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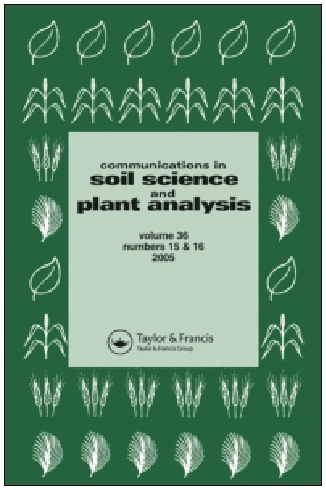

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Influence of Soil and Fertilizer Nutrients on Sustainability of Rainfed Finger Millet Yield and Soil Fertility in Semi-arid Alfisols

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Productivity of rainfed finger millet in semiarid tropical Alfisols is predominantly constrained by erratic rainfall, limited soil moisture, low soil fertility, and less fertilizer use by the poor farmers. In order to identify the efficient nutrient use treatment for ensuring higher yield, higher sustainability, and improved soil fertility, long term field experiments were conducted during 1984 to 2008 in a permanent site under rainfed semi-arid tropical Alfisol at Bangalore in Southern India. The experiment had two blocks—Farm Yard Manure (FYM) and Maize Residue (MR) with 5 fertilizer treatments, namely: control, FYM at 10 t ha^{-1}, FYM at 10 t ha^{-1} + 50% NPK [nitrogen (N), phosphorus (P), potassium (K)], FYM at 10 t ha^{-1} + 100% NPK (50 kg N + 50 kg P + 25 kg K ha^{-1}) and 100% NPK in FYM block; and control, MR at 5 t ha^{-1}, MR at 5 t ha^{-1} + 50% NPK, MR at 5 t ha^{-1} + 100% NPK and 100% NPK in MR block. The treatments differed significantly from each other at $p < 0.01$ level of probability in influencing finger millet grain yield, soil N, P, and K in different years. Application of FYM at 10 t ha^{-1} + 100% NPK gave a significantly higher yield ranging from 1821 to 4552 kg ha^{-1} with a mean of 3167 kg ha^{-1} and variation of 22.7%, while application of maize residue at 5 t ha^{-1} + 100% NPK gave a yield of 593 to 4591 kg ha^{-1} with a mean of 2518 kg ha^{-1} and variation of 39.3% over years. In FYM block, FYM at 10 t ha^{-1} + 100% NPK gave a significantly higher organic carbon (0.45%), available N (204 kg ha^{-1}), available P (68.6 kg ha^{-1}), and available K (107 kg ha^{-1}) over years. In maize residue block, application of MR at 5 t ha^{-1} + 100% NPK gave a significantly higher organic carbon (0.39%), available soil N (190 kg ha^{-1}), available soil P (47.5 kg ha^{-1}), and available soil K (86 kg ha^{-1}). The regression model (1) of yield as a function of seasonal rainfall, organic carbon, and soil P and K nutrients gave a predictability in the range of 0.19 under FYM at 10 t ha^{-1} to 0.51 under 100% NPK in FYM block compared to 0.30 under 100% NPK to 0.67 under MR at 5 t ha^{-1} application in MR block. The regression model (2) of yield as a function of seasonal rainfall, soil N, P, and K nutrients gave a predictability in the range of 0.11 under FYM at 10 t ha^{-1} to 0.52 under 100% NPK in FYM block compared to 0.18 under MR at 5 t ha^{-1} + 50% NPK to 0.60 under MR at 5 t ha^{-1} application in MR block. An assessment of yield sustainability under different crop seasonal rainfall situations indicated that FYM at 10 t ha^{-1} + 100% NPK was efficient in FYM block with a maximum Sustainability Yield Index (SYI) of 41.4% in <500 mm, 64.7% in 500–750 mm, 60.2%

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in 750–1000 mm and 60.4% in 1000–1250 mm rainfall, while MR at 5 t ha^{-1} + 100% NPK was efficient with SYI of 29.6% in <500 mm, 50.2% in 500–750 mm, 40.6% in 750–1000 mm, and 39.7% in 1000–1250 mm rainfall in semi-arid Alfisols. Thus, the results obtained from these long term studies incurring huge expenditure provide very good conjunctive nutrient use options with good conformity for different rainfall situations of rainfed semiarid tropical Alfisol soils for ensuring higher finger millet yield, maintaining higher SYI, and maintaining improved soil fertility.

Keywords Crop seasonal rainfall, crop yield sustainability, regression analysis, semi-arid Alfisols, soil fertility, sustainability yield index

Introduction

Alfisols are most abundant soils in semi–arid tropics and cover nearly 16% of tropics and 33% of semi–arid tropics (SAT). These soils are mostly found in south Asia, west and central Africa, and many parts of South America, particularly north eastern Brazil (Cocheme and Franquin 1967). Mostly these soils are shallow with a compacted sub–surface layer that limits the root development and water percolation. The loamy sand texture of top soil and abundance of 1:1 type clay minerals, namely kaolinite, make them structurally inert (Charreau 1977). These soils are constrained by crusting and hard setting tendencies under erratic rainfall distribution and occurrence of dry spells (Bansal, Awadhwal, and Mayande 1987). Owing to less contribution of root biomass due to low crop intensity, high temperature mediated fast oxidation of organic matter, poor recycling back of crop residues, washing away of top soil, reckless tillage, and imbalanced fertilizer use results in low organic carbon and low fertility of these soils. (Kampen and Burford 1980; El-Swaify, Singh, and Pathak 1983). Often these soils encounter a diversity of soil physical, chemical, and biological constraints and provide a low productivity of crops.

Finger millet is one of the important cereals grown in Alfisols of Southern India; especially in Bangalore region. The productivity of finger millet *(Eleusine coracana)* is significantly influenced by the distribution of seasonal rainfall during cropping season, soil fertility status, and amount of fertilizer nutrient applied (Maruthi Sankar et al., 2008). Research studies have shown that among different variables, the quantity of rainfall received during crop growing period would significantly influence the response of a crop to fertilizer application under rainfed conditions (Behera et al. 2007; Mohanty et al. 2008). Vikas et al. (2007), while optimizing the fertilizer requirement of rainfed maize in a dry sub-humid Inceptisol at Jammu in north India, opined that if fertilizer doses are judiciously optimized considering the rainfall distribution pattern during the cropping season, higher productivity could be achieved in rainfed crops. Nema, Maruthi Sankar, and Chauhan (2008) examined the effects of crop seasonal rainfall and soil moisture availability at different days after sowing on yield and identified suitable tillage and fertilizer practices for attaining sustainable pearl millet yield in a semi-arid Inceptisol at Agra in north India. Further, to attain sustainable yield of crops in any soil and agro-climatic conditions and to save on fertilizers, it is important that while optimizing the fertilizer doses, changes in soil fertility also need to be periodically monitored (Maruthi Sankar 1986; Vittal et al. 2003). Long term effects of fertilizer on crop yield and soil properties have also been examined for different crops in order to suitably restore soil fertility and prescribe soil test based fertilizer recommendation for different crops (Prasad and Goswami 1992; Bhat, Beri, and Sindhu 1991; Dalal and Mayer 1986; Mathur 1997). The present study was conducted with the authors objective to (1) assess the response of finger millet and changes in soil fertility [with special emphasis on nitrogen (N), phosphorus (P), and potassium (K)] due to long term application of organic and inorganic sources of nutrients under changing crop seasonal rainfall situations, and (2) to identify an efficient treatment for attaining sustainable yield over long-term basis in a semi-arid Alfisol in south India.

Materials and Methods

The study was undertaken under All India Coordinated Research Project for Dryland Agriculture funded by Indian Council of Agricultural Research. Field experiments on finger millet (*Eleusine coracana* L.) were conducted in a permanent site for 25 years from 1984 to 2008 in a semi-arid Alfisol at the research farm of University of Agricultural Sciences, Bangalore. Experimental site is situated at latitude of 12.97° North, longitude of 77.58° East, and an altitude of 930 m above mean sea level. The experimental area was divided into two permanent blocks of Farm Yard Manure (FYM) and Maize Residue (MR) where FYM and maize residue based fertilizer treatments were applied every year. The treatments under FYM block comprised of (1) Control; (2) FYM at 10 t ha^{-1}; (3) FYM at 10 t ha^{-1} + 50% NPK; (4) FYM at 10 t ha^{-1} + 100% NPK; and (5) 100% recommended NPK while the treatments under MR block were (1) Control; (2) MR at 5 t ha^{-1}; (3) MR at 5 t ha^{-1} + 50% NPK; (4) MR at 5 t ha^{-1} + 100% NPK; and (5) 100% recommended NPK. The 100% recommended NPK dose comprised of 50 kg N, 50 kg P_2O_5, and 25 kg K_2O ha^{-1}. The experiment was conducted in a net plot size of 2.7 m × 11.0 m each with a row spacing of 30 cm and plant spacing of 10 cm. The treatments were replicated thrice and were tested in FYM and MR blocks in a Randomized Block Design. The treatments were superimposed to the same plots every year. Before superimposing fertilizer treatments, initial soil samples were collected from each plot at a soil depth of 0–30 cm and analyzed for soil organic carbon (Walkley and Black 1934), available (easily oxidizable) N (Subbaiah and Asija 1956), available P (Olsen et al. 1954), and available K (Jackson 1973).

Descriptive Statistics of Rainfall Received from Sowing to Harvest in Different Years

The earliest date of sowing of finger millet was on 14 July 2004, while the latest was on 30 September 2002. The earliest date of harvest of the crop was on 25 October 2004, while the latest was on 3 January 2003. The crop had a minimum duration of 96 days in 2002 and maximum of 155 days in 1994 with a mean of 126 days and variation of 9.2%. The rainfall received from June to November was in a range of 396.6 mm in 1990 to 1174.7 mm in 2005 with a mean of 756 mm and variation of 28.1%. Four crop seasonal rainfall situations: <500, 500–750, 750–1000, and 1000–1250 mm, were observed during 1984 to 2008. The crop seasonal rainfall was <500 mm in 3 years, 500–750 mm in 11 years, 750–1000 mm in 8 years, and 1000–1250 mm in 3 years. June received a mean rainfall of 81 mm with a variation of 77.4%; while July received 98 mm with variation of 59.1%. August received a mean rainfall of 139 mm with a variation of 61.2%, while September received a mean rainfall of 200 mm with variation of 50.3%. October received a mean rainfall of 188 mm with a variation of 66.7%, while November received 50 mm with variation of 95.5% over 25 years of study.

The mean rainfall in a month increased from <500 mm to 1000–1250 mm crop seasonal rainfall group. Under <500 mm crop seasonal rainfall situation occurred for 3 years (1990, 2002, and 2006), the mean monthly rainfall ranged from 54 mm with a variation of 51.1% in July to 105 mm with a variation of 62.9% in October. Under 500–750 mm crop seasonal rainfall situation for 11 years (1984, 1985, 1986, 1987, 1989, 1994, 1995, 1996, 2001, 2003, and 2007), the mean monthly rainfall ranged from 38 mm with a variation of 83.2% in November to 199 mm with a variation of 47.7% in September. Under 750–1000 mm crop seasonal rainfall situation for 8 years (1988, 1992, 1993, 1997, 1999, 2000, 2004, and 2008), the mean monthly rainfall ranged from 51 mm with a variation of 125.2% in November to 263 mm with a variation of 31.0% in September. Under 1000–1250 mm crop seasonal rainfall situation for 3 years (1991, 1998, and 2005), the mean monthly rainfall ranged from 77 mm with a variation of 84.8% in November to 435 mm with a variation of 38.6% in October. The mean crop growing period was 121 days with variation of 17.9% under <500 mm; 131 days with variation of 8.8% under 500–750 mm rainfall; 122 days with variation of 7.1% under 750–1000 mm rainfall; and 125 days with variation of 2.9% under 1000–1250 mm rainfall situation. The details of crop growing period, rainfall, date of sowing, and harvest of finger millet under different crop seasonal rainfall situations during 1984 to 2008 are given in Table 1. The changes in crop seasonal rainfall and crop growing period are shown in Figure 1 and Figure 2.

Statistical Analysis

The differences in effects of treatments in influencing soil fertility of N, P, and K nutrients and harvested yield in FYM and MR blocks were tested based on the standard Analysis of Variance (ANOVA) procedure. The treatments with a significantly higher effect on soil nutrients and yield were identified based on Least Significant Difference (LSD) criteria (Gomez and Gomez 1985). Based on correlation coefficients measured between pairs of variables, the type (positive or negative), and extent of relation between yield, crop seasonal rainfall, and soil N, P, and K nutrients were assessed for each treatment over years. Assessment of changes in organic carbon, soil N, P, and K, and their effect on yield of finger millet over years were made by regressing each variable with time period (T in years) under each treatment as:

1. $Y = \pm \alpha \pm \beta 1$ (Years)
2. $OC = \pm \alpha \pm \beta 1$ (Years)
3. $SN = \pm \alpha \pm \beta 1$ (Years)
4. $SP = \pm \alpha \pm \beta 1$ (Years)
5. $SK = \pm \alpha \pm \beta 1$ (Years)

In models (1) to (5), α is intercept and $\beta 1$ is regression coefficient measuring change in a variable with time period. Multivariate regression models of yield attained by each treatment were calibrated for assessing influence of crop seasonal rainfall, organic carbon, soil N, P, and K nutrients in FYM, and maize residue blocks over years as suggested earlier by Draper and Smith (1998). The regression model through crop seasonal rainfall, organic carbon, and soil P and K variables could be postulated as:

6. $Y = \pm \alpha \pm \beta 1\,(CRF) \pm \beta 2\,(OC) \pm \beta 3\,(OC)^2 \pm \beta 4\,(SP)$
$\pm \beta 5\,(SP)^2 \pm \beta 6\,(SK) \pm \beta 7\,(SK)^2$

The regression model through crop seasonal rainfall, soil N, P, and K could be postulated as:

7. $Y = \pm \alpha \pm \beta 1\,(CRF) \pm \beta 2\,(SN) \pm \beta 3\,(SN)^2 \pm \beta 4\,(SP)$
$\pm \beta 5\,(SP)^2 \pm \beta 6\,(SK) \pm \beta 7\,(SK)^2$

In models (6) and (7), a is intercept and $\beta 1$ to $\beta 7$ are regression coefficients measuring effects of variables on yield. The usefulness of a regression model for yield prediction

Table 1
Descriptive statistics of monthly rainfall (mm) received during 1984 to 2008 at Bangalore

Year	DOS	DOH	CGP	Jun	Jul	Aug	Sep	Oct	Nov	CRF
1984	23–Jul	27–Nov	128	70.4	103.7	131.2	200.0	148.1	57.9	711.3
1985	20–Jul	24–Nov	126	40.9	87.5	51.0	214.8	60.3	75.0	529.5
1986	21–Jul	21–Nov	124	153.0	74.1	70.0	333.6	28.0	59.6	718.3
1987	30–Jul	30–Nov	124	80.8	45.0	124.4	158.5	123.1	100.2	632.0
1988	19–Jul	18–Nov	123	7.7	272.0	167.7	388.1	123.9	18.9	978.3
1989	18–Jul	12–Dec	148	9.3	154.4	48.2	283.0	193.4	22.6	710.9
1990	12–Aug	22–Dec	133	48.0	32.2	79.7	92.6	111.9	32.2	396.6
1991	6–Aug	12–Dec	129	212.9	21.1	152.2	66.9	540.9	152.2	1146.2
1992	6–Aug	30–Nov	117	167.6	135.8	98.6	194.2	107.6	70.8	774.6
1993	4–Aug	14–Dec	133	145.2	58.5	150.6	328.1	273.4	21.6	977.4
1994	28–Jul	29–Dec	155	30.8	92.3	94.8	115.3	212.1	21.0	566.3
1995	4–Aug	4–Dec	123	36.4	86.6	189.4	75.9	126.4	26.6	541.3
1996	14–Aug	28–Dec	137	230.6	26.7	158.2	211.2	84.4	2.0	713.1
1997	27–Aug	28–Dec	124	53.0	30.4	67.8	294.9	316.8	193.8	956.7
1998	29–Jul	29–Nov	124	32.0	132.2	352.2	245.7	241.7	37.5	1041.3
1999	14–Aug	17–Dec	126	95.2	49.4	205.3	238.7	196.8	71.2	856.6
2000	4–Aug	7–Dec	126	104.8	97.3	312.4	239.8	168.4	5.8	928.5
2001	31–Jul	5–Dec	128	18.8	136.0	78.1	347.6	121.8	32.6	734.9
2002	30–Sep	3–Jan	96	150.4	44.0	31.8	43.8	167.8	52.2	490.0
2003	18–Jul	20–Nov	116	30.2	90.4	107.6	65.8	231.9	4.8	530.7
2004	14–Jul	25–Oct	104	73.2	142.2	55.4	290.4	193.2	16.0	770.4
2005	23–Jul	21–Nov	122	40.2	122.4	249.2	198.2	523.6	41.1	1174.7
2006	15–Jul	25–Nov	134	112.6	84.4	60.0	61.0	36.0	110.4	464.4
2007	18–Jul	24–Nov	130	60.3	149.2	189.8	179.1	151.6	12.4	742.4
2008	15–Jul	17–Nov	126	31.0	182.8	249.8	126.0	205.4	7.6	802.6
Min			96	7.7	21.1	31.8	43.8	28	2	396.6
Max			155	230.6	272	352.2	388.1	540.9	193.8	1174.7
Mean			126	81	98	139	200	188	50	756
CV			9.2	77.4	59.1	61.2	50.3	66.7	95.5	28.1

Notes. CGP: Crop growing period (days) CRF: Cumulative rainfall (mm).
CV: Coefficient of variation (%); DOS: Date of sowing; DOH: Date of harvest.

could be assessed based on coefficient of determination (R^2) and unexplained variation measured by prediction error (Φ) in FYM and maize residue blocks. The sustainability of a fertilizer treatment could be assessed based on ratio of the "difference between mean yield and prediction error" and "maximum mean yield" attained by any treatment in the study period (Behera et al. 2007; Nema et al. 2008).

Results and Discussion

Based on the 25-year-long term study conducted at Bangalore during 1984 to 2008, data on the mean and coefficient of variation of soil organic carbon, N, P, and K nutrients and grain yields attained in each block along with Least Significant Difference (LSD) at $P < 0.05$ level are given in Table 2. The mean soil organic carbon ranged from 0.31% (control) to

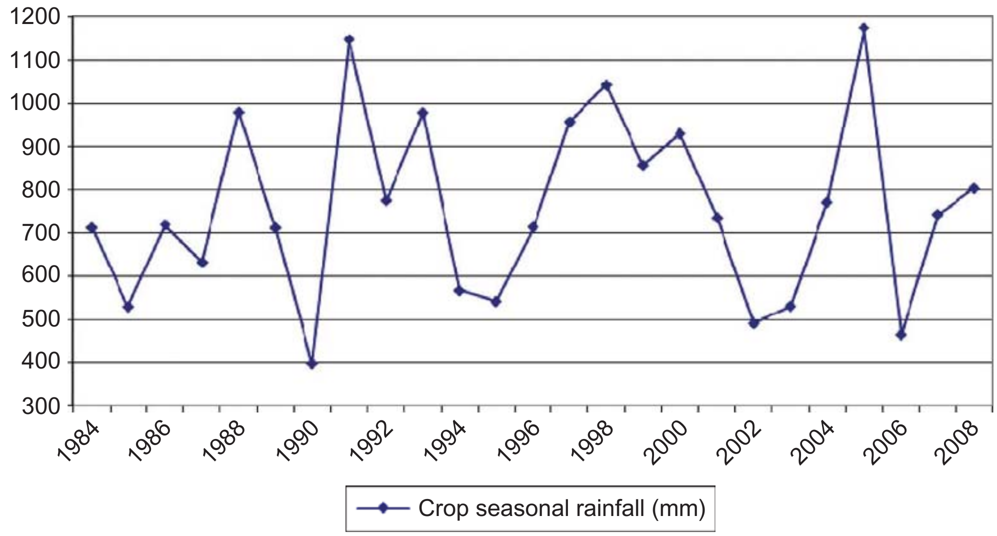

Figure 1. Crop seasonal rainfall (mm) during the study period (color figure available online).

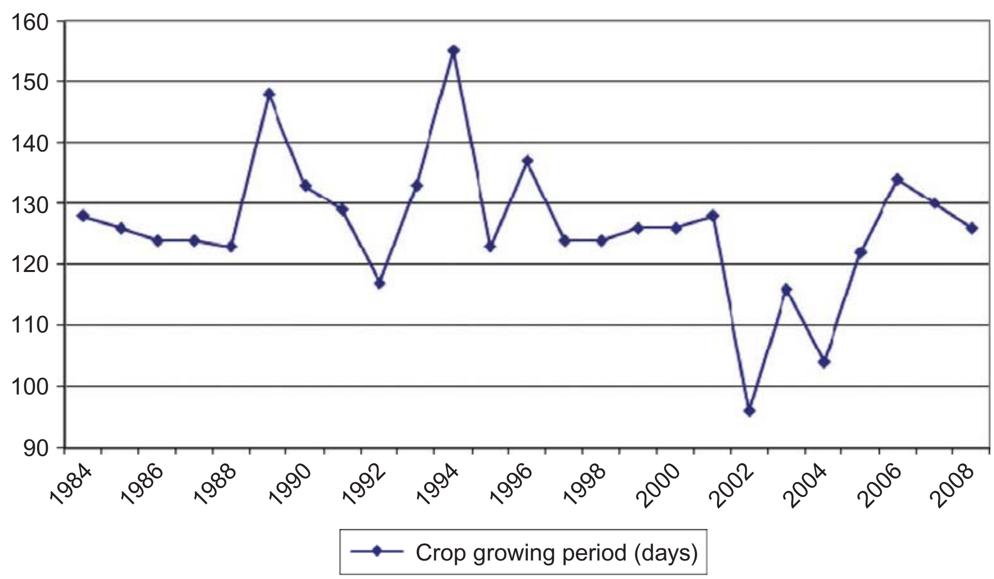

Figure 2. Changes in crop growing period (days) over years (color figure available online).

0.45% (FYM at 10 t ha^{-1} + 100% NPK) with a variation of 13.5% (control) to 17.8% (FYM at 10 t ha^{-1} + 100% NPK) in FYM block while in maize residue block, it ranged from 0.30% (control) to 0.39% (MR at 5 t ha^{-1} + 100% NPK) with a variation of 11.0% (control) to 15.3% (100% NPK). The mean soil N ranged from 163 kg ha^{-1} (control) to 204 kg ha^{-1} (FYM at 10 t ha^{-1} + 100% NPK) with a variation of 4.7% (FYM at 10 t ha^{-1} + 50% NPK) to 12.5% (100% NPK) in FYM block and while in maize residue block, it ranged from 152 kg ha^{-1} (control) to 190 kg ha^{-1} (MR at 5 t ha^{-1} + 100% NPK) with a variation of 8.8% (MR at 5 t ha^{-1}) to 16.0% (control). The mean soil P was in a range of 9.7 kg ha^{-1} (control) to 68.6 kg ha^{-1} (FYM at 10 t ha^{-1} + 100% NPK) with a variation of 18.7% (FYM at 10 t ha^{-1} + 100% NPK) to 46.1% (control) in FYM block, compared to 13.1 kg ha^{-1} (control) to 47.5 kg ha^{-1} (MR at 5 t ha^{-1} + 100% NPK) with a

Table 2
Descriptive statistics of finger millet grain yield, organic carbon, and available soil nutrients during 1984 to 2008 at Bangalore

		FYM block						Maize residue block					
Variable	Statistic	T1	T2	T3	T4	T5	LSD	T1	T2	T3	T4	T5	LSD
Yield	Min	54	1146	1432	1821	756	–	24	115	302	593	407	–
	Max	1356	3125	3836	4552	3429	–	4051	4282	4475	4591	4128	–
	Mean	537	2452	2891	3167	1826	535	740	1141	1985	2518	1965	393
	CV	79.7	23.4	21.9	22.7	45.4	–	129.8	87.2	44.8	39.3	51.0	–
OC	Min	0.24	0.28	0.32	0.29	0.17	–	0.24	0.25	0.29	0.29	0.17	–
	Max	0.45	0.53	0.57	0.71	0.53	–	0.39	0.51	0.54	0.53	0.50	–
	Mean	0.31	0.43	0.45	0.45	0.33	0.03	0.30	0.38	0.39	0.39	0.34	0.03
	CV	13.5	14.1	13.8	17.8	18.7	–	11.0	14.9	14.9	12.1	15.3	–
Soil N	Min	87	146	170	174	103	–	87	146	127	143	103	–
	Max	210	241	217	242	245	–	196	218	235	247	219	–
	Mean	163	195	196	204	190	13	152	180	185	190	179	13
	CV	12.4	8.2	4.7	7.5	12.5	–	16.0	8.8	10.0	9.5	12.6	–
Soil P	Min	4.5	15.7	24.0	35.2	21.4	–	4.1	12.3	12.8	14.5	18.6	–
	Max	27.9	61.6	90.4	91.9	76.4	–	27.9	54.7	90.4	74.7	76.4	–
	Mean	9.7	43.8	59.4	68.6	50.4	6.7	13.1	28.8	38.9	47.5	40.9	7.6
	CV	46.1	28.8	27.2	18.7	27.0	–	41.8	34.3	38.3	29.9	28.5	–
Soil K	Min	37	59	61	67	50	–	38	49	49	51	47	–
	Max	88	116	152	157	114	–	76	93	94	119	100	–
	Mean	59	88	95	107	78	13.0	54	71	76	86	71	11
	CV	19.5	16.6	18.3	20.4	16.2	–	17.7	13.8	16.1	18.1	15.6	–

Notes. Treatments in FYM block: T1: Control; T2: FYM @ 10 t ha^{-1}; T3: FYM @ 10 t ha^{-1} + 50% NPK; T4: FYM @ 10 t ha^{-1} + 100% NPK; T5: 100% NPK.

Treatments in MR block: T1: Control; T2: MR @ 5 t ha^{-1}; T3: MR @ 5 t ha^{-1} + 50% NPK; T4: MR @ 5 t ha^{-1} + 100% NPK; T5: 100% NPK.

LSD: Least significant difference at $p < 0.05$; CV: Coefficient of variation (%).

variation of 28.5% (100% NPK) to 41.8% (control) in maize residue block. The mean soil K was found to range from 59 kg ha^{-1} (control) to 107 kg ha^{-1} (FYM at 10 t ha^{-1} + 100% NPK) with a variation of 16.2% (100% NPK) to 20.4% (FYM at 10 t ha^{-1} + 100% NPK) in FYM block compared to 54 kg ha^{-1} (control) to 86 kg ha^{-1} (MR at 5 t ha^{-1} + 100% NPK) with a variation of 13.8% (MR at 5 t ha^{-1}) to 18.1% (MR at 5 t ha^{-1} + 100% NPK) in maize residue block. In FYM block, maximum mean finger millet yield of 3167 kg ha^{-1} with a variation of 22.7%, was attained under FYM at 10 t ha^{-1} + 100% NPK; followed by 2891 kg ha^{-1} with variation of 21.9% under FYM at 10 t ha^{-1} + 50% NPK; 2452 kg ha^{-1} with a variation of 23.4% under FYM at 10 t ha^{-1}; 1826 kg ha^{-1} with a variation of 45.4% under 100% NPK; compared to a control yield of 537 kg ha^{-1} with a variation of 79.7% over years. In maize residue block, maximum mean finger millet yield of 2518 kg ha^{-1} with a variation of 39.3% was attained under MR at 5 t ha^{-1} + 100% NPK; followed by 1985 kg ha^{-1} with variation of 44.8% under MR at 5 t ha^{-1} + 50% NPK; 1965 kg ha^{-1} with a variation of 51.0% under 100% NPK; 1141 kg ha^{-1} with a variation of 87.2% under MR at 5 t ha^{-1}; compared to a control yield of 740 kg ha^{-1} with a variation of 129.8% over years.

The ANOVA indicated that the fertilizer treatments differed significantly in influencing soil organic carbon, N, P, and K nutrients, and finger millet yield in both FYM and maize residue blocks during 1984 to 2008. Among the treatments tested in FYM block, FYM at 10 t ha^{-1} + 100% NPK was superior with a significantly higher yield and maintained maximum soil organic carbon, N, P, and K status over years. The study has indicated the superiority of conjunctive use of organic and inorganic sources of nutrients compared to either sole organic or inorganic sources for attaining significantly higher finger millet yield and also maintenance of soil nutrient status over years. It was quite interesting to observe that FYM based nutrient treatments maintained significantly higher yields of finger millet and soil fertility status in terms of organic carbon, available N, P, and K compare to maize residue based treatments over years.

Changes in Soil Fertility Nutrients Over Years

Based on the regression models given in Table 3, changes in organic carbon, soil N, P, and K nutrients over years were assessed under FYM and maize residue blocks. In case of FYM blocks, the models indicated that there was a marginal build up of organic carbon over years in all treatments except 100% inorganic application where the β coefficient had negative value. However, the change in organic carbon was not significant over years. The soil N tended to decrease in all treatments, however, the decrease was significant only in control plot. There was a build–up of soil P in all treatments, however, the increase was significant only in FYM at 10 t ha^{-1}, FYM at 10 t ha^{-1} + 50% NPK and 100% NPK treatments. There was a decrease of soil K over years; however, the decrease was significant only in FYM at 10 t ha^{-1} + 100% NPK treatment. Based on the predictability of changes in soil nutrient status over years (R^2), the percent prediction ranged from 1% to 9% for organic carbon; 1% to 26% for soil N; 2% to 44% for soil P; and 1% to 26% for soil K for different treatments over years. The prediction error based on the regression model of treatments ranged from 0.043% to 0.081% for organic carbon; 9.3 to 23.1 kg ha^{-1} for soil N; 4.5 to 12.3 kg ha^{-1} for soil P; and 11.4 to 19.2 kg ha^{-1} for soil K under FYM block.

In case of maize residue block, the regression models calibrated for assessing the soil fertility changes indicated that the organic carbon had increased in all treatments except 100% NPK over years. There was a marginal and non–significant increase of organic carbon in all treatments, while there was a significant decrease in the plot with 100% NPK

Table 3
Regression models to assess changes in soil fertility and yield over years

Treatment	FYM block	R^2	PE	Maize residue block	R^2	PE
Grain yield (kg ha^{-1})						
T1	Y = 1126** − 45.30** T	0.61**	274	Y = 1999** − 96.82** T	0.55**	657
T2	Y = 2801** − 26.87 T	0.12	550	Y = 2512** − 105.47** T	0.61**	635
T3	Y = 3142** − 19.32 T	0.05	630	Y = 2943** − 73.72** T	0.37**	721
T4	Y = 3857** − 53.13** T	0.30**	616	Y = 3701** − 90.94** T	0.46**	743
T5	Y = 2809** − 75.63** T	0.45**	626	Y = 3259** − 99.55** T	0.53**	699
Organic carbon (%) #						
T1	OC = 0.327** + 0.0001 T	0.02	0.043	OC = 0.299** + 0.0001 T	0.01	0.033
T2	OC = 0.399** + 0.002 T	0.09	0.058	OC = 0.375** + 0.001 T	0.01	0.058
T3	OC = 0.425** + 0.002 T	0.06	0.062	OC = 0.366** + 0.002 T	0.06	0.059
T4	OC = 0.437** + 0.001 T	0.01	0.081	OC = 0.375** + 0.001 T	0.03	0.047
T5	OC = 0.367** − 0.003 T	0.09	0.060	OC = 0.376** − 0.003* T	0.18*	0.048
Soil N (kg ha^{-1})						
T1	SN = 180.6** − 1.40** T	0.26**	17.7	SN = 174.4** − 1.77** T	0.29**	20.9
T2	SN = 199.5** − 0.37 T	0.03	16.1	SN = 185.4** − 0.37 T	0.03	16.1
T3	SN = 196.1** − 0.02 T	0.01	9.3	SN = 185.2** − 0.02 T	0.01	18.9
T4	SN = 208.4** − 0.33 T	0.03	15.5	SN = 196.5** − 0.54 T	0.05	18.0
T5	SN = 203.8** − 1.04 T	0.10	23.1	SN = 189.4** − 0.77 T	0.06	22.4
Soil P (kg ha^{-1})						
T1	SP = 8.7** + 0.08 T	0.02	4.5	SP = 16.1** − 0.22 T	0.09	5.4
T2	SP = 29.3** + 1.11** T	0.42**	9.8	SP = 24.2** + 0.36 T	0.07	9.7
T3	SP = 40.4** + 1.46** T	0.44**	12.3	SP = 25.2** + 1.05** T	0.27**	13.0

(*Continued*)

Table 3
(Continued)

Treatment	FYM block	R^2	PE	Maize residue block	R^2	PE
T4	SP = 60.9** + 0.60 T	0.12	12.3	SP = 34.4** + 1.01** T	0.27**	12.4
T5	SP = 38.9** + 0.88* T	0.23*	12.2	SP = 31.8** + 0.69* T	0.19*	10.7
Soil K (kg ha^{-1})						
T1	SK = 59.8** − 0.08 T	0.01	11.8	SK = 51.3** + 0.22 T	0.03	9.7
T2	SK = 96.8** − 0.69 T	0.12	13.9	SK = 64.2** + 0.52* T	0.15*	9.1
T3	SK = 105.8** − 0.87 T	0.14	16.5	SK = 73.4** + 0.16 T	0.01	12.4
T4	SK = 127.3** − 1.52** T	0.26**	19.2	SK = 84.2** + 0.17 T	0.01	16.0
T5	SK = 88.9** − 0.82* T	0.23*	11.4	SK = 69.4** + 0.12 T	0.01	11.2

Notes. *and **indicate significance at $p < 0.05$ and $p < 0.01$ level respectively.
R^2: coefficient of determination; PE: Prediction error (kg ha^{-1}); # The values of PE of organic carbon are in %; T: Time in years.
Treatments in FYM block: T1: Control; T2: FYM @ 10 t ha^{-1}; T3: FYM @ 10 t ha^{-1} + 50% NPK; T4: FYM @ 10 t ha^{-1} + 100% NPK; T5: 100% NPK.
Treatments in MR block: T1: Control; T2: MR @ 5 t ha^{-1}; T3: MR @ 5 t ha^{-1} + 50% NPK; T4: MR @ 5 t ha^{-1} + 100% NPK; T5: 100% NPK.

application over years. In case of soil N, there was a tendency of decrease in all treatments over years, however, the decrease was significant only in control plot. There was an increase in soil P status in all treatments except control plot over years. However, the increase was significant only in MR at 5 t ha^{-1} + 50% NPK, MR at 5 t ha^{-1} + 100% NPK and 100% NPK treatments. There was a build-up of soil K status over years in all treatments. However, the soil K build-up was significant in only MR at 5 t ha^{-1} treatment. Based on the regression models, the percent predictability of change in soil fertility status ranged from 1% to 18% for organic carbon; 1% to 29% for soil N; 7% to 27% for soil P; and 1% to 15% for soil K over years. The prediction error based on the models ranged from 0.033% to 0.059% for organic carbon; 16.1 to 22.4 kg ha^{-1} for soil N; 5.4 to 13.0 kg ha^{-1} for soil P; and 9.1 to 16.0 kg ha^{-1} for soil K under maize residue block.

The trends of changes in yield, and soil nutrients as affected by fertilizer treatments over years are shown in Figures 3–7 for FYM block and Figures 8–12 for maize residue block data. The data presented in the figures indicated that in general, the organic carbon and soil P have tended to increase, while soil N reflected the decreasing tendency over years. However, the soil K had decreased in FYM block, while it increased in the maize residue block. Thus, the trends of soil fertility changes in FYM and maize residue blocks were similar for organic carbon, soil N and P nutrients (except in control), while it was opposite for soil K over years.

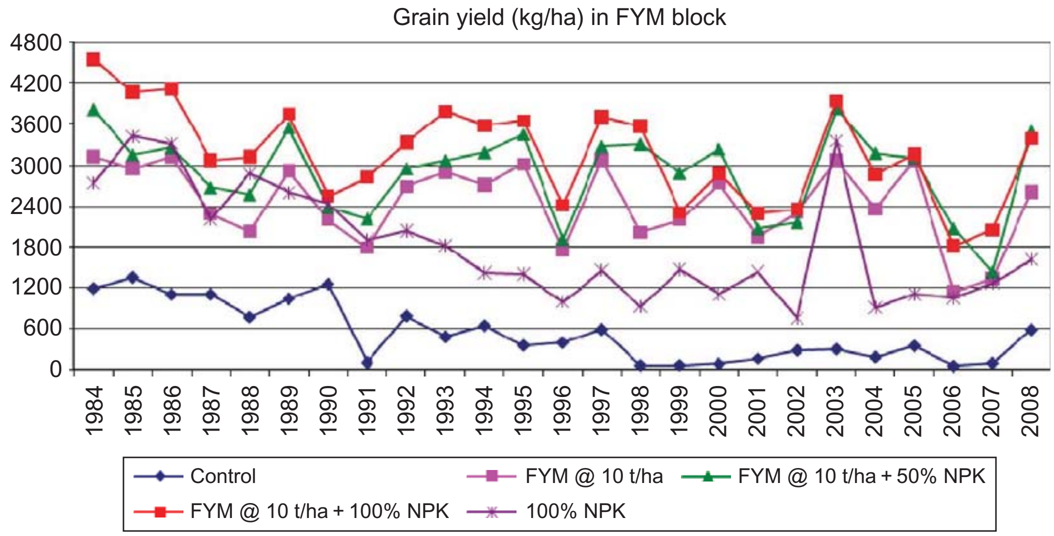

Figure 3. Grain yield trends of finger millet as influenced by different nutrient management treatments over years under Farm Yard Manure (FYM) block (color figure available online).

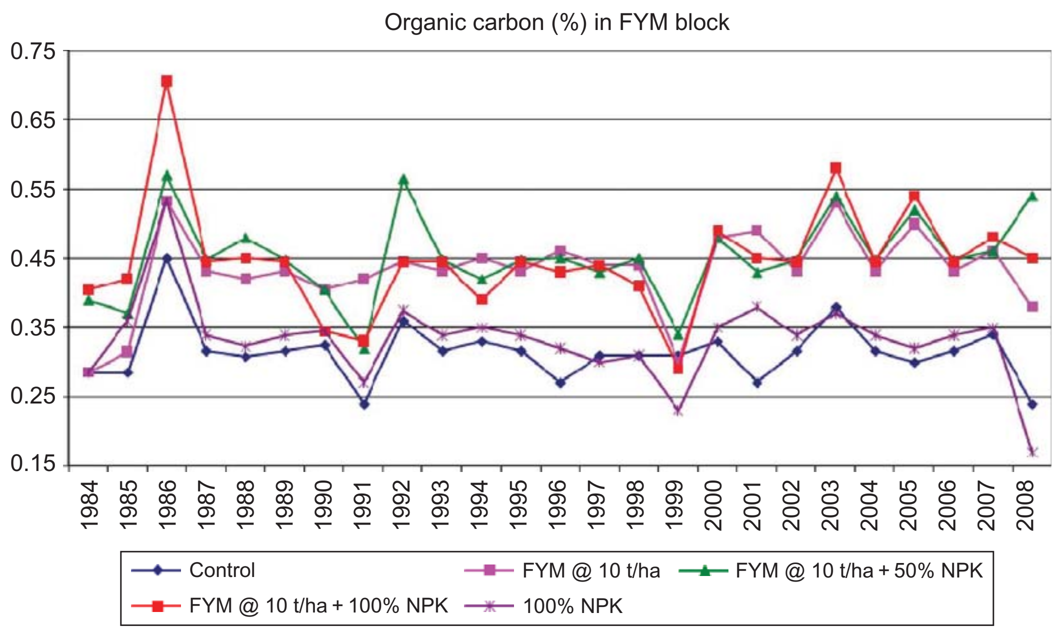

Figure 4. Percent organic carbon trend as influenced by different nutrient management treatments over years under Farm Yard Manure (FYM) block (color figure available online).

Relationship between Finger Millet Yield, Soil Nutrients, and Rainfall Over Years

The estimates of correlation between finger millet yield, soil status of N, P, and K nutrients, and crop seasonal rainfall variables during 1984 to 2008 along with their significance at $P < 0.05$ and $P < 0.01$ level of probability are given in Table 4. The analysis indicated that with an application of 100% NPK over years, the grain yield had a significant negative correlation with soil P under FYM block. There was a significant positive correlation of yield with soil P in control over years under maize residue block. The yield had a significant

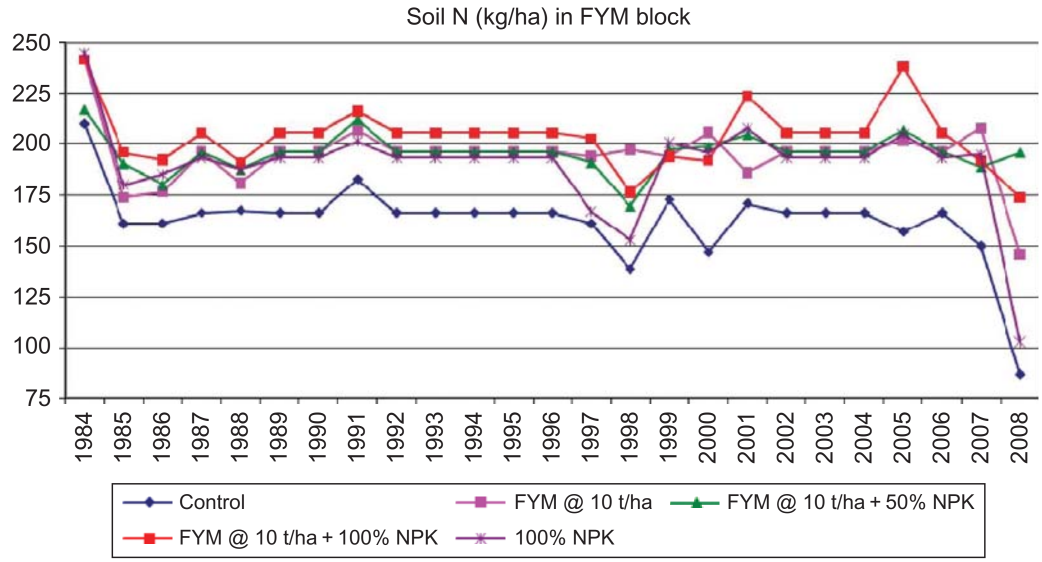

Figure 5. Available soil nitrogen trend as influenced by different nutrient management treatments over years under Farm Yard Manure (FYM) block (color figure available online).

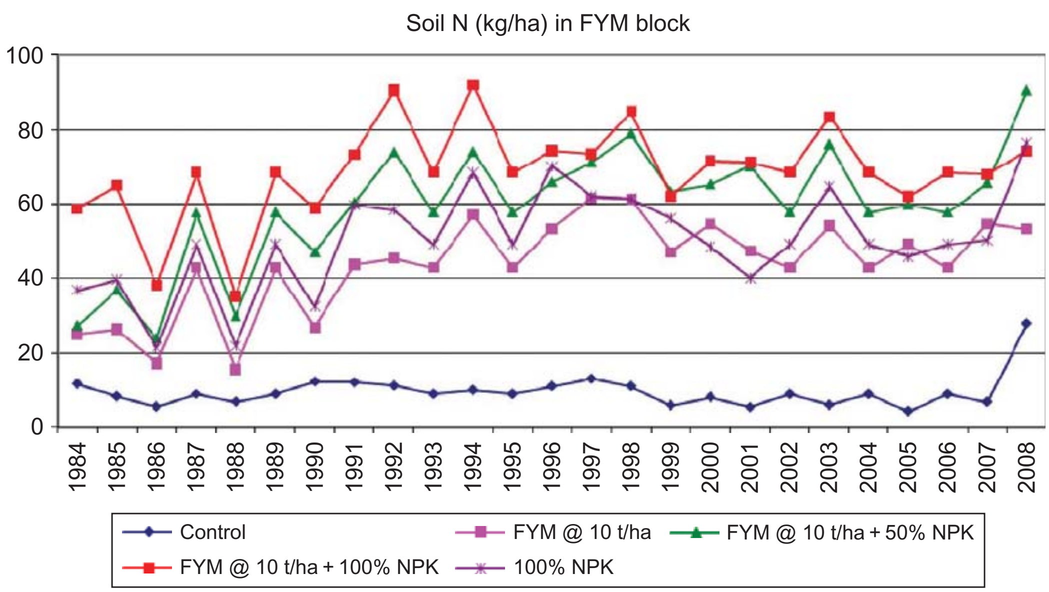

Figure 6. Available soil phosphorus trend as influenced by different nutrient management treatments over years under Farm Yard Manure (FYM) block (color figure available online).

negative correlation with soil K with an application of MR at 5 t ha^{-1} in the maize residue block. The analysis indicated a positive correlation of yield with organic carbon in FYM block compared to negative correlation in maize residue block in all treatments except in case of 100% NPK. The grain yield had positive relationship with soil N in all treatments in maize residue block compared to only control, FYM at 10 t ha^{-1} + 100% NPK and 100% NPK treatments in FYM block. The grain yield had a positive correlation with soil K in all treatments except 100% NPK in FYM block, while it had a negative correlation under all treatments in the maize residue block. The crop seasonal rainfall had a negative effect on

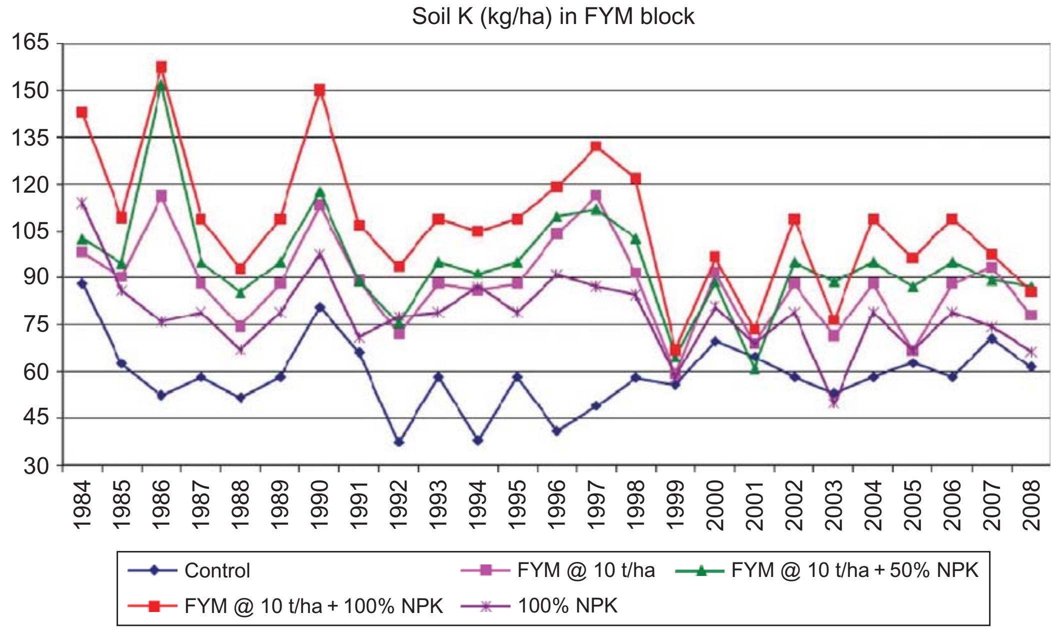

Figure 7. Available soil potassium trend as influenced by different nutrient management treatments over years under Farm Yard Manure (FYM) block (color figure available online).

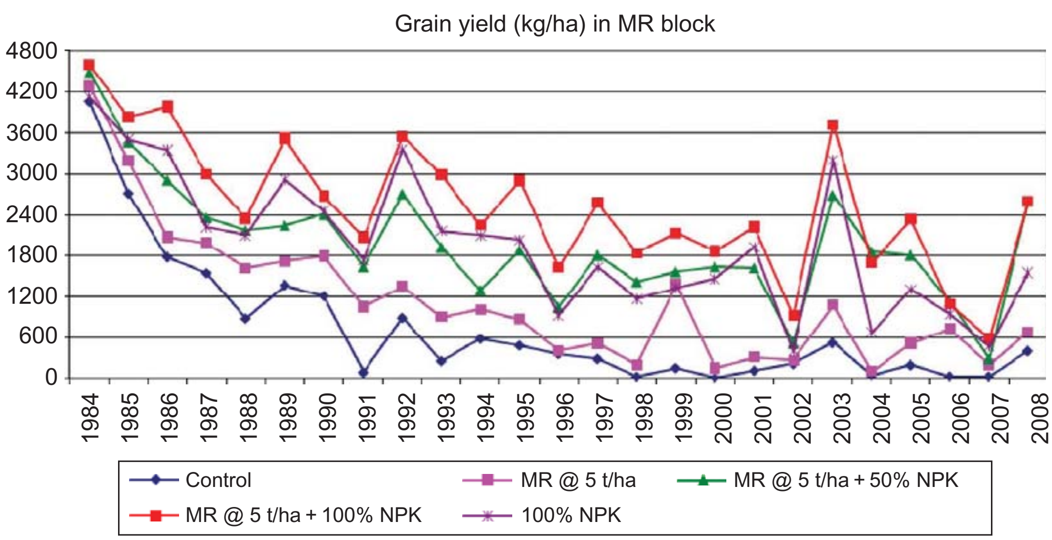

Figure 8. Grain yield trends of finger millet as influenced by different nutrient management treatments over years under maize residue (MR) block (color figure available online).

finger millet yield in all treatments under maize residue block compared to only control and 100% NPK in FYM block. The crop growing period had a positive correlation with grain yield attained by all treatments except FYM at 10 t ha^{-1} and FYM at 10 t ha^{-1} + 50% NPK over years. Among all 10 treatments of FYM and maize residue blocks, the negative correlation of yield (in all treatments), soil N (except MR at 5 t ha^{-1} + 50% NPK) and soil K (except all treatments in maize residue block) with time period indicated a decrease, while a positive correlation of organic carbon (except control and 100% NPK in both blocks) and

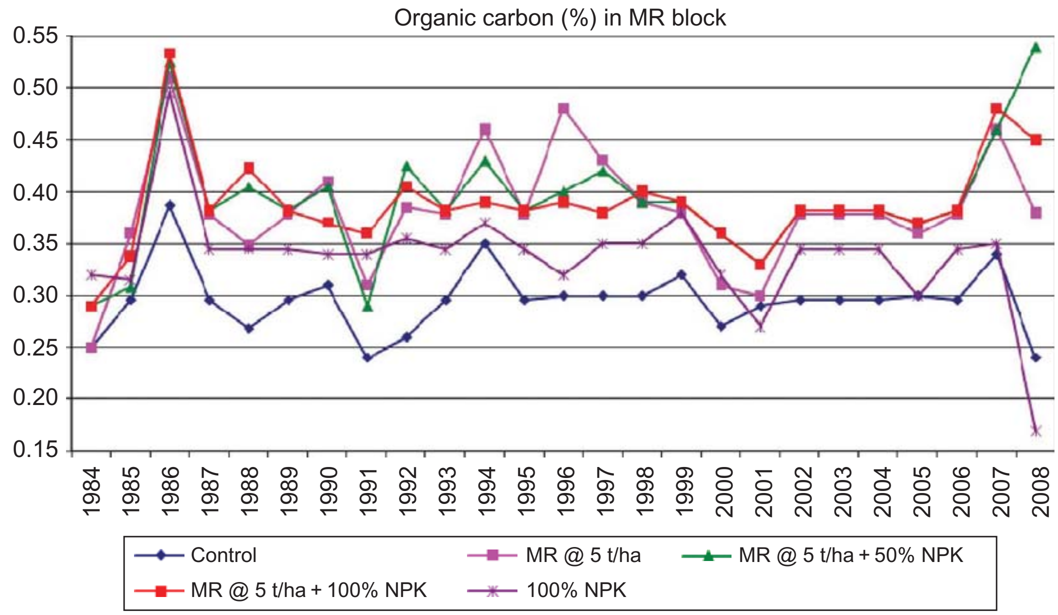

Figure 9. Percent organic carbon trend as influenced by different nutrient management treatments over years under maize residue (MR) block (color figure available online).

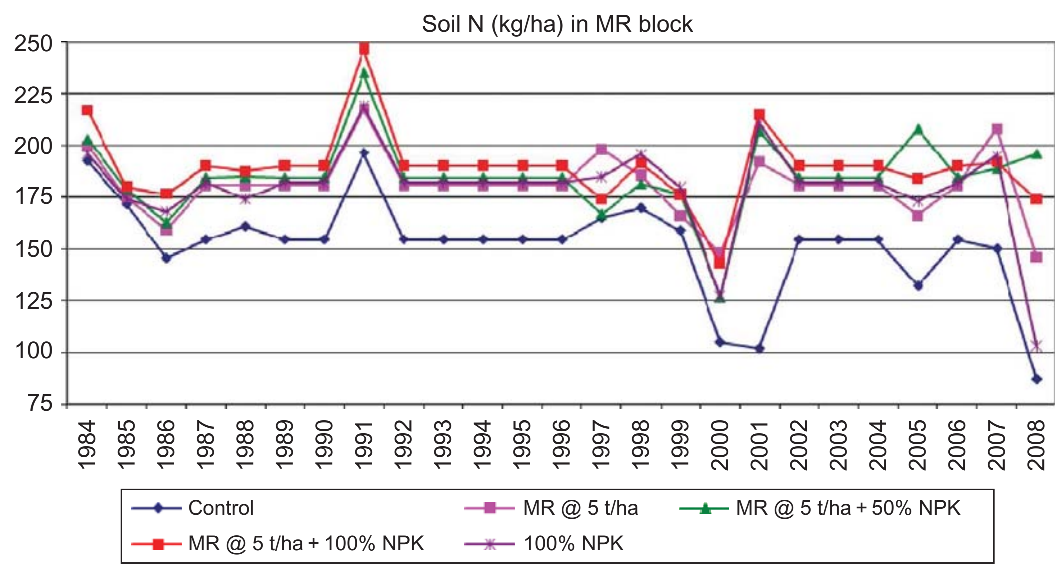

Figure 10. Available soil nitrogen trend as influenced by different nutrient management treatments over years under maize residue (MR) block (color figure available online).

soil P (except control in maize residue block) with time period indicated an increase with application of nutrient treatments.

Multiple Regression Models of Yield Through Soil Nutrients and Rainfall Over Years

Multiple regression models for yield attained by each treatment owing to simultaneous influence of (1) crop seasonal rainfall, organic carbon, soil P and K nutrients (model 1);

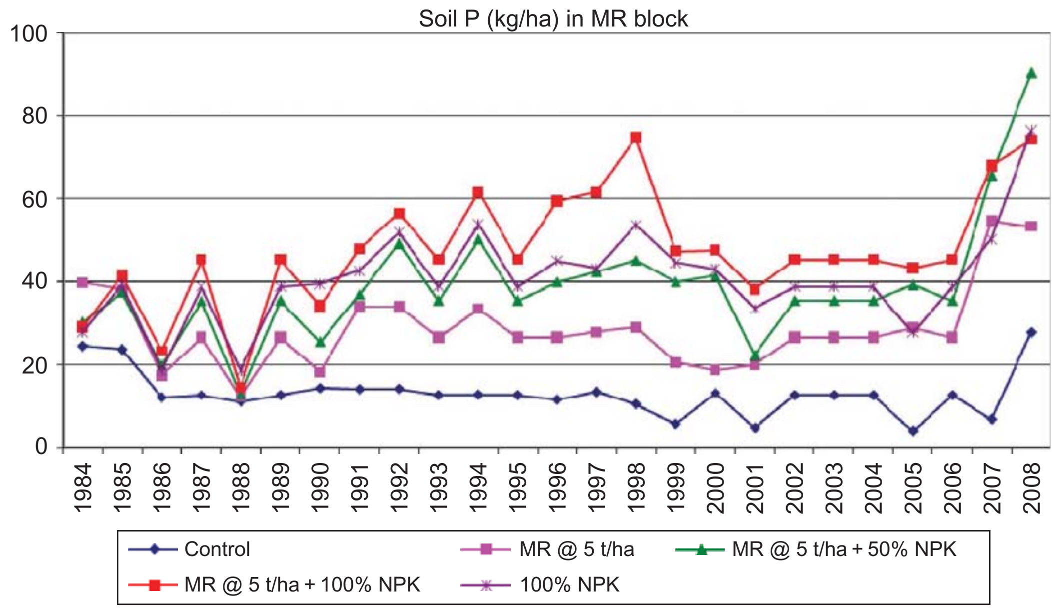

Figure 11. Available soil phosphorus trend as influenced by different nutrient management treatments over years under maize residue (MR) block (color figure available online).

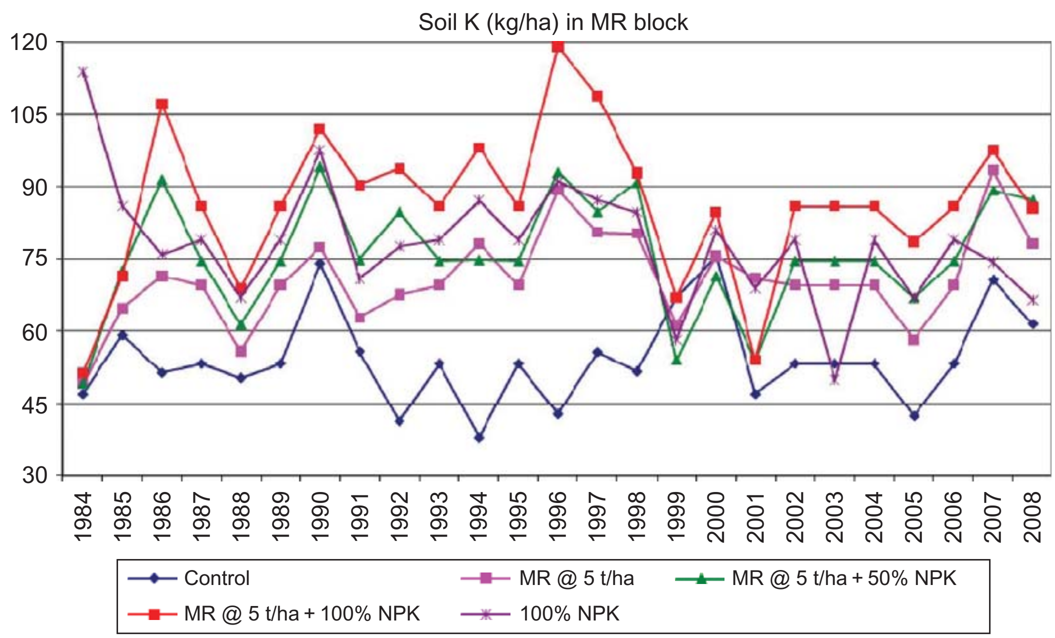

Figure 12. Available soil potassium trend as influenced by different nutrient management treatments over years under maize residue (MR) block (color figure available online).

(2) crop seasonal rainfall, soil N, P, and K nutrients (model 2) were calibrated for both FYM and maize residue blocks and the regression coefficients of variables along with coefficient of determination (R2) and prediction error (PE) are given in Table 5. Under FYM block, the yield predictability was in a range of 19% for FYM at 10 t ha^{-1} to 51% for the yield attained by 100% NPK based on model 1, while the predictability ranged from 11% to 52% for the respective treatments based on model 2. Under maize residue block, the yield

Table 4
Relation (correlation coefficients 'r') between yield, soil nutrients and crop seasonal rainfall over years

Variables		FYM block					Maize residue block				
		T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
GY	OC	0.20	0.01	0.24	0.31	0.34	−0.05	−0.27	−0.15	−0.16	0.21
GY	SN	0.17	−0.02	−0.02	0.07	0.11	0.39	0.07	0.04	0.05	0.04
GY	SP	0.13	−0.13	−0.01	−0.03	−0.46*	0.58**	0.06	−0.19	−0.40	−0.30
GY	SK	0.12	0.07	0.15	0.34	−0.02	−0.13	−0.58**	−0.25	−0.24	−0.26
GY	CGP	0.21	−0.07	−0.01	0.09	0.12	0.12	0.18	0.01	0.12	0.21
GY	CRF	−0.34	0.04	0.09	0.09	−0.22	−0.30	−0.26	−0.09	−0.10	−0.20
GY	Years	−0.78**	−0.34	−0.23	−0.54**	−0.67**	−0.74**	−0.78**	−0.61**	−0.68**	−0.73**
OC	Years	−0.15	0.31	0.25	0.08	−0.31	−0.03	0.08	0.24	0.16	−0.43*
SN	Years	−0.51**	−0.17	−0.02	−0.16	−0.32	−0.54**	−0.17	0.01	−0.22	−0.25
SP	Years	0.13	0.65**	0.67**	0.34	0.48*	−0.30	0.27	0.52**	0.52**	0.44*
SK	Years	−0.05	−0.35	−0.37	−0.51**	−0.47*	0.17	0.39	0.10	0.08	0.08

Notes. *& **indicate significance at $p < 0.05$ & $p < 0.01$ respectively.
CRF: Crop seasonal rainfall (mm); CGP: Crop growing period (days); GY: Grain Yield; OC: Organic carbon; SN: Soil nitrogen; SP: Soil phosphorus; SK: Soil Potassium.

Table 5
Multiple regression models of finger millet yield through crop seasonal rainfall and available soil nutrients over years

Treatment	Model (1)	R^2	PE	Model (2)	R^2	PE
	FYM block					
T1	Y = 3911 − 0.47 (CRF) − 11462.9 (OC) + 20448.4 $(OC)^2$ + 38.99 (SP) − 0.82 $(SP)^2$ − 66.21 (SK) + 0.59 $(SK)^2$	0.31	423	Y = − 2579 − 0.48 (CRF) + 65.89 (SN) − 0.19 $(SN)^2$ − 62.94 (SP) + 4.08 $(SP)^2$ − 78.42 (SK) + 0.69 $(SK)^2$	0.27	435
T2	Y = 9377 + 0.30 (CRF) − 42029.9 (OC) + 51492.2 $(OC)^2$ + 10.06 (SP) − 0.14 $(SP)^2$ + 18.23 (SK) − 0.07 $(SK)^2$	0.19	613	Y = 13534 + 0.08 (CRF) − 82.60 (SN) + 0.21 $(SN)^2$ − 3.83 (SP) + 0.02 $(SP)^2$ − 73.68 (SK) + 0.43 $(SK)^2$	0.11	646
T3	Y = 4289 + 0.16 (CRF) − 13387.6 (OC) + 16319.1 $(OC)^2$ − 81.92 (SP) + 0.73 $(SP)^2$ + 64.71 (SK) − 0.31 $(SK)^2$	0.24	655	Y = 1341 + 0.21 (CRF) + 4.38 (SN) + 0.01 $(SN)^2$ − 96.25 (SP) + 0.89* $(SP)^2$ + 47.40 (SK) − 0.21 $(SK)^2$	0.23	660
T4	Y = 2029 + 0.62 (CRF) + 10435.1 (OC) − 8658.2 $(OC)^2$ − 63.46 (SP) + 0.57 $(SP)^2$ − 25.65 (SK) + 0.17 $(SK)^2$	0.28	724	Y = 26227 + 0.04 (CRF) − 213.30 (SN) + 0.53 $(SN)^2$ − 102.16 (SP) + 0.85 $(SP)^2$ + 12.26 (SK) − 0.01 $(SK)^2$	0.30	717
T5	Y = 12143** − 0.40 (CRF) + 2798.8 (OC) + 569.6 $(OC)^2$ − 108.48 (SP) + 0.92 $(SP)^2$ − 198.17* (SK) + 1.19* $(SK)^2$	0.51*	686	Y = 12422** − 0.47 (CRF) + 54.92 (SN) − 0.18 $(SN)^2$ − 101.2 (SP) + 0.74 $(SP)^2$ − 277.05* (SK) + 1.72* $(SK)^2$	0.52*	679
	Maize residue block					
T1	Y = 1889 − 0.49 (CRF) − 6086.9 (OC) + 20296.9 $(OC)^2$ + 52.45 (SP) + 1.98 $(SP)^2$ − 49.61 (SK) + 0.27 $(SK)^2$	0.44	852	Y = 372 − 0.90 (CRF) + 58.89 (SN) − 0.14 $(SN)^2$ − 135.85 (SP) + 7.61 $(SP)^2$ − 149.5 (SK)+ 1.22 $(SK)^2$	0.59**	727

(*Continued*)

Table 5
(Continued)

Treatment	Model (1)	R^2	PE	Model (2)	R^2	PE
T2	$Y = 18416^{**} - 1.78^{*}$ (CRF) $- 41143.9$ (OC) $+ 57287.2$ $(OC)^2 + 25.77$ (SP) $- 0.09\ (SP)^2$ $- 185.84$ (SK) $+ 0.74\ (SK)^2$	0.67^{**}	683	$Y = 27108 - 2.22^{*}$ (CRF) $- 90.68$ (SN) $+ 0.24\ (SN)^2$ $+ 45.73$ (SP) $- 0.59\ (SP)^2$ $- 405.63^{*}$ (SK) $+ 2.36\ (SK)^2$	0.60^{**}	750
T3	$Y = 20178^{**} - 0.63$ (CRF) $- 72516.9^{*}$ (OC) $+ 88430.9^{*}$ $(OC)^2 - 11.51$ (SP) $- 0.02\ (SP)^2 - 64.61$ (SK) $+ 0.38\ (SK)^2$	0.39	828	$Y = 9718 - 0.47$ (CRF) $- 5.57$ (SN) $+ 0.01\ (SN)^2$ $- 53.98$ (SP) $+ 0.48\ (SP)^2 - 136.37$ (SK) $+ 0.82\ (SK)^2$	0.18	957
T4	$Y = 23702^{*} - 0.18$ (CRF) $- 113870.6$ (OC) $+ 130211.9$ $(OC)^2 - 49.26$ (SP) $+ 0.36$ $(SP)^2 + 104.86$ (SK) $- 0.57\ (SK)^2$	0.31	979	$Y = 2444 - 0.05$ (CRF) $+ 41.66$ (SN) $- 0.11\ (SN)^2$ $- 14.29$ (SP) $- 0.10\ (SP)^2$ $- 61.38$ (SK) $+ 0.33\ (SK)^2$	0.19	1060
T5	$Y = 16673 - 1.24$ (CRF) $- 27119.2$ (OC) $+ 45473.4$ $(OC)^2 + 45.0$ (SP) $- 0.64\ (SP)^2$ $- 265.39$ (SK) $+ 1.60\ (SK)^2$	0.30	998	$Y = 11945 - 1.39$ (CRF) $- 2.57$ (SN) $+ 0.01\ (SN)^2$ $- 64.24$ (SP) $+ 0.50\ (SP)^2 - 176.62$ (SK) $+ 1.08\ (SK)^2$	0.24	1038

Notes. *& **indicate significance at $p < 0.05$ and $p < 0.01$ level.
R^2: Coefficient of determination; PE: Prediction error (kg ha^{-1}).

predictability ranged from 30% for 100% NPK to 67% for the yield attained by MR at 5 t ha^{-1} treatment based on model 1, while the predictability ranged from 18% for MR at 5 t ha^{-1} + 50% NPK to 60% for MR at 5 t ha^{-1} treatment based on model 2. The prediction error ranged from 423 to 724 kg ha^{-1} based on model 1 and 435 to 717 kg ha^{-1} based on model 2 in FYM block, while it had a higher range of 683 to 998 kg ha^{-1} under model 1 and 727 to 1038 kg ha^{-1} under model 2 in the maize residue block in the 25-year study.

Based on models 1 and 2 of yield attained by treatments in FYM block, the crop seasonal rainfall had a positive effect under FYM at 10 t ha^{-1}, FYM at 10 t ha^{-1} + 50% NPK and FYM at 10 t ha^{-1} + 100% NPK. Based on model 1, the effect of organic carbon under FYM at 10 t ha^{-1} + 100% NPK and 100% NPK; soil P under control and FYM at 10 t ha^{-1}; soil K under FYM at 10 t ha^{-1}; and FYM at 10 t ha^{-1} + 50% NPK were positive. Based on model 2, the effect of soil N under control, FYM at 10 t ha^{-1} + 50% NPK and 100% NPK, soil K under FYM at 10 t ha^{-1} + 50% NPK and FYM at 10 t ha^{-1} + 100% NPK were positive. The analysis indicated that soil P had a significant negative effect on

Table 6
Sustainability of fertilizer treatments under different crop seasonal rainfall situations at Bangalore

	Mean yield (kg ha^{-1}) under different rainfall situations						Sustainability Yield Index (SYI)					Sustainability Yield Index (SYI)			
Treatment	<500	500–750	750–1000	1000–1250	Mean	PE (1)	<500	500–750	750–1000	1000–1250	PE (2)	<500	500–750	750–1000	1000–1250
FYM block															
T1	532	706	444	172	537	423	3.4	8.9	0.7	−7.9	435	3.1	8.6	0.3	−8.3
T2	1883	2567	2572	2283	2452	613	40.1	61.7	61.8	52.7	646	39.1	60.6	60.8	51.7
T3	2206	2941	3082	2880	2891	655	**49.0**	72.2	76.6	70.3	660	**48.8**	72.0	76.5	70.1
T4	2239	3409	3176	3183	**3167**	724	47.8	**84.8**	**77.4**	**77.6**	717	48.1	**85.0**	**77.6**	**77.9**
T5	1415	2197	1662	1315	1826	686	23.0	47.7	30.8	19.9	679	23.2	47.9	31.0	20.1
Maize residue block															
T1	497	1240	377	118	740	852	−14.1	15.4	−18.9	−29.2	727	−9.1	20.4	−13.9	−24.2
T2	935	1562	843	595	1141	683	10.0	34.9	6.4	−3.5	750	7.4	32.2	3.7	−6.2
T3	1360	2211	2041	1630	1985	828	21.1	54.9	48.2	31.8	957	16.0	49.8	43.0	26.7
T4	1566	2931	2471	2086	**2518**	979	**23.3**	**77.5**	**59.2**	**44.0**	1060	**20.1**	**74.3**	**56.0**	**40.7**
T5	1272	2436	1787	1408	1965	998	10.9	57.1	31.3	16.3	1038	9.3	55.5	29.8	14.7

Notes. PE (1) and PE (2) are prediction error based on models 1 and 2 respectively.

yield attained by FYM at 10 t ha^{-1} + 50% NPK based on model 2. Similarly, soil K had a significant negative effect on yield attained by 100% NPK under both models 1 and 2.

Under maize residue block, the crop seasonal rainfall had a negative effect on yield attained by all treatments based on both models. Based on model 1, the effects of soil P under control, MR at 5 t ha^{-1} and 100% NPK, and soil K under MR at 5 t ha^{-1} + 100% NPK were positive. Similarly, based on model 2, the effects of soil N under control and MR at 5 t ha^{-1} + 100% NPK, and soil P under MR at 5 t ha^{-1} were positive. However, only the negative effects of crop seasonal rainfall on yield attained under MR at 5 t ha^{-1} under both models; organic carbon under MR at 5 t ha^{-1} + 50% NPK based on model 1; and soil K under MR at 5 t ha^{-1} based on model 2 were significant.

Identification of Efficient Treatments under Different Rainfall Situations

Using the mean yield of treatments over years under different crop seasonal rainfall situations, prediction error based on models 1 and 2, and maximum mean yield attained by any treatment over years, the estimates of sustainability yield index of treatments were derived for different crop seasonal rainfall situations and are given in Table 6. In FYM block, the estimates were in a range of 3.4% to 49.0% under <500 mm; 8.9% to 84.8% under 500–750 mm; 0.7% to 77.4% under 750–1000 mm; and −7.9% to 77.6% under 1000–1250 mm of crop seasonal rainfall based on the prediction error of model 1. They were in a range of 3.1% to 48.8% under <500 mm; 8.6% to 85.0% under 500–750 mm; 0.3% to 77.6% under 750–1000 mm; and −8.3% to 77.9% under 1000–1250 mm of rainfall based on the prediction error of model 2. In maize residue block, the estimates were in a range of −14.1% to 23.2% under <500 mm; 15.1% to 77.5% under 500–750 mm; −18.9% to 59.2% under 750–1000 mm; and −29.2% to 44.0% under 1000–1250 mm of rainfall based on the prediction error of model 1. They were in a range of −9.1% to 20.1% under <500 mm; 20.4% to 74.3% under 500–750 mm; −13.9% to 56.0% under 750–1000 mm; and −24.2% to 40.7% under 1000–1250 mm of crop seasonal rainfall based on the prediction error of model 2.

The study indicated the superiority of FYM at 10 t ha^{-1} under <500 mm rainfall; while FYM at 10 t ha^{-1} + 100% NPK was superior under 500–750, 750–1000, and 1000–1250 mm rainfall situations for attaining maximum mean yield and sustainability over years in the FYM block. Similarly, MR at 5 t ha^{-1} + 100% NPK was superior for attaining maximum mean yield with better sustainability under all of the four crop seasonal rainfall situations in the maize residue block. Thus, based on the long term study, an efficient fertilizer treatment having a high sustainability has been identified for attaining maximum productivity under semi–arid Alfisols of Bangalore in southern India.

Conclusively, the results obtained from these long term studies incurring huge expenditure provide very good conjunctive nutrient use options with good conformity for different rainfall conditions of rainfed semi-arid tropical Alfisol soils for ensuring higher finger millet yield, maintaining higher SYI, and maintaining improved soil fertility.

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