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Sustainable yield index: An approach to evaluate long term sustainability of finger millet and maize under finger millet-maize cropping system in *Alfisols*

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Abstract
A randomised block experiment was carried out at Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bengaluru to determine the effect of long term manuring and fertilization on sustainability yield index of finger millet and maize in *Alfisols*. The experimental plot received different organic manures and inorganic fertilizers with continuous cropping of finger millet-maize for the last 33 years. The treatments were 50% NPK (T_1), 100% NPK (T_2), 150% NPK (T_3), 100% NPK + Hand weeding (T_4), 100% NPK + Lime (T_5), 100% NP (T_6), 100% N (T_7), 100% NPK + FYM (T_8), 100% NPK (-S) (T_9), 100% NPK + FYM + Lime (T_{10}), Control (T_{11}). The higher grain yield of finger millet was recorded in the application of 150% NPK (36.85 q ha^{-1}) whereas higher maize yield was recorded in 100% NPK + FYM + Lime (45.81 q ha^{-1}) during 2019-20. The lowest finger millet and maize yield was recorded in control and imbalanced fertilizer application (100% N and 100% NP). The maximum sustainable yield index was found in finger millet (0.64) > maize (0.22) with 100% NPK + FYM + Lime application followed by 100% NPK + FYM and 150% NPK. However, lowest sustainable yield index (0.16) in finger millet and 0.01 in maize was recorded in imbalanced fertilizer application. So, rescheduling the rates of organic and inorganic fertilizers to guarantee a balanced supply of plant nutrients can be an effective technique to boost the sustainable yield of finger millet and maize.

Keywords: FYM, long term fertilizer, sustainable yield index, inorganic fertilizers

1. Introduction
Soil is a non-renewable resource that has the ability to degrade quickly and has extremely slow in formation and regeneration processes [18]. Due to indiscriminate use of agrochemicals, deep ploughing, luxury irrigation, intense cropping with high yielding varieties, little or no use of organic materials, and incorrect soil management practises, the majority of cultivable lands are degrading day by day [9]. In peninsular India, finger millet and maize are important premier crops. In Karnataka, these crops occupy 6.63 and 13.20 lakh hectares area, respectively with an average productivity of 1645 and 3470 kg ha^{-1}, respectively in the year 2020-21 as against of respective productivity of 1709 and 2559 kg ha^{-1} from total area of 10.13 and 92 lakh hectares in the country. In agriculture, fertilizers consumption is increasing rapidly due to their importance in raising agricultural production. Intensive cropping of finger millet-maize system with continuous application of inorganic fertilizers results in loss of soil organic matter and may have some adverse deleterious effect on soil fertility as well as production and that system is not sustainable [16].
The term "sustainability" refers to the long-term maintenance and development of productivity through integrated land management [14]. No agricultural system can be sustained unless its soil productivity and quality are consistently maintained [8]. The sustainable yield index (SYI) as a quantitative measure to assess the long-term viability of an agricultural practice in this direction [17]. In the SYI concept, a low standard deviation (SD) indicates the system's long-term viability. If SD is high, however, SYI will be low, indicating an unsustainable management practice [17].

The index takes values between zero and unity. The ideal treatment is one in which SD = 0 and mean = highest observed yield (y_m), implying SYI = 1. This treatment consistently produces maximum yield in all years. But invariably SD is always greater than zero in turn SYI will be less indicating improper management practices [15].

Long-term trials are critical for comprehending the intricate interactions between plants, soils, climate, and management approaches, as well as their effects on crop productivity. Long-term trails have been acknowledged by agricultural scientists as significant tools in the study of agro ecosystem dynamics. A long-term evaluation of the application of organic manure for preserving soil fertility to improve the productivity of the rice-wheat system in Bangladesh [1]. The combined application of mineral fertilizers and organic manure has generally provided the optimum crop output and soil quality in most long-term trails [19] and [2]. As a result, the current study was conducted to analyse the sustainable yield index of finger millet-maize cropping system using an integrated application of organic manure and chemical fertilizer. To achieve this goal, yield data generated from initiation of experiment (1986) up to 2019 from long term fertilizer experiment were considered.

2. Material and Methods

2.1 Experimental Site and Treatment Details

The long-term fertilizer experiment was initiated in 1986 at Zonal Agricultural Research Station of University of Agricultural Sciences, GKVK, Bengaluru located in Eastern Dry Zone of Karnataka at an altitude of 930 meters above MSL, latitude of 13° north, longitude of 77° 33" east with finger millet-maize cropping system. The experimental soil was lateritic and sandy clay loam of texture with red colour. It belongs to the *Isohyperthermic* family of the sub group typic *kandic paleustalfs* of Vijayapura series. The pH of the soil is 6.17 (slightly acidic) with sandy clay loam in texture, low in organic carbon content (4.6 g kg^{-1}). The available nitrogen (256.7 kg ha^{-1}) was low, available phosphorus (34.3 kg ha^{-1}) was medium and available potassium content (123.1 kg ha^{-1}) was low. The physico-chemical properties of initial soil sample (1986) of the experiment site were given in Table 1. Finger millet and hybrid maize crops were grown in sequence during Kharif and Rabi seasons, respectively. The details of experiment, treatments, recommended dose of fertilizers for the study crops, sources of fertilizers *etc.* are as follows.

Table 1: Initial soil characteristics of experimental site, GKVK, Bangalore

Number of Treatments: 11			
Number of Replications: 4			
Design: Randomized Block Design			
Plot dimension: 16 m x 9 m			
Cropping Sequence: Finger millet-Hybrid maize			
Season	**Crop**	**Variety**	**Period**
Kharif	Finger millet	Indaf-5 GPU-28	1987 to 1999 2000 to till date
Rabi	Hybrid maize	DCH-103 NAC-6004 MAH 14-5	1986 to 2004 2005 to 2016 2017 to till date
Summer	Fodder cowpea		1987-1992 (discounted 1992-93 onwards)

Subgroup	:	*Kandi Paleustalfs*		
Series	:	Vijayapura		
Taxonomy	:	Fine, mixed *IsohyperthermicKandicpaleustalfs*		
Mechanical composition				
Depth (cm)	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural class**
0-20	62.0	8.6	29.4	Sandy clay loam
20-36	52.1	11.7	36.2	Sandy clay
36-55	35.6	12.6	54.8	Clay
55-87	34.9	13.0	52.1	Clay
87-120	33.6	11.7	54.6	Clay
Physical properties				
Bulk density (Mgm^{-3})		:		1.51
Max water holding capacity (%)		:		30.00
Field capacity moisture (%)		:		22.70
Wilting point moisture (%)		:		8.40
Pore space (%)		:		40.10
Infiltration rate (cm h^{-1})		:		4.20
Water stable aggregates (%) (2 mm)		:		23.70
Chemical properties				
pH (1:2.5, soil: Water suspension)		:		6.17
Electrical conductivity (EC, dS m^{-1})		:		0.059
CEC [c mol (p+) kg^{-1}]		:		12.20
Organic carbon (%)		:		0.46
Available nitrogen (kg ha^{-1})		:		256.7
Available phosphorus (kg ha^{-1})		:		34.3
Available potassium (kg ha^{-1})		:		123.1
Total calcium (%)		:		0.46
Total magnesium (%)		:		0.35
Total sulphur (%)		:		0.028

Exchangeable calcium (kg ha^{-1})	:	1456.00
Exchangeable magnesium (kg ha^{-1})	:	415.20
Available sulphur (kg ha^{-1})	:	20.34
DTPA extractable micronutrients (mg kg^{-1})		
Zinc	:	2.34
Copper	:	2.30
Manganese	:	108.40
Iron	:	5.22

The normal meteorological data of annual rainfall for the last 33 years (from 1986 to 2019) was ranged from 361 to 1363 mm, the average being 908.22 mm. The rainfall is distributed mainly during the period May-November with peak being in the months of September and October. The total rainfall of 2020 at AICRP-LTFE, GKVK, and Bengaluru was 1180 mm with maximum rainfall during July (242.8 mm) and minimum during January and Feb (0.0 mm). Comparing to the normal rainfall data, a higher positive deviation in rainfall was observed during July (146.8 mm) and negative deviation during August (71.2 mm). The mean temperature during the *kharif* (May-September), *Rabi* (November-February) and summer (March-April) seasons is 24.31, 21.35 and 26.16. °C, respectively. Maximum mean temperature during May (26.8 °C) and minimum during December (20.8 ^{0}C) represented in Fig. 1.

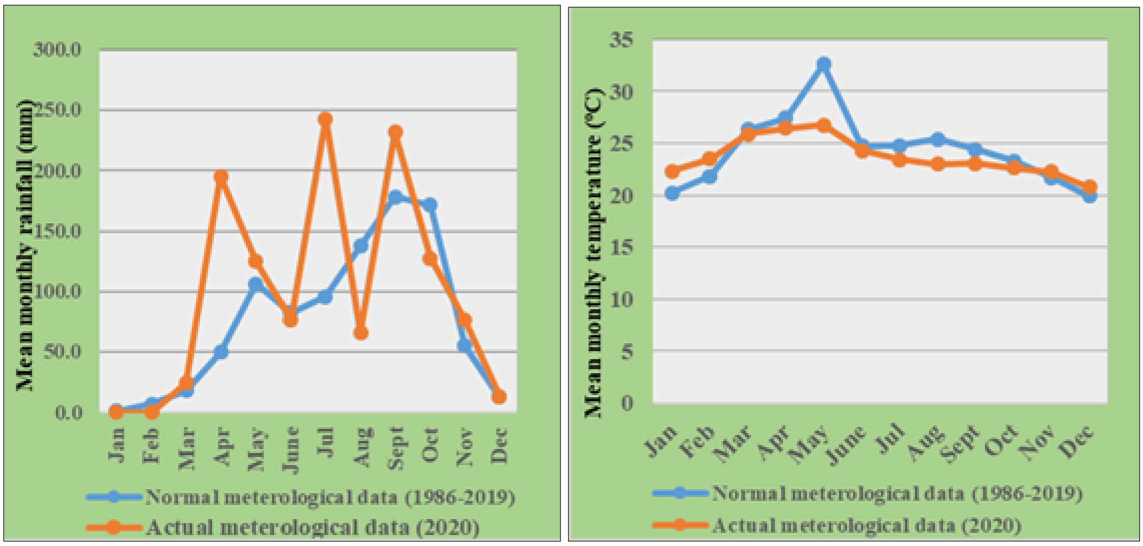

Fig 1: Normal and actual monthly weather data during 2020 at GKVK, Bengaluru.

The current study was conducted at Gandhi Krishi Vignan Kendra (GKVK), University of Agricultural Sciences, and Bengaluru. In a randomised block design with individual plot sizes of 16 m × 9 m, the experiment was carried out having eleven treatments which are replicated four times. 50% NPK (T_1), 100% NPK (T_2), 150% NPK (T_3), 100% NPK + Hand weeding (T_4), 100% NPK + Lime (T_5), 100% NP (T_6), 100% N (T_7), 100% NPK + FYM (T_8), 100% NPK (-S) (T_9), 100% NPK + FYM + Lime (T_{10}), Control (T_{11}). The treatment details with NPK doses and fertilizer sources are given in Table 2.

Table 2: Details of the Treatments (Main Treatments)

Treatment	NPK dosage (kg ha^{-1})		Fertilizer Source
	Finger millet	Hybrid maize	
T_1: 50% NPK	50-11-21	50-16-41	Urea, SSP, MOP
T_2: 100% NPK	100-22-42	100-32-82	Urea, SSP, MOP
T_3: 150% NPK	150-33-63	150-48-123	Urea, SSP, MOP
T_4: 100% NPK + HW	100-22-42	100-32-82	Urea, SSP, MOP
T_5: 100% NPK + lime	100-22-42	100-32-82	Urea, SSP, MOP, lime
T_6: 100% NP	100-22-00	100-32-00	Urea, SSP
T_7: 100% N	100-00-00	100-00-00	Urea
T_8: 100% NPK + FYM	100-22-42	100-32-82	Urea, SSP, MOP
T_9: 100% NPK (S-free)	100-22-42	100-32-82	Urea, DAP, MOP
T_{10}: 100% NPK + FYM + lime	100-22-42	100-32-82	Urea, SSP, MOP, lime
T_{11}: Control	00-00-00	00-00-00	----------

The recommended dose of NPK used in finger millet was 100:22:42 kg ha^{-1} and maize 100:33:82 kg ha^{-1}. All eleven treatments employed chemical weed management, with the exception of 100% NPK + HW. About 15 t ha^{-1} of well decomposed farmyard manure (FYM) on dry weight basis was mixed into the soil 10-15 days just before the transplanting of finger millet crop to treatments T_8 and T_{10}. In a sulphur-free treatment [T_9], diammonium phosphate (DAP) is used as a source of P and N, together with urea and muriate of potash (MOP) as a source of K. To avoid S in treatment T_9, a single superphosphate was not employed. Urea, single super phosphate (SSP), and MOP are used as NPK sources in the remaining treatments (excluding T_9). Neither any chemical fertilizer nor any organic manure is used in absolute control treatment (T_{11}). Lime has been applied based on lime requirement following the method given by Shoemaker *et.al*. (1961) at 15 days before sowing of finger millet crop to the treatments T_5 and T_{10}. However, if the soil pH exceeds 6.00 then lime was applied @ 500 kg ha^{-1}. After 25 to 30 days of sowing/transplanting of crops, 50 percent of the recommended nitrogen dose, 100 percent of the recommended P and K doses were applied as a basal, and the remaining 50 percent nitrogen dose was administered in two equal splits as a top dress.

2.2 Sustainable Yield Index (SYI)

Sustainable yield index of finger millet and maize were analysed to determine the yield sustainability of finger millet and maize. SYI of were calculated finger millet and maize using the equation [17].

$$SYI = (y-s) / Y_{max}$$

Where, y = Estimated average yield
s = Standard deviation of yield across years
Y_{max} = Maximum observed yield

SYI nearness to 1 implies the closeness to an ideal condition that can sustain maximum crop yields over year.

2.3 Statistical analysis

For the interpretation of results, the data obtained in the laboratory studies will be subjected to statistical analysis using the technique of analysis of variance for randomised block design [5]. The level of significance used in "F" and "t" test was P=0.05. Critical difference (CD) values were calculated for the P=0.05 whenever "F" test was found significant.

3. Results and Discussion

3.1 Yield of finger millet and maize

The mean grain yields of maize for the period from 1986 to 2020 at eight year interval except 2003-04 due to crop failure are shown in Table 3. The results of the long-term study from 1986 indicated that, under finger millet and maize cropping system application of super optimal dose of NPK (150% NPK) had recorded highest grain yield of finger millet (43.18 q ha^{-1}) when compared to application of optimal and sub optimal dose of NPK. Initially grain yield was higher, then gradually decreases to 33.27 q ha^{-1} (2012-2020). Application of FYM along with 100% NPK in the treatment T_8 (41.62 q ha^{-1}) and T_{10} (39.31 q ha^{-1}) resulted in higher yield of finger millet compare to 100% NPK alone but lower than the 150% NPK. This may be due to beneficial effect of the organic matter accumulation due to the addition of FYM. The continuous growing of crop without any fertilizer application (control) causes decrease in crop yield compared to other treatments. Initially, crop yield maintained higher and it gradually decreased from 6.18 to 4.74 q ha^{-1} (2004-2012) and later it shows increasing trend with mean yield of 6.10 q ha^{-1}. Application of N alone without P and K resulted in better grain yield than control during initial phase of the experiment, but later it was not able to sustain the yield afterwards. The mean grain yields of maize for the period from 1986 to 2020 at eleven-year interval are shown in Table 4. Application of super optimal dose of NPK (150% NPK) had record the superior grain yield of maize (33.56 q ha^{-1}) over sub optimal dose of NPK and non-superior over optimal dose of NPK. Application of FYM and lime along with 100% NPK in treatments T_{10} (36.09 q ha^{-1}) and T_8 (34.21 q ha^{-1}) resulted higher yield of maize than that of 150% NPK alone. This may be due to beneficial effect of the organic matter accumulation due to the addition of FYM. The continuous growing of crop without any fertilizer application (control) and imbalanced application of nutrients (100% NP and 100% N alone) recorded lowest maize yield compare to rest of the treatments. Application of lime increases the yield of maize *i.e.*, T_{10}: 100% NPK + lime (36.09 q ha^{-1}) and T_5: 100% NPK + Lime (30.66 q ha^{-1}) compare to treatment without lime application over the years T_8: (34.21 q ha^{-1}) and T_2: (29.28 q ha^{-1}).

Over time, the use of FYM and lime resulted in increased yield of the finger millet and maize. Higher crop yields were attributed to the release of nutrients in accessible forms from FYM during decomposition and absorption by the crops [7]. The crop yield was significantly lower in the treatment with unbalanced nutrient application (T_6 and T_7) and control (T_{11}). This might be due to decrease in soil organic matter and associated nutrients in an imbalanced fertilizer application [3]. Higher crop yields with 150% of NPK indicates that 100% NPK was inadequate to provide enough N or P or K to the crops [10].

The addition of FYM supplies significant amounts of crop accessible nitrogen, phosphate, potassium, and micronutrients while also buffering yield fluctuations, resulting in long-term productivity [4] and [6]. Manna *et al*. (2005) found a similar positive yield trend in a soybean– wheat system on *Alfisols* at Ranchi using higher doses of NPK and NPK + FYM treatments. This clearly shows that adding organic materials to the soil and maintaining or increasing soil organic matter content can help in sustain substantial crop yields in dry land finger millet production systems. Over a 20-year period, continuous mono cropping without the addition of organics or artificial fertilisers reduced crop output significantly.

Table 3: Effect of long term fertilization and manuring on grain yield of finger millet in finger millet-maize cropping sequence in *Alfisols* (1986-2020).

Treatments	Finger millet (q ha^{-1})				
	1986-1995	1995-2003	2004-2012	2012-2020	Average yield (1986-2020)
T_1: 50% NPK	27.65	29.52	20.89	21.19	24.81
T_2: 100% NPK	39.74	47.12	33.45	26.79	36.78
T_3: 150% NPK	46.67	53.98	38.81	33.27	43.18
T_4: 100% NPK+ HW	40.31	46.61	33.48	28.17	37.14
T_5: 100% NPK+ Lime	37.58	45.51	32.33	28.18	35.90
T_6: 100% NP	14.12	6.71	7.52	6.14	8.62
T_7: 100% N	9.66	6.43	4.87	8.42	7.35
T_8: 100% NPK+ FYM	43.98	52.92	36.86	32.71	41.62
T_9: 100% NPK (S-free)	37.34	45.24	34.50	26.86	35.98
T_{10}:100% NPK+ FYM+ Lime	39.57	47.05	37.02	33.59	39.31
T_{11}: Control	6.18	5.96	4.74	7.52	6.10

Table 4: Effect of long term fertilization and manuring on grain yield of finger millet in finger millet-maize cropping sequence in *Alfisols* (1986-2020)

Treatments	Maize yield (q ha^{-1})			
	1986-1998	1998-2009	2009-2020	Average yield (1986-2020)
T_1: 50% NPK	14.50	14.93	32.48	20.63
T_2: 100% NPK	21.94	25.47	40.43	29.28
T_3: 150% NPK	24.98	29.51	46.19	33.56
T_4: 100% NPK+ HW	21.68	26.26	41.92	29.95
T_5: 100% NPK+ Lime	22.45	28.19	41.34	30.66
T_6: 100% NP	8.68	5.81	10.08	8.19
T_7: 100% N	5.84	2.13	8.59	5.52
T_8: 100% NPK+ FYM	26.27	30.18	46.19	34.21
T_9: 100% NPK (S-free)	20.03	21.54	40.68	27.42
T_{10}:100% NPK+ FYM+ Lime	24.25	32.97	51.06	36.09
T_{11}: Control	3.52	3.02	8.45	4.99

3.2 Sustainability yield index

The data pertaining to SYI influenced by long term manuring and fertilization in finger millet-maize cropping sequence have been presented in Table 5 and Fig. 2. The data on SYI values of finger millet indicate that, 100% NPK + FYM + lime (T_{10}) was superior for finger-millet with maximum SYI of 0.64 followed by T_3: 150% NPK (0.56). Lowest SYI of finger-millet was noticed in 100% NP (0.16) and followed by 100% N (0.24) treatments. Whereas in maize maximum sustainable yield index was observed in 100% NPK + FYM + Lime (T_{10}) followed by T_8: 100% NPK + FYM, T_3: 150% NPK and T_5: 100% NPK + Lime with 0.22. Lowest SYI of maize was noticed in application of 100% N (0.01) and 100% NP (0.07) treatments. This further supports the notion that unbalanced fertilizer application will not be able to sustain the yields in finger millet and maize cropping sequence in the long run. Although 150 percent RDF had a higher SYI (next to 100 percent NPK + FYM), in the context of balanced diet, need-based micronutrient and sulphur consumption would be more acceptable. Imbalanced supply of N alone or NP or NPK (-S) led to unsustainability and a steady loss in production over period of cropping. This may be ascribed to the decline in soil fertility leading to nutritional deficiencies in crop plant.

Imbalanced and continuous use of nitrogen alone resulted in the greatest yield decline and had a negative impact on long-term yield sustainability and soil quality, indicating that other major and micronutrients were becoming limiting factors and that adequate N response could not be achieved unless those factors limiting yield were addressed. The sustainability of crop production was obtained by the application of organic manures [13]. The integrated use of lime or FYM coupled with balanced NPK is essential for increasing as well as sustaining crop production in the acid soils of Bangalore under finger-millet maize cropping system [11].

Table 5: Sustainable yield index of finger millet and maize as affected by continuous application of fertilizers and manuring from 1986-2020

Treatments	Finger millet	Maize
T_1: 50% NPK	0.50	0.14
T_2: 100% NPK	0.51	0.20
T_3: 150% NPK	0.56	0.22
T_4: 100% NPK+ HW	0.54	0.20
T_5: 100% NPK+ Lime	0.54	0.22
T_6: 100% NP	0.16	0.07
T_7: 100% N	0.24	0.01
T_8: 100% NPK+ FYM	0.51	0.22
T_9: 100% NPK(S-free)	0.49	0.19
T_{10}:100% NPK+ FYM+ Lime	0.64	0.22
T_{11}: Control	0.29	0.06

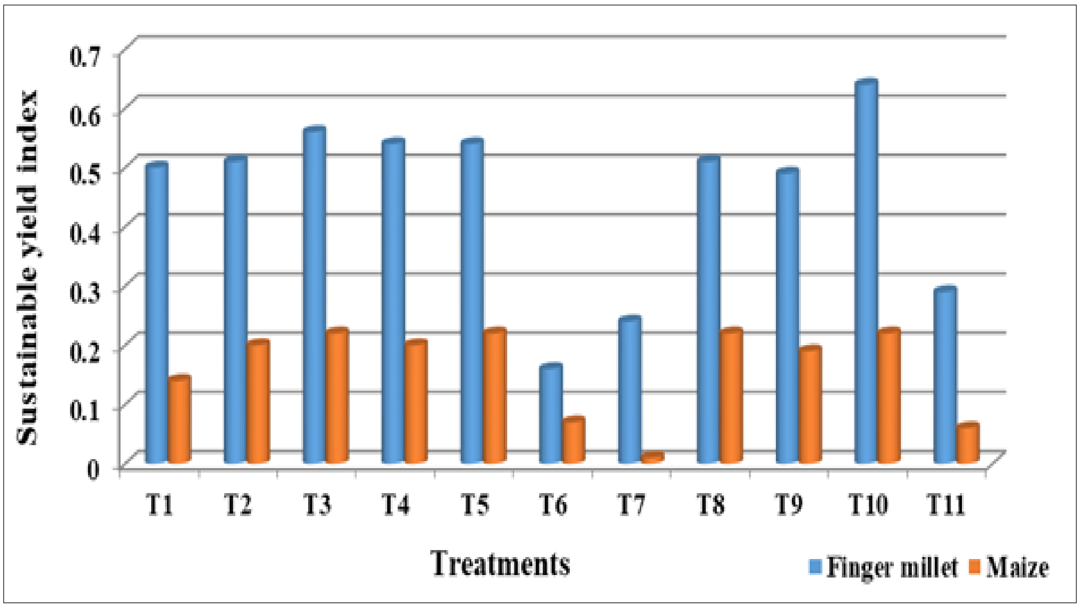

Fig 2: Sustainable yield index of finger millet and maize as affected by continuous use of fertilizer and manuring from 1986-2020

4. Conclusion

The results revealed that SYI was able to accurately predict a minimum feasible yield. The SYI of NP, N alone, and control (unfertilized and unmanured) treatments were all very low after 33 years of continuous cropping, implying that such imbalanced treatments degrade soil fertility and crop yield. Regardless of the crops the treatments having greatest SYI values was with 100 percent NPK + FYM + Lime, which is comparable to 100 percent NPK + FYM and 150 percent NPK. The FYM and lime served as a soil ameliorant, improving soil fertility and productivity by ameliorate unfavourable soil ecological conditions (in particular, soil acidity). Thus, by providing balanced nutrition and correcting marginal secondary and micronutrient deficiencies, integrated use of organic and inorganic manures has considerable potential in providing higher stability and sustainability in crop output under current intensive farming.

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