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Sustainable production potential of maize-wheat cropping system in Ranchi based on the permanent manurial trial (PMT)

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Abstract
The study was worked out during 2015-16 on Permanent Manurial Trial (PMT) initiated during 1956 at Birsa Agricultural University, Kanke, Ranchi, India, to evaluate the long-term effect of nutrient management practices on crop productivity and sustainability of the system in an acid soil under maize-wheat cropping system. The selected treatments were T_1-$N_0P_0K_0$ (control), T_2-100%N, T_3-100%NP, T_4-100%NPK, T_5-100%NPK+Lime, T_6-Farmyard manure (FYM) alone, T_7- - ½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$] and T_8-Lime+N.

System productivity in terms of mean MEY (maize equivalent yield in kg ha^{-1}) followed the following order: Lime+ NPK (7843) >½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$] (6673) > FYM (5449) > Lime +N (4091) > NPK (3487) > NP (2768) > Control (1295) > N (623). Sustainable yield index (SYI) of the system varied from -0.03 to 0.43. 100% NPK + lime treatment recorded the highest sustainable yield index (SYI) of the system (0.43) followed by integrated use of organics and chemical fertilizers (0.36). Negative SYI value was obtained in the treatment receiving 100% N alone (-0.03). The highest value of mean MEY as well as sustainable yield index(SYI) in treatmentT_5(100%NPK+Lime) followed by T7- - ½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$] suggests that continuous application of lime/ FYM in integration with NPK fertilizers maintained the system productivity and enhanced the sustainability under maize-wheat cropping system in acid soils over the years.

Keywords: Maize-wheat cropping system, system productivity, sustainable yield index, acid soil

Introduction
Food security and food quality together with environment protection forms the key basis of any agricultural production system. One of the major issues that the world is facing today is to feed the ever-increasing population with limited land. Crop intensification both in time and space are the main options to increase crop production to meet future challenges. So, it is essential to increase the production per unit area of land within a calendar year which is possible through proper management of the soil. It is well established that chemical fertilizers or organic manures alone cannot sustain the desired levels of crop production under continuous cropping as observed in many long-term fertilizer experiments (Singh and Wanjari 2013) [10]. There are reports which suggest that imbalanced use chemical fertilizers (N or NP alone) in continuous cropping, without organic manure have led to the decline in level of crop productivity (Tiwari *et al*. 2002; Panwar 2008) [12, 6]. The need in today's scenario is to strive for enhanced sustainable crop production. A system with increased sustainability ensures a stability in the level of food production and quality on a long-term basis the sustenance of

crop yields levels, following integrated nutrient management practices has been documented by a number of workers for different cropping systems in India and abroad. (Pathak *et al*. 2005; Bedada *et al*. 2014; Bhattacharya *et al*. 2016) [7, 1].

Maize (*Zea mays*)-Wheat (*Triticum aestivum*) is an important cropping system in India covering an area of 1.80 million ha (Jat *et al*. 2011) [3]. By 2020, the demand for maize in developing countries would surpass the demand for both wheat and rice (due to high population pressure) and to meet the rising demand, higher maize production is necessary (Srinivasan *et al.* 2004) [11]. The present investigation was therefore conducted to assess the long-term effect of manure, fertilizer and lime application on yield trend, system productivity and sustainability under maize-wheat cropping system in an acid soil after 60 cycles of cropping.

Materials and Methods

Experimental site

The present investigation was conducted on permanent manurial trial (PMT) with maize-wheat cropping system, started in 1956 on an acidic red loam soil at Birsa Agricultural University, Kanke, Ranchi (85^0 19' East longitude, 23^0 17' North latitude 625 m above the mean sea level) in Jharkhand state of India. The climate of experimental site is tropical with hot wet summers and mild winters. Temperature can soar up to 42 ºC in summer. The monsoon season is July to September and the state receives an annual rainfall of 1450 mm.

Cropping pattern

A fixed crop rotation of maize in *Kharif* and wheat in *Rabi* was followed since, 1956 but the varieties of both crops were changed from time to time. A number of varieties of both the crops were tested. During 2015-16 the varieties grown were Suwan and K 9107 for maize and wheat, respectively.

Treatment details

The experiment consisted of fourteen treatments, each replicated thrice in randomized block design (RBD) having individual plot size of $10m^2$. Out of 14 treatments under PMT, only eight treatments were selected for this study. The selected treatments were T_1 –$N_0P_0K_0$ (Control), T_2 -100% N, T_{3-} 100% NP, T_{4-} 100% NPK, T_{5-}100% NPK + Lime, T_{6-} FYM, T_{7-} ½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$] and T_{8-} Lime + N. for. The treatment Lime +N was introduced in *kharif* 1977. Ammonium sulphate was used as a source of N fertilizer till the year 1994 after which urea has been used. The recommended dose of fertilizer for the treatment (T_5) for maize and wheat were 110-90-70 kg N-P_2O_5-K_2O ha^{-1} supplied through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively. In lime treated plot lime was supplied as per lime requirement (LR) once in four years. In $T_{6,}$ FYM was applied @22-ton ha^{-1} 15 days before sowing of each crop. In treatment $T_{7,}$ A and B stand for full dose of P and K i.e. 90 kg P_2O_5 and 70 Kg K_2O ha^{-1}, respectively. X and Y represent the amount of P and K present in full dose of FYM applied on N basis to meet 110 kg N $ha^{-1.}$ The amount of N, P and K contained in FYM were taken into consideration in adjusting the final dose when applied in conjunction with fertilizers. In T_7, 50% of N was substituted through FYM and NPK @ of 55kg N ha^{-1} as urea + 55.6 kg P_20_5 ha^{-1} as SSP + 42.9 kg MOP ha^{-1} was supplied.

System productivity

Grain yield of both the crops under maize-wheat cropping and system productivity in terms of mean maize equivalent yield (MEY) were computed and pooled for the years of experimentation. The grain yield of wheat was converted into maize equivalent yield taking into consideration the prevailing price of maize and wheat as follows:

MEY= (Maize yield) + ((wheat yield x Price of wheat)/ Price of maize)

Sustainability

Minimum guaranteed yield that could be obtained relative to maximum observed yield over the years of maize-wheat cropping system was quantified through sustainable yield index (SYI), which was calculated following the equation suggested by Singh *et al.* (1990).

$$SYI=(Y-\sigma_{n-1}) / Y_m$$

Where, Y is the mean grain yield of a given treatment in the system

σ_{n-1} is the standard deviation of yield for that treatment across years

Y_m is the maximum yield obtained under a set of management practice for any of the treatment in any year of the experiment.

Results and Discussion

Crop productivity

Mean grain yield of maize and wheat as influenced by continuous use of fertilizers, manures and lime decade wise for the last six decades as well as the mean over years has been presented in table-1. The highest grain yield of maize (3953 kg $ha^{-1)}$ and wheat (3502 kg ha^{-1}) was obtained in the treatment receiving 100% NPK along with lime (T_5). Integrated use of FYM / lime with chemical fertilizers as well as FYM alone increased the grain yield of both the crops over the years as compared to full dose of NPK through chemical fertilizers.

The yield declined steadily in control, N, NP and NPK treatments. The decline in control is quite obvious because of absence of external supply of plant nutrients. Application of nitrogenous fertilizer alone had deleterious effect on long run and reduced the yield level even less than the control after two decades which could be due to sharp decline in pH. Addition of P resulted in significant increase in the grain yield as compared to 100% N alone which may be attributed to the stimulating effect of phosphorus in early root development and growth resulting in enhanced water and nutrient absorption. Sharma *et al.* (2005) [15] also reported increase in yield due to addition of P over 100% N treatment.

Application of NP or NPK also showed a steady reduction in grain yield up to four decades and thereafter there was steady increase in grain yield of maize due to change of N source from ammonium sulphate to urea. Kumari *et al*. (2013) [4] also observed reduction in grain yield of maize and wheat in treatments receiving only chemical fertilizers. Maximum reduction in grain yield of both the crops was in 100% N followed by 100% NP over 100% NPK.

Application of lime along with balanced NPK fertilizers significantly increased the grain yield of maize (3953 kg ha^{-1}) mainly due to improvement in pH of the soil which was at par with the treatment receiving FYM alone (2906 kg ha^{-1}) and treatment receiving integrated application of FYM and inorganic fertilizers (2885 kg ha^{-1}). In case of wheat, 100% NPK +lime treatment (3502 kg ha^{-1}) was statistically superior to rest of the treatments except T_7treatment (2983 kg ha^{-1})

being at par. This might be due to the fact that application of lime in acid soil reduces exchangeable acidity and increases the soil pH. The striking beneficial effect of lime on acid soils can be explained by comparing the lime +N treatment (T_8) with 100%N treatment (T_2).After six decades, the conjunctive use of lime along with N resulted in 438% and 850%increase in grain yield of maize and wheat crop, respectively, as compared to 100% N only.

Increased crop yields due to addition of FYM alone or in combinations with chemical fertilizers are generally ascribed to its spectacular beneficial effect on the physical, chemical and biological condition of the soils. Buffering action of the organic manure stabilizes the soil pH. Insoluble nutrients present in soil are solubilized due to fulvic acid and humic acid liberated from the organic materials and become available to plants for their growth (Kumari *et al*. 2013) [4]. The organic manure acts as a chelate and help to mobilize the micronutrients increasing their availability to the plants. Mishra *et al*. (2008) [5] also reported the yield of maize and wheat to be significantly influenced by the application of lime or FYM in combination with 100% NPK over inorganic fertilizers.

Mean maize equivalent yield (MEY)

In order compare the treatment effects on productivity under maize-wheat cropping sequence, the mean maize equivalent yield (MEY) was calculated. The effect of continuous application of fertilizers, manure and lime on mean maize equivalent yield is presented in table2. Highest mean maize equivalent yield (MEY) after 60 cycles of cropping was recorded for the treatment 100%NPK +lime (7843 kg ha^{-1}) which was statistically superior to the rest of the treatments except the treatment receiving combined application of inorganic fertilizer and FYM (6673). Mean maize equivalent yield (MEY)followed the following order: Lime+ NPK (7843) >½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$] (6673) > FYM (5449) > Lime +N (4091) > NPK (3487) > NP (2768) > Control (1295) > N (623). Proper liming of the acid soils has the potential of contributing to an overall increase in grain yield of crops cultivated in such soils because of reducing exchangeable acidity and increasing pH. In a long run integrated use of FYM/lime with chemical fertilizers supplying single nutrient or combination of nutrients increased the grain yield of crops over the years as compared to their respective treatments through chemical fertilizers.

Table 1: Mean grain yield (kg ha^{-1}) of maize and wheat (decade wise) as influenced by continuous use of fertilizer, manure and lime.

Treatment	1956-1965		1966-1975		1976- 1985		1986-1995		1996-2005		2006-2015		Overall mean 1956-2015	
	M	W	M	W	M	W	M	W	M	W	M	W	M	W
Control	612	550	671	601	524	689	505	965	323	807	443	620	506	707
N	1597	657	1029	235	93	0	9	40	107	102	137	157	432	174
NP	2131	1533	2436	2163	434	846	26	573	800	1531	805	2207	1069	1517
NPK	2283	1869	2726	2285	626	1607	46	972	1077	1766	1938	2389	1171	1846
Lime + NPK	2336	1485	3399	2857	3970	3339	4718	4914	4499	3939	4301	4088	3953	3502
FYM	2585	1525	2242	1418	2086	2085	3325	3369	3659	2873	3495	2387	2906	2295
½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$]	2268	1706	2580	2277	2895	2855	4048	4103	3943	3393	4056	3266	2885	2983
Lime + N	-**	-**	-**	-**	3153	2190	2343	2085	2102	1352	1790	1184	2325	1654
CD (P=0.05)	429.6	484.2	539.0	571.9	596.8	743.4	563.5	511.9	452.9	330.3	485.1	300.6	1114.6	845.5
CV (%)	19.95	34.21	23.88	32.29	35.47	37.16	30.63	24.55	22.40	17.11	23.34	15.05	44.83	38.0

****-** Lime+ N treatment was introduced in *kharif* 1977

Table 2: Mean maize equivalent yield (MEY) (kg ha^{-1}) of maize-wheat system (decade wise) as affected by continuous use of fertilizers, manure and lime.

Treatment	1956-1965	1966-1975	1976- 1985	1986-1995	1996-2005	2006- 2015	Overall mean1956-2015
Control	1245	1361	1318	1474	1251	1155	1295
N	2352	1299	75	33	225	317	623
NP	3894	4923	1375	514	2561	3343	2768
NPK	4432	5354	2324	972	3108	4685	3487
Lime + NPK	3759	6684	7880	9795	9029	9002	7843
FYM	4338	3872	4431	6800	6963	6240	5449
½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$]	4231	5199	6254	7791	7845	7812	6673
Lime + N	-**	-**	5670	4542	3656	3151	4091
CD (P=0.05)	729.1	103.11	1285	1319.8	561.6	669.2	2022
CV (%)	19.3	24.06	29.91	35.04	13.24	15.3	40.67

******Lime+ N treatment was introduced in *kharif* 1977

Sustainability

Sustainable yield index (SYI) helps to establish the minimum guaranteed yield that can be obtained relative to maximum observed yield. A higher value of SYI indicates a more progressive management practice capable of producing high yields over the years. The nearness of the SYI to 1 implies the closeness to an ideal condition that can sustain maximum crop yields, whereas deviation from 1 indicates losses to sustainability (Reddy *et al*. 1999) [8]. The sustainable yield index (SYI) for maize-wheat cropping system over the years (1960–2015) has been presented in table- 3. Highest sustainable yield index (SYI) of the system 0.43 for 100%NPK + lime treatment followed by integrated use of organics & chemical fertilizers (0.36) followed by application of FYM alone (0.28) and least and negative SYI values were recorded in application of N alone (-0.03). Imbalanced and continuous use of N alone produced greatest decline in yield and had deleterious effect on long term yield sustainability indicating that other major and micronutrients were becoming limiting factors and adequate response of N could not be obtained unless those factors limiting yield were taken care of. The decline in yield with N was most spectacular and it also showed negative response to the added N i.e. the yield recorded in 100% N was less than the control for both the crops over the years. The result showed the beneficial impact of integrated use of lime or FYM coupled with balanced NPK for increasing as well as sustaining crop production in the acid upland soils of Jharkhand under maize-wheat cropping system. Application of both lime and FYM at places (Ranchi and Palampur) maximized SYI (Singh, 2010). Sharma *et al.* (2014) [13] also reported that the application of FYM and lime along with NPK fertilizers gave better and more sustainable yields.

Table 3: Sustainable Yield Index of maize, wheat and maize-wheat system as affected by continuous use of fertilizer, manure and lime application (1956-2015)

Treatment	Maize	Wheat	Maize-wheat system
Control	0.04	0.08	0.06
N	-0.05	-0.01	-0.03
NP	-0.20	0.12	0.06
NPK	0.05	0.18	0.11
Lime + NPK	0.51	0.41	0.43
FYM	0.34	0.26	0.28
½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$]	0.41	0.35	0.36
Lime + N	0.25	0.16	0.24

Conclusions

The results of the study indicated that the sustainability in crop production under intensive cropping in acid soil could not be achieved either without fertilization or by use of only imbalanced chemical fertilizers. Application of only 100% N had deleterious effect on long term yield sustainability and recorded negative value of SYI whereas use of lime along with 100% N achieved positive and higher SYI as compared to 100% N, suggesting the beneficial effect of lime in acid soils. Application of balanced NPK fertilizers as well as FYM alone maintained higher system productivity and SYI as compared to control. The highest value of mean MEY as well as sustainable yield index (SYI) in treatment T_5 (100% NPK +Lime) followed by T_{7}- - ½ [(N+FYM) + P $_{(A-X/2)}$ + K $_{(B-Y/2)}$] suggests that integrated application of lime/FYM along with NPK fertilizers maintained the system productivity and enhanced the sustain ability under maize-wheat cropping system in acid soils over the years.

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