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Efficient Nutrient Management Practices for Sustainable Crop Productivity and Soil Fertility Maintenance Based on Permanent Manorial Experiments in Different Soil and Agro-Climatic Conditions

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Additional information is available at the end of the chapter

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1. Introduction

Rainfed agriculture plays an important role in contributing to the food bowl of the world. Its importance varies regionally but produces food for poor communities in developing countries. In India, rainfed agriculture is in about 85 million hectare, constituting about 60 % of net cultivated areas supporting 40% of the population of the country. In Sub-Saharan Africa, more than 95 % farm land is rainfed, while the corresponding figure for Latin America is almost 90%, for South Asia about 60 %, for East Asia 65% and for the Near East and North Africa 75% (Wani, *et al.*, 2009). Besides, the climatic constraints especially erratic and uncertain pattern of rainfall, soils in the rainfed areas are under severe grip of degradation in terms of their physical, chemical and biological properties.

In AICRPDA, permanent manorial experiments (PME) are conducted on different rainfed crops viz., upland rice, sorghum, finger millet, pearl millet, cotton, maize, soybean, groundnut crops under varying soil and agro-climatic conditions at different centers. They are conducted in alfisols, vertisols, inceptisols, entisols, aridisols and other soil types. Alfisols are most abundant soils in the semi-arid tropics and cover about 16% of tropics and 33% of semi-arid tropics (SAT). These soils are mostly found in the 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 viz., 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.

Vertisols are the predominant soil groups found across the world. The majority of the acreage of Vertisols and associated soils in the world is spread in Australia (70.5 million ha), India (70 million ha), Sudan (40 million ha), Chad (16.5 million ha), and Ethiopia (10 million ha). These five countries constitute over 80% of the total area (250 million ha) of Vertisols in the world (Dudal 1965). In India, substantial Vertisol areas are found in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, and Tamil Nadu (Murthy 1981). Most of these regions receive 500 to 1300 mm of annual rainfall, concentrated in a short period of 3 to 3½ rainy months interspersed with droughts. Crop yields in these areas are miserably low and may vary from year to year. Virmani et al., (1989) have comprehensively characterized Vertisols found in India. Their texture may vary from clay to clay loam, or silty clay loam, with the clay content generally varying from 40% to 60% or more. They have high bulk density when dry, with clod density values ranging from 1.5 to 1.8 g cm⁻³; high CEC (47 to 65 cmol kg soil⁻¹); and pH values usually above 7.5. Tropical Vertisols are low in organic matter and available plant nutrients, particularly N, P, and Zinc. The dominant clay mineral is smectite. High clay content, better effective soil depth associated with other physical properties makes these soils to store higher amount of moisture. Low organic matter status accompanied by poor soil fertility is one of the predominant constraints in these Vertisol soils. Farmers of the rainfed SAT regions, being poor, are not able to use adequate amount of chemical fertilizers. Earlier researchers have established that the productivity of these soils can be enhanced by way of supplying adequate nutrient inputs (Virmani et al., 1989; Willey et al., 1989; Burford et al., 1989). Based on numerous agronomic experiments, it has been found that supplementation of N, P and Zinc through fertilizer is inevitable to ensure satisfactory crop production in SAT soils especially in Vertisols (Kanwar 1972; Randhawa and Tandon 1982). Despite many efforts, there is a low adoption of fertilizers in rainfed crops which could probably be attributed to many reasons viz., incapability of the farmers to purchase fertilizers, erratic and uncertain rainfall leading to risk of crop failures, uncertainty and variability in crop responses (Jha and Sarin, 1984; Kanwar et al., 1973).

The productivity of any rainfed crop is significantly influenced by the distribution of seasonal rainfall during cropping season, soil fertility status and amount of fertilizer nutrient applied

(Maruthi Sankar, 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 et al., (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 et al., 1991; Dalal and Mayer 1986; Mathur 1997). Permanent manorial experiments are conducted at different research centers of AICRPDA with an objective to i) assess the response of rainfed crops and changes in soil fertility (with special emphasis on nitrogen, phosphorus, and potassium) due to long term application of organic and inorganic sources of nutrients under changing crop seasonal rainfall situations and ii) identify an efficient treatment for attaining sustainable yield over long-term basis under different soils and climatic conditions. The details of PME conducted on (i) finger millet at Bangalore; (ii) sorghum/pearl millet rotation at Kovilpatti; (iii) groundnut at Anantapur; (iv) cotton + green gram (1:1) at Akola; (v) soybean at Indore are discussed in this paper.

2. Materials and methods

2.1. Experimental details

The permanent manorial experiments (PME) have been conducted on different crops with a set of organic and inorganic fertilizer treatments at different AICRPDA research centers for more than 20-25 years (Table 1). The PME were conducted on (i) finger millet at Bangalore (Karnataka); (ii) groundnut at Anantapur (Andhra Pradesh); (iii) soybean at Indore (Madhya Pradesh); (iv) cotton + green gram in 1:1 row ratio at Akola (Maharashtra); (v) sorghum rotated with pearl millet (yearly) at Kovilpatti (Tamil Nadu); (vi) rice at Phulbani (Orissa); (vii) rice at Varanasi (Uttar Pradesh); (viii) rice at Ranchi (Jharkhand); (ix) pearl millet at Agra (Uttar Pradesh); (x) rabi sorghum at Solapur (Maharashtra); (xi) rabi sorghum at Bijapur (Karnataka); (xii) pearl millet/castor/cluster bean rotation (yearly) at SK Nagar (Gujarat); (xiii) rice in kharif followed by wheat in rabi at Rewa (Madhya Pradesh). The treatments were replicated thrice and tested in a Randomized Block Design. The treatments were randomized only in the first year and were fixed and superimposed to the same plots every year. Before superimposing the 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). Soil sulphur was estimated by turbidity method (Chesnin and Yien, 1950) in each season. Observations on daily rainfall, variety, date of sowing and harvest, crop growing period, length of dry spells and other related details were also recorded every year and used for analysis.

Center	Climate	Soil type	Crop	Year	Treatments
Bangalore	Semi-arid	Alfisols	Finger millet	1984-2008	T1 : Control; T2 : FYM @ 10 t/ha; T3 : FYM @ 10 t/ha + 50% NPK; T4 : FYM @ 10 t/ha + 100% NPK; T5 : 100% recommended NPK
Anantapur	Arid	Alfisols	Groundnut	1985-2006	T1: Control; T2: 100% NPK (20-40-40 kg/ha); T3: 50% NPK (10-20-20 kg/ha); T4: 100% N (groundnut shells ~ 20 kg N/ha); T5: 50% N (FYM ~ 10 kg N/ha); T6: 100% N (groundnut shells ~ 20 kg N/ha) + 50% NPK (10-20-20 kg/ha); T7: 50% N (FYM~10 kg N/ha) + 50% NPK (10-20-20 kg/ha); T8: 100% NPK (20-40-40 kg/ha) + ZnSO ₄ @ 25 kg/ha; T9: Farmers practice (FYM @ 5 t/ha)
Indore	Semi-arid	Vertisols	Soybean	1992-2006	T1 : Control; T2 : 20 kg N (urea) + 13 kg P/ha; T3 : 30 kg N (urea) + 20 kg P/ha; T4 : 40 kg N (urea) + 26 kg P/ha; T5 : 60 kg N (urea) + 35 kg P/ha; T6 : 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha; T7 : 20 kg N (urea) + 13 kg P + FYM @ 5 t/ha; T8 : FYM @ 6 t/ha; T9 : Crop residue @ 5 t/ha
Kovilpatti	Semi-arid	Vertisols	Sorghum/ Pearl millet	1987-2005	T1 : Control; T2 : 40 kg N (urea) + 20 kg P/ha; T3 : 20 kg N (urea) + 10 kg P/ha; T4 : 20 kg N (crop residue)/ha; T5 : 20 kg N (FYM)/ha; T6 : 20 kg N (crop residue) + 20 kg N (urea)/ha; T7 : 10 kg N (FYM) + 10 kg N (urea)/ha; T8 : 40 kg N (urea) + 20 kg P + 25 kg ZnSO ₄ /ha; T9 : FYM @ 5 t/ha
Akola	Semi-arid	Vertisols	Cotton + green gram (1:1)	1987-2006	T1 : Control; T2 : 50 kg N + 25 kg P/ha; T3 : 25 kg N + 12.5 kg P/ha; T4 : 25 kg N/ha (<i>Leucaena</i>); T5 : 25 kg N/ha (FYM); T6 : 25 kg N (<i>Leucaena</i>) + 25 kg N (urea) + 25 kg P/ha; T7 : 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha; T8 : 25 kg N (<i>Leucaena</i>) + 25 kg P/ha

Table 1. Permanent manorial experiments conducted at different AICRPDA centers

At Bangalore, 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. The 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 treatments were (i) Control; (ii) FYM @ 10 t/ha; (iii) FYM @ 10 t/ha + 50% NPK; (iv) FYM @ 10 t/ha + 100% NPK; and (v) 100% recommended NPK. The 100% recommended NPK dose comprised of 50 kg N, 50 kg P₂O₅ and 25 kg K₂O/ha. The experiment was conducted in a net plot size of 2.7 m x 11.0 m each with row spacing of 30 cm and plant spacing of 10 cm.

At Akola, PME on cotton + green gram (1:1) was conducted for 20 years in a fixed site during South-West monsoon of 1987 to 2006 (June to November) in a semi-arid Vertisol. The research center is located at a latitude of 12.97° North, longitude of 77.58° East and an altitude of 930 m above mean sea level. The fertilizer treatments were applied in the same plot every year and are T1 : Control; T2 : 50 kg N + 25 kg P/ha; T3 : 25 kg N + 12.5 kg P/ha; T4 : 25 kg N/ha (*Leucaena*); T5 : 25 kg N/ha (FYM); T6 : 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha; T7 : 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha; and T8 : 25 kg N (*Leucaena*) + 25 kg P/ha. The trials were conducted in a net plot size of 8.4 m x 9.4 m with spacing of 60 x 30 cm for cotton and 30 x 10 cm for green gram every year.

At Kovilpatti, 15 experiments on sorghum (*Sorghum bicolor* L.) and 9 experiments on pearl millet (*Pennisetum americanum* L.) were conducted in a permanent site during North-East monsoon season (October to January) of 1987 to 2005 in a semi-arid vertic Inceptisol. The center is located at a latitude of 9.12° North, longitude of 77.53° East and an altitude of 166.42 m above mean sea level. Sorghum was grown every year up to 1987, and was rotated with pearl millet. Nine treatments which are combinations of urea, FYM and crop residue were tested in a net plot size of 7.5 m x 3.6 m and row spacing of 45 cm for both crops. The treatments tested were (i) Control; (ii) 40 kg N (urea) + 20 kg P/ha; (iii) 20 kg N (urea) + 10 kg P/ha; (iv) 20 kg N (crop residue)/ha; (v) 20 kg N (FYM)/ha; (vi) 20 kg N (crop residue) + 20 kg N (urea)/ha; (vii) 10 kg N (FYM) + 10 kg N (urea)/ha; (viii) 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha; and (ix) FYM @ 5 t/ha. The crop residue contained 1.2% N, while FYM contained 0.5% N.

At Indore, 15 field experiments of soybean were conducted on a permanent site during *khari* season (June to October) of 1992 to 2006 in a semi-arid Vertisol. The research center is located at a latitude of 20°43' N and longitude of 76°54' E. The experiments were conducted with a set of 9 fertilizer treatments which are combinations of urea, farmyard manure (FYM) and crop residue superimposed to the same plots in each season. The treatment combinations tested were (i) control (ii) 20 kg N (urea) + 13 kg P/ha (iii) 30 kg N (urea) + 20 kg P/ha (iv) 40 kg N (urea) + 26 kg P/ha (v) 60 kg N (urea) + 35 kg P/ha (vi) 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha (vii) 20 kg N (urea) + 13 kg P + FYM @ 5 t/ha (viii) FYM @ 6 t/ha and (ix) Crop residue @ 5 t/ha. The crop residue contained 0.75% N, 0.045 P and 0.14% K, whereas FYM contained 0.66% N, 0.45% P and 0.50% K. The field experiments were conducted in a net plot size of 9.0 m x 6.4 m with row spacing of 30 cm. The fertilizer treatments were randomized and superimposed to plots in a Randomized Block Design

with 4 replications. FYM was applied 10 days prior to sowing, while the crop residue was applied as surface mulch after emergence of the crop in the prescribed treatments.

At Anantapur, 22 experiments were conducted on groundnut (*Arachis hypogea*) in a fixed site in *kharif* (July to November) during 1985 to 2006 under arid Alfisols. Anantapur is located at a latitude of 14.68° North, longitude of 77.62° East and an altitude of 350 m above mean sea level. The permanent site where trials were conducted was a shallow Alfisol with soil depth of 30 cm. The earliest date of sowing of groundnut was on 1st July in 2000, while the farthest was on 12th September in 2006. The earliest date of harvest was on 23rd October in 2000, while the farthest was on 3rd January in 2006. The crop had a minimum duration of 107 days in 1996 and 1999 and maximum duration of 127 days in 1985 with mean duration of 116 days having variation of 5.3% over years. A general recommended fertilizer NPK dose of 20–40–40 kg/ha was used for rainfed groundnut under Alfisols in Andhra Pradesh. Nine fertilizer NPK treatments which are combinations of inorganic and organic sources were tested every year. Apart from inorganic N through urea, P through single super phosphate and K through muriate of potash, organic N through groundnut shells and FYM were included in the different treatment combinations. The trials were conducted based on Randomized Block Design with 3 replications. The fertilizer NPK and organic N treatments tested were : T1: Control; T2: 100% NPK (20–40–40 kg/ha); T3: 50% NPK (10–20–20 kg/ha); T4: 100% N (groundnut shells ~ 20 kg N/ha); T5: 50% N (FYM ~ 10 kg N/ha); T6: 100% N (groundnut shells ~ 20 kg N/ha) + 50% NPK (10–20–20 kg/ha); T7: 50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha); T8: 100% NPK (20–40–40 kg/ha) + ZnSO₄ @ 25 kg/ha; T9: Farmers practice (FYM @ 5 t/ha). The FYM contained 0.5% N, 1% P and 0.75% K on dry weight basis. All the improved agronomic practices prescribed for groundnut were adopted while conducting the trials.

2.2. Statistical analysis

The differences in effects of treatments in influencing soil fertility of N, P and K nutrients and crop yield 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, 1984). 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. Regression models of yield attained by each treatment were calibrated for assessing the influence of crop seasonal rainfall, soil N, P and K nutrients on yield of a crop over years as suggested by Draper and Smith (1998). The regression model through crop seasonal rainfall, soil N, P and K could be postulated as

$$Y = \pm\alpha \pm\beta_1 (\text{Jun}) \pm\beta_2 (\text{Jul}) \pm\beta_3 (\text{Aug}) \pm\beta_4 (\text{Sep}) \pm \beta_5 (\text{Oct}) \pm\beta_6 (\text{Nov}) \pm\beta_7 (\text{SN}) \pm\beta_8 (\text{SP}) \pm\beta_9 (\text{SK}) \quad (1)$$

In model (1), α is intercept and β_1 to β_9 are regression coefficients measuring effects of variables on yield. The variables of monthly rainfall are retained depending on the dates of sowing and harvest and crop growing period. Soil sulphur was also included in the model calibrated for soybean at Indore. 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. The sustainability yield index (SYI) of a fertilizer treatment could be derived as a 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; Maruthi Sankar et al., 2011, 2012a, 2012b).

At Kovilpatti, observations were recorded on daily rainfall (mm) and Pan Evaporation (E_p , in mm) during 1987 to 2005. Accordingly, the daily soil water balance computational procedure of Rijtema and Aboukhaled (1975) was used to calculate the Water Requirement (WR, mm), Potential Evapotranspiration (PET, mm) and Actual Evapotranspiration (AET, mm) for sorghum and pearl millet. The Crop Water Stress (CWS) was estimated by using the procedure as discussed by Hiler and Clark (1971). The crop coefficient values were determined by interpolating the values given by Doorenbos and Kassam (1979). The CWS ranged from 0.1% in 1987, 1993 and 1997 to 60.5% in 1995 with mean of 15.6% and variation of 119.9% for sorghum. In pearl millet, it ranged from 0.1% in 1996 to 71.5% in 1994 with mean of 31.7% and variation of 71.8% for pearl millet.

At Kovilpatti, the treatment-wise regression models of yield were developed using different variables of soil N, P, and K, crop seasonal rainfall, crop growing period, crop water stress measured under each treatment (Maruthi Sankar, 1986). The regression model of yield could be postulated as

$$Y = \pm \alpha \pm \beta_1 (\text{CGP}) \pm \beta_2 (\text{CRF}) \pm \beta_3 (\text{CWS}) \pm \beta_4 (\text{SN}) \pm \beta_5 (\text{SP}) \pm \beta_6 (\text{SK}) \quad (2)$$

In (2), α is intercept and β_1 to β_6 are regression coefficients of variables considered in the model.

3. Rainfall and its distribution in different years

3.1. Semi-arid alfisols at Bangalore

At Bangalore, the earliest date of sowing of finger millet was on 14th July in 2004, 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 and maximum of 155 days in 1994 with a mean of 126 days and variation of 9.2%. The crop seasonal 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 viz., < 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 the 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 2.

3.2. Semi-arid vertisols at Akola

In the long term study, both cotton and green gram were sown on the same date every year, but had different dates of harvest. The earliest date of sowing of was on 11th June in 1993, while the latest was on 23rd July in 2004. The earliest date of harvest of green gram was on 22nd August in 2001, while the latest was on 15th October in 1997. In case of cotton, the earliest date of harvest was on 28th November in 1990, while the latest was on 26th March in 1997. The duration of green gram ranged from 62 days in 1989 to 103 days in 1997 with a mean of 75 days and variation of 14.5%. Cotton had a duration in the range of 155 days in 1991 to 265 days in 1997 with mean of 202 days and variation of 16.9%. The total crop seasonal rainfall received during June to November ranged from 351.7 mm in 2003 to 1307.8 mm in 1988. The monthly rainfall received was erratic and had a high variation. June rainfall ranged from 24.4 mm (1996) to 339 mm (1990), while July rainfall ranged from 53.4 mm (2002) to 392.5 mm (1988). August received a rainfall in the range of 12.6 mm (1995) to 393.8 mm (1992), while September received 'no' rainfall (1991) to a maximum of 301.2 mm (1988). October received 'no' rainfall (1991, 2000 and 2003) to a maximum of 183.6 mm (1990), while November received 'no' rainfall in 14 years to a maximum of 164.3 mm (1997). A mean rainfall of 145.2 mm (CV of 57%), 184.4 mm (CV of 56.9%), 195.9 mm (CV of 48.5%), 127.6 mm (CV of 63.9%), 65.3 mm (CV of 93.1%) and 17.9 mm (CV of 224%) was received in June, July, August, September, October and November respectively. The crop seasonal rainfall was found to be < 500 mm in 3 years (1991, 2003 and 2004); 500–750 mm in 8 years (1987,

1989, 1995, 1996, 2000, 2001, 2002 and 2005); 750–1000 mm in 7 years (1992, 1993, 1994, 1997, 1998, 1999 and 2006); and 1000–1250 mm in 2 years (1988 and 1990) (Table 2).

3.3. Semi-arid vertic inceptisols at Kovilpatti

At Kovilpatti, the earliest DOS of sorghum was on 29th September in 1995, while the farthest was on 27th October in 1984 and 1985. The earliest date of harvest of sorghum was on 7th January in 2004, while the farthest was on 25th February in 1986. The crop had a minimum growing period of 88 days in 1983 to a maximum of 138 days in 2005 with mean of 112 days and variation of 12.6%. The lowest crop seasonal rainfall of 96.4 mm occurred on 8 days in 1995, while the highest of 634.6 mm occurred on 21 days in 1989 with a mean of 380.3 mm and variation of 42.6%. However, maximum number of 39 rainy days occurred in 1997 with a crop seasonal rainfall of 585.7 mm. The crop received rainfall from mean of 21 rainy days with variation of 37.6%. The earliest DOS of pearl millet was on 30th September in 2000, while the farthest was on 10th November in 1998. The earliest date of harvest of pearl millet was on 3rd January in 2003, while the farthest was on 16th February in 2005. The crop had a growing period of 80 days in 1988 to 136 days in 2004 with a mean of 99 days and variation of 16.5%. Rainfall occurred on only 6 days in 1994, while it occurred on a maximum of 35 days in 2004 with a mean of 16 days and variation of 61.3%. The actual rainfall received during crop growing period ranged from 181.1 mm in 1988 to 789.2 mm in 1996 with a mean of 495.8 mm and variation of 34.9% (Table 2).

3.4. Semi-arid vertisols at Indore

The earliest date of sowing of soybean was on 17th June in 2004, whereas the farthest was on 20th July in 1996. The earliest date of harvest of soybean was on 1st October in 2001, as against the farthest on 29th October in 1996. The crop had a minimum growing period of 91 days in 1992 compared to a maximum of 117 days in 2004 and had a mean of 106 days with variation of 6.6% during 15 years. The lowest crop seasonal rainfall of 354.1 mm (64.9% of annual rainfall) occurred in 2002, whereas the highest of 1308.3 mm (98.3% of annual rainfall) occurred in 1996 with a mean of 840.9 mm and variation of 30.2% over years. The rainfall ranged from 54.7 mm in 1996 to 329.7 mm in 2001 in June, 50.3 mm in 2002 to 676.9 mm in 1996 in July, 91.1 in 1999 to 429.7 mm in 2006 in August, 9 mm in 2000 to 350.3 mm in 2003 in September and 'no rainfall' in 1994 and 2003 to 79.8 mm in 1996 in October. A mean rainfall of 132.1 mm with a variation of 57.5% in June, 294.7 mm with a variation of 53.1% in July, 243.7 mm with a variation of 44.4% in August, 140.6 mm with a variation of 70.3% in September and 29.9 mm with a variation of 96.1% in October was received (Table 2).

3.5. Arid alfisols at Anantapur

A wide range was observed in the monthly rainfall received from May to November during 1985 to 2006. The total rainfall of May to November ranged from 255.0 to 842.8 mm with a mean rainfall of 538.7 mm and variation of 33.2%. The rainfall received in May ranged from

0.2 to 155.6 mm; June from 5.2 to 212.2 mm; July from 0.6 to 453.7 mm; August from 4.4 to 343 mm; September from 13.2 to 354.6 mm; October from 22.2 to 211.8 mm; and November from 2.6 to 127.8 mm. A maximum mean rainfall of 117.5 mm was received in September; compared to 106.4 mm in October; 101.0 mm in August; 91.3 mm in July; 58.9 mm in June; 44.8 mm in May; and 31.1 mm in November in the study. It is observed that July received rainfall with a maximum variation of 119.9%; compared to November with 111.3%; August with 91.4%; June with 88.7%; May with 79.3%; September with 64.8%; and October with 56.3%.

Statistic	CGP	Jun	Jul	Aug	Sep	Oct	Nov	CRF
Bangalore : Finger millet : 1984-2008								
Minimum	96	7.7	21.1	31.8	43.8	28.0	2.0	396.6
Maximum	155	230.6	272.0	352.2	388.1	540.9	193.8	1174.7
Mean	126	81.0	98.0	139.0	200.0	188.0	50.0	756.0
CV (%)	9.2	77.4	59.1	61.2	50.3	66.7	95.5	28.1
Akola : Cotton + green gram (1:1) : 1987-2006								
Minimum	155 (62)	24.4	53.4	12.6	0.0	0.0	0.0	351.7
Maximum	265 (103)	339.0	392.5	393.8	301.2	183.6	164.3	1307.8
Mean	203 (74)	145.8	189.0	194.9	127.9	62.2	18.0	737.9
CV (%)	16.5 (14.5)	55.4	55.2	47.6	62.1	98.0	216.2	31.9
Kovilpatti : Sorghum : 1987-2005								
		Sep	Oct	Nov	Dec	Jan		
Minimum	96	0.0	71.6	14.0	0.0	0.0		181.1
Maximum	138	181.0	503.1	262.2	212.3	212.0		789.2
Mean	113	72.3	202.5	125.1	64.5	31.5		495.8
CV (%)	12.7	85.3	60.6	73.6	102.3	204.7		34.9
Kovilpatti : Pearl millet : 1987-2005								
Minimum	80	24.5	20.8	63.4	4.2	0.0		209.3
Maximum	136	178.6	412.2	268.8	162.2	14.6		692.0
Mean	99	98.1	197.4	144.1	54.2	4.3		498.1
CV (%)	16.5	56.6	67.3	52.6	100.6	138.0		30.5
Indore : Soybean : 1992-2006								
Minimum	91	54.7	50.3	91.1	9.0	0.0		354.1
Maximum	117	329.7	676.9	429.7	350.3	79.8		1308.3
Mean	106	132.1	294.7	243.7	140.6	29.9		840.9
CV (%)	6.6	57.5	53.1	44.4	70.3	96.1		30.2
Anantapur : Groundnut : 1985-2006								
Minimum	107	5.2	0.6	4.4	13.2	22.2	2.6	255.0
Maximum	127	212.2	453.7	343.0	354.6	211.8	127.8	801.4
Mean	116	58.9	91.3	101.0	117.5	106.4	31.1	502.1
CV (%)	5.0	88.7	119.9	91.4	64.8	56.3	111.3	37.0

Table 2. Mean and variation of rainfall and crop growing period at different locations

4. Results and discussion

4.1. ANOVA of soil test values and yield in different seasons

The mean and coefficient of variation of soil fertility of nutrients and yield of crops attained under each rainfall situation at Bangalore, Akola, Kovilpatti and Indore are given in Table 3.

TR	Yield (kg/ha)				Soil N (kg/ha)				Soil P (kg/ha)				Soil K (kg/ha)			
	Min	Max	Mean	CV	Min	Max	Mean	CV	Min	Max	Mean	CV	Min	Max	Mean	CV
Bangalore : Finger millet : 1984-2008																
T1	54	1356	537	79.7	87	210	163	12.4	4.5	27.9	9.7	46.1	37	88	59	19.5
T2	1146	3125	2452	23.4	146	241	195	8.2	15.7	61.6	43.8	28.8	59	116	88	16.6
T3	1432	3836	2891	21.9	170	217	196	4.7	24.0	90.4	59.4	27.2	61	152	95	18.3
T4	1821	4552	3167	22.7	174	242	204	7.5	35.2	91.9	68.6	18.7	67	157	107	20.4
T5	756	3429	1826	45.4	103	245	190	12.5	21.4	76.4	50.4	27.0	50	114	78	16.2
LSD			535				13				6.7				13	
Akola : Green gram: 1987-2007																
T1	74	700	362	42.4	110	290	217	24.0	11.0	32.2	25.2	17.4	243	395	289	12.6
T2	90	790	488	37.0	123	306	239	18.9	15.0	35.9	30.0	16.6	256	393	320	11.6
T3	87	770	453	38.4	113	299	227	20.8	16.8	35.4	28.8	17.1	252	389	313	11.6
T4	83	768	447	40.3	117	297	230	23.7	16.5	35.9	30.1	16.2	256	389	323	9.0
T5	83	880	480	39.9	119	328	239	24.2	16.5	42.8	32.3	18.3	260	417	351	12.3
T6	88	840	491	37.9	125	313	250	21.1	15.7	42.5	31.8	19.4	277	485	358	15.1
T7	97	930	547	35.6	123	328	254	22.5	20.0	42.8	33.4	15.3	294	491	369	16.1
T8	96	910	505	40.3	123	320	243	24.3	18.4	46.2	32.4	19.0	276	492	344	18.9
LSD	10	379	108	73.3												
Akola : Cotton: 1987-2007																
T1	91	1016	492	51.2	110	290	217	24.0	11.0	32.2	25.2	17.4	243	395	289	12.6
T2	171	1637	699	52.6	123	306	239	18.9	15.0	35.9	30.0	16.6	256	393	320	11.6
T3	152	1338	637	53.6	113	299	227	20.8	16.8	35.4	28.8	17.1	252	389	313	11.6
T4	112	1404	625	51.6	117	297	230	23.7	16.5	35.9	30.1	16.2	256	389	323	9.0
T5	101	1637	678	55.3	119	328	239	24.2	16.5	42.8	32.3	18.3	260	417	351	12.3
T6	174	1795	737	54.3	125	313	250	21.1	15.7	42.5	31.8	19.4	277	485	358	15.1
T7	217	1910	805	54.8	123	328	254	22.5	20.0	42.8	33.4	15.3	294	491	369	16.1
T8	126	1725	702	55.4	123	320	243	24.3	18.4	46.2	32.4	19.0	276	492	344	18.9
LSD	18	290	134	58.9												
Kovilpatti : Sorghum: 1987-2005																
T1	157	1520	709	66.2	76	146	112	18.5	6.0	8.8	7.1	13.8	236	389	328	13.3
T2	415	2122	1118	48.3	79	168	132	19.0	3.3	12.1	8.3	28.9	193	449	361	21.4
T3	340	1840	917	53.3	76	159	124	18.2	6.5	11.9	8.9	19.3	270	435	355	15.7
T4	130	1821	867	61.9	69	149	121	18.9	5.7	11.2	8.4	18.6	236	448	369	16.2
T5	175	1919	867	60.4	76	145	125	17.1	7.5	10.3	8.8	10.0	237	450	360	16.3
T6	147	2407	1031	68.5	70	159	126	21.9	3.3	11.3	9.4	24.1	271	475	375	16.4
T7	325	2320	1163	55.5	80	187	142	20.8	9.0	12.9	10.7	10.8	215	528	394	21.4
T8	342	2451	1246	50.2	84	163	136	16.6	6.3	12.3	10.1	17.9	252	481	382	19.9
T9	195	2164	999	70.0	79	156	131	18.0	6.3	12.5	9.4	20.4	215	546	382	25.2

TR	Yield (kg/ha)				Soil N (kg/ha)				Soil P (kg/ha)				Soil K (kg/ha)			
	Min	Max	Mean	CV	Min	Max	Mean	CV	Min	Max	Mean	CV	Min	Max	Mean	CV
Kovilpatti : Pearl millet : 1987-2005																
T1	163	936	453	51.8	77	107	87	12.4	6.0	8.2	6.5	9.9	243	357	319	12.2
T2	230	1212	670	42.4	98	149	118	14.2	7.3	10.6	9.4	11.6	275	438	374	15.1
T3	333	1083	626	33.2	82	123	104	14.1	6.5	10.0	7.7	12.7	256	437	360	18.2
T4	253	1067	577	42.0	84	119	102	12.5	6.5	9.5	7.9	13.6	250	450	364	21.1
T5	247	1135	561	45.2	80	116	96	12.7	7.0	10.0	8.4	11.8	270	468	385	19.1
T6	265	1194	676	40.7	92	120	107	10.0	8.3	10.5	9.0	6.6	248	490	403	21.8
T7	419	1220	774	32.1	90	122	107	10.9	8.0	12.1	9.7	13.4	248	460	382	18.7
T8	502	1190	761	29.7	81	114	103	10.9	8.5	11.0	9.5	7.9	280	453	385	13.8
T9	331	1046	552	41.0	87	125	100	12.5	6.0	10.3	7.9	15.9	290	493	407	16.9
Indore : Soybean : 1992-2006																
T1	691	2066	1275	31.1	161	209	178	8.4	5.0	21.5	11.4	57.5	325	830	540	22.2
T2	987	2448	1620	29.4	185	232	202	7.0	5.8	24.9	14.1	53.8	340	743	552	18.1
T3	1147	2720	1774	29.5	167	240	206	10.3	6.0	27.7	16.1	53.1	360	980	585	25.7
T4	1250	2828	1886	27.7	204	280	225	8.4	5.0	28.2	16.9	46.6	320	721	545	19.0
T5	1308	3050	1994	26.4	171	284	224	11.5	4.8	29.2	17.7	42.6	347	1042	629	25.6
T6	1449	3247	2095	25.3	216	384	274	20.3	4.2	28.4	22.2	30.3	373	1132	741	24.3
T7	997	3102	1790	34.0	185	337	254	18.9	4.5	27.8	15.0	53.1	340	943	642	23.2
T8	1152	3061	1863	30.3	189	426	264	26.2	5.2	27.0	18.3	32.8	360	892	677	20.9
T9	897	2504	1629	32.6	176	347	239	23.4	5.6	25.4	15.6	46.8	320	1215	629	31.7
LSD			241				23	67.8			2.4	53.7			52.8	53.3

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

Table 3. Descriptive statistics of finger millet grain yield, and available soil nutrients

4.1.1. Semi-arid alfisols at Bangalore

At Bangalore, the changes in soil N, P and K nutrients over years were assessed. The trends indicated that the soil N decreased in all treatments, however, the decrease was significant only in control. There was a build-up of soil P in all treatments, but, the increase was significant only in FYM @ 10 t/ha, FYM @ 10 t/ha + 50% NPK and 100% NPK treatments. There was a decrease of soil K over years, in all treatments, but the decrease was significant only in FYM @ 10 t/ha ha + 100% NPK application. Based on the predictability of changes in soil nutrient status over years (R^2), the prediction (%) of yield ranged from 1 to 26% for soil N; 2 to 44% for soil P; and 1 to 26% for soil K for different treatments. The standard error based on a regression model ranged from 9.3 to 23.1 kg/ha for soil N; 4.5 to 12.3 kg/ha for soil P; and 11.4 to 19.2 kg/ha for soil K over years. The trends of changes in yield, and soil nutrients as affected by treatments over years indicated that in general, the soil P tended to increase, while soil N reflected the decreasing tendency over years. However, soil K decreased over years. Thus, the trends of soil fertility changes were similar for soil N and P nutrients (except in control), while it was the opposite trend for soil K over years.

4.1.2. *Semi-arid vertisols at Akola*

At Akola, the ANOVA indicated that fertilizer treatments differed significantly in influencing soil fertility of nutrients and yield in all years. They were also significantly different when pooled over years under each rainfall situation (Gomez and Gomez, 1985). A minimum mean yield of 360 kg/ha (variation of 43.7%) and 492 kg/ha (variation of 52.5%) was attained under control, while a maximum of 527 kg/ha (variation of 33.9%) and 807 kg/ha (variation of 56.1%) was attained under 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha in case of green gram and cotton respectively. Application of 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha was also superior for enhancing soil fertility status by providing a maximum mean soil N of 251.8 kg/ha (variation of 22.8%), soil P of 33.5 kg/ha (variation of 19.5%) and soil K of 368.6 kg/ha (variation of 20.4%) over years. A build-up of soil N and a depletion of soil K were observed under all treatments over years. A build-up of soil P was observed under control and 25 kg N + 12.5 kg P/ha, while there was a depletion under all the remaining treatments. Comparison of pairs of treatments for differences in yield, soil N, P and K nutrients indicated that 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha was superior to all other treatments by attaining a significantly higher yield of cotton and green gram and maintaining higher soil fertility status over years.

4.1.3. *Semi-arid vertic inceptisols at Kovilpatti*

At Kovilpatti, the ANOVA of sorghum data indicated a significant difference among treatments in individual years and also when pooled over years in influencing soil nutrients and grain yield. The mean sorghum yield ranged from 642 kg/ha with variation of 69.9% under control to 1190 kg/ha with variation of 50.9% under 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha. This treatment gave maximum potential yield of 2451 kg/ha in 1999. 40 kg N (urea) + 20 kg P/ha had a minimum variation of 47.8%, while FYM @ 5 t/ha had a maximum variation of 72.4% for sorghum yield. The mean soil N ranged from 97 kg/ha with 22.1% variation under control to 118 kg/ha with 16.3% variation under an application of 40 kg N (urea) + 20 kg P/ha. However, minimum soil N of 76 kg/ha was observed under 40 kg N (urea) + 20 kg P/ha, 20 kg N (urea) + 10 kg P/ha and 20 kg N (crop residue)/ha in 1986, while maximum of 154 kg/ha was observed under 20 kg N (FYM)/ha in 1985. Soil N had minimum variation of 14.1% under 20 kg N (crop residue) + 20 kg N (urea)/ha and maximum variation of 22.2% under 20 kg N (FYM)/ha. The mean soil P ranged from 8.8 kg/ha with 21.9% variation under 20 kg N (crop residue)/ha to 10.8 kg/ha with 79.2% under FYM @ 10 t/ha. However, minimum soil P of 6 kg/ha was observed under control and FYM @ 5 t/ha in 1987 and 1999, while maximum of 18.3 kg/ha was observed under 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha in 1983. Soil P had minimum variation of 14.5% under 40 kg N (urea) + 20 kg P/ha and maximum variation of 36.4% under control. The mean soil K ranged from 407 kg/ha with 43.3% variation under control to 473 kg/ha with 35.5% variation under 20 kg N (crop residue) + 20 kg N (urea)/ha. However, minimum soil K of 243 kg/ha was observed under control in 2005, while maximum of 854 kg/ha was under 10 kg N (FYM) + 10 kg N (urea)/ha in 1982. Minimum variation of 32.5% under 40 kg N (urea) + 20 kg P/ha and maximum variation of 43.3% under control was observed for soil K.

In case of pearl millet at Kovilpatti, the yield ranged from 399 kg/ha with 43% variation under control to 725 kg/ha with 28.3% variation under 10 kg N (FYM) + 10 kg N (urea). This treatment gave a maximum potential yield of 1062 kg/ha in 1994. 20 kg N (urea) + 10 kg P/ha had minimum variation of 24.3%, while control had maximum of 43% for yield. The mean soil N ranged from 110 kg/ha with 19.1% variation under control to 140 kg/ha with 21.7% variation under 10 kg N (FYM) + 10 kg N (urea) kg/ha. However, minimum soil N of 69 kg/ha was observed under 20 kg N (crop residue)/ha in 1988, while maximum of 187 kg/ha was observed under 10 kg N (FYM) + 10 kg N (urea)/ha in 1996. Soil N had minimum variation of 17% under 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha compared to maximum of 22.4% under 20 kg N (crop residue) + 20 kg N (urea)/ha.

The mean soil P ranged from 7 kg/ha with variation of 12.1% under control to 10.5 kg/ha with variation of 10.3% under 10 kg N (FYM) + 10 kg N (urea)/ha. However, minimum soil P of 3.3 kg/ha was observed under 40 kg N (urea) + 20 kg P/ha and 20 kg N (crop residue) + 20 kg N (urea)/ha in 2004, while maximum of 12.9 kg/ha was observed under 10 kg N (FYM) + 10 kg N (urea)/ha in 1994. The soil P had variation in the range of 10.3% under 10 kg N (FYM) + 10 kg N (urea)/ha to 26.7% under 40 kg N (urea) + 20 kg P/ha. The mean soil K ranged from 325 kg/ha with 14% variation under control to 389 kg/ha with 22.6% variation under 10 kg N (FYM) + 10 kg N (urea)/ha. However, minimum soil K of 193 kg/ha was observed under 40 kg N (urea) + 20 kg P/ha in 2004, while maximum of 546 kg/ha was observed under FYM @ 5 t/ha in 1992. Soil K had variation ranging from 14% under control to 26.8% under FYM @ 5 t/ha. A higher mean soil N was observed in sorghum trials, while higher mean soil P and K were observed in pearl millet trials under all treatments. A higher variation of yield was observed in sorghum compared to pearl millet in all treatments. In sorghum, soil K had maximum variation in 8 treatments compared to soil P in only one treatment, while soil N had minimum variation in all treatments. In pearl millet, soil P had maximum variation in 4 treatments, followed by soil K in 3 treatments and soil N in 2 treatments.

4.1.4. Semi-arid vertisols at Indore

The F-test indicated that the organic and inorganic treatment combinations were significantly different in both individual years and also when pooled over years in influencing the soybean yield and soil nutrients. The mean soybean yield ranged from 1275 kg/ha with variation of 31.1% under control to 2095 kg/ha with a variation of 25.3% under 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha. The superior treatment also gave a maximum potential yield of 3247 kg/ha in 2006. Application of 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha was also superior with a maximum mean soil N (274 kg/ha), soil P (22.2 kg/ha), soil K (741 kg/ha), and soil Sulphur (18.1 kg/ha). The control gave a minimum soil N of 178 kg/ha, soil P of 11.4 kg/ha, soil K of 540 kg/ha, and soil Sulphur of 13.6 kg/ha. 20 kg N (urea) + 13 kg P/ha had a minimum variation of 7% for soil N and 18.1% for soil K. The control had a maximum variation of 57.5% for soil P and 43.2% for soil S. FYM @ 6 t/ha had a maximum variation of 26.2% for soil N, while crop residue @ 5 t/ha had a maximum of 31.7% for soil K.

4.1.5. Arid alfisols at Anantapur

The distribution of organic carbon, soil P and K under each treatment as indicated by minimum, maximum, mean and variation are given in Table 4. A wide range of 0.13 to 0.69% in organic carbon; 9.7 to 171.8 kg/ha in soil P; and 89 to 454 kg/ha in soil K was observed. The mean organic carbon ranged from 0.23% in control to 0.38% in 50% N (FYM ~ 10 kg N/ha) and farmers practice (FYM @ 5 t/ha); soil P from 34.5 kg/ha in control to 100.6 kg/ha in 100% NPK (20–40–40 kg/ha) + ZnSO₄ @ 25 kg/ha; and soil K from 163 kg/ha in control to 297 kg/ha in 50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha) over years. 100% NPK (20–40–40 kg/ha) had lowest variation of 12.2%, while Farmers practice (FYM @ 5 t/ha) had highest variation of 38.6% for organic carbon. The variation ranged from 37.8% in 50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha) to 49.5% in Farmer's practice (FYM @ 5 t/ha) for soil P and 32.5% in 50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha) to 51.4% in 50% NPK (10–20–20 kg/ha) for soil K.

The groundnut pod yield attained by different treatments ranged from 171 kg/ha attained by 50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha) to 1546 kg/ha attained by 100% NPK (inorganic) application. Based on the ANOVA, the fertilizer treatments differed significantly from each other in all the years except 1992, 1996, 2000, 2002 and 2006. The crop failed to produce any pod yield in 1988 and 2001 due to insufficient soil moisture. The yield attained in different years along with LSD at $p < 0.05$ level are given in Table 3. Based on the LSD criteria, 100% NPK (20–40–40 kg/ha) gave significantly higher yield of 1367, 609, 745 and 1546 kg/ha in 1985, 1991, 1993 and 2004; while 100% N (groundnut shells ~ 20 kg N/ha) was superior with yield of 1300, 1518 and 1348 kg/ha in 1986, 1987 and 1990 respectively. Application of 100% N (groundnut shells ~ 20 kg N/ha) + 50% NPK (10–20–20 kg/ha) was superior with yield of 757, 388 and 588 kg/ha in 1994, 1997 and 2003 respectively; while 50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha) gave significantly higher yield of 1541 kg/ha in 1989 and 1123 kg/ha in 2005. Application of 100% NPK (20–40–40 kg/ha) + ZnSO₄ @ 25 kg/ha was superior with pod yield of 1131 kg/ha in 1995, 1329 kg/ha in 1998 and 1348 kg/ha in 1999. The study indicated that 100% NPK (20–40–40 kg/ha) + ZnSO₄ @ 25 kg/ha was superior with maximum mean pod yield of 926 kg/ha (variation of 46.6%), while control gave minimum yield of 741 kg/ha (variation of 44.6%). However, 100% N (groundnut shells ~ 20 kg N/ha) + 50% NPK (10–20–20 kg/ha) had minimum variation of 41.5%, while 100% NPK (20–40–40 kg/ha) had maximum variation of 47.4%. Highest yield increase of 24.9% was attained by 100% NPK (20–40–40 kg/ha) + ZnSO₄ @ 25 kg/ha, followed by 100% NPK (20–40–40 kg/ha) with 23.5%, 50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha) with 23.1%, while 100% N (groundnut shells ~ 20 kg N/ha) gave lowest yield increase of 16.5% over years (Table 4).

4.2. Relationship between yield, soil nutrients and rainfall over years

4.2.1. Finger millet experiments at Bangalore

The estimates of correlation between finger millet yield, soil fertility of nutrients and monthly rainfall are given in Table 5. At Bangalore, with application of 100% NPK over years, the grain yield had a significant negative correlation with soil P. It had a positive

relationship with soil N in control, FYM @ 10 t/ha + 100% NPK and 100% NPK; soil K in all treatments except 100% NPK. The crop seasonal rainfall had a negative effect on finger millet yield in control and 100% NPK. The crop growing period had a positive correlation with grain yield attained by all treatments except FYM @ 10 t/ha and FYM @ 10 t/ha + 50% NPK. Among different treatments, the negative correlation of yield (in all treatments), soil N and soil K with time period indicated a decrease, while a positive correlation of soil P with time period indicated an increase with fertilizer application.

Treatment	Yield (kg/ha)				Organic carbon (%)				Soil P (kg/ha)				Soil K (kg/ha)			
					Min	Max	Mean	CV	Min	Max	Mean	CV	Min	Max	Mean	CV
T1	237	1364	741	44.6	0.13	0.32	0.23	28.5	9.7	48.0	34.5	44.6	94	272	163	38.9
T2	210	1546	916	47.4	0.24	0.33	0.26	12.2	57.0	162.1	97.1	41.1	133	393	234	37.0
T3	247	1428	879	44.3	0.19	0.38	0.26	24.0	45.5	161.6	84.8	44.9	89	454	233	51.4
T4	226	1518	863	42.0	0.21	0.45	0.33	21.2	19.4	79.0	55.2	39.5	121	391	241	36.9
T5	219	1516	876	43.4	0.21	0.54	0.38	33.3	29.1	103.0	61.8	46.5	116	393	263	33.6
T6	193	1478	889	41.5	0.26	0.49	0.36	19.1	34.3	143.6	89.1	44.1	104	415	253	40.1
T7	171	1541	912	45.6	0.24	0.61	0.36	36.9	51.0	153.6	100.0	37.8	119	371	297	32.5
T8	226	1473	926	46.6	0.18	0.38	0.28	23.1	40.0	171.8	100.6	40.1	111	394	258	38.4
T9	205	1507	833	45.8	0.26	0.69	0.38	38.6	34.0	128.2	65.5	49.5	141	358	269	35.4

Table 4. Effect of fertilizer treatments on soil test values of organic carbon, P and K nutrients at Anantapur

Variable1	Variable2	T1	T2	T3	T4	T5
Bangalore						
GY	SN	0.17	-0.02	-0.02	0.07	0.11
GY	SP	0.13	-0.13	-0.01	-0.03	-0.46*
GY	SK	0.12	0.07	0.15	0.34	-0.02
GY	CGP	0.21	-0.07	-0.01	0.09	0.12
GY	CRF	-0.34	0.04	0.09	0.09	-0.22
GY	Years	-0.78**	-0.34	-0.23	-0.54**	-0.67**
SN	Years	-0.51**	-0.17	-0.02	-0.16	-0.32
SP	Years	0.13	0.65**	0.67**	0.34	0.48*
SK	Years	-0.05	-0.35	-0.37	-0.51**	-0.47*

Table 5. Relation between yield, soil nutrients and crop seasonal rainfall at Bangalore

4.2.2. Cotton and green gram experiments at Akola

The estimates of correlation of cotton and green gram yield with soil fertility of nutrients and monthly rainfall are given in Table 6. At Akola, June rainfall had a significant positive correlation with green gram yield of all treatments except 25 kg N/ha (FYM) compared to August rainfall with yield attained by control, 25 kg N + 12.5 kg P/ha, 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha and 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha. The yield had a significant negative correlation with soil N under all treatments except 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha; while a significant positive correlation with soil K under 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha. There was no significant correlation between any pair of variables in case of cotton. The analysis indicated that rainfall of June, July, August and September, soil P, and soil K had a positive correlation, while soil N have a negative correlation with green gram yield over years. Similarly, the monthly rainfall of June to October, and soil K have a positive correlation, while November rainfall, soil N and P have a negative correlation with cotton yield over years.

Var 1	Var 2	T1	T2	T3	T4	T5	T6	T7	T8
Green gram									
Yield	Jun	0.61**	0.51*	0.55**	0.63**	0.42	0.60**	0.54**	0.62**
Yield	Jul	0.05	0.01	0.02	0.03	0.20	0.16	0.08	0.15
Yield	Aug	0.51*	0.41	0.45*	0.41	0.43	0.47*	0.48*	0.43
Yield	Sep	0.14	0.17	0.17	0.05	0.30	0.14	0.17	0.08
Yield	Soil N	-0.64**	-0.50*	-0.58**	-0.55**	-0.46*	-0.54**	-0.38	-0.58**
Yield	Soil P	0.06	0.09	-0.03	0.09	-0.04	0.04	0.10	0.10
Yield	Soil K	0.08	0.05	0.04	0.00	0.37	0.46*	0.30	0.33
Cotton									
Yield	Jun	0.15	0.15	0.10	0.18	0.09	0.10	0.01	0.12
Yield	Jul	0.42	0.42	0.42	0.39	0.40	0.39	0.40	0.39
Yield	Aug	0.25	0.21	0.27	0.23	0.23	0.22	0.24	0.24
Yield	Sep	0.08	0.01	0.08	-0.01	0.08	0.07	-0.15	0.05
Yield	Oct	-0.02	0.07	0.01	0.02	0.06	0.08	0.06	0.05
Yield	Nov	-0.24	-0.23	-0.25	-0.24	-0.27	-0.30	-0.26	-0.29
Yield	Soil N	-0.21	-0.21	-0.24	-0.30	-0.18	-0.37	-0.29	-0.31
Yield	Soil P	-0.38	-0.20	-0.29	-0.29	-0.26	-0.22	-0.29	-0.18
Yield	Soil K	0.31	0.35	0.33	0.37	0.31	0.30	0.07	0.24
Soil nutrients									
Soil N	Year	0.74**	0.44*	0.59**	0.64**	0.65**	0.53*	0.56**	0.59**
Soil P	Year	0.16	-0.17	0.02	-0.20	-0.25	-0.14	-0.10	-0.27
Soil K	Year	-0.11	-0.34	-0.51*	-0.18	-0.40	-0.71**	-0.71**	-0.71**

* and ** indicate significance at $p < 0.05$ and $p < 0.01$ level respectively

Table 6. Relation between yield, crop seasonal rainfall and soil nutrients at Akola

4.2.3. Sorghum and pearl millet experiments at Kovilpatti

The estimates of correlation of sorghum and pearl millet yield with soil fertility of nutrients and monthly rainfall are given in Table 7. At Kovilpatti, sorghum yield had a significant positive correlation with years under 20 kg N (crop residue) + 20 kg N (urea)/ha, 10 kg N (FYM) + 10 kg N (urea)/ha and FYM @ 5 t/ha and negative correlation with soil N under 20 kg N (crop residue) + 20 kg N (urea)/ha. It had positive correlation with the crop growing period (CGP) under application of FYM @ 5 t/ha and negative correlation with the crop water stress (CWS) under application of 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha. The soil N had a negative relation with years under control, 20 kg N (crop residue) + 20 kg N (urea)/ha, 10 kg N (FYM) + 10 kg N (urea)/ha and 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha, and positive correlation under FYM @ 5 t/ha. The soil P had negative correlation with years under control, 20 kg N (urea) + 10 kg P/ha, 20 kg N (crop residue)/ha and 20 kg N (FYM)/ha, while soil K was negatively correlated with years only under control.

Var1	Var2	T1	T2	T3	T4	T5	T6	T7	T8	T9
<i>Sorghum (1987-2005)</i>										
GY	Year	0.42	0.34	0.40	0.40	0.43	0.60*	0.60*	0.44	0.52*
	SN	-0.28	-0.23	-0.43	-0.37	-0.08	-0.71**	-0.55*	-0.39	0.02
	SP	-0.06	0.16	0.02	-0.25	-0.14	-0.22	-0.20	-0.14	0.06
	SK	-0.07	0.10	0.08	-0.12	-0.08	-0.12	-0.09	-0.10	0.08
	CGP	0.29	0.24	0.29	0.38	0.36	0.14	0.23	0.34	0.53*
	CRF	-0.06	0.06	-0.02	0.09	0.05	0.06	0.09	0.06	-0.19
	CWS	-0.26	-0.43	-0.29	-0.33	-0.38	-0.34	-0.41	-0.53*	-0.01
SN	Year	-0.62*	-0.47	-0.46	-0.40	-0.39	-0.89**	-0.71**	-0.92**	0.53*
SP	Year	-0.65**	-0.26	-0.60*	-0.69**	-0.54*	-0.47	-0.44	-0.43	-0.44
SK	Year	-0.57*	-0.40	-0.43	-0.34	-0.35	-0.33	-0.36	-0.44	-0.32
<i>Pearl millet (1987-2005)</i>										
GY	Year	0.77*	0.35	0.01	0.52	0.68*	0.40	0.59	0.19	0.82*
	SN	0.46	0.17	0.68*	0.60	0.58	0.65*	0.62	0.69*	0.53
	SP	-0.39	0.53	0.29	0.01	0.14	0.56	0.41	0.66*	-0.36
	SK	0.25	0.57	0.20	0.66*	0.68*	0.39	0.39	0.52	0.26
	CGP	0.11	0.37	0.66*	0.41	0.09	0.65*	0.45	0.52	0.13
	CRF	0.41	0.50	0.51	0.86**	0.72*	0.70*	0.61	0.65*	0.65*
	CWS	-0.38	0.23	-0.30	-0.65*	-0.54	-0.13	0.04	0.03	-0.66*
SN	Year	0.42	0.39	0.45	0.57	0.46	0.76*	0.39	0.56	0.45
SP	Year	-0.34	0.65*	-0.25	-0.57	-0.33	-0.36	-0.45	-0.19	-0.44
SK	Year	0.52	0.84**	0.65*	0.77*	0.87**	0.76*	0.47	0.52	0.41

Table 7. Relation between yield, soil nutrients, crop seasonal rainfall, CGP and CWS at Kovilpatti

In case of pearl millet at Kovilpatti, the grain yield had significant positive correlation with years under control, 20 kg N (FYM)/ha and FYM @ 5 t/ha; soil N under 20 kg N (urea) + 10 kg P/ha, 20 kg N (crop residue) + 20 kg N (urea)/ha and 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha; soil P under 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha and soil K under 20 kg N (crop residue)/ha and 20 kg N (FYM)/ha. Pearl millet yield had significant correlation with CGP under 20 kg N (urea) + 10 kg P/ha and 20 kg N (crop residue) + 20 kg N (urea)/ha. It had significant positive correlation with crop seasonal rainfall under 20 kg N (crop residue)/ha, 20 kg N (FYM)/ha, 20 kg N (crop residue) + 20 kg N (urea)/ha, 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha and FYM @ 5 t/ha; and significant negative correlation with CWS under 20 kg N (crop residue)/ha and FYM @ 5 t/ha. Soil N had a significant positive correlation with years under 20 kg N (crop residue) + 20 kg N (urea)/ha compared to soil P under 40 kg N (urea) + 20 kg P/ha; and soil K under 40 kg N (urea) + 20 kg P/ha, 20 kg N (crop residue)/ha, 20 kg N (FYM)/ha and 20 kg N (crop residue) + 20 kg N (urea)/ha.

4.2.4. Soybean experiments at Indore

The estimates of correlation between soybean yield, soil fertility of nutrients and monthly rainfall are given in Table 8. The soybean yield had a significant and positive correlation with uptake N under all the 9 treatments. It ranged from 0.90** for application of 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha to 0.97** under control plot. The soybean yield was found to have a significant negative correlation with soil N (-0.56*) observed under FYM @ 6 t/ha over years. Similarly, the control yield had a significant negative correlation with crop growing period (-0.54*).

Var1	Var2	T1	T2	T3	T4	T5	T6	T7	T8	T9
GY	Jun	0.13	0.06	0.01	-0.01	-0.05	0.03	-0.01	0.01	0.04
GY	Jul	-0.27	-0.04	0.02	0.01	0.01	0.06	-0.07	0.01	-0.11
GY	Aug	-0.09	0.13	0.14	0.12	0.20	0.25	0.17	0.24	0.07
GY	Sep	0.07	0.28	0.30	0.32	0.34	0.38	0.36	0.36	0.34
GY	Oct	0.18	0.15	0.15	0.16	0.13	0.16	0.05	0.08	0.05
GY	CGP	-0.54*	-0.40	-0.43	-0.42	-0.37	-0.25	-0.33	-0.28	-0.37
GY	SN	0.40	0.20	-0.01	-0.16	-0.10	-0.48	-0.47	-0.56*	-0.49
GY	SP	0.05	0.17	0.21	0.18	0.18	-0.23	0.30	0.17	0.23
GY	SK	-0.24	-0.20	-0.25	-0.49	-0.28	-0.11	-0.21	-0.26	-0.09
GY	SS	-0.16	-0.11	0.01	0.06	0.01	0.08	-0.02	-0.03	-0.23

Table 8. Relation between yield, soil nutrients, crop seasonal rainfall, and CGP at Indore

4.2.5. Groundnut experiments at Anantapur

The estimates of correlation between groundnut pod yield, soil fertility of nutrients and monthly rainfall are given in Table 9. The groundnut pod yield had a better correlation with July rainfall in the range of 0.22 to 0.53 compared to other months in different years. The pod yield attained by all the 9 fertilizer treatments was found to decrease over years as indicated by the negative correlation. The correlations were found to be non-significant over years although they indicated the likely positive or negative trends or effects on the yield. It is observed that yield had a better correlation with July and September rainfall in T9; August rainfall in T8; November rainfall in T3. Maximum pod yield decrease was observed under T4 over years.

Var 1	Var 2	T1	T2	T3	T4	T5	T6	T7	T8	T9
Yield	Jul	0.34	0.42	0.41	0.22	0.48	0.28	0.45	0.43	0.53
Yield	Aug	0.06	0.10	0.08	0.03	0.03	0.10	0.11	0.15	0.07
Yield	Sep	0.17	0.19	0.19	0.18	0.26	0.18	0.21	0.21	0.26
Yield	Oct	0.04	-0.04	-0.03	0.08	-0.09	0.01	-0.04	-0.05	-0.07
Yield	Nov	0.18	0.17	0.21	0.20	0.14	0.17	0.15	0.20	0.16
Yield	CGP	0.04	-0.03	-0.02	-0.03	-0.05	-0.07	-0.07	-0.08	-0.04
Yield	Year	-0.53	-0.45	-0.48	-0.54	-0.42	-0.46	-0.40	-0.45	-0.37

Table 9. Relation between yield, monthly rainfall, and CGP over years at Anantapur

4.3. Regression model of yield through soil nutrients and rainfall

Multiple regression models for yield attained by each treatment owing to simultaneous influence of crop seasonal rainfall, soil N, P and K nutrients were calibrated and the regression coefficients of variables along with coefficient of determination (R^2) and standard error (SE) are given in Table 10 for Bangalore, Table 11 for Akola and Table 12 for Kovilpatti.

4.3.1. Regression model of finger millet yield at Bangalore

At Bangalore, the yield predictability (R^2) was in the range of 11% for FYM @ 10 t/ha to 52% for the yield attained with application of 100% NPK over years based on the model. The standard error ranged from 435 to 717 kg/ha in the 25 year study. Based on the model, the crop seasonal rainfall had a positive effect under application of FYM @ 10 t/ha, FYM @ 10 t/ha + 50% NPK and FYM @ 10 t/ha + 100% NPK. The effect of soil N under control, FYM @ 10 t/ha + 50% NPK and 100% NPK; soil K under FYM @ 10 t/ha + 50% NPK and FYM @ 10 t/ha + 100% NPK were positive. The analysis indicated that soil P had a significant negative effect on finger millet yield attained by FYM @ 10 t/ha + 50% NPK. Similarly, soil K had a significant negative effect on the yield attained by 100% NPK application as given in Table 10.

Treatment	Regression model	R ²	SE (kg/ha)
T1	$Y = -2579 - 0.48 (CRF) + 65.89 (SN) - 0.19 (SN)^2 - 62.94 (SP) + 4.08 (SP)^2 - 78.42 (SK) + 0.69 (SK)^2$	0.27	435
T2	$Y = 13534 + 0.08 (CRF) - 82.60 (SN) + 0.21 (SN)^2 - 3.83 (SP) + 0.02 (SP)^2 - 73.68 (SK) + 0.43 (SK)^2$	0.11	646
T3	$Y = 1341 + 0.21 (CRF) + 4.38 (SN) + 0.01 (SN)^2 - 96.25 (SP) + 0.89^* (SP)^2 + 47.40 (SK) - 0.21 (SK)^2$	0.23	660
T4	$Y = 26227 + 0.04 (CRF) - 213.30 (SN) + 0.53 (SN)^2 - 102.16 (SP) + 0.85 (SP)^2 + 12.26 (SK) - 0.01 (SK)^2$	0.30	717
T5	$Y = 12422^{**} - 0.47 (CRF) + 54.92 (SN) - 0.18 (SN)^2 - 101.2 (SP) + 0.74 (SP)^2 - 277.05^* (SK) + 1.72^* (SK)^2$	0.52*	679

Table 10. Regression model of finger millet yield through rainfall and soil nutrients at Bangalore

4.3.2. Regression models of cotton and green gram yield at Akola

At Akola, the model of green gram yield through rainfall of June to September, crop duration, soil N, P and K gave a predictability in the range of 0.53 for 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha to 0.73 for control (Table 11). The model gave a standard error of yield in the range of 108 kg/ha for control to 161 kg/ha for 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha. June and September rainfall had a positive effect, while July had a negative effect on yield attained by all treatments except 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha and 25 kg N (*Leucaena*) + 25 kg P/ha. August rainfall had a positive effect on yield attained by control, 25 kg N/ha (FYM), 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha and 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha. Soil N had a negative effect on yield of all treatments, while soil P had a positive effect for all treatments except 25 kg N + 12.5 kg P/ha and 25 kg N/ha (*Leucaena*). Soil K had a negative effect on yield of all treatments except 25 kg N/ha (FYM), 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha and 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha. The model indicated that effect of June rainfall on yield of all treatments except 25 kg N/ha (FYM), 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha and 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha; September rainfall and crop duration on yield of 25 kg N/ha (FYM); and soil N for control were significant.

In case of cotton at Akola (Table 11), the model of yield through rainfall of June to November, crop duration, soil N, P and K gave predictability of 0.36 for 25 kg N/ha (FYM) to 0.47 for 25 kg N/ha (*Leucaena*). The standard error ranged from 286 kg/ha for control to 516 kg/ha for 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha. July rainfall had a positive effect, while November rainfall had negative effect on yield of all treatments. June rainfall had a positive effect on yield of control, 25 kg N + 12.5 kg P/ha, 25 kg N/ha (*Leucaena*) and 25 kg N/ha (FYM); August rainfall had a positive effect in all treatments except 25 kg N/ha (*Leucaena*); and October rainfall had a positive effect on yield attained by 50 kg N + 25 kg/ha, 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha and 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha. September rainfall had a negative effect on yield of all treatments except control and 25 kg N + 12.5 kg P/ha. Crop duration had a positive effect on yield attained by all treatments except control. Soil N had a positive effect on

yield attained by all treatments except control, while soil P had a negative effect on yield attained by all treatments. Soil K had a positive effect on yield of 50 kg N + 25 kg/ha, 25 kg N + 12.5 kg P/ha, 25 kg N/ha (*Leucaena*) and 25 kg N/ha (FYM).

Variable	T1	T2	T3	T4	T5	T6	T7	T8
Green gram								
α	223	321	526	606	-379	-64	-142	256
β 1 (CGP)	1.69	4.02	2.49	2.54	7.39*	3.03	3.81	3.38
β 2 (Jun)	1.07*	1.49*	1.41*	1.68*	1.11	1.30	1.24	1.55*
β 3 (Jul)	-0.05	-0.10	-0.13	-0.14	-0.02	0.01	-0.13	0.16
β 4 (Aug)	0.16	-0.09	-0.12	-0.29	0.07	0.05	0.22	-0.12
β 5 (Sep)	0.60	0.92	0.93	0.96	1.25*	0.79	0.90	0.64
β 6 (SN)	-1.33*	-1.50	-1.50	-1.27	-1.12	-0.96	-0.40	-1.46
β 7 (SP)	3.07	1.52	-0.66	-2.59	1.50	2.71	2.99	2.31
β 8 (SK)	-0.13	-0.40	-0.60	-0.84	0.52	0.47	0.19	-0.15
R ²	0.73*	0.62	0.67*	0.65*	0.68*	0.64*	0.53	0.67*
SE (kg/ha)	108	147	131	142	142	145	161	152
SYI (%)	27.7	36.6	34.3	32.8	36.0	36.8	40.3	37.3
Cotton								
α	853	172	38	435	725	1517	2337	1270
β 1 (CGP)	-1.58	2.44	0.83	2.40	1.64	2.18	1.35	3.53
β 2 (Jun)	0.63	-0.28	0.42	1.18	0.31	-0.40	-0.57	-0.09
β 3 (Jul)	1.00	1.44	1.10	0.97	1.29	1.55	2.14	1.32
β 4 (Aug)	0.43	0.33	0.54	-0.27	0.34	0.09	0.50	0.003
β 5 (Sep)	0.97	-1.64	0.19	-0.60	-0.71	-1.62	-1.27	-1.63
β 6 (Oct)	-0.97	0.13	-1.03	-0.76	-0.68	0.26	0.45	-0.07
β 7 (Nov)	-0.50	-1.90	-1.62	-2.95	-2.62	-2.61	-1.16	-3.55
β 8 (SN)	0.03	-2.61	-0.36	-1.19	-0.99	-3.26	-3.17	-2.80
β 9 (SP)	-14.40	-3.05	-13.42	-23.58	-18.27	-11.08	-15.63	-15.31
β 10 (SK)	-0.29	2.16	1.92	1.75	0.79	-0.19	-2.01	-0.18
R ²	0.42	0.38	0.37	0.47	0.36	0.41	0.38	0.41
SE (kg/ha)	286	431	403	352	448	459	516	444
SYI (%)	10.8	14.0	12.4	14.3	12.0	14.6	15.2	13.7

Table 11. Regression models of yield through rainfall and soil nutrients at Akola

4.3.3. Regression models of sorghum and pearl millet yield at Kovilpatti

In sorghum at Kovilpatti, the model of 20 kg N (FYM)/ha had minimum R² of 0.26 with standard error of 573 kg/ha, while model of 20 kg N (crop residue) + 20 kg N (urea)/ha had maximum predictability of 0.77 with an error of 464 kg/ha. Soil N significantly influenced the yield attained under 20 kg N (crop residue) + 20 kg N (urea)/ha and 10 kg N (FYM) + 10 kg N (urea)/ha, while both soil N and CGP significantly influenced yield attained with 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha. The models indicated that CGP had a positive

influence on yield of all treatments except control and 40 kg N (urea) + 20 kg P/ha. Both crop seasonal rainfall and CWS had negative influence on yield of all treatments except 20 kg N (crop residue)/ha. Soil N negatively influenced the yield attained by all treatments except 20 kg N (crop residue)/ha and FYM @ 5 t/ha, while soil P had positive influence on yield attained by all treatments except 20 kg N (crop residue)/ha, 20 kg N (FYM)/ha and 10 kg N (FYM) + 10 kg N (urea)/ha. Soil K had a positive influence on yield attained by all treatments except control and 40 kg N (urea) + 20 kg P/ha (Table 12).

Treatment	Multiple regression model	R ²	SE (kg/ha)	SYI (%)
Sorghum (1987-2005)				
Control	Y = 3383 – 8.52 (CGP) – 1.90 (CRF) – 2194.27 (CWS) – 16.99 (SN) + 227.71 (SP) – 2.34 (SK)	0.41	474	0.08
40 kg N (urea) + 20 kg P/ha	Y = 1499 – 2.62 (CGP) – 1.78 (CRF) – 2317.53 (CWS) – 1.31 (SN) + 108.14 (SP) – 0.05 (SK)	0.28	570	0.25
20 kg N (urea) + 10 kg P/ha	Y = 1296 + 4.79 (CGP) – 0.61 (CRF) – 985.85 (CWS) – 7.48 (SN) + 18.80 (SP) + 0.07 (SK)	0.32	506	0.17
20 kg N (crop residue)/ha	Y = –1618 + 26.39 (CGP) + 1.36 (CRF) + 530.11 (CWS) – 5.52 (SN) – 124.84 (SP) + 1.34 (SK)	0.37	555	0.15
20 kg N (FYM)/ha	Y = 182 + 7.95 (CGP) – 0.81 (CRF) – 1373.72 (CWS) + 3.0 (SN) – 4.64 (SP) + 0.02 (SK)	0.26	573	0.15
20 kg N (crop residue) + 20 kg N (urea)/ha	Y = 2767 + 14.52 (CGP) – 0.36 (CRF) – 1606.54 (CWS) – 35.81 ** (SN) + 97.49 (SP) + 0.47 (SK)	0.77*	464	0.21
10 kg N (FYM) + 10 kg N (urea)/ha	Y = 2753 + 13.83 (CGP) – 0.41 (CRF) – 1430.45 (CWS) – 38.21 ** (SN) – 39.22 (SP) + 2.62 (SK)	0.74*	444	0.27
40 kg N (urea) + 20 kg P + 25 kg ZnSO ₄ /ha	Y = –200 + 29.0 * (CGP) – 0.38 (CRF) – 1820.54 (CWS) – 28.28 ** (SN) + 83.34 (SP) + 2.22 (SK)	0.71*	458	0.30
FYM @ 5 t/ha	Y = –23 + 9.46 (CGP) – 2.71 (CRF) – 2556.99 (CWS) + 9.1 (SN) + 14.73 (SP) + 0.7 (SK)	0.38	757	0.20
Pearl millet (1987-2005)				
Control	Y = 2723 – 13.15 (CGP) + 0.21 (CRF) – 239.81 (CWS) + 6.22 (SN) – 212.62 * (SP) – 0.78 (SK)	0.95*	84	0.33
40 kg N (urea) + 20 kg P/ha	Y = – 4079 + 13.93 (CGP) – 0.78 (CRF) + 1373.54 (CWS) + 20.09 (SN) + 453.74 (SP) – 8.73 (SK)	0.81	268	0.53
20 kg N (urea) + 10 kg P/ha	Y = – 653 + 2.64 (CGP) – 0.60 (CRF) – 580.17 (CWS) + 3.43 (SN) + 87.74 (SP) + 0.49 (SK)	0.73	189	0.49
20 kg N (crop residue)/ha	Y = – 422 + 6.58 (CGP) + 0.41 (CRF) – 590.53 (CWS) – 6.69 (SN) + 22.39 (SP) + 2.66 * (SK)	0.98*	52	0.44
20 kg N (FYM)/ha	Y = 1787 – 6.26 (CGP) + 0.77 (CRF) + 4.18 (CWS) + 9.02 (SN) – 162.38 (SP) – 1.72 (SK)	0.77	194	0.42
20 kg N (crop residue) + 20 kg N (urea)/ha	Y = – 2472 + 9.79 (CGP) + 0.74 (CRF) – 36.16 (CWS) – 2.15 (SN) + 140.34 (SP) + 2.14 (SK)	0.97*	101	0.53
10 kg N (FYM) + 10 kg N (urea)/ha	Y = – 1049 + 1.38 (CGP) + 1.30 (CRF) + 43.84 (CWS) – 4.47 (SN) + 100.62 (SP) + 1.95 (SK)	0.91*	170	0.63
40 kg N (urea) + 20 kg P + 25 kg ZnSO ₄ /ha	Y = – 869 + 11.16 (CGP) – 0.15 (CRF) + 869.91 (CWS) + 20.78 (SN) – 43.19 (SP) – 5.25 (SK)	0.90*	157	0.62
FYM @ 5 t/ha	Y = 273 + 2.62 (CGP) + 0.07 (CRF) – 17.55 (CWS) + 6.36 (SN) – 74.04 (SP) – 0.41 (SK)	0.92*	103	0.42

* and ** indicate significance at p < 0.05 and p < 0.01 level respectively

Table 12. Regression models of yield through rainfall, CGP, CWS and soil nutrients at Kovilpatti

In case of pearl millet at Kovilpatti, the model of 20 kg N (urea) + 10 kg P/ha had minimum R^2 of 0.73 with an error of 189 kg/ha, while the model of 20 kg N (crop residue)/ha had maximum R^2 of 0.98 with an error of 52 kg/ha. Soil P had a significant influence on control yield, while soil K had significant influence on yield attained by 20 kg N (crop residue)/ha. The models indicated that CGP positively influenced the yield of all treatments except control and 20 kg N (FYM)/ha. The crop seasonal rainfall had positive influence on yield attained by all treatments except 40 kg N (urea) + 20 kg P/ha, 20 kg N (urea) + 10 kg P/ha and 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha. The CWS negatively influenced the yield of all treatments except 40 kg N (urea) + 20 kg P/ha, 20 kg N (FYM)/ha, 10 kg N (FYM) + 10 kg N (urea)/ha and 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha. Soil N positively influenced the yield attained by all treatments except 20 kg N (crop residue)/ha, 20 kg N (crop residue) + 20 kg N (urea)/ha and 10 kg N (FYM) + 10 kg N (urea)/ha. Soil P positively influenced yield of all treatments except control, 20 kg N (FYM)/ha, 40 kg N (urea) + 20 kg P + 25 kg ZnSO₄/ha and FYM @ 5 t/ha, while soil K negatively influenced yield of all treatments except 20 kg N (urea) + 10 kg P/ha, 20 kg N (crop residue)/ha, 20 kg N (crop residue) + 20 kg N (urea)/ha and 10 kg N (FYM) + 10 kg N (urea)/ha (Table 12).

4.3.4. Regression model of soybean yield at Indore

Based on the regression model of soybean yield as a function of monthly rainfall received during June to October, crop growing period, soil N, P, K and S, crop growing period had a significant effect on yield attained by all treatments except control and crop residue @ 5 t/ha. July rainfall had a significant effect on yield attained by 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha and 20 kg N (urea) + 13 kg P + FYM @ 5 t/ha, while August rainfall had a significant effect on yield attained by all treatments except control and crop residue @ 5 t/ha. September rainfall had a significant effect on yield attained by all treatments except control based on the model. Among soil nutrients, soil N and P had a significant influence on yield attained by 20 kg N (urea) + 13 kg P + FYM @ 5 t/ha. The R^2 ranged from 0.81 for control to 0.98 for 20 kg N (urea) + 13 kg P + FYM @ 5 t/ha, while standard error ranged from 130 kg/ha for 20 kg N (urea) + 13 kg P + FYM @ 5 t/ha to 320 kg/ha for control. The regression model indicated that maximum rate of change in yield of 31.07 for a unit change in soil N and 1.81 for soil K occurred in control compared to a minimum of -21.23 in 30 kg N (urea) + 20 kg P/ha and -2.16 in 40 kg N (urea) + 26 kg P/ha for the two soil nutrients respectively. The yield attained by 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha had a minimum rate of change for soil P and maximum rate of change for soil Sulphur, while 20 kg N (urea) + 13 kg P/ha had maximum rate of change for soil P and control had a minimum rate of change for soil S (Table 13).

4.3.5. Regression model of groundnut pod yield at Anantapur

The regression models of yield through monthly rainfall gave R^2 in the range of 0.18 for 100% N (groundnut shells ~ 20 kg N/ha) and 100% N (groundnut shells ~ 20 kg N/ha) + 50% NPK (10-20-20 kg/ha) to 0.43 for Farmers practice (FYM @ 5 t/ha). The estimate of

standard error based on regression models was in the range of 315 kg/ha for control and Farmers practice (FYM @ 5 t/ha) to 397 kg/ha for 100% NPK (20–40–40 kg/ha). Among the effects of rainfall on yield, the rainfall received in July, September, October and November had a positive influence, while rainfall received in August had negative influence on the yield attained by all treatments. July rainfall had significant influence on yield attained by all treatments except 100% N (groundnut shells ~ 20 kg N/ha) and 100% N (groundnut shells ~ 20 kg N/ha) + 50% NPK (10–20–20 kg/ha); while November rainfall had significant influence on yield attained by 100% NPK (20–40–40 kg/ha), 50% NPK (10–20–20 kg/ha), 50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha), 100% NPK (20–40–40 kg/ha) + ZnSO₄ @ 25 kg/ha and Farmers practice (FYM @ 5 t/ha). The rate of change in yield of all treatments was positive and maximum for an unit change in November rainfall, followed by July, October and September, while it was negative for August. The analysis indicated that the model of farmers practice (FYM @ 5 t/ha) had maximum R² and minimum standard error, while the models of 100% NPK (20–40–40 kg/ha) and 100% N (groundnut shells ~ 20 kg N/ha) + 50% NPK (10–20–20 kg/ha) had minimum R² and maximum standard error (Table 14).

Variable	T1	T2	T3	T4	T5	T6	T7	T8	T9
α	-1926	4065	12409*	9645**	7728	5223*	9248**	8225**	8794**
β_1 (CGP)	-14.6	-77.9**	-77.8**	-61.1*	-86.5*	-77.0**	-94.5**	-69.9**	-53.5
β_2 (Jun)	-6.83	3.68	2.04	-0.02	5.24	4.87	2.75	3.54	-2.19
β_3 (Jul)	0.15	-1.63	-2.49	-0.78	-2.98	-3.48*	-2.81**	-1.47	-0.81
β_4 (Aug)	0.35	4.22*	6.72*	4.02*	7.33*	7.36**	6.71**	5.29*	3.44
β_5 (Sep)	1.65	5.07**	7.01**	5.61**	7.93*	7.68**	8.12**	6.11**	5.34*
β_6 (Oct)	17.90	-1.24	-0.34	4.95	-10.65	-7.30	-3.21	-3.71	7.98
β_7 (SN)	31.07	13.81	-21.23	-2.79	-2.36	4.45	-3.44*	-1.54	-3.33
β_8 (SP)	-7.17	13.30	-33.95	-27.40	-20.25	-40.98	-28.15*	-18.94	-38.17
β_9 (SK)	1.81	1.64	-0.48	-2.16	1.17	1.27	1.64	-0.47	-0.38
β_{10} (SS)	-125.04	16.54	46.23	-41.05	76.68	87.68	37.85	5.45	-73.22
R ²	0.81	0.94*	0.95*	0.94*	0.96**	0.96**	0.98**	0.95*	0.91
SE (kg/ha)	320	215	216	238	191	187	130	225	290
SYI (kg/ha)	29.4	43.3	48.0	50.8	55.5	58.8	51.1	50.4	41.2

Table 13. Regression model of soybean yield through rainfall, CGP and soil nutrients

Treatment	Regression model	R ²	SE (kg/ha)	SYI (%)
Control	$Y = 376 + 1.30^* (\text{Jul}) - 0.09 (\text{Aug}) + 0.58 (\text{Sep}) + 1.02 (\text{Oct}) + 2.97 (\text{Nov})$	0.24	315	27.6
100% NPK (20–40–40 kg/ha)	$Y = 433 + 1.95^* (\text{Jul}) - 0.04 (\text{Aug}) + 0.82 (\text{Sep}) + 0.99 (\text{Oct}) + 4.01^* (\text{Nov})$	0.30	397	33.6
50% NPK (10–20–20 kg/ha)	$Y = 423 + 1.76^* (\text{Jul}) - 0.09 (\text{Aug}) + 0.80 (\text{Sep}) + 0.96 (\text{Oct}) + 4.04^* (\text{Nov})$	0.32	351	34.2
100% N (GS ~ 20 kg N/ha)	$Y = 473 + 1.03 (\text{Jul}) - 0.11 (\text{Aug}) + 0.80 (\text{Sep}) + 1.16 (\text{Oct}) + 3.30 (\text{Nov})$	0.18	357	32.7
50% N (FYM ~ 10 kg N/ha)	$Y = 477^* + 1.86^* (\text{Jul}) - 0.46 (\text{Aug}) + 1.13 (\text{Sep}) + 0.54 (\text{Oct}) + 3.23 (\text{Nov})$	0.36	330	35.3
100% N (GS ~ 20 kg N/ha) + 50% NPK (10–20–20 kg/ha)	$Y = 527^* + 1.11 (\text{Jul}) + 0.14 (\text{Aug}) + 0.73 (\text{Sep}) + 0.72 (\text{Oct}) + 3.11 (\text{Nov})$	0.18	363	34.0
50% N (FYM ~ 10 kg N/ha) + 50% NPK (10–20–20 kg/ha)	$Y = 432 + 1.97^* (\text{Jul}) - 0.03 (\text{Aug}) + 0.82 (\text{Sep}) + 0.99 (\text{Oct}) + 3.75^* (\text{Nov})$	0.32	373	34.9
100% NPK (20–40–40 kg/ha) + ZnSO ₄ @ 25 kg/ha	$Y = 399 + 1.94^* (\text{Jul}) + 0.24 (\text{Aug}) + 0.88 (\text{Sep}) + 0.94 (\text{Oct}) + 4.55^* (\text{Nov})$	0.34	383	35.1
Farmers practice (FYM @ 5 t/ha)	$Y = 366 + 2.08^{**} (\text{Jul}) - 0.32 (\text{Aug}) + 1.02 (\text{Sep}) + 0.84 (\text{Oct}) + 3.69^* (\text{Nov})$	0.43*	315	33.5

Table 14. Regression models of groundnut pod yield through monthly rainfall at Anantapur

4.4. Sustainability yield index of treatments under different rainfall situations

Using the mean yield of treatments over years under different crop seasonal rainfall situations, standard error, 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 15.

Treatment	Mean yield (kg/ha) under different rainfall situations				SE (kg/ha)	Sustainability Yield Index (%)			
	<500	500-750	750-1000	1000-1250		<500	500-750	750-1000	1000-1250
Bangalore : Finger millet : 1984 – 2008									
T1	532	706	444	172	435	3.1	8.6	0.3	-8.3
T2	1883	2567	2572	2283	646	39.1	60.6	60.8	51.7
T3	2206	2941	3082	2880	660	48.8	72.0	76.5	70.1
T4	2239	3409	3176	3183	717	48.1	85.0	77.6	77.9
T5	1415	2197	1662	1315	679	23.2	47.9	31.0	20.1
Akola : Green gram : 1987-2007									
T1	258	316	392	580	108	16.5	22.8	31.2	51.9
T2	330	435	558	610	147	20.1	31.6	45.2	50.9
T3	303	407	500	600	131	18.9	30.3	40.6	51.5
T4	318	392	488	650	142	19.3	27.4	38.1	55.8
T5	328	398	553	680	142	20.4	28.1	45.1	59.1
T6	329	427	539	710	145	20.2	31.0	43.3	62.1
T7	365	469	623	670	161	22.4	33.8	50.8	55.9
T8	356	435	534	775	152	22.4	31.0	42.0	68.5
Akola : Cotton : 1987-2007									
T1	233	524	551	545	286	-2.8	12.5	13.9	13.6
T2	309	765	760	800	431	-6.4	17.5	17.2	19.3
T3	268	709	693	725	403	-7.1	16.0	15.2	16.9
T4	289	681	695	670	352	-3.3	17.2	17.9	16.6
T5	326	706	785	700	448	-6.4	13.5	17.7	13.2
T6	349	795	821	800	459	-5.8	17.6	18.9	17.9
T7	371	851	948	795	516	-7.6	17.5	22.6	14.6
T8	345	745	795	775	444	-5.2	15.8	18.4	17.3
Kovilpatti : Sorghum : 1987-2005									
Rainfall (mm)	<250	250-500	500-750			<250	250-500	500-750	
T1	250	785	493		474	-36.4	12.7	1.4	
T2	488	1195	997		570	-13.4	25.5	31.8	
T3	448	965	765		506	-9.5	18.7	19.3	
T4	354	879	870		555	-32.6	13.2	23.4	
T5	290	923	756		573	-45.9	14.3	13.6	
T6	317	1102	944		464	-23.9	26.0	35.7	
T7	394	1246	1072		444	-8.1	32.7	46.8	
T8	480	1339	1168		458	3.5	35.9	52.9	
T9	436	1136	619		757	-52.1	15.4	-10.3	

Treatment	Mean yield (kg/ha) under different rainfall situations				SE (kg/ha)	Sustainability Yield Index (%)			
Kovilpatti : Pearl millet : 1987-2005									
T1	290	531	454		84	41.0	51.7	30.3	
T2	408	622	721		268	27.9	41.0	37.1	
T3	463	543	673		189	54.6	40.9	39.7	
T4	253	575	624		52	40.0	60.5	46.9	
T5	358	578	585		194	32.7	44.4	32.1	
T6	265	646	743		101	32.7	63.1	52.6	
T7	419	837	807		170	49.6	77.2	52.2	
T8	502	667	825		157	68.7	59.0	54.7	
T9	336	619	564		103	46.4	59.7	37.8	
Indore : Soybean : 1992-2006									
T1	985	1617	1292	1137	320	39.3	54.8	40.3	25.2
T2	1181	1835	1600	1708	215	57.2	68.4	57.3	46.0
T3	1365	1902	1730	1950	216	68.0	71.2	62.7	53.4
T4	1460	2041	1830	2065	238	72.3	76.1	65.9	56.3
T5	1573	2175	1889	2225	191	81.8	83.8	70.3	62.6
T6	1608	2257	1983	2386	187	84.1	87.4	74.4	67.7
T7	1290	2122	1674	1964	130	68.6	84.1	63.9	56.5
T8	1379	1980	1787	2133	225	68.3	74.1	64.7	58.8
T9	1178	1906	1599	1693	290	52.5	68.2	54.2	43.2
Anantapur : Groundnut : 1985-2006									
T1	726	738	966		315	26.6	27.4	49.0	
T2	879	941	1250		397	31.2	35.3	64.2	
T3	846	910	1112		351	32.0	36.3	57.3	
T4	857	854	1013		357	32.3	32.2	49.4	
T5	833	932	1088		330	32.5	39.1	57.0	
T6	883	848	1256		363	33.6	31.5	67.2	
T7	863	971	1182		373	31.7	38.8	60.9	
T8	879	960	1329		383	32.1	37.5	71.2	
T9	776	912	1087		315	29.8	38.7	58.1	

Table 15. Sustainability of fertilizer treatments under different crop seasonal rainfall situations

4.4.1. Bangalore

At Bangalore, the SYI was 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 standard error. The study indicated the superiority of FYM @ 10 t/ha under < 500 mm rainfall; while FYM @ 10 t/ha + 100% NPK was superior under 500–750, 750–1000 and 1000–1250 mm rainfall situations for attaining maximum mean yield and sustainability over years. Thus, based on the long term study, an efficient fertilizer treatment having a high sustainability has been identified for attaining maximum productivity. Conclusively, the results obtained from this long term study incurring huge expenditure provide very good conjunctive nutrient use options with good conformity for different

rainfall conditions of rainfed semi-arid Alfisol for ensuring higher finger millet yield, maintaining higher SYI, and maintaining improved soil fertility.

4.4.2. Akola

At Akola, the SYI of each treatment was determined for green gram and cotton using mean yield of a treatment, standard error determined from the treatment-wise regression models and maximum yield of 910 kg/ha of green gram and 1910 kg/ha of cotton attained in the study. The SYI was determined under each of the 4 rainfall situations of < 500, 500–750, 750–1000 and 1000–1250 mm. Based on the regression model of green gram yield, 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha had a maximum SYI of 22.4% under < 500 mm, 33.8% under 500–750 mm, 50.8% under 750–1000 mm, while 25 kg N (*Leucaena*) + 25 kg P/ha had a maximum of 68.5% under 1000–1250 mm rainfall. An increase in rainfall significantly increased the sustainability of treatments in green gram. This is evident from SYI range of 16.5 to 22.4% under < 500 mm; 22.8 to 33.8% under 500–750 mm; 31.2 to 50.8% under 750–1000 mm for control and 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha respectively; and 50.9% for 50 kg N + 25 kg/ha to 68.5% for 25 kg N (*Leucaena*) + 25 kg P/ha under 1000–1250 mm rainfall situation.

At Akola, based on regression model of cotton yield through rainfall and soil nutrient variables, control had a maximum SYI of –2.8% under < 500 mm; while 25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha had 17.6% under 500–750; 25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha had 22.6% under 750–1000 mm; and 50 kg N + 25 kg/ha had 19.3% under 1000–1250 mm rainfall situation. In case of cotton also, an increase in rainfall increased the sustainability of treatments. This is evident from a SYI range of –7.6 (25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha) to –2.8% (control) under < 500 mm; 12.5 (control) to 17.6% (25 kg N (*Leucaena*) + 25 kg N (urea) + 25 kg P/ha) under 500–750 mm; 13.9 (control) to 22.6% (25 kg N (FYM) + 25 kg N (urea) + 25 kg P/ha) under 750–1000 mm; and 13.2% (25 kg N/ha (FYM)) to 19.3% (50 kg N + 25 kg/ha) under 1000–1250 mm rainfall. Thus fertilizer treatments have a better sustainability for green gram compared to cotton. The study indicated that cotton is unsustainable under < 500 mm rainfall situation.

4.4.3. Kovilpatti

At Kovilpatti, using mean yield of a treatment over 9 years each for sorghum and pearl millet; standard error based on the models; and maximum yield potential of sorghum of 617, 2451 and 1342 kg/ha under < 250, 250-500 and 500-750 mm rainfall situations respectively, SYI of each treatment was derived. In sorghum, T8 had SYI of 3.5%; while the other treatments had a negative SYI under < 250 mm. The SYI ranged from 12.7% for T1 to 35.9% for T8 under 250-500 mm rainfall situation. It ranged from 1.4% for T1 to 52.9% for T8 under 500-750 mm rainfall situation. In pearl millet, the maximum potential yield was 502, 864 and 1220 under < 250, 250-500 and 500-750 mm rainfall situations respectively. In pearl millet, the SYI ranged from 27.9% for T2 to 68.7% for T8 under < 250 mm. The SYI ranged from 40.9% for T3 to 77.2% for T7 under 250-500 mm rainfall situation. It ranged from 30.3% for T1 to 54.7% for T8 under 500-750 mm rainfall situation.

4.4.4. Indore

At Indore, the sustainable yield index of fertilizer treatments was measured by using the mean yield of treatments over years, standard error of the respective treatment under regression model; and maximum yield attained by treatments under different rainfall situations. The maximum yield attained was 1690 kg/ha under < 500 mm; 2368 kg/ha under 500-750 mm; 2415 kg/ha under 750-1000 mm; and 3247 kg/ha under 1000-1250 mm rainfall situation. The SYI ranged from 39.3 to 84.1% under < 500 mm; 54.8 to 87.4% under 500-750 mm; 40.3 to 74.4% under 750-1000 mm; 25.2 to 67.7% under 1000-1250 mm rainfall situations attained by control and 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha respectively. 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha was found to be most efficient treatment for attaining sustainable soybean yield over years. The treatment was also superior with a maximum available mean soil N, P, K and S at the end of 15 years. Based on the study, 20 kg N (urea) + 13 kg P + FYM @ 6 t/ha could be recommended for large scale adoption under farmer's fields for attaining maximum sustainable yields and maintenance of soil fertility of N, P, K and S under semi-arid Vertisols.

4.4.5. Anantapur

Using mean yield of each treatment over years; standard error based on regression model of yield; and maximum pod yield (Y_{max}) of 1546 kg/ha attained by 100% NPK (20-40-40 kg/ha) in 2004, SYI was derived for each treatment. The index ranged from 27.6% for control to 35.3% for 50% N (FYM~10 kg N/ha) based on the model through monthly rainfall. The SYI indicated that 50% N (FYM~10 kg N/ha) was superior for attaining sustainable yield based on model of monthly rainfall. 100% NPK (20-40-40 kg/ha) + $ZnSO_4$ @ 25 kg/ha was the 2nd best treatment based on the study. The maximum pod yield was 1546 kg/ha under < 500 mm; 1541 kg/ha under 500-750 mm; 1329 kg/ha under 750-1000 mm rainfall situation. The SYI ranged from 26.6 for control to 33.6% for T6 under < 500 mm; 27.4% for control to 39.1% for T5 under 500-750 mm; 49.0 for control to 71.2% for T8 under 750-1000 mm rainfall situation.

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5. References

- Bansal, R.K., N.K.Awadhwai and V.M.Mayande (1987). Implement development for SAT Alfisols. In Alfisols in the semi-arid tropics : Proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils, 97 – 107. India : ICRISAT Center. Patancheru, Andhra Pradesh 502324, India.
- Behera, B., G.R. Maruthi Sankar., S.K.Mohanty., A.K.Pal ., G.Ravindra Chary., G.Subba Reddy and Y.S.Ramakrishna (2007). Sustainable fertilizer practices for upland rice from permanent manorial trials under sub-humid Alfisols. *Indian Journal of Agronomy*, 52 (2): 33-38.
- Bhat, A.K., V.Beri and B.S.Sindhu (1991). Effect of long term recycling of crop residue on soil properties. *Journal of Indian Society of Soil Science*, 39: 380–382.
- Charreau, C. (1977). Controversial points in dryland farming practices in semi –arid West Africa. In Symposium on *Rainfed Agricultural Semi – arid Regions*, ed. G.H.Cannell, 313 – 360. Riverside, Calif. : University of California, Riverside.
- Chesnin, L. and Yien, C.H. (1950). Turbedimetric determination of available sulphur. *Soil Science Society of America Proceeding* 15, 149-151.
- Cocheme, J., and P.Franquin. (1967). *An agroclimatology survey of a semiarid area in Africa south of Sahara* (FAO/Unesco/WMO interagency Project on Agroclimatology Technical Note 86 – 160). Rome, Italy: FAO.

- Dalal, R.C. and R.J.Mayer (1986). Long term trends in fertility of soils under continuous cultivation and cereal cropping in Southern Queensland: In Overall changes in soil properties and trends in winter cereal yields. *Australian Journal of Soil Research*, 24: 265-279.
- Doorenbos, J. and Kassam, A.H. (1979). Yield response to water. FAO Irrigation and Drainage. Paper 33. FAO, Rome.
- Draper, N.R. and H.Smith (1998). *Applied Regression Analysis*. John Wiley Inc., New York.
- El-Swaify, S.A., S.Singh, and P.Pathak (1983). Physical and conservation constraints and management components for SAT Alfisols. In *ALFISOLS in the semi-arid tropics : Proceedings of the Consultants' Workshop on the State of the Art and Management Alternatives for Optimizing the Productivity of SAT Alfisols and Related Soils*. ICRISAT Center. Patancheru, Andhra Pradesh 502324, India.
- Gomez, K.A. and A.A.Gomez (1984). *Statistical Procedures for Agricultural Research*. John Wiley Inc., New York.
- Hiler, E.A. and Clark, R.N. (1971). Stress day index to characterize effects of water stress on crop yields. *Transactions American Society of Agricultural Engineers*, 14 : 757 – 761.
- Jackson, M.L. (1973). *Soil Chemical Analysis*. Prentice Hall of India, New Delhi.
- Kampen, J., and J.Burford (1980). Production systems, soil related constraints, and potential in the semi-arid tropics, with special reference to India. In *Priorities for alleviating soil-related constraints to food production in the tropics*. International Rice Research Institute, Los Banos, Laguna, Phillipines : 141-165.
- Maruthi Sankar, G.R. (1986). On screening of regression models for selection of optimal variable subsets. *Journal of Indian Society of Agricultural Statistics*, 38 (2): 161-168.
- Maruthi Sankar, G.R., G.Ravindra Chary., G.Subba Reddy., G.G.S.N.Rao., Y.S.Ramakrishna and A.Girija (2008). Statistical modeling of rainfall effects for assessing efficiency of fertilizer treatments for sustainable crop productivity under different agro-eco sub-regions. Paper presented in the International symposium on “Agro-meteorology and food security” at CRIDA, Hyderabad during 18–21: February.
- Maruthi Sankar, G.R., Vittal, K.P.R., Ravindra Chary, G., Ramakrishna, Y.S. and Girija, A. (2006). Sustainability of tillage practices for rainfed crops under different soil and climatic situations in India. *Indian Journal of Dryland Agricultural Research and Development*, 21 (1), 60–73.
- Maruthi Sankar, G.R., Sonar, K.R. and Reddy K.C.K. (1988). Pooling of experimental data for predicting fertilizer requirements of *Rabi* sorghum for varying soil test values. *Journal of Maharashtra Agricultural Universities*, 13 (1) : 59 – 62.
- Maruthi Sankar, G.R. (1992). Application of Statistical Model-Building and Optimization techniques in Fertiliser Use Research. Chapter 28 in the book on Dryland Agriculture: State of Art of Research in India. pp: 653-671.
- Maruthi Sankar, G.R. and Vanaja, M. (2003). Crop growth prediction in sunflower using weather variables in a rainfed alfisol. *Helia*, 26 (39): 125 – 140.
- Maruthi Sankar, G.R. and Raghuram Reddy, P. (2005). Identification of maize (*Zea mays* L.) genotypes for rainfed condition based on modelling of plant traits. *Indian Journal of Genetics and Plant Breeding*, 65 (2): 88–92.

- Mathur, G.M. (1997). Effects of long term application of fertilizers and manures on soil properties under cotton–wheat rotation in North West Rajasthan. *Journal of Indian Society of Soil Science*, 42 (2): 288–292.
- Mohanty, S.K., G.R. Maruthi Sankar., B.Behera., A.Mishra., A.K.Pal and C.R.Subudhi. (2008). Statistical evaluation and optimization of fertilizer requirement of upland rice (*Oryza sativa*) genotypes at varying levels of crop seasonal rainfall under moist sub-humid Alfisols. *Indian Journal of Agricultural Science*, 78 (3): 18–23.
- Nema, A.K., G.R.Maruthi Sankar and S.P.S.Chauhan. (2008). Selection of superior tillage and fertilizer practices based on rainfall and soil moisture effects on pearl millet yield under semi-arid inceptisols. *Journal of Irrigation and Drainage Engineering*, 134 (3): 361–371.
- Olsen, S.R., C.V.Cole., F.S.Watanabe and L.A.Dean. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular of US Department of Agriculture, 939.
- Pal, A.K., Behera, B., and Mohanty, S.K. (2006). Long term effect of chemical fertilizers and organic manures on sustainability of rice (*Oryza sativa* L.)–horse gram (*Microtyloma uniflorum*) cropping sequence under rainfed upland soil. *Indian Journal of Agricultural Sciences*, 76 (4) : 211–274.
- Prasad, R. and N.N.Goswami. (1992). Soil fertility restoration and management for sustainable agriculture in South Asia. *Advances in Soil Science*. Soil Sci. 17, 37–77.
- Prihar, S.S. and Gajri, P.R. (1988). Fertilization of dryland crops. *Indian Journal of Dryland Agricultural Research and Development*, 3 (1), 1–33.
- Rijtema, P.E. and Aboukhaled, A. (1975). Crop water use. In. Research on Crop water use in salt affected soils and drainage in the Arab Republic of Egypt. Edited by Aboukhaled, A., Arara. Balba, A.M., Bishay, B.G., Kadry, L.T., Rijtema, P.E. and Taher, A. FAO Regional Office for the near East. pp: 5–61.
- Singh, N.P., Sachan, R.S., Pandey, P.C., and Bisht, P.S. (1999). Effect of a decade long fertilizer and manure application on soil fertility and productivity of rice – wheat system in a mollisol. *Journal of Indian Society of Soil Science*, 47 (1) : 72 – 80.
- Singh, R., Singh, Y., Prihar, S.S. and Singh, P. (1975). Effect of N fertilization on yield and water use efficiency of dryland winter wheat as affected by stored water and rainfall. *Agronomy Journal*, 67, 599–603.
- Snedecor, G.W. and Cochran, W.G. (1967). Statistical methods. Iowa State University Press, Ames, Iowa, USA.
- Subbaiah, B.V. and G.L.Asija. (1956). A rapid procedure for determination of available nitrogen in soil. *Current Science*, 25 : 259–260.
- Velayutham, M., Reddy, K.C.K. and Maruthi Sankar, G.R. (1985). All India Coordinated Research Project on Soil Test Crop Response Correlation and its impact on Agricultural Production. *Fertilizer News*, 30 (4): 81–85.
- Venkateswarlu, J. and Singh, R. (1982). Crop response to applied nutrients under limited water conditions. Review of Soils Research in India. Transactions of 12th International Soil Science Congress, New Delhi.
- Vikas Abrol, G.R.Maruthi Sankar., Mahinder Singh and J.S.Jamwal. (2007). Optimization of fertilizer requirement of maize based on yield and rainfall variations from permanent

- manorial trials under dry-sub humid Inceptisols. *Indian Journal of Dryland Agricultural Research and Development*, 22 (1) : 15–21.
- Vittal, K.P.R., Maruthi Sankar, G.R., Singh, H.P. and Samra, J.S. (2002). Sustainability of Practices of Dryland Agriculture – Methodology and Assessment. Research Bulletin of AICRP for Dryland Agriculture, CRIDA, Hyderabad, 100 pages.
- Vittal, K.P.R., G.R.Maruthi Sankar., H.P.Singh., D.Balaguravaiah., Y.Padamalatha and T.Yellamanda Reddy.(2003). Modeling sustainability of crop yield on rainfed groundnut based on rainfall and land degradation. *Indian Journal of Dryland Agricultural Research and Development*, 18 (1):7–13.
- Vittal, K.P.R., Basu, M.S., Ravindra Chary, G., Maruthi Sankar, G.R., Srijaya, T., Ramakrishna, Y.S., Samra, J.S., and Gurbachan Singh. (2004). District wise promising technologies for rainfed groundnut based production system in India. Research Bulletin – An AICRPDA contribution, CRIDA, Hyderabad. (92 pages).
- Walkley, A.J., and Black, C.A. (1934) Estimation of organic carbon by chromic acid titration method. *Soil Science*, 37: 29-38.