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ABSTRACT

Field experiments were conducted in farm yard manure (FYM) and maize-residue (MR) blocks during 1984–2011 with the objective of identifying a superior treatment for attaining maximum finger millet yield and soil-fertility at Bangalore. The treatments tested were Control; FYM@10tha^{-1}; FYM@10tha^{-1}+50% nitrogen, phosphorus, and potassium (NPK); FYM@10tha^{-1}+100%NPK; 100%NPK in FYM-block; Control; MR@5tha^{-1}; MR@5t ha^{-1}+50%NPK; MR@5tha^{-1}+100%NPK; 100%NPK in MR-block.

FYM@10t/ha+100%NPK gave maximum mean yield of 3207kg/ha in FYM-block, while MR@5t/ha+100%NPK gave 2548kg/ha in MR-block. Regression and principal component (PC) models of yield were developed through soil-fertility and rainfall variables to assess superiority of treatments. Maximum yield predictability of 60 and 65% under regression; 76 and 75% under PC model were observed in FYM and MR-blocks respectively. FYM@10t/ha+50%NPK was superior with maximum gross returns of Rs.41286/ha and benefit-cost ratio (BCR) of 2.27 in FYM-block compared to MR@5t/ha+100%NPK (gross returns of Rs.34530/ha and BCR of 2.09) in MR-block with maximum soil-fertility and are recommended for adoption under semi-arid Alfisols.

Keywords: Monthly rainfall, Soil fertility, Regression model, Principal component model, Sustainability yield index, Benefit-cost ratio, Alfisols

INTRODUCTION

Among different factors of production, yield of rainfed crops is greatly influenced by the native soil fertility, rainfall received during the crop growing period, apart from the external inputs like organic and inorganic fertilizers applied to the crop. The effect of fertilizer application on crop yield would be directly influenced by the quantity of rainfall received from sowing to harvest. Maruthi Sankar et al. (2011) emphasized that application of nutrients through farm yard manure and maize residue would be beneficial for (i) enhancing the soil fertility; (ii) reducing the chemical fertilizer requirement; (iii) ensuring sustainability by minimizing the risk of crop failure due to dry spells or reduction in yield due to erratic rainfall; (iv) improving the water holding capacity of a soil apart from many other benefits. Barbarick et al. (2010) and Maruthi Sankar et al. (2011) suggested to monitor the changes in soil fertility over years and efficiently calibrate an optimum fertilizer dose for attaining sustainable yield of a crop and maintain maximum soil fertility under different soil and agro-climatic conditions. Prasad and Goswami (1992) examined the usefulness of soil fertility restoration and its management for sustainable agriculture in South Asia. Mathur (1997) studied the long–term effects of fertilizer application on yield and soil fertility under cotton–wheat rotation in arid soils of North-West Rajasthan.

Finger millet is one of the important cereals grown in Alfisols of Bangalore region of Karnataka state of India. The crop productivity is significantly influenced by the seasonal rainfall received during cropping season, available soil nutrients and fertilizer doses applied (Maruthi Sankar et al., 2008). The studies conducted by Behera et al. (2007) and Mohanty et al. (2008) have shown that among different variables, the rainfall received during crop growing period would significantly influence the crop response to fertilizer application under moist sub-humid Alfisols. Nema et al. (2008) and Sharma et al., (2009) 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 in north India. To attain a sustainable crop yield in any soil and agro-climatic condition and to save on chemical fertilizers, it is important that while optimizing the fertilizer doses, changes in soil fertility also need to be periodically monitored (Maruthi Sankar et al., 2010; Vittal et al. 2003a).

Based on the results of long-term experiments reported by Vikas et al. (2008) for maize; Behera et al. (2007) and Mohanty et al. (2008) for rice; Nema et al. (2008) for pearl millet; Sanjay Sharma et al. (2009) for soybean and Anil Sharma et al. (2013) for maize, the crop yield was significantly influenced by the distribution of rainfall from sowing to harvest, apart from the applied fertilizer doses. The authors also observed that if the fertilizer is judiciously applied by considering the distribution of rainfall, maximum sustainable yields could be achieved under any soil and agro-climatic condition. The long-term effects of fertilizer on yield and soil properties were examined to suitably restore the soil fertility and calibrate the soil test based fertilizer doses for different crops (Prasad and Goswami, 1992; Bhat et al., 1991; Dalal and Mayer, 1986; Mathur, 1997; Maruthi Sankar et al., 2012b). Although several authors studied the effects of fertilizer on crop yield, the studies on fertilizer use efficiency for attaining sustainable yield and maintenance of soil fertility under erratic rainfall condition are limited.

Among semi-arid tropical (SAT) regions with rainfed Alfisols, Bangalore in Karnataka State of India representing Deccan Plateau is famous for growing finger millet in red soils. It is one of the economically remunerative cereal crops adopted by about 80% of the farmers in this region. As the region is rainfed, besides moisture constraint, yield is severely affected by the low soil organic-matter content and poor soil fertility conditions. A need is often felt to identify an efficient fertilizer treatment for attaining maximum sustainable yield and profitability from finger millet and maintain maximum soil fertility and quality under Alfisols (Sharma et al., 2005 and 2008). Regression models are calibrated to assess the effect of rainfall on the effectiveness of fertilizer treatments in influencing the crop yield. Principal component (PC) model could be explored to assess the variability of different variables in influencing the crop yield. The model would reduce the dimensionality from a large number of variables to a few significant components for explaining maximum variability in the data (Rao, 1973;

Krzanowski, 1979; Jolliffe, 1986; Dunteman, 1989). The PC analysis could be explored for assessing the efficiency of fertilizer treatments and identifying a superior treatment for attaining sustainable yield of a crop, apart from assessing the changes in soil fertility over years. Such changes in organic matter status using PC models have been earlier studied by Moslem et al. (2010). A few significant PCs for explaining maximum variability in the data could often be better interpretable than the original data of many variables (Norris, 1972). Such a reduction in the dimensionality would be an important economic consideration, especially if potential information recoverable from the transformed data is just as good as original data (Anderson and Furley, 1975). The long-term sustainability of treatments could be assessed based on the procedure described by Maruthi Sankar et al. (2006, 2011, 2012a, and 2013).

Considering the above facts, the present study was conducted for 28 years during 1984 to 2011 to monitor the effects of fertilizer treatments on (i) finger millet yield and soil fertility of nutrients; (ii) establish relationship between yield, rainfall and soil fertility and assess variability in data using regression and PC models; (iii) assess efficiency of treatments for attaining maximum yield, monetary returns and soil fertility under semi-arid Alfisols.

MATERIALS AND METHODS

Details of Location, Climate and Soil

Field experiments on finger millet (Eleusine coracana L.) were conducted under All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in a permanent site for 28 years from 1984 to 2011 in a semi-arid Alfisol at the research farm of University of Agricultural Sciences, Bangalore. The study was primarily initiated with the objective of identifying an efficient treatment for attaining sustainable finger millet yield, apart from maintaining maximum soil organic carbon (SOC), phosphorus (P) and potassium (K) nutrients over years. The experimental site is situated at a latitude of 13º 05' 13" North, longitude of 77º 39' 22" East, and an altitude of 929 m above mean sea level. The soils represent an Alfisol order. They are very deep, well drained, sandy loam to sandy clay loam with clay content increasing with depth of the profile. Predominantly, these soils are susceptible to severe water erosion with moderate loss of top soil. The soils are medium to high in available water holding capacity (AWHC), and are subjected to frequent occurrence of crop stress causing yield reduction. The pH of soils in general, is in acidic range at the surface, with pH increasing with depth. The soils are low to medium in organic carbon, low to medium in P with high P-fixation capacity, and medium to high in K.

The experimental area was divided into two permanent blocks viz. farm yard manure (FYM) and maize residue (MR), where FYM and MR based fertilizer combination treatments were applied every year. The FYM consisted 0.54, 0.35 and 0.63%, while MR contained 1.2, 0.31 and 1.16% of total N P and K nutrients respectively. The treatments under FYM block were (i) Control; (ii) FYM @ 10 t ha^{-1}; (iii) FYM @ 10 t ha^{-1} + 50% NPK; (iv) FYM @ 10 t ha^{-1} + 100% NPK; and (v) 100% recommended NPK; while the treatments under MR block were (i) Control; (ii) MR @ 5 t ha^{-1}; (iii) MR @ 5 t ha^{-1} + 50% NPK; (iv) MR @ 5 t ha^{-1} + 100% NPK; and (v) 100% recommended NPK. The 100% recommended NPK dose comprised of 50 kg N, 50 kg phosphorus pentoxide (P_2O_5), and 25 kg potassium oxide (K_2O) ha^{-1}. The fertilizer N was supplemented through urea, while fertilizer P was applied through single superphosphate (SSP) and fertilizer K was applied through muriate of potash. The experiment was conducted in a net plot size of 2.7 m × 11.0 m with row x plant spacing of 30 cm x 10 cm. The treatments were triplicated and tested separately under FYM and MR blocks in a Randomized Block Design. They were superimposed to the same plots every year.

Initial soil samples were collected from each plot at a soil depth of 0–30 cm before superimposing the organic and inorganic fertilizer treatments to experimental plots. The sieved soils that passed through 2 mm sieve were used for measuring the organic carbon, P and K nutrients. Soil organic carbon was measured by wet oxidation with sulfuric acid (H_2SO_4) + potassium dichromate ($K_2Cr_2O_7$) (Walkley and Black, 1934); available P by hydrochloric acid + ammonium fluoride (Bray and Kurtz, 1945); and available K (Hanway and Heidal, 1952) using neutral normal ammonium acetate method. With the onset of monsoon, the crop was sown in July in 16 years; August in 11 years and September in one year. It was harvested in October in one year; November in 14 years; December in 12 years; and January in one year. However, the period of harvest spread from November to January. Other management practices were followed as per the recommendations given for the region (Vittal et al., 2003b).

Experimental Data

Distribution of Rainfall Received From Sowing To Harvest in Different Years

The earliest date of sowing of finger millet was on 13th July in 2010, while the latest was on 30th September in 2002. The earliest date of harvest of the crop was on 25th October in 2004, while the latest was on 3rd January in 2003. The crop had a minimum duration of

96 days in 2002 compared to maximum of 155 days in 1994 with a mean of 125 days coefficient of variation (CV of 9.6%). The rainfall received from July to November was in the range of 339.6 mm in 2002 to 1134.5 mm in 2005 with a mean of 661.7 mm (CV of 31.2%). July received a mean rainfall of 98 mm (CV of 57.0%), while August received a mean rainfall of 142.6 mm (CV of 58.4%). September received a mean rainfall of 191.9 mm (CV of 52.4%), while October received a mean rainfall of 177.1 mm (CV of 69.2%), and November received a mean rainfall of 52.0 mm (CV of 91.2%) over years. The monthly rainfall was found to increase from year to year with a decreasing coefficient of variation over years. The details of crop growing period, monthly rainfall from July to November, date of sowing and date of harvest of finger millet during 1984 to 2011 are given in Table 1. The changes in mean monthly rainfall and its standard deviation are presented in Figure 1.

Statistical Analysis

The differences in effects of treatments in influencing the soil organic carbon and P and K nutrients and yield attained by treatments under FYM and MR blocks were tested based on the standard analysis of variance (ANOVA) procedure using Statistical Package for Social Sciences (SPSS Inc., Chicago, IL) software. The differences among fertilizer treatments were tested based on F-test under ANOVA derived as a ratio of the 'treatment mean sum of squares' and 'error mean sum of squares'. The treatments which had a significantly higher effect on the soil nutrients and yield compared to other treatments were identified based on the Least Significant Difference (LSD) criteria at $p < 0.05$ level of significance (Gomez and Gomez, 1984). Before calibrating a model to predict the yield attained by a fertilizer treatment through soil and rainfall variables, the relationships of the variables with finger millet yield attained by treatments applied in the two blocks were assessed. The effects of monthly rainfall and soil fertility of nutrients on finger millet yield were assessed using (i) multiple linear regression with original variables and (ii) multiple linear regression with PCs derived from the original variables and the two approaches were compared for the sustainability of treatments in the long-term study.

Regression Analysis

A regression model of yield attained by a fertilizer treatment could be calibrated through crop seasonal rainfall, soil organic carbon (SOC), soil P (SP) and soil K (SK) nutrients as observed under FYM and MR blocks in different years (Maruthi Sankar, 1986; Draper and Smith, 1998). The regression model of yield could be postulated as:

$Y = \pm \alpha \pm \beta 1\ (Jul) \pm \beta 2\ (Jul)^2 \pm \beta 3\ (Aug) \pm \beta 4\ (Aug)^2 \pm \beta 5\ (Sep) \pm \beta 6\ (Sep)^2 \pm \beta 7\ (Oct) \pm \beta 8\ (Oct)^2 \pm \beta 9\ (Nov) \pm \beta 10\ (Nov)^2 \pm \beta 11\ (SOC) \pm \beta 12\ (SP) \pm \beta 13\ (SK)$ ……… (1)

In model (1), α is the intercept and β's are the regression coefficients measuring the change in yield for unit change in a variable. The usefulness of a regression model for yield prediction could be assessed based on the coefficient of determination (R^2) and unexplained variation measured by the prediction error (PE) under FYM and MR blocks.

Principal Component Model

Based on the principal component analysis as described by Dunteman (1989), Jolliffe (1986) and Krzanowski (1979), the PCs of each treatment were determined through monthly rainfall received from July to November, SOC, SP and SK nutrients. Based on the PC model, the i^{th} PC 'P_i' could be postulated as

$P_i = \pm a_{i1}(Jul) \pm a_{i2}(Aug) \pm a_{i3}(Sep) \pm a_{i4}(Oct) \pm a_{i5}(Nov) \pm a_{i6}(SOC) \pm a_{i7}(SP) \pm a_{i8}(SK)$ ....(2)

In (2), a_{ij} are loadings of variables on 'P_i', which are chosen such that they satisfy two conditions, viz., (i) the PCs are orthogonal with respect to each other; and (ii) 1st PC, say P_1 will account for maximum variance of the variables; 2nd PC will account for maximum of the remaining variance in variables after eliminating the variance accounted by 1st PC and so on. An eigen value 'λ_k' indicates the variance extracted by the k^{th} PC and can be expressed as percentage of total variance of all components, i.e. $P_k = (\lambda_k/k) \times 100$. The computational procedure of 1st PC is repeated for the 2nd PC and all subsequent PCs. The 1st PC would always have a higher eigen value than the 2nd PC; the 2nd PC has a higher eigen value than the 3rd PC and so on. Based on the analysis, we determined (i) the significant number of PCs with eigen value of more than 'one' to extract maximum variance in the data; (ii) variables which have a significantly higher loading of more than +0.60 or less than –0.60 on PCs; and (iii) percent of variance explained by a PC. We can identify a superior treatment for which the PC model (i) explained maximum variance in the data; (ii) provided maximum number of variables with a significantly higher loading on PCs.

Regression Analysis of Yield of Treatments through PCs

Let $P_1, P_2, P_3, ..., P_k$ are PCs derived from the 8 independent variables considered in the study. The yield of a given treatment can be fitted using the PCs fulfilling the above specified criteria as under.

$$Y = \alpha + \sum_{i=1}^{k} \beta_i P_i D_i + \varepsilon$$

where α is the intercept

P_i is i^{th} the PC

β_i is the regression coefficient corresponding to i^{th} PC

D_i is a dummy variable which takes a value of '1' if the i^{th} PC is included in the model and '0' otherwise.

Sustainability Yield Index

The sustainability yield index (SYI) of a treatment could be measured as a ratio of the "difference between mean yield and prediction error" and "maximum yield" attained by the treatment in any year in the study period. The SYI of treatment 'i' could be derived by using the mean yield ($\bar{A}_i$) of a treatment over years; prediction error (Φ_i) derived based on the model of i^{th} treatment; and maximum yield (Y_{max}) attained by any treatment in the long-term study. The SYI 'η' of treatment 'i' is derived as

$$\eta_i = [(\bar{A}_i - \Phi_i) / (Y_{max})] * 100 \qquad \text{……… (3)}$$

In (3), the mean yield of a treatment would get detrended by elimination of the unexplained variation as measured by the regressor variables in the MR model and principal components in the PC model through rainfall, SOC, P and K nutrients over years. The detrended yields are compared with the maximum yield attained by a treatment in any year in the study period for assessing the sustainability of the respective treatment. We also derived the cost of cultivation incurred, and gross returns, net returns and benefit-cost ratio attained by treatments to identify a profitable treatment over years.

Based on different criteria, an efficient treatment, which provides maximum SYI, monetary returns and maintains maximum soil fertility of nutrients over years was identified for finger millet grown in semi-arid Alfisols.

RESULTS AND DISCUSSION

Analysis Of Variance of Soil Nutrients and Yield

The mean soil organic carbon ranged from 0.31% under control to 0.46% under FYM @ 10 t/ha + 50% NPK and FYM @ 10 t/ha + 100% NPK in FYM block; while it ranged from 0.29% under control to 0.41% under MR @ 5 t/ha + 50% NPK in MR block over 28 years. The soil P ranged from 22.6 kg/ha under control to 154.7 kg/ha under FYM @ 10 t/ha + 100% NPK in FYM block; while it ranged from 32.1 kg/ha under control to 112.0 kg/ha under MR @ 5 t/ha + 100% NPK in MR block. The soil K ranged from 73 kg/ha under control to 131 kg/ha under FYM @ 10 t/ha + 100% NPK in FYM block; while it ranged from 67 kg/ha under control to 110 kg/ha under MR @ 5 t/ha + 100% NPK in MR block. The finger millet yield of more than 3000 kg/ha was attained in 20 years under FYM block compared to 6 years under MR block. The mean finger millet yield over years ranged from 506 kg/ha under control to 3207 kg/ha under FYM @ 10 t/ha + 100% NPK in FYM block; while it ranged from 674 kg/ha under control to 2548 kg/ha under MR @ 5 t/ha + 100% NPK in MR block during the study period.

Based on the ANOVA, the treatments were significantly different from each other at $p < 0.05$ level in influencing the soil fertility of nutrients and finger millet yield attained under the two blocks. Based on the LSD criteria, application of FYM @ 10 t/ha, FYM @ 10 t/ha + 50% NPK and FYM @ 10 t/ha + 100% NPK were at par and significantly superior compared to either control or 100% NPK in influencing the SOC observed under FYM block. Similarly, MR @ 5 t/ha, MR @ 5 t/ha + 50% NPK and MR @ 5 t/ha + 100% NPK were at par and significantly superior to control and 100% NPK in influencing SOC observed in MR block. FYM @ 10 t/ha + 50% NPK and FYM @ 10 t/ha + 100% NPK in FYM block and MR @ 5 t/ha + 100% NPK and 100% NPK in MR block were superior compared to other treatments in influencing soil P. Similarly, FYM @ 10 t/ha, FYM @ 10 t/ha + 50% NPK and FYM @ 10 t/ha + 100% NPK were superior in FYM block, while MR @ 5 t/ha + 50% NPK and MR @ 5 t/ha + 100% NPK were superior in MR block in influencing soil K. Application of FYM @ 10 t/ha + 50% NPK and FYM @ 10 t/ha + 100% NPK in FYM block and MR @ 5 t/ha + 50% NPK and MR @ 5 t/ha + 100% NPK in MR block were at par and significantly superior compared to other treatments in influencing finger millet yield attained in different years. The mean and standard deviation of grain yield, SOC, soil P and K nutrients along with LSD values are given in Table 2. Our results are in agreement with the findings of Sharma et al., (2005) and Maruthi Sankar et al., (2011) who observed superiority of a combination of organic and inorganic fertilizer application for improving the soil fertility of nutrients and attaining sustainable yield based on long-term studies conducted under semi-arid Alfisols.

Relationship between Soil Test Values and Yield

The relationship between SOC, P and K nutrients and finger millet yield by different treatments under FYM and MR blocks was assessed over years based on correlation coefficients and the results are depicted in Figure 2 (a) to (f). An increase in yield with an increase in soil fertility under different treatments was observed over years. This is indicated by a higher yield attained under treatments with application of FYM @ 10 t/ha + 50% NPK and FYM @ 10 t/ha + 100% NPK in FYM block and MR @ 5 t/ha + 50% NPK and MR @ 10 t/ha + 100% NPK in MR block compared to other treatments. In FYM block, the correlation ranged between 0.03 to 0.36 for SOC, -0.45 to 0.11 for soil P, and 0.01 to 0.33 for soil K with finger millet yield attained by treatments in different years. However, only the negative correlation of -0.45 observed between soil P and yield was significant at $p < 0.05$ level. Under MR block, the correlation ranged between -0.29 to 0.21 for SOC, -0.35 to 0.40 for soil P, and -0.58 to -0.09 for soil K with yield attained by treatments in different years. However, only the positive correlation of 0.40 observed between soil P and yield under control was significant at $p < 0.05$ level; and the negative correlation of -0.58 between soil K and yield under MR @ 5 t/ha was significant at $p < 0.01$ level. Vittal et al. (2003) reported similar type of relationships between soil fertility of nutrients and groundnut pod yield attained under arid Alfisols. They observed a negative relationship of long-term application of inorganic fertilizers with soil fertility of nutrients compared to a combined dose of organic and inorganic fertilizers during 16 years of study.

Regression Model

Using the observations collected every year on finger millet yield, SOC, P and K nutrients and monthly rainfall received during the crop growing period for 28 years, a regression model was calibrated for each treatment to assess the effect of variables on yield over years. The regression models of yield attained by each treatment were calibrated as a function of monthly rainfall of July to November, SOC, P and K nutrients and are given in Table 3 for assessing the long-term sustainability of treatments. The coefficient of determination (R^2) of a model which indicates the predictability of yield ranged from 0.37 for 100% NPK application to 0.60 for control in FYM block; while it ranged from 0.28 for MR @ 5 t/ha + 50% NPK to 0.65 for MR @ 5 t/ha application in MR block. The prediction error which is a measure of the difference between observed and expected yields, ranged from 367 kg/ha under control to 889 kg/ha under 100% NPK in FYM block; while it ranged from 784 kg/ha under MR @ 5 t/ha to 1101 kg/ha under 100% NPK in MR block. The regression models indicated that the finger millet yield was significantly influenced by long-term fertilizer application and the changes could be efficiently predicted with minimum prediction error. In a study by Anil Sharma et al., (2013) and Maruthi Sankar et al. (2013), the authors observed a significant influence of long-term application of fertilizer nutrients on yield of crops attained under rainfed conditions.

Principal Component Model

The PCs of monthly rainfall received from July to November, SOC, P and K nutrients were calibrated as described in (2) with the objective of explaining maximum variance in the variables through a few significant PCs. The analysis would give scope for dimensionality reduction and yield prediction through a few significant PCs over years. The Eigen values and variance (%) explained by PCs in model (2) calibrated for different treatments under FYM and MR blocks are given in Table 4.

Based on the PC model calibrated for data observed in FYM block, 4 PCs of control, FYM @ 10 t/ha + 100% NPK and 100% NPK and 3 PCs of FYM @ 10 t/ha and

FYM @ 10 t/ha + 50% NPK were significant with Eigen value of more than 'one' and explained maximum variance in the data. The Eigen values ranged from 1.98 for control to 2.21 for 100% NPK in PC1; 1.69 for control to 1.93 for FYM @ 10 t/ha + 100% NPK in PC2 and 1.05 for FYM @ 10 t/ha + 50% NPK to 1.18 for 100% NPK in PC3. The variance (%) explained by PCs ranged from 61.9% for FYM @ 10 t/ha to 76.4% for 100% NPK.

Based on the PC model of treatments calibrated for the observations recorded in MR block, 4 PCs of control, MR @ 5 t/ha + 100% NPK and 100% NPK explained maximum variance, while 3 PCs explained maximum variance in case of MR @ 5 t/ha and MR @ 5 t/ha + 50% NPK. The Eigen values ranged from 1.93 for control to 2.18 for MR @ 5 t/ha + 100% NPK in PC1; 1.69 for MR @ 5 t/ha to 1.82 for 100% NPK in PC2; and 1.31 for 100% NPK to 1.53 for MR @ 5 t/ha + 50% NPK in PC3. The variance (%) explained by PCs ranged from 64.3% for MR @ 5 t/ha to 75.8% for control. The Eigen values and variance explained by PCs are useful for assessing the efficiency of fertilizer treatments and identifying a superior treatment. In a similar study by Moslem Ladoni et al., (2010), the authors developed a PC model and assessed the changes in organic matter status over years. In a study by Anderson and Furley (1975), the authors observed that capturing variability through a few significant PCs would be useful compared to a prediction model with many non-significant variables.

Loadings of Variables on PCs of Treatments

The loadings of variables on PCs calibrated for each treatment in FYM block are given in Table 5. Based on the PC model, the loadings of July rainfall on PC2 were significant in all treatments compared to PC1 in FYM @ 10 t/ha. The loadings of August rainfall were significant on PC1 for FYM @ 10 t/ha and FYM @ 10 t/ha + 50% NPK; PC2 for control;

and PC4 for FYM @ 10 t/ha + 100% NPK. The September rainfall had a significant loading on PC3 in FYM @ 10 t/ha + 50% NPK. The October rainfall had a significant loading on PC2 in FYM @ 10 t/ha and FYM @ 10 t/ha + 50% NPK; PC3 in control and FYM @ 10 t/ha + 100% NPK; and PC1 in FYM @ 10 t/ha + 100% NPK and 100% NPK. The November rainfall had a significant loading on PC1 in FYM @ 10 t/ha, FYM @ 10 t/ha + 50% NPK; PC2 in control, FYM @ 10 t/ha + 100% NPK and 100% NPK. The SOC had a significant loading on PC1 in control, FYM @ 10 t/ha + 100% NPK and 100% NPK; while it had on PC3 in FYM @ 10 t/ha. Soil P had a significant loading on PC1 in control, FYM @ 10 t/ha + 100% NPK and 100% NPK; while it had on PC2 in FYM @ 10 t/ha + 50% NPK. Soil K had a significant loading on PC1 in FYM @ 10 t/ha; PC2 in FYM @ 10 t/ha + 100% NPK; and PC4 in control.

The loadings of variables on PCs for each treatment in MR block are given in Table 5. Based on the model, the loadings of July and November rainfall were significant on PC2 for all treatments. The loadings of August rainfall were significant on PC3 for MR @ 5 t/ha, MR @ 5 t/ha + 50% NPK and MR @ 5 t/ha + 100% NPK. The September rainfall had a significant loading on PC1 in control; and PC2 in MR @ 5 t/ha + 50% NPK. The October rainfall had a significant loading on PC3. The SOC had a significant loading on PC1 in all treatments. The soil P had a significant loading on PC1 in control, MR @ 5 t/ha + 50% NPK, MR @ 5 t/ha + 100% NPK and 100% NPK; while it had on PC3 in MR @ 5 t/ha. Similarly, soil K had a significant loading on PC1 in MR @ 5 t/ha, MR @ 5 t/ha + 50% NPK and MR @ 5 t/ha + 100% NPK; and PC4 in control. Our results are in agreement with the findings of Maruthi Sankar et al., (2014), who observed significant loadings of rainfall and soil fertility of nutrients on PCs calibrated for the observations recorded from long-term experiments on cotton conducted under semi-arid Vertisols.

Regression Model of Yield through PC Scores

Based on the loadings of variables on PCs and the observed data of variables under different treatments in each year, PC scores were determined for each PC under FYM and MR blocks. Using the grain yield attained by a treatment and PC scores derived for each PC in each treatment, regression model of yield through PC scores were calibrated for each treatment and are given in Table 6. In FYM block, the PC1 had a positive effect on finger millet yield attained by FYM @ 10 t/ha + 50% NPK, FYM @ 10 t/ha + 100% NPK and 100% NPK, while it was negative in control and FYM @ 10 t/ha. The effect of PC3 was positive on all treatments; while the effective of PC2 was negative in all treatments except FYM @ 10 t/ha + 50% NPK. The PC4 had a positive effect on yield in control, FYM @ 10 t/ha + 100% NPK and 100% NPK for which the PC model gave 4th significant PC based on the analysis.

In MR block, PC1 had a positive effect in case of control and MR @ 5 t/ha, while it had a negative effect in case of the other 3 treatments. The PC2 and PC3 had a positive effect on yield of control and 100% NPK, while it had a negative effect on yield attained by other 3 treatments. The PC4 had a positive effect on yield of control for which the PC model gave 4th significant PC based on the analysis. The coefficient of determination was low and ranged from 0.03 to 0.19 in FYM block and 0.06 to 0.17 in MR block. Sanjay Sharma et al., (2009) observed that the relationship of soil fertility and plant uptake of nutrients had a significant influence on the predictability of rainfed soybean yield under semi-arid Vertisols. They found that application of fertilizers through organic and inorganic sources would provide a better yield predictability compared to either only inorganic or organic sources of nutrients.

Sustainability Yield Index

Using the (i) mean yield of fertilizer treatments over years; (ii) prediction error of each treatment based on the regression and PC models; and (iii) maximum yield attained by any treatment during 1984 to 2011, the SYI of treatments in each block were calibrated for assessing the treatments (Maruthi Sankar et al., 2011, 2012b and 2014). The mean yield had a wider range of 506 kg/ha under control to 3207 kg/ha under FYM @ 10 t/ha + 100% NPK in FYM block; while it had a range of 674 kg/ha under control to 2548 kg/ha under MR @ 5 t/ha + 100% NPK in MR block. This indicated that fertilizer application through FYM source had a better impact on finger millet compared to MR source.

Based on the regression model of finger millet yield, the prediction error ranged from 367 kg/ha in control plot to 889 kg/ha in the plot with 100% NPK application in FYM block. Compared to this, the prediction error ranged from 784 kg/ha in the plot with MR @ 5 t/ha to 1101 kg/ha in the plot with 100% NPK application in MR block. Based on the PC model, the prediction error ranged from 405 kg/ha in control plot to 801 kg/ha in 100% NPK application in FYM block. Compared to this, the prediction error ranged from 864 kg/ha in the plot with MR @ 5 t/ha + 50% NPK application to 949 kg/ha in the plot with MR @ 5 t/ha + 100% NPK application in MR block. The prediction error and SYI values based on regression and PC models derived for treatments under FYM and MR blocks are given in Table 7.

SYI based on Regression Model

The SYI ranged from 10.3% for control to 60.3% for FYM @ 10 t/ha in FYM block; -3.7% for control to 32.8% for MR @ 5 t/ha + 100% NPK in MR block based on the regression model. Application of FYM @ 10 t/ha was superior in FYM block; while application of MR @ 5 t/ha + 100% NPK was superior in MR block. Application of FYM @ 10 t/ha + 50% NPK was the 2nd best treatment with marginally lower SYI of 59.8% under FYM block; while MR @ 5 t/ha + 50% NPK was the 2nd best with SYI of 22.6% under MR block. The assessment based on regression model of FYM block indicated that the treatment with a combination of FYM and inorganic fertilizers had a higher sustainability compared to application of MR in combination with inorganic fertilizers under MR block. Our results are in agreement with the findings of Nema et al., (2008) who assessed the sustainability of pearl millet with application of fertilizer through 100% organic, 100% inorganic and 50% organic + 50% inorganic sources in combination with conventional and low tillage levels under semi-arid Inceptisols. They found a better sustainable yield with a mixed application of organic and inorganic fertilizers compared to application through only one source. In a similar study by Behera et al., (2012), the authors found that the integrated use of organic and inorganic fertilizers would influence the sustainability of yield of rice and pigeonpea under rainfed conditions. They assessed the SYI of rice equivalent yield based on a regression model calibrated through soil fertility and crop seasonal rainfall and its monthly distribution from sowing to harvest of crops. Girija et al. (2008) identified a superior treatment combination of organic and inorganic sources at varying soil tests for attaining sustainable finger millet yield under semi-arid Alfisols. The authors explored a regression model of yield through rainfall and soil fertility of nutrients for yield prediction and fertilizer optimization.

SYI based on PC Model

The SYI ranged from 2.2% in control plot to 54.6% in the plot with application of FYM @ 10 t/ha + 100% NPK in FYM block; and -5.2% in control plot to 34.8% in the plot with application of MR @ 5 t/ha + 100% NPK in MR block based on the PC model. Thus application of FYM @ 10 t/ha + 100% NPK in FYM block and MR @ 5 t/ha + 100% NPK in MR block were superior based on the PC model. Application of FYM @ 10 t/ha + 50% NPK with SYI of 50.3% in FYM block and MR @ 5 t/ha + 50% NPK with SYI of 24.7% in MR block were the 2nd best treatments. Thus the assessment based on PC model also indicated that the treatment with a combination of FYM and inorganic fertilizers had a higher SYI compared to MR in combination with inorganic fertilizers. Although FYM @ 10 t/ha + 100% NPK in FYM block and MR @ 5 t/ha + 100% NPK in MR block gave maximum mean yield over years, application of FYM @ 10 t/ha + 50% NPK in FYM block and MR @ 5 t/ha + 50% NPK in MR block could be considered as more efficient for attaining sustainable yield of finger millet over years. Maruthi Sankar et al., (2014) assessed the sustainability yield index of organic and inorganic fertilizer treatments based on a principal component model developed for cotton under semi-arid Vertisols. They found that application of fertilizer through organic and inorganic sources had a better sustainability yield index and provided higher monetary returns, apart from improving the soil fertility of nutrients.

Superior Fertilizer Treatments in FYM and MR Blocks

Under FYM block, with application of FYM @ 10 t/ha, mean yield of 2453 kg/ha was sustainable, while with application of FYM @ 10 t/ha + 50% NPK a higher but at par yield of 2921 kg/ha was sustainable based on both regression and PC models. Although a higher mean yield of 3207 kg/ha with lower SYI was attainable with application of FYM @ 10 t/ha + 100% NPK in the FYM block, it was at par with FYM @ 10 t/ha + 50% NPK over years. Under MR block, MR @ 5 t/ha + 100% NPK was superior with maximum mean yield of 2548 kg/ha and SYI based on both regression and PC models. A lower but at par mean yield of 2000 kg/ha with lower SYI were attained with application of MR @ 5 t/ha + 50% NPK over years. From the soil fertility point of view, higher values of SOC, P and K nutrients were observed in the plot with application of FYM @ 10 t/ha + 50% NPK in FYM block and MR @ 5 t/ha + 100% NPK in MR block based on the study conducted for 28 years.

We have considered the mean cost of cultivation, gross returns, net returns and benefit-cost (BC) ratio of three years (2008, 2009 and 2010) for comparison of the profitability of treatments and are given in Table 7. Based on the cost of cultivation, gross returns, net returns and BC ratio of treatments, application of FYM @ 10 t/ha + 100% NPK was superior with maximum gross returns of Rs.43325/ha and BC ratio of 2.22 in the FYM block. Application of FYM @ 10 t/ha + 50% NPK was the 2nd best with gross returns of Rs.41286/ha and maximum BC ratio of 2.27. In MR block, application of MR @ 5 t/ha + 100% NPK gave maximum gross returns of Rs.34530/ha with BC ratio of 2.09, while MR @ 5 t/ha + 50% NPK was the 2nd best with gross returns of Rs.27878/ha and BC ratio of 1.82. Although the net returns attained by FYM @ 10 t/ha + 100% NPK was higher, the benefit derived from the treatment was reduced due to higher cost of cultivation as a result of use of more inorganic fertilizers compared to application of FYM @ 10 t/ha + 50% NPK. In MR block, application of MR @ 5 t/ha + 100% NPK gave higher net returns than MR @ 5 t/ha + 50% NPK. Thus higher BC ratio of 2.26 and 2.09 was possible with application of FYM @ 10 t/ha + 50% NPK in FYM block and MR @ 5 t/ha + 100% NPK in MR block respectively. Based on the monetary returns point of view, FYM @ 10 t/ha + 50% NPK in FYM block and MR @ 5 t/ha + 100% NPK in MR block were superior compared to other treatments tested in the long-term study. We recommend these two treatments for attaining significantly higher finger millet yield with maximum sustainability yield index and profit, apart from maintenance of maximum soil fertility of nutrients under semi-arid Alfisols.

CONCLUSION

Based on the field experiments of finger millet conducted to assess the sustainability of organic and inorganic fertilizer treatments at Bangalore for 28 years during 1984 to 2011, application of FYM @ 10 t/ha + 100% NPK was superior with significantly higher mean yield of 3207 kg/ha compared to control (506 kg/ha) in FYM block, while MR @ 5 t/ha + 100% NPK was superior with mean yield of 2548 kg/ha compared to control (674 kg/ha) in MR block. Regression and PC models were explored for assessing the yield predictability and long-term sustainability through monthly rainfall and soil fertility variables. Application of FYM @ 10 t/ha + 50% NPK gave 2nd best yield of 2921 kg/ha with maximum SYI compared to FYM @ 10 t/ha + 100% NPK which attained highest yield of 3207 kg/ha with lower SYI. In MR block, MR @ 5 t/ha + 100% NPK was superior with yield of 2548 kg/ha and maximum SYI compared to other treatments. Application of FYM @ 10 t/ha + 100% NPK gave maximum gross returns of Rs.43325/ha with BC ratio of 2.22 in FYM block, while MR @ 5 t/ha + 100% NPK gave maximum returns of Rs.34530/ha with BC ratio of 2.09 in MR block. However, FYM @ 10 t/ha + 50% NPK was the 2nd best with gross returns of Rs.41286/ha and BC ratio of 2.27. The long-term study indicated that FYM @ 10 t/ha + 50% NPK and MR @ 5 t/ha + 100% NPK were superior for attaining maximum yield, SYI, monetary returns and soil fertility under occurrence of monthly rainfall with a high variability during 28 years. The farmers could greatly benefit with the application of these two treatments by attaining maximum finger millet yield and monetary returns, apart from retaining soils with maximum fertility under semi-arid Alfisols.

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Table 1 : Monthly rainfall and crop growing period of finger millet at Bangalore

Year	DOS	DOH	CGP	Jul	Aug	Sep	Oct	Nov	CRF
1984	23-Jul	27-Nov	128	103.7	131.2	200.0	148.1	57.9	640.9
1985	20-Jul	24-Nov	126	87.5	51.0	214.8	60.3	75.0	488.6
1986	21-Jul	21-Nov	124	74.1	70.0	333.6	28.0	59.6	565.3
1987	30-Jul	30-Nov	124	45.0	124.4	158.5	123.1	100.2	551.2
1988	19-Jul	18-Nov	123	272.0	167.7	388.1	123.9	18.9	970.6
1989	18-Jul	12-Dec	148	154.4	48.2	283.0	193.4	22.6	701.6
1990	12-Aug	22-Dec	133	32.2	79.7	92.6	111.9	32.2	348.6
1991	6-Aug	12-Dec	129	21.1	152.2	66.9	540.9	152.2	933.3
1992	6-Aug	30-Nov	117	135.8	98.6	194.2	107.6	70.8	607.0
1993	4-Aug	14-Dec	133	58.5	150.6	328.1	273.4	21.6	832.2
1994	28-Jul	29-Dec	155	92.3	94.8	115.3	212.1	21.0	535.5
1995	4-Aug	4-Dec	123	86.6	189.4	75.9	126.4	26.6	504.9
1996	14-Aug	28-Dec	137	26.7	158.2	211.2	84.4	2.0	482.5
1997	27-Aug	28-Dec	124	30.4	67.8	294.9	316.8	193.8	903.7
1998	29-Jul	29-Nov	124	132.2	352.2	245.7	241.7	37.5	1009.3
1999	14-Aug	17-Dec	126	49.4	205.3	238.7	196.8	71.2	761.4
2000	4-Aug	7-Dec	126	97.3	312.4	239.8	168.4	5.8	823.7
2001	31-Jul	5-Dec	128	136.0	78.1	347.6	121.8	32.6	716.1
2002	30-Sep	3-Jan	96	44.0	31.8	43.8	167.8	52.2	339.6
2003	18-Jul	20-Nov	116	90.4	107.6	65.8	231.9	4.8	500.5
2004	14-Jul	25-Oct	104	142.2	55.4	290.4	193.2	16.0	697.2
2005	23-Jul	21-Nov	122	122.4	249.2	198.2	523.6	41.1	1134.5
2006	15-Jul	25-Nov	134	84.4	60.0	61.0	36.0	110.4	351.8
2007	18-Jul	24-Nov	130	149.2	189.8	179.1	151.6	12.4	682.1
2008	15-Jul	17-Nov	126	182.8	249.8	126.0	205.4	7.6	771.6
2009	17-Aug	25-Nov	101	55.6	106.8	231.7	29.6	42.6	466.3
2010	13-Jul	15-Nov	126	142.2	158.6	89.4	119.2	128.6	638.0
2011	6-Aug	8-Dec	125	95.8	253.2	59.7	122.6	38	569.3
Mean			*125*	*98.0*	*142.6*	*191.9*	*177.1*	*52.0*	661.7
SD			*12.0*	*55.9*	*83.4*	*100.6*	*122.6*	*47.4*	206.8
CV			*9.6*	*57.0*	*58.4*	*52.4*	*69.2*	*91.2*	31.2

DOS: Date of sowing DOH: Date of harvest CGP: Crop growing period
CRF: Crop seasonal rainfall (mm) SD: Standard deviation CV: Coefficient of variation (%)

Table 2 : Mean and standard deviation of effect of treatments on soil nutrients and finger millet yield at Bangalore

Variable	FYM block					Maize Residue block				
	T1	**T2**	**T3**	**T4**	**T5**	**T1**	**T2**	**T3**	**T4**	**T5**
Soil Organic carbon (%)	0.31 ± 0.04 b	0.44 ± 0.06 a	0.46 ± 0.07 a	0.46 ± 0.09 a	0.33 ± 0.06 b	0.29 ± 0.03 b	0.40 ± 0.07 a	0.41 ± 0.07 a	0.40 ± 0.06 a	0.34 ± 0.05 b
Soil P (kg/ha)	22.6 ± 10.1 d	95.6 ± 32.8 c	134.2 ± 35.5 ab	154.7 ± 29.3 a	112.5 ± 32.8 bc	32.1 ± 13.9 d	66.4 ± 21.4 c	89.3 ± 32.4 b	112.0 ± 32.5 a	96.3 ± 27.0 ab
Soil K (kg/ha)	73 ± 15 d	106 ± 18 abc	118 ± 27 ab	131 ± 26 a	97 ± 17 bcd	67 ± 13 c	86 ± 11 b	95 ± 19 ab	110 ± 27 a	89 ± 17 b
Grain yield (kg/ha)	506 ± 415 d	2453 ± 544 bc	2921 ± 604 ab	3207 ± 690 a	1890 ± 803 c	674 ± 926 c	1095 ± 947 c	2000 ± 841 ab	2548 ± 936 a	1943 ± 948 b

FYM block : T1: Control T2: FYM @ 10 t/ha T3: FYM @ 10 t/ha + 50% NPK
T4: FYM @ 10 t/ha + 100% NPK T5: 100% NPK

LSD ($p < 0.05$): Grain yield = 676 kg/ha; SOC = 0.08%; Soil P = 33 kg/ha; Soil K = 26 kg/ha

Maize residue block : T1: Control T2: MR @ 5 t/ha T3: MR @ 5 t/ha + 50% NPK
T4: MR @ 5 t/ha + 100% NPK T5: 100% NPK

LSD ($p < 0.05$): Grain yield = 589 kg/ha; SOC = 0.05%; Soil P = 19.6 kg/ha; Soil K = 15 kg/ha

Treatments with same letter (a, b, c, d) are at par with each other for each parameter within a block

Table 3 : Regression model of finger millet yield calibrated through monthly rainfall and soil nutrient variables

Treatment	Regression model	R^2
FYM Block		
Control	$Y = -2359^* - 8.06 (Jul) + 0.035 (Jul)^2 - 1.55 (Aug) - 0.003 (Aug)^2 + 7.44^* (Sep) - 0.017 (Sep)^2 + 0.57 (Oct) + 0.001 (Oct)^2 + 8.97 (Nov) - 0.056 (Nov)^2 + 5073^* (SOC) + 22.58^* (SP) + 6.92 (SK)$	0.60*
FYM @ 10 t/ha	$Y = 2419 + 8.20 (Jul) - 0.045 (Jul)^2 - 2.43 (Aug) + 0.006 (Aug)^2 + 5.48 (Sep) - 0.012 (Sep)^2 + 9.42^* (Oct) - 0.014 (Oct)^2 - 9.99 (Nov) + 0.058 (Nov)^2 + 2093 (SOC) - 15.54^* (SP) + 6.81 (SK)$	0.44
FYM @ 10 t/ha + 50% NPK	$Y = 525 + 8.74 (Jul) - 0.035 (Jul)^2 - 1.06 (Aug) + 0.004 (Aug)^2 + 4.74 (Sep) - 0.012 (Sep)^2 + 9.42^* (Oct) - 0.014 (Oct)^2 - 0.19 (Nov) + 0.008 (Nov)^2 + 3581 (SOC) - 8.79 (SP) + 1.34 (SK)$	0.44
FYM @ 10 t/ha + 100% NPK	$Y = -4273 - 1.14 (Jul) + 0.013 (Jul)^2 + 7.11 (Aug) - 0.021 (Aug)^2 + 3.81 (Sep) - 0.006 (Sep)^2 + 8.65 (Oct) - 0.013 (Oct)^2 + 15.60 (Nov) - 0.087 (Nov)^2 + 4207 (SOC) + 8.58 (SP) + 14.63^* (SK)$	0.44
100% NPK	$Y = 1199 - 6.04 (Jul) + 0.035 (Jul)^2 + 6.64 (Aug) - 0.023 (Aug)^2 + 7.49 (Sep) - 0.022 (Sep)^2 + 1.50 (Oct) - 0.004 (Oct)^2 + 4.18 (Nov) - 0.014 (Nov)^2 + 4522 (SOC) - 8.23 (SP) - 7.45 (SK)$	0.37
Maize residue Block		
Control	$Y = -4757 - 7.51 (Jul) + 0.037 (Jul)^2 + 1.70 (Aug) - 0.013 (Aug)^2 + 13.41 (Sep) - 0.029 (Sep)^2 + 4.10 (Oct) - 0.005 (Oct)^2 + 26.10^* (Nov) - 0.147^* (Nov)^2 + 9215 (SOC) + 46.11^{**} (SP) - 10.74 (SK)$	0.59*
MR @ 5 t/ha	$Y = 5401^* - 8.95 (Jul) + 0.029 (Jul)^2 + 1.17 (Aug) - 0.007 (Aug)^2 + 10.69 (Sep) - 0.026 (Sep)^2 - 0.30 (Oct) - 0.005 (Oct)^2 + 4.05 (Nov) - 0.011 (Nov)^2 + 888 (SOC) + 10.91 (SP) - 64.30^* (SK)$	0.65*
MR @ 5 t/ha + 50% NPK	$Y = 1274 + 8.16 (Jul) - 0.014 (Jul)^2 + 3.71 (Aug) - 0.014 (Aug)^2 + 16.62 (Sep) - 0.044 (Sep)^2 - 0.45 (Oct) + 0.001 (Oct)^2 + 4.11 (Nov) - 0.004 (Nov)^2 + 3102 (SOC) - 11.71 (SP) - 15.68 (SK)$	0.28
MR @ 5 t/ha + 100% NPK	$Y = 774 + 15.15 (Jul) - 0.060 (Jul)^2 + 8.43 (Aug) - 0.026 (Aug)^2 + 12.67 (Sep) - 0.030 (Sep)^2 + 4.10 (Oct) - 0.008 (Oct)^2 + 4.60 (Nov) - 0.005 (Nov)^2 + 2072 (SOC) - 18.01 (SP) + 1.21 (SK)$	0.36
100% NPK	$Y = 1094 + 10.00 (Jul) - 0.030 (Jul)^2 + 6.70 (Aug) - 0.026 (Aug)^2 + 9.18 (Sep) - 0.023 (Sep)^2 + 2.05 (Oct) - 0.005 (Oct)^2 + 10.44 (Nov) - 0.046 (Nov)^2 + 770 (SOC) - 11.78 (SP) - 2.89 (SK)$	0.30

* and ** indicate significance at $p < 0..05$ and $p < 0.01$ level respectively
SOC : Soil organic carbon (%) SP : Soil P (kg/ha) SK : Soil K (kg/ha)
R^2 : Coefficient of determination

Table 4 : Eigen values and variance of principal components calibrated through rainfall and soil nutrients

Treatment	Eigen values				Variance (%) explained				Total
	PC-1	PC-2	PC-3	PC-4	PC-1	PC-2	PC-3	PC-4	
FYM Block									
Control	1.98	1.69	1.11	1.05	24.8	21.1	13.8	13.2	72.9
FYM @ 10 t/ha	2.10	1.76	1.10		26.2	21.9	13.8		61.9
FYM @ 10 t/ha + 50% NPK	2.14	1.83	1.18		26.7	22.9	14.8		64.3
FYM @ 10 t/ha + 100% NPK	2.00	1.93	1.08	1.00	25.0	24.1	13.5	12.5	75.1
100% NPK	2.21	1.81	1.05	1.04	27.6	22.6	13.1	13.0	76.4
Maize residue Block									
Control	1.93	1.71	1.40	1.03	24.1	21.4	17.5	12.8	75.8
MR @ 5 t/ha	1.95	1.69	1.50		24.4	21.2	18.7		64.3
MR @ 5 t/ha + 50% NPK	2.12	1.77	1.53		26.4	22.2	19.1		67.7
MR @ 5 t/ha + 100% NPK	2.18	1.78	1.52		27.2	22.2	19.0		68.4
100% NPK	2.05	1.82	1.31		25.6	22.7	16.3		64.7

PC-1, PC-2, PC-3 and PC-4 are 1st, 2nd, 3rd and 4th principal components respectively

Table 5 : Loadings of rainfall and soil nutrient variables on PCs of different treatments

Treatment	JUL	AUG	SEP	OCT	NOV	SOC	SP	SK
FYM Block								
Control								
PC-1	-0.20	0.40	-0.55	0.46	0.35	-0.77	0.60	0.43
PC-2	0.77	0.65	0.32	-0.03	-0.68	-0.19	0.26	0.04
PC-3	0.02	0.25	0.44	0.77	0.26	0.01	-0.44	-0.06
PC-4	0.23	-0.16	0.19	-0.25	0.16	-0.18	-0.37	0.82
FYM @ 10 t/ha								
PC-1	0.46	0.68	0.10	0.36	-0.60	0.36	0.58	-0.68
PC-2	-0.67	0.14	-0.55	0.64	0.48	0.13	0.57	0.08
PC-3	0.23	0.11	0.33	0.46	0.38	-0.72	-0.09	-0.23
FYM @ 10 t/ha + 50% NPK								
PC-1	0.60	0.62	0.16	0.13	-0.70	0.52	0.54	-0.55
PC-2	-0.47	0.25	-0.46	0.73	0.35	-0.39	0.62	-0.39
PC-3	0.25	-0.12	0.73	0.30	0.08	-0.54	-0.21	-0.39
FYM @ 10 t/ha + 100% NPK								
PC-1	0.35	-0.25	0.47	-0.62	-0.15	0.61	-0.78	0.45
PC-2	0.74	0.57	0.31	0.05	-0.72	0.05	0.10	-0.65
PC-3	0.14	0.19	0.54	0.61	0.44	-0.20	-0.35	0.08
PC-4	-0.05	0.60	-0.44	0.26	0.07	0.56	-0.13	0.23
100% NPK								
PC-1	0.09	-0.54	0.31	-0.70	0.04	0.71	-0.79	0.45
PC-2	0.79	0.40	0.55	-0.12	-0.74	0.03	-0.10	-0.40
PC-3	0.31	0.39	0.16	0.19	0.35	-0.41	-0.36	0.57
PC-4	0.01	-0.31	0.57	0.48	0.43	0.07	-0.15	-0.42
Maize residue Block								
Control								
PC-1	-0.12	0.30	-0.61	0.02	0.24	-0.78	0.76	0.47
PC-2	0.81	0.57	0.36	-0.14	-0.70	-0.28	0.11	0.04
PC-3	0.03	-0.54	0.03	-0.92	-0.19	0.17	0.40	0.17
PC-4	0.20	-0.36	0.14	0.13	0.14	-0.37	0.33	-0.75
MR @ 5 t/ha								
PC-1	0.36	0.02	0.53	0.31	-0.11	-0.80	-0.35	-0.81
PC-2	0.72	0.44	0.35	-0.36	-0.78	0.18	0.11	0.30
PC-3	0.08	0.65	-0.40	0.69	-0.02	-0.24	0.61	0.02
MR @ 5 t/ha + 50% NPK								
PC-1	0.25	0.43	-0.30	-0.25	-0.26	0.85	0.66	0.70
PC-2	-0.75	-0.35	-0.61	0.09	0.71	0.06	0.02	0.44
PC-3	-0.08	0.62	-0.30	0.82	0.03	-0.30	0.47	-0.26
MR @ 5 t/ha + 100% NPK								
PC-1	-0.29	0.16	-0.47	-0.10	0.27	0.70	0.70	0.88
PC-2	0.75	0.42	0.40	-0.38	-0.68	0.51	0.10	0.07
PC-3	0.07	0.77	-0.21	0.72	-0.15	-0.29	0.45	-0.24
100% NPK								
PC-1	0.04	0.51	-0.50	0.13	-0.05	-0.69	0.89	0.50
PC-2	-0.82	-0.41	-0.49	0.06	0.73	0.31	0.06	0.35
PC-3	0.09	-0.30	0.07	-0.93	-0.25	0.12	0.15	0.49

PC-1, PC-2, PC-3 and PC-4 are 1st, 2nd, 3rd and 4th principal components respectively
SOC : Soil organic carbon (%) SP : Soil P (kg/ha) SK : Soil K (kg/ha)

Table 6 : Regression models of yield of treatments through principal component scores in different blocks

Treatment	Principal component regression model	R^2
FYM Block		
Control	Y = 667 – 1.18 (PC1) – 0.98 (PC2) + 0.16 (PC3) + 1.37 (PC4)	0.19
FYM @ 10 t/ha	Y = 2236** – 0.38 (PC1) – 0.14 (PC2) + 1.58 (PC3)	0.03
FYM @ 10 t/ha + 50% NPK	Y = 2768** + 0.87 (PC1) + 0.03 (PC2) + 0.19 (PC3)	0.03
FYM @ 10 t/ha + 100% NPK	Y = 2657** + 3.84 (PC1) – 1.43 (PC2) + 2.30 (PC3) + 3.98 (PC4)	0.07
100% NPK	Y = 1966** + 3.17 (PC1) – 0.89 (PC2) + 2.32 (PC3) + 0.18 (PC4)	0.15
Maize residue Block		
Control	Y = 1302** + 2.52 (PC1) + 0.84 (PC2) + 2.53 (PC3) + 9.30 (PC4)	0.17
MR @ 5 t/ha	Y = 1632** + 1.28 (PC1) – 1.80 (PC2) - 2.91* (PC3)	0.13
MR @ 5 t/ha + 50% NPK	Y = 2192** - 1.42 (PC1) – 0.59 (PC2) – 1.23 (PC3)	0.06
MR @ 5 t/ha + 100% NPK	Y = 3043** - 2.80 (PC1) – 1.13 (PC2) – 1.63 (PC3)	0.09
100% NPK	Y = 2391** - 3.79 (PC1) + 0.58 (PC2) + 0.49 (PC3)	0.12

PC-1, PC-2, PC-3 and PC-4 are 1st, 2nd, 3rd and 4th principal components respectively
* and ** indicate significance at $p < 0..05$ and $p < 0.01$ level respectively
R^2 : Coefficient of determination

Table 7 : Sustainability yield index and monetary returns of treatments in finger millet at Bangalore

Treatments	**Yield (kg/ha)**			**PE**		**SYI**		**CC**	**GR**	**NR**	**BC**
	Min	**Max**	**Mean**	**REG**	**PC**	**REG**	**PC**				
FYM Block											
Control	54	1356	506	367	405	10.3	2.2	8138	3751	-4387	0.46
FYM @ 10 t/ha	1146	3125	2453	568	570	60.3	41.4	16973	30526	13553	1.80
FYM @ 10 t/ha + 50% NPK	1432	3836	2921	628	632	59.8	50.3	18206	41286	23080	2.27
FYM @ 10 t/ha + 100% NPK	1821	4552	3207	714	721	54.8	54.6	19506	43325	23819	2.22
100% NPK	756	3429	1890	889	801	29.2	23.9	14672	27215	12543	1.85
Maize residue Block											
Control	24	4051	674	822	912	-3.7	-5.2	7805	2768	-5037	0.35
MR @ 5 t/ha	115	4282	1095	784	938	7.3	3.4	12305	9055	-3250	0.74
MR @ 5 t/ha + 50% NPK	302	4475	2000	990	864	22.6	24.7	15319	27878	12559	1.82
MR @ 5 t/ha + 100% NPK	593	4591	2548	1043	949	32.8	34.8	16506	34530	18024	2.09
100% NPK	407	4128	1943	1101	943	20.4	21.8	13756	21029	7273	1.53

Value of finger millet : Rs.10/kg

PE: Prediction error (kg/ha) SYI: Sustainability yield index (%) CC: Cost of cultivation (Rs/ha)

GR : Gross returns (Rs/ha) NR : Net returns (Rs/ha) BC: Benefit-cost ratio

REG : Regression model PC : Principal component model

Fig 1. Mean and standard deviation of monthly rainfall at Bangalore during 1984 to 2011

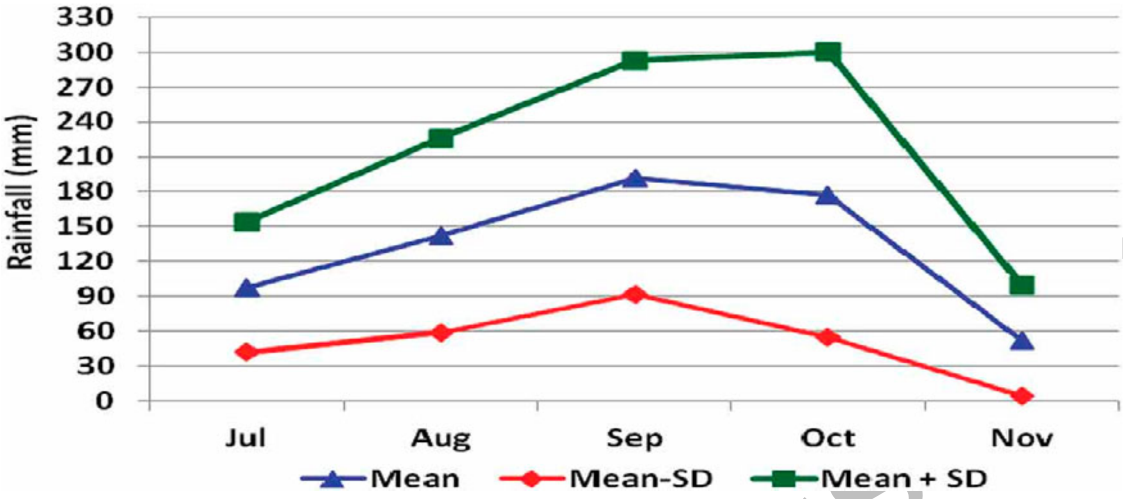

Fig 2. Relationship between soil test values and finger millet yield in different treatments under FYM and maize residue blocks