkaline potassium permanganate method of Subbaiah and Asija (1956) was adopted for the estimation of available N content in the soil. Similarly, Available P content was extracted by using Brays1 extractant. The P content in the extract was determined by chloromolybdic blue colour method using spectrophotometer. The intensity of blue colour was determined at 660 nm. The concentration of K in the extractant was determined by Flame photometer (Mc.Lean *et al.*, 1982).

The experiment was laid out in a randomized complete block design (RCBD) comprising twelve treatments including the control with different organic sources of nutrients replicated four times (Table 2). The organic sources of nitrogen used were FYM (Farm yard manure), paddy straw and Glyricidia with nitrogen content of 0.5 per cent, 0.4 per cent and 0.8 per cent on dry weight basis, respectively. Nutrient equivalent basis of organic sources to meet the required quantity of N were incorporated in the soil 15 days before planting of *kharif* paddy. Entire dose of P, K and 50 per cent of inorganic N were applied at the time of planting in the form of Single Super Phosphate, Muriate of Potash and Urea, respectively as per the treatment requirement. The remaining dose of nitrogenous fertilizer was top dressed in equal splits at 30 and 60 days after transplanting in the form of Urea. Twenty-five days old seedlings were transplanted in rows of 22.5 cm apart with 10cm spacing between hills. For maize as *summer*, 50 per cent N and full dose of P and K were applied as basal application based on the treatments at the time of sowing and remaining 50 per cent N was applied at 30 days after sowing. Seeding was done in rows of 60 cm apart with 30 cm spacing between maize seeds. Intercultural operations were done before top dressing of nitrogen. Plant protection measures were adopted for both the crops as and when pest and diseases were noticed. Yield data on paddy crop during *kharif* followed by maize crop during *summer* has been considered for the statistical analysis.

Soil samples were collected after the harvest of *summer* maize crop and analyzed for different parameters such as pH, electrical conductivity, organic carbon [27], available phosphorus contents were estimated by using spectrophotometer (Analytic Jena, A.G. Germany) and For the estimation of potassium, Flame photometer (Systronics 128, India by following the standard methods to study the changes in the soil fertility levels. All the results were subjected to statistical analysis for drawing conclusions using standard multivariate statistical technique and descriptive statistical analysis tools.

Results and Discussion

Soil pH

The result of long term trial crop rotation on Soil pH over the years varied from 5.73 to 5.97 (Fig. 1 and Table 3).

The soil pH recorded highest in treatment that received 50 per cent N plus 50 per cent N through FYM during *kharif* and 100 per cent NPK through inorganic fertilizers during *summer* (T_6) (5.97), followed by the treatment that received 75 per cent N plus 25 per cent N through Glyricidia during *kharif* and 75 per cent NPK through inorganic fertilizers during *summer* (T_{11}) (5.96). Conjoint use of organic manures and chemical fertilizers was due to moderating effect of organic manures as it decreases the activity of exchangeable Al^{+3} ions in soil solution due to chelation effect of organic molecules [17].

The soil pH increased due to application of organic sources, as they are basically a source of basic cations particularly calcium [25] and deactivation Fe^{3+} and Al^{3+} by Chelating effect and release of basic cation through decomposition of organic matter [17,10].

The lowest per cent change was observed in the treatment which received 75 per cent NPK through inorganic fertilizer during both *kharif* and *summer* (T_4) (5.73). Decline in pH was due to the application of chemical fertilizers alone over the years attributed to the acid producing nature of nitrogenous fertilizers that upon nitrification release H^+ ions which are potential source of soil acidity [3].

Electrical Conductivity (EC)

The results on per cent change in electrical conductivity of the soil varied from 0.17 to 0.21 dS m^{-1} (Fig. 2 and Table 4).

The EC recorded highest in treatments received 50 per cent NPK through inorganic fertilizers during *kharif* and *summer* (T_2) (0.21 dS m^{-1}) and similar trend was observed in treatment T_3 and T_4. The lowest EC (0.17 dS m^{-1}) was noticed in treatment (T_9) received 75 per cent N plus 25 per cent N Paddy Straw during *kharif* and 75 per cent NPK through inorganic fertilizers during *summer*.

The higher soluble salt content observed in the integrated nutrient treated plots as compared to the plot treated with only chemical fertilizers, could be attributed to increased CO_2 concentration, bicarbonates and addition of organic salts in the materials *viz.*, Fe, Mn and NH_3; release of the soluble salt of calcium [12, 8] and also by the higher solubilization by production of organic acids [9].

Organic Carbon (OC)

The result on per cent change in organic carbon status of 25 year rotation cycle of cropping system was ranged from 0.59 to 0.72 per cent (Fig. 3 and Table 5).

The highest organic carbon buildup (0.72 %) was noticed in treatment that received 75 per cent N plus 25 per cent N through paddy straw during *kharif* and 75 per cent NPK through inorganic fertilizers during *summer* (T_9), followed by the treatment (T_{10}) which received 50 per cent N plus 50 per cent N through Glyricidia during *kharif* and 100 per cent NPK through inorganic fertilizers during *summer* (0.70%). This mainly due to addition of organic source which upon decomposition might have resulted in enhanced organic carbon content of the soil by stimulating the growth and activity of micro-organism [19, 6].

The reduction in organic carbon was noticed in the control treatment (0.59 %) when compared to initial level, could be to non-addition of organic manures as well as intensive oxidation process aided by degradation and decomposition of organic matter [23].

Available phosphorus (P)

The result on available phosphorus status of the soil varied from 16.65 to 22.91 kg ha^{-1} (Fig. 4 and Table 6).

The highest available P of 22.91 kg ha^{-1} was observed under plots treated with 50 per cent N plus 50 per cent N through Glyricidia during *kharif* and 100 per cent NPK through inorganic fertilizers during *summer* (T_{10}), the build-up of available phosphorus in the organic manure treated plots might be due to the release of organic acids during microbial decomposition of organic matter, which might have helped in the solubility of native phosphorous, in addition to the direct addition of phosphorus to the soil, thus, increase in the valuable phosphorous content in the soil [6, 21].

The phosphorus fraction varied from 190.34 to 444.76 mg kg^{-1} with the highest phosphorus fraction (444.76 mg/kg) obtained in plots that received 75 per cent N plus 25 per cent N through Paddy Straw during *kharif* and 75 per cent NPK through inorganic fertilizers during *summer* (T_9).

The higher available soil phosphorus fraction was recorded in integrated treatments due to higher phosphorus addition through organic manure and higher organic matter build up in soil [5].

Lowest per cent available P of 16.65 kg ha^{-1} was observed under control treatment (T_1) during both *kharif* and *summer* season. This could be attributed due to fixation of phosphorus by Al in soil [6, 21].

Similarly, the decline in soil phosphorus fraction content in control plots (190.34 mg/kg) might be due to continuous cropping system and non-application of organic manures as external source [26].

Fig.1 Percent change in soil pH over the years

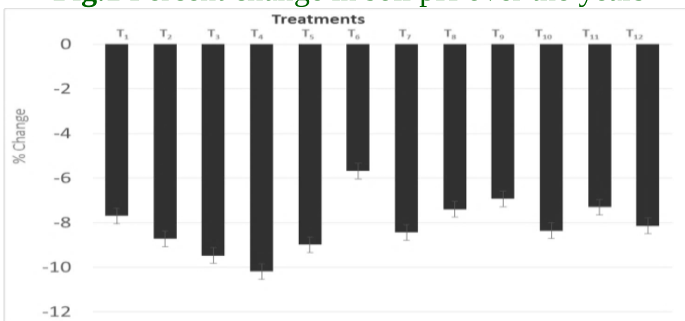

Fig.2 Percent change in electrical conductivity over the years

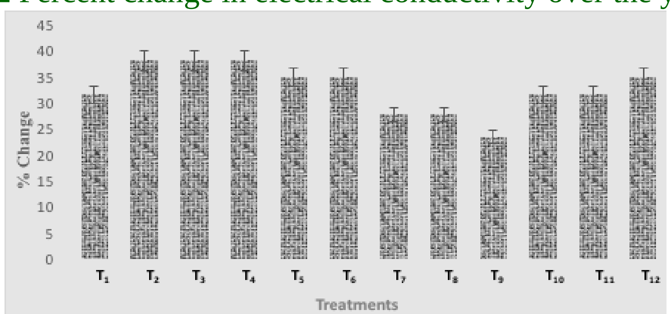

Fig.3 Percent change in organic carbon content over the years

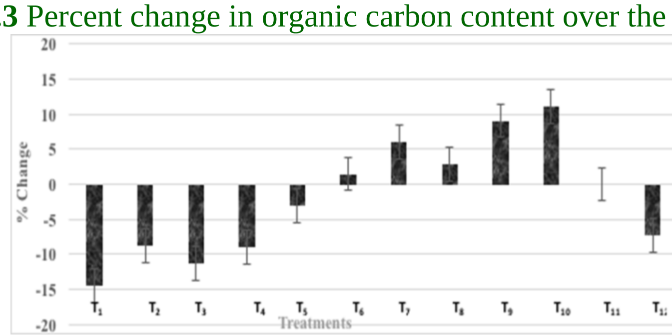

Fig.4 Percent change in available phosphorus content over the years

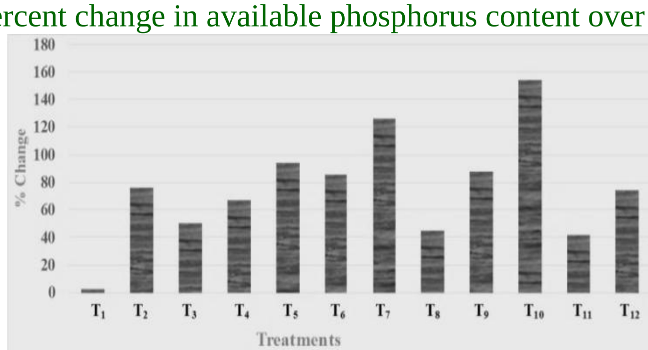

Fig.5 Percent change in available potassium content over the years

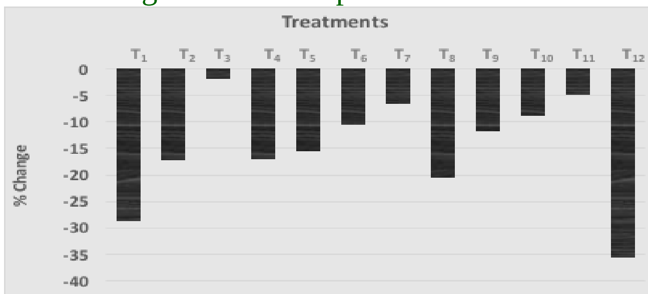

Fig.6 Grain yield of rice and maize as influenced by integrated Nutrient management practices in a long term experiment

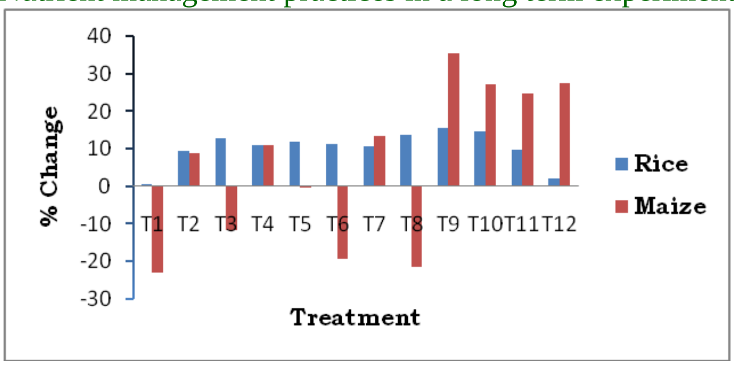

Table.1 Initial soil fertility status

SI. No.	*Soil properties*	*Initial soil fertility level*
1	*Soil pH*	*6.40*
2	*Electrical conductivity (EC) (dS m^{-1})*	*0.13*
3	*Organic carbon (OC) (%)*	*0.68*
4	*Available N (kg ha^{-1})*	*288.0*
5	*Available P (kg ha^{-1})*	*12.3*
6	*Available K (kg ha^{-1})*	*211.4*

Table.2 Treatments Details

Sl. No	**Nutrient Source**	
	***Kharif* (Rice)**	***Summer* (maize)**
1	Control	Control
2	50% NPK	50% NPK
3	50% NPK	100% NPK
4	75% NPK	75% NPK
5	100% NPK	100% NPK
6	50% N + 50% N FYM	100% NPK
7	75% N + 25% N FYM	75% NPK
8	50% N + 50% N Paddy Straw	100% NPK
9	75% N + 25% N Paddy Straw	75% NPK
10	50% N + 50% N Glyricidia	100% NPK
11	75% N + 25% N Glyricidia	75% NPK
12	Farmers Practice (85:50:30 kg NPK/ha & FYM 5 t/ha)	Farmers Practice (75:37.5:38.75 kg NPK/ha)

Table.3 Soil pH changes under integrated nutrient supply in rice-maize sequence, over ten years

Treatments	Soil pH (1:2.5)												
	1989-90	*2005-06*	*2006-07*	*2007-08*	*2008-09*	*2009-10*	*2010-11*	*2011-12*	*2012-13*	*2013-14*	*2014-15*	*Pooled data*	*% Increase /Decrease*
T_1	6.23	5.10	5.27	5.28	6.10	5.39	5.56	6.23	6.36	6.13	6.11	5.75	-7.70
T_2	6.30	5.20	5.50	5.56	5.92	5.65	5.60	6.07	5.96	6.07	6.05	5.75	-8.73
T_3	6.33	5.05	5.32	5.42	5.91	5.60	5.94	5.97	6.02	6.03	6.00	5.73	-9.48
T_4	6.38	5.12	5.39	5.43	5.99	5.63	5.80	5.98	5.96	5.93	6.10	5.73	-10.19
T_5	6.45	5.68	5.75	5.81	5.78	5.65	5.90	5.95	6.00	6.10	6.06	5.87	-8.99
T_6	6.33	5.15	5.40	5.51	5.91	6.10	6.96	6.05	6.10	6.27	6.25	5.97	-5.69
T_7	6.40	5.20	5.59	5.62	5.96	6.18	5.99	5.82	5.85	6.23	6.19	5.86	-8.44
T_8	6.35	4.98	5.22	5.38	6.14	5.99	6.10	5.89	6.01	6.60	6.50	5.88	-7.40
T_9	6.35	5.12	5.29	5.49	6.00	6.04	6.11	6.04	5.98	6.43	6.63	5.91	-6.93
T_{10}	6.45	5.20	5.50	5.61	5.96	6.02	5.99	6.24	6.14	6.24	6.21	5.91	-8.37
T_{11}	6.43	5.19	5.53	5.72	6.08	6.00	6.03	6.17	6.20	6.38	6.28	5.96	-7.31
T_{12}	6.50	5.25	5.90	5.95	6.09	5.99	5.95	6.01	6.18	6.10	6.25	5.97	-8.15
SEm±	0.101	0.016	0.014	0.015	0.028	0.01	-	0.385	0.14	0.24	0.16	NA	
CD @ 5%	NS	0.045	0.040	0.042	0.080	0.03	-	1.11O	0.40	NS	NS		

Table.4 Soil EC changes under integrated nutrient supply in rice-maize sequence, over ten years

Treatments	Soil EC (dSm^{-1})												
	1989-90	*2005-06*	*2006-07*	*2007-08*	*2008-09*	*2009-10*	*2010-11*	*2011-12*	*2012-13*	*2013-14*	*2014-15*	*Pooled data*	*% Increase /Decrease*
T_1	0.10	0.18	0.16	0.16	0.21	0.21	0.17	0.17	0.15	0.20	0.27	0.19	31.58
T_2	0.11	0.20	0.20	0.22	0.17	0.18	0.18	0.17	0.18	0.30	0.25	0.21	38.10
T_3	0.09	0.23	0.22	0.21	0.17	0.18	0.17	0.20	0.16	0.30	0.26	0.21	38.10
T_4	0.10	0.20	0.22	0.22	0.18	0.18	0.17	0.18	0.17	0.30	0.27	0.21	38.10
T_5	0.12	0.25	0.23	0.24	0.17	0.18	0.18	0.17	0.16	0.21	0.24	0.20	35.00
T_6	0.13	0.18	0.20	0.22	0.18	0.16	0.19	0.17	0.18	0.30	0.21	0.20	35.00
T_7	0.12	0.15	0.19	0.16	0.20	0.15	0.18	0.18	0.16	0.22	0.19	0.18	27.78
T_8	0.10	0.14	0.14	0.17	0.23	0.16	0.17	0.18	0.19	0.21	0.18	0.18	27.78
T_9	0.12	0.17	0.15	0.15	0.21	0.17	0.16	0.18	0.16	0.21	0.18	0.17	23.53
T_{10}	0.13	0.21	0.21	0.22	0.21	0.18	0.17	0.17	0.15	0.20	0.20	0.19	31.58
T_{11}	0.13	0.19	0.19	0.19	0.23	0.18	0.18	0.18	0.17	0.20	0.20	0.19	31.58
T_{12}	0.10	0.20	0.21	0.22	0.17	0.21	0.15	0.16	0.21	0.20	0.25	0.20	35.00
SEm±	0.0056	0.0087	0.008	0.012	0.014	0.07	-	0.035	0.02	0.03	-	NA	
CD @ 5%	0.018	0.025	0.023	0.040	0.04	0.21	-	0.100	0.07	NS	NS		

Table.5 Soil organic carbon changes under integrated nutrient supply in rice-maize sequence, over ten years

Treatments	Soil OC (%)											
	1989-90	*2005-06*	*2006-07*	*2007-08*	*2008-09*	*2009-10*	*2010-11*	*2011-12*	*2012-13*	*2013-14*	*2014-15*	*Pooled data*	*% Increase /Decrease*
T_1	0.69	0.60	0.60	0.62	0.57	0.62	0.62	0.59	0.57	0.58	0.56	0.59	-14.49
T_2	0.68	0.63	0.63	0.65	0.61	0.63	0.63	0.62	0.61	0.61	0.59	0.62	-8.82
T_3	0.71	0.64	0.64	0.65	0.63	0.65	0.64	0.62	0.60	0.63	0.61	0.63	-11.27
T_4	0.67	0.58	0.61	0.62	0.55	0.63	0.61	0.60	0.62	0.66	0.61	0.61	-8.96
T_5	0.67	0.64	0.65	0.67	0.59	0.67	0.65	0.64	0.65	0.70	0.62	0.65	-2.99
T_6	0.68	0.69	0.69	0.70	0.60	0.76	0.73	0.70	0.71	0.70	0.66	0.69	1.47
T_7	0.66	0.71	0.71	0.72	0.62	0.75	0.73	0.71	0.73	0.69	0.65	0.70	6.06
T_8	0.69	0.74	0.72	0.72	0.63	0.73	0.72	0.71	0.72	0.70	0.70	0.69	2.90
T_9	0.66	0.70	0.74	0.72	0.63	0.73	0.75	0.75	0.76	0.70	0.70	0.72	9.09
T_{10}	0.63	0.75	0.72	0.73	0.59	0.73	0.70	0.72	0.71	0.67	0.63	0.70	11.11
T_{11}	0.69	0.68	0.70	0.70	0.59	0.75	0.71	0.72	0.73	0.70	0.62	0.69	0.00
T_{12}	0.68	0.64	0.64	0.64	0.54	0.71	0.63	0.62	0.60	0.67	0.59	0.63	-7.35
SEm±	0.025	0.0115	0.008	0.014	0.0.013	0.09	-	0.036	0.03	0.03	0.02	NA	
CD @ 5%	NS	0.033	0.022	0.040	0.04	0.28	-	0.103	0.10	0.08	0.06		

Table.6 Soil available P changes under integrated nutrient supply in rice-maize sequence, over ten years

Treatments	Soil Av. P (kg/ha)												**P Fraction**
	1989-90	*2005-06*	*2006-07*	*2007-08*	*2008-09*	*2009-10*	*2010-11*	*2011-12*	*2012-13*	*2013-14*	*2014-15*	*Pooled data*	*% Increase /Decrease*	
T_1	15.30	10.63	11.03	10.97	21.80	15.39	18.25	17.71	17.70	16.51	16.50	16.65	12.29	190.34
T_2	10.80	17.78	17.75	18.06	22.56	19.65	17.66	20.58	19.35	19.53	17.75	19.07	76.57	242.49
T_3	13.33	18.18	18.27	18.85	22.18	21.02	19.23	20.61	21.60	21.57	18.88	20.04	50.34	263.52
T_4	11.25	17.13	17.84	17.84	22.05	18.78	18.85	19.33	20.45	17.31	18.66	18.82	67.29	281.09
T_5	11.25	21.10	22.13	21.92	21.38	21.86	21.99	21.16	21.64	23.32	21.75	21.83	94.04	305.93
T_6	11.60	20.18	21.43	20.55	21.72	23.98	23.12	21.50	21.53	18.65	22.25	21.49	85.26	360.26
T_7	9.83	22.35	22.21	22.01	23.23	21.56	22.01	22.53	21.98	21.47	23.38	22.27	126.55	404.98
T_8	15.00	20.13	21.62	20.60	21.48	20.94	21.38	21.92	23.00	22.30	24.50	21.79	45.27	426.23
T_9	12.23	21.26	22.25	21.96	22.61	22.99	22.06	23.11	23.95	23.40	25.53	22.91	87.33	444.76
T_{10}	8.63	21.38	21.48	21.62	21.47	22.18	21.85	22.92	21.10	22.23	23.13	21.94	154.23	345.43
T_{11}	14.75	20.23	21.13	21.40	20.94	22.08	21.98	21.52	19.79	18.78	22.00	20.99	42.31	313.21
T_{12}	11.53	18.81	18.91	18.90	21.24	20.90	19.01	21.09	22.42	19.65	19.93	20.09	74.24	225.35
SEm±	2.284	0.354	0.087	0.13	0.25	0.97	-	3.243	1.63	1.15	0.72	NA		13.24
CD @ 5%	NS	1.021	0.25	0.38	0.75	2.96	-	9.357	4.70	3.29	2.06			38.03

Table.7 Soil available K changes under integrated nutrient supply in rice-maize sequence, over ten years

Treatments	Soil Av. K (kg/ha)													*K Fraction*
	1989-90	*2005-06*	*2006-07*	*2007-08*	*2008-09*	*2009-10*	*2010-11*	*2011-12*	*2012-13*	*2013-14*	*2014-15*	*Pooled data*	*% Increase /Decrease*	
T_1	201.05	123.60	124.30	125.80	197.54	135.22	128.81	156.99	153.46	145.76	140.00	143.15	-28.80	1811.61
T_2	211.68	162.86	164.29	163.05	193.67	172.82	169.63	188.37	185.75	211.01	141.75	175.32	-17.18	2028.20
T_3	183.58	181.73	182.52	183.80	196.76	186.91	184.24	174.75	176.45	192.37	142.68	180.22	-1.83	2112.46
T_4	213.35	186.03	186.50	187.26	197.62	184.53	187.85	166.08	168.72	160.41	144.00	176.90	-17.08	2256.61
T_5	210.55	185.64	186.13	185.67	194.63	185.15	182.36	163.83	173.45	172.40	147.50	177.68	-15.61	2352.17
T_6	212.90	183.73	185.41	184.41	192.97	192.53	190.63	195.00	198.40	208.52	172.65	190.43	-10.55	2638.27
T_7	200.60	188.37	184.47	188.81	192.74	191.67	189.18	182.37	184.46	192.50	179.63	187.42	-6.57	2677.20
T_8	237.55	180.81	185.48	181.30	194.67	189.67	188.24	192.93	196.23	193.41	186.25	188.90	-20.48	2697.39
T_9	218.08	183.46	188.52	184.15	195.03	188.21	189.34	184.95	198.45	214.95	196.13	192.32	-11.81	2758.15
T_{10}	204.95	187.58	184.43	187.79	193.54	191.67	185.86	184.64	188.35	185.53	178.50	186.79	-8.86	2452.79
T_{11}	192.93	182.96	183.44	182.64	192.91	187.48	185.16	185.16	186.40	168.18	181.50	183.58	-4.85	2297.70
T_{12}	244.50	141.26	143.41	141.75	195.40	148.92	142.88	166.50	164.35	168.53	162.50	157.55	-35.56	1863.27
SEm±	14.02	0.549	0.964	0.84	0.37	5.70	-	4.471	4.15	4.96	4.40	NA		**65.39**
CD @ 5%	NS	1.581	0.278	2.43	1.09	17.10	-	12.898	11.13	14.26	12.65			**187.85**

Table.8 Yield as influenced by integrated nutrient

Treatments	**1989 (Initial Year)**		**2005-06**		**2006-07**		**2007-08**		**2008-09**		**2009-10**	
	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield (kg/ha)	Rice grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)
T_1	2797	2672	3137	988	2734	4299	1000	1264	3511	1772	4299	2434
T_2	4813	2646	5198	2065	4327	5556	2852	3557	5519	2573	5556	3428
T_3	4356	5195	5350	2722	4547	5848	3427	4329	5512	4204	5848	4335
T_4	4953	3898	5979	2463	4927	6067	3316	4189	5684	4267	6067	3721
T_5	5449	4831	6505	3260	6177	6281	3453	4362	6098	4892	6281	4605
T_6	5270	6003	6353	3748	6279	6111	3913	4943	5958	4437	6111	4357
T_7	5012	4022	6578	2878	6367	6089	3199	4041	5955	3907	6089	3809
T_8	5514	6199	6644	3630	6287	6756	3590	4535	6293	5379	6756	4686
T_9	5577	3701	7017	3012	6542	6588	3729	4711	6333	5535	6588	5015
T_{10}	5278	4360	6557	3188	6272	6082	3344	4224	5915	4294	6082	4298
T_{11}	5463	3460	6966	2784	6361	6188	3197	4038	5946	4138	6188	3428
T_{12}	5501	2959	*5811*	*2468*	*5132*	*5355*	*2989*	*3775*	*5939*	*3953*	*5355*	*3348*
SEm±	**439**	**714**	**268.3**	**173.57**	**101.36**	**292**	**-**	**321.86**	**150.4**	**714**	**292**	**285**
CD ($P \leq 0.05$)	**892**	**1454**	**773**	**499.78**	**305.44**	**842**	**-**	**926.7**	**433**	**1454**	**842**	**820**

Cont…..

Treatments	**2010-11**		**2011-12**		**2012-13**		**2013-14**		**2014-15**		**Average yield (2005-06 to 2014-15)**		**% Increase / Decrease**	
	Rice grain yield (kg/ha)	Rice grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield (kg/ha)	Maize grain yield (kg/ha)	Rice grain yield	Maize grain yield
T_1	4101	4101	3966	1221	3966	1221	3500	1243	3329	2023	3174	2057	0.63	-23.02
T_2	6213	6213	5906	3724	5906	3724	5525	3754	5639	4020	5264	3861	9.37	8.71
T_3	6287	6287	6287	4558	6287	4558	5750	4616	5987	4362	5528	4582	12.91	-11.80
T_4	6469	6469	6557	3830	6557	3830	6275	3830	6124	4595	5796	4326	11.02	10.98
T_5	6506	6506	6542	4569	6542	4569	6675	4576	6242	4582	6102	4820	11.98	-0.23
T_6	6250	6250	5848	5117	5848	5117	5750	3779	6286	4629	5860	4849	11.20	-19.22
T_7	6396	6396	6406	4572	6406	4572	6600	4572	6477	4772	6047	4561	10.65	13.40
T_8	6798	6798	6506	3951	6506	3951	6725	3951	6567	5093	6267	4873	13.66	-21.39
T_9	7149	7149	6616	3779	6616	3779	6975	5157	6798	5369	6436	5009	15.40	35.34
T_{10}	6308	6308	6447	3615	6447	3615	6525	3615	6531	4229	6043	5347	14.49	27.22
T_{11}	6360	6360	6067	4028	6067	4028	6450	4028	6292	4161	5989	4318	9.63	24.80
T_{12}	*5894*	*5694*	5921	3286	*5921*	*3286*	*5725*	*3286*	5992	3271	5648	3772	1.96	27.48
SEm±	**341**	**341**	**290.3**	**241.8**	**290**	**242**	**177**	**249**	**164**	**133**	NA			
CD (P≤0.05)	**981**	**981**	**870.5**	**725.0**	**871**	**725**	**508**	**715**	**470**	**383**				

Available potassium (K)

The result on available K status decreased over the years (Fig. 5 and Table 7), and was more prominent in plots that received only inorganic fertilizers during both the seasons.

The available K content of soil varied from a minimum of 143.15 kg ha^{-1} under control (T_1) during both *kharif* and *summer* to a maximum of 190.43 kg/ha under plots amended with 50 per cent NPK through inorganic fertilizers during *kharif* and 100 per cent NPK through inorganic fertilizers during *summer* (T_6), followed by plots that received 75 per cent N plus 25 per cent N through Glyricidia during *kharif* and 75 per cent NPK through inorganic fertilizers during *summer* (T_9) (192.32 kg/ha).

Relatively higher available K was observed in integrated nutrient management treatments and lower values were obtained in control which did not receive any fertilizer over period of 25 years of cycle. This could be due to continuous cropping and non-addition of organic manure in control [13].

Potassium fraction varied from 1811.61 to 2758.15 mg kg^{-1} after 25th year of crop rotation cycle. Higher buildup of K fraction in soil was observed in integrated treatments, and may be due to addition of K from organic sources [14]. The relatively lower contents of K fraction observed in control treatment might be due to the depletion of K by crop removal without supplement through external inputs and partly due to leaching of K with colloidal fractions of the soil to the lower layers [25, 4].

Grain yield of rice and maize

The long term crop rotation sequence indicated that treatment (T_9) (75% N + 25% N through Paddy Straw and 75% NPK during *kharif* and *summer*) gave the highest rice and maize grain. Over the years of experiment, an increasing trend in yield of rice and maize was observed which could be due to gradual decomposition of organic manure and its slow nutrients release throughout the growing period of the crop [11, 17]. Treatment (T_9) (75% N + 25% N through Paddy Straw) recorded higher rice grain yield (6.4 t/ha) over the years which is followed by treatment (T_{10})(50% N + 50% N Glyricidia) of 6.2 t ha^{-1} (Fig. 6 and Table 8), when compared to the control which might be attributed to incorporation of rice straw and supply of naturally available N derived from mineralized soil and biological nitrogen fixation by free living and plant associated diazotrophs present in submerged rice soils [2].

The result of yield data on maize in *summer* season, indicated that treatment (T_9) (75% NPK - 5.0 t/ha) recorded higher grain yield over the years, which is followed by (T_{10}) (100% NPK) (3.8 t/ha). This might be due to slow release of nutrients in FYM applied treatments as lower grain yield was observed in control treatment where no fertilizers were applied. The yield data of both crops over the years indicated an improvement in the efficiency of NPK fertilizers when used in combination with organic manure in at least one season (minimum of 25% N through organic manures) for obtaining higher yield [15]. Hence, in order to derive maximum benefit both in terms of higher yield as well as maintaining soil fertility and fertilizer use efficiency, rice – maize cropping system has to be followed with integrated nutrient supply.

Rice-rice is the predominant mono-cropping system with injudicious use of chemical fertilizers and irrigation water (Excessive) method in studied area, resulting in nutrients depletion of the soil and buildup of soil salinity. In overcoming this, present study was carried out to investigate other cropping systems/patterns with combined use of organic and inorganic sources over the 25 years of study on soil fertility and crop yield improvement. The 25 years of crop rotation cycle has shown that growing rice-maize cropping system in alternative to the existing rice-rice cropping with integrated nutrient source has proved the efficiency of integrating NPK fertilizers with organic manure at least in one season (minimum of 25% N through organic manures) for sustainable higher yield.

Further, incorporation of naturally available rice straw or green leaf manures and supply of naturally available nitrogen from mineralized soil nitrogen and biological nitrogen fixation by free living and plant-associated diazotrophs present in submerged rice soils has contributed to nitrogen pool in soil.

Hence, effective use of naturally available organic source of nutrients after harvest of crop and by adoption of alternative cropping system (rice –maize) in order to derive maximum benefit both in terms of sustainable higher yields as well as save the recommended nitrogen level (25%) and also avoid occurrence of nutrient deficiency in the system.

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How to cite this article:

Kumara, O., H.G. Sannathimmappa, S.R. Rajini, Vijay S. Danaraddi and Sanjeev Kyatappanavar. 2017. Integrated Nutrient Management on Sustainable Production of Rice- Maize Cropping System in Bhadra Command area of Karnataka. *Int.J.Curr.Microbiol.App.Sci.* 6(8): 1501-1513.
doi: https://doi.org/10.20546/ijcmas.2017.608.181