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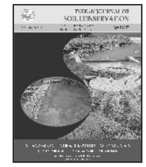

Long-term effect of fertilizer application on rainwater use efficiency, soil fertility and sustainability of yield and profitability from sorghum and pigeonpea in semi-arid Vertisols

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ABSTRACT

A long-term intercropping experiment with sorghum and pigeonpea was conducted during 1998 to 2008 under semi-arid Vertisols at Akola to identify a superior treatment for sustaining maximum rainwater use efficiency (RWUE), yield and monetary returns and maintaining soil fertility over years. The experiment was conducted with 9 fertilizer treatments with recommended dose of nutrients @ 80:40:0 NPK kg ha^{-1} for sorghum. The treatments were: (i) T_1: Control; (ii) T_2: 100% recommended N; (iii) T_3: 50% recommended N; (iv) T_4: FYM @ 4 t ha^{-1}; (v) T_5: FYM @ 4 t ha^{-1} + 10 kg N ha^{-1}; (vi) T_6: FYM @ 4 t ha^{-1} + 20 kg N ha^{-1}; (vii) T_7: 2 t ha^{-1} green leaf + 10 kg N ha^{-1}; (viii) T_8: 2 t ha^{-1} green leaf + 20 kg N ha^{-1} and (ix) T_9: FYM @ 4 t ha^{-1} + 2 t ha^{-1} green leaf. A common dose of P_2O_5 @ 40 kg ha^{-1} was applied to both crops and N was given to only sorghum. The soil was low in N, P and high in K. The study indicated a significant effect of treatments on soil nutrients, RWUE, yield and monetary returns over years. T_6 gave significantly higher sorghum equivalent yield of 4471 kg ha^{-1} and RWUE of 6.47 kg ha^{-1} mm^{-1}. This treatment also gave maximum gross returns of ₹42291 ha^{-1}; net returns of ₹ 25416 ha^{-1}; benefit-cost (B:C) ratio of 2.51; apart from maintaining soil carbon of 6.7 g kg^{-1}; N of 255 kg ha^{-1}; P_2O_5 of 28.9 kg ha^{-1} and K_2O of 339 kg ha^{-1}. Maximum sustainability yield index of 53% with lowest rank sum were attained by T_6. We conclude that the farmers could adopt treatment T_6 to attain maximum profitability, RWUE and maintenance of soil fertility under semi-arid Vertisols.

1. INTRODUCTION

Efficient utilization of rainwater combined with optimum fertilizer dose of nutrients are essential for sustaining higher yield levels and monetary returns under rainfed agriculture. Studies were conducted to maximize the RWUE and monetary returns from different rainfed crops under different soil and agro-climatic conditions (Behera *et al.,* 2012; Nema *et al.,* 2008 and Maruthi Sankar *et al.,* 2012a and 2012b). Sharma *et al.,* 2013 examined the relationships between RWUE, sustainability yield index, production efficiency index and monetary returns by growing maize and black gram under dry sub-humid Inceptisols. Based on long-term nutrient experiments, Jawahar *et al.,* 2014 assessed the sustainability of productivity and monetary returns of sorghum and pearl millet and their influence on build-up of soil fertility under semi-arid Vertisols. Due to erratic rainfall, rise in temperature, imbalanced fertilization and less use of organic manures, there is a continuous mining of nutrients which deteriorated the soil health.

An intercropping of cereal and pulse could be grown in for enhancing the soil health and nutrition. In this system, the duration of sorghum would not interfere with the growth of pigeonpea, apart from the fact that the crop residue of pigeonpea incorporated in the field would be useful for subsequent crops. A cereal+pulse system would also reduce nitrogen dose as legumes would fix nitrogen in soil. The integrated nutrient management would reduce the use of inorganic fertilizers to such a level that farmers could easily adopt the practice. The cereal and pulse based system would also help in improving the monetary returns and livelihood of farmers. Incorporation of FYM along with chemical fertilizers would improve the soil fertility in the long run. With the objective of maintenance of soil fertility and plant nutrient supply to optimum level for sustaining the crop productivity through organic sources, a long-term experiment was conducted with sorghum and pigeonpea during 1998 to 2008 under semi-arid Vertisols.

2. MATERIALS AND METHODS

Experimental Details

A field experiment was conducted with sorghum (CSH-9) as base crop and pigeonpea (C-11) as intercrop in 3:2 ratio with 9 fertilizer treatments with recommended dose (80:40:0 NPK kg ha^{-1} for sorghum) during 1998 to 2008 under semi-arid Vertisols at Akola. The soil had available N of 210 kg ha^{-1}, P of 22.5 kg ha^{-1} and K of 345 kg ha^{-1}. The treatments tested were: (i) T_1: Control (No fertilizer); (ii) T_2: 100% recommended N; (iii) T_3: 50% recommended N; (iv) T_4: FYM @ 4t ha^{-1}; (v) T_5: FYM @ 4t ha^{-1} + 10 kg N ha^{-1}; (vi) T_6: FYM @ 4 t ha^{-1} + 20 kg N ha^{-1}; (vii) T_7: 2 t ha^{-1} green leaf + 10 kg N ha^{-1}; (viii) T_8: 2 t ha^{-1} green leaf + 20 kg N ha^{-1}; and (ix) T_9: FYM @ 4 t ha^{-1} + 2 t ha^{-1} green leaf. The study was conducted in a Randomized Block Design with 3 replications. Randomization was done in the first year and treatments were superimposed to the plots. In subsequent years, treatments were superimposed to the same plots to study the effect of fertilizer application. A common dose of P_2O_5 @ 40 kg ha^{-1} was applied to both crops and N was applied to only sorghum. Row x plant spacing of 45 x 15 cm for sorghum and 60 x 20 cm for pigeonpea were maintained. Surface soil samples (0-15 cm depth) were collected from each plot after harvest of crops. The organic carbon (%) was determined by Walkley and Black (1934) rapid titration method, while N (kg ha^{-1}) was determined by alkaline permanganate method (Subbaiah and Asija, 1956). Available P (kg ha^{-1}) was extracted by Olsen's method (Olsen *et al.*, 1954), while K (kg ha^{-1}) was extracted by neutral normal ammonium acetate method (Jackson, 1973). Observations were recorded on grain and straw yield (kg ha^{-1}) of sorghum, grain and stalk yield (kg ha^{-1}) of pigeonpea, organic carbon (%), N, P and K nutrients (kg ha^{-1}), harvest index (%), productivity rating index (%), RWUE (kg ha^{-1} mm^{-1}), gross returns (₹ ha^{-1}), net returns (₹ ha^{-1}) and B:C ratio. The grain and straw yields of crops were converted to sorghum grain equivalent yield for comparison and selection of a superior treatment.

Rainfall and its distribution

The rainfall and its distribution during 1998 to 2008 are given in Table 1. The crop seasonal rainfall ranged between 352 mm in 2003 to 984 mm in 2006, with mean of 656 mm and variation of 30.0%. June received rainfall of 26 mm (2005) to 205 mm (2001) with mean of 110 mm and variation of 55.5%, while July received rainfall of 53 mm (2002) to 281 mm (2007) with mean of 160 mm and variation of 49.2%. August received rainfall of 98 mm (2004) to 333 mm (2006) with mean of 179 mm and variation of 43.9%, while September received rainfall of 55 mm (2000) to 261 mm (2006) with mean of 145 mm and variation of 43.7%. October and November received rainfall in the range of 0 to 137 mm (2001) and 0 to 68 mm (1998) with mean of 51 and 11 mm and variation of 93.6 and 215.4%, respectively. October received no rainfall in 2000, 2003 and 2007, while November received no rainfall in all years except 1998, 2004 and 2008.

Statistical Analysis

The observations of sorghum and pigeonpea grain and fodder yield, sorghum equivalent yield were analyzed using analysis of variance procedure (Gomez and Gomez, 1984). The sustainability yield index (SYI) of a treatment is measured as a ratio of the "difference between mean yield and prediction error" and "maximum yield" attained by any treatment in

Table: 1
Distribution of monthly rainfall (mm) during 1998 to 2008

Year	Jun	July	Aug	Sept	Oct	Nov	Total
1998	96	164	160	225	80	68	794
1999	192	138	296	188	122	0	937
2000	102	226	151	55	0	0	534
2001	205	89	112	76	137	0	619
2002	170	53	195	111	30	0	559
2003	76	67	108	102	0	0	352
2004	48	108	98	112	50	46	461
2005	26	222	228	152	70	0	698
2006	72	262	333	261	57	0	984
2007	158	281	175	135	0	0	749
2008	68	147	113	178	18	6	529
Min	26	53	98	55	0	0	352
Max	205	281	333	261	137	68	984
Mean	110	160	179	145	51	11	656
SD	61	79	79	63	48	23	197
CV	55.5	49.2	43.9	43.7	93.6	215.4	30.0

SD: Standard deviation; CV: Coefficient of variation (%)

any year. The SYI of treatment "t" can be derived by using its mean yield (Yt) over years; standard error (SE) derived based on the model of t^{th} treatment; and maximum yield (Y_{max}) attained by any treatment as discussed by Maruthi Sankar *et al.* (2011 and 2013). The SYI of treatment "t" is given as:

$$SYI = (Yt-SE)/Y_{max} \quad ...(1)$$

The RWUE, kg ha^{-1} mm^{-1} is derived as a ratio of grain yield (kg ha^{-1}) and crop seasonal rainfall (mm) and is given as:

$$RWUE = \text{Grain yield (kg ha}^{-1}\text{) / Crop seasonal rainfall (mm)} \quad ...(2)$$

The harvest index (HI, %) is derived as a ratio of grain and straw yield and is expressed as:

$$HI = (\text{Grain yield / Straw yield}) * 100 \quad ...(3)$$

The productivity rating index (PRI) is derived as a ratio of actual and standard yield and is given as:

$$PRI = (\text{Actual yield / Standard yield}) * 100 \quad ...(4)$$

The treatments could be compared for their performance for SYI, RWUE, HI and PRI and a superior treatment could be identified.

3. RESULTS AND DISCUSSION

Effect of Fertilizer on Yield of Sorghum and Pigeonpea

The effect of fertilizer treatments on yield of sorghum and pigeonpea are given in Table 2. The long-term application of T_6 gave significantly higher yield of sorghum (1777 kg ha^{-1}) and pigeonpea (751 kg ha^{-1}) compared to T_1 (720 and 546 kg ha^{-1}). The treatments had a variation of 14.4% for sorghum equivalent yield over years. Based on LSD, T_6 was superior for grain and fodder yield of sorghum, grain and stalk yield of pigeonpea and grain equivalent yield of sorghum over years. The sorghum grain equivalent yield ranged from 2622 (T_1) to 4471 kg ha^{-1} (T_6). In a study by Ncube and Twomlow (2007), the beneficial effects of legumes on yields of subsequent sorghum were observed, apart from improvements in soil nitrogen.

Effect of Fertilizer Treatments on Harvest Index and Productivity Rating Index

The harvest index and productivity rating index of treatments in sorghum and pigeonpea are given in Table 3. The harvest index ranged from 17.8% under T_1 to 29.5% under T_6 in sorghum, while it ranged from 19.7% under T_2 to 23.2% under T_6 in pigeonpea. The treatments had a variation of 14.3% in sorghum compared to 5.3% in pigeonpea for the harvest index. This indicated a significant role of organic manures in enhancing the harvest index of sorghum and pigeonpea. The yield of 4500 kg ha^{-1} of sorghum and 1200 kg ha^{-1} of pigeonpea were considered as potential yield to derive the PRI values. The PRI ranged from 16.0 to 39.5% in sorghum and 45.5 to 62.6% in pigeonpea with mean of 30.8 and 53.5% under T_1 and T_6, respectively. A variation of 22.0% in sorghum and 9.3% in pigeonpea were observed in PRI. The FYM and reduction of 50% recommended N could not sustain crop yields, which was due to insufficient soil moisture which affected the *in-situ* decomposition and release of nutrients to the plants during crop growth period.

Effect of Fertilizer Treatments on RWUE and Sustainable Yield Index

Using mean yield of treatments, maximum yield attained by any treatment and standard error based on regression

Table: 2
Effect of fertilizer treatments on sorghum and pigeonpea yield

Treatments	Sorghum yield (kg ha^{-1})		Pigeonpea yield (kg ha^{-1})		Sorghum grain equivalent yield (kg ha^{-1})
	Grain	Fodder	Grain	Stalk	Grain
T_1: Control	720^d	3315^d	546^c	2113^b	2622^e
T_2: 100% recommended N	1570^b	4082^{ab}	648^{abc}	2645^a	3856^{bc}
T_3: 50% recommended N	1306^c	3827^{bc}	597^{bc}	2395^{ab}	3390^{cd}
T_4: FYM @ 4 t ha^{-1}	1264^c	3838^{bc}	600^{bc}	2369^{ab}	3328^d
T_5: FYM @ 4 t ha^{-1} + 10 kg N ha^{-1}	1578^b	3867^{bc}	657^{abc}	2426^{ab}	3896^{bc}
T_6: FYM @ 4 t ha^{-1} + 20 kg N ha^{-1}	1777^a	4240^a	751^a	2482^{ab}	4471^a
T_7: 2 t ha^{-1} green leaf + 10 kg N ha^{-1}	1241^c	3915^{bc}	617^{bc}	2325^{ab}	3385^{cd}
T_8: 2 t ha^{-1} green leaf + 20 kg N ha^{-1}	1535^b	3814^{bc}	675^{ab}	2457^{ab}	3912^b
T_9: FYM @ 4 t ha^{-1} + 2 t ha^{-1} green leaf	1492^b	3676^c	682^{ab}	2404^{ab}	3914^b
LSD ($p < 0.05$)	172	284	120	375	513

Treatments with same letter (a, b, c,…) are at par; LSD : Least significant difference; FYM: Farm yard manure model of yield through rainfall, SYI was derived for comparing treatments and identifying a superior treatment (Maruthi Sankar *et al.,* 2011 and 2013). The SYI and RWUE are given in Table 3. The SYI ranged from 38% for T_1 to 57% for T_8, while T_2 and T_6 attained 2nd best SYI of 53%. The RWUE ranged from 3.58 kg ha^{-1} mm^{-1} for T_1 to 6.47 kg ha^{-1} mm^{-1} for T_6. This indicated that conjunctive use of organics with chemical fertilizers resulted in sustaining yield under Vertisols. Nayak *et al.* (2012) observed highest SYI under rice-wheat system with NPK+FYM over NPK. Abrol *et al.* (2015) attained maximum RWUE with maize grown under low and erratic rainfall received under dry sub-humid Inceptisols. We determined a relationship between SYI and RWUE and is depicted in Fig. 1. Based on regression model of SYI through RWUE, SYI significantly increased at a rate of 5.47 times with unit increase in RWUE. The model gave predictability of 0.67 for SYI.

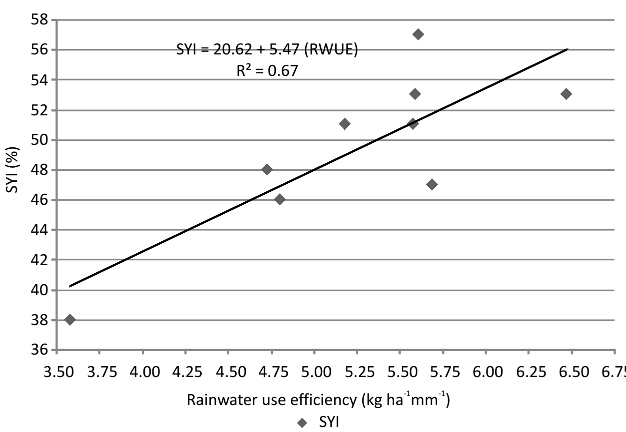


Fig. 1. Relationship between RWUE & SYI in sorghum+pigeonpea

Higher RWUE was observed which was beneficial for sustaining yields of crops.

Effect of Fertilizer Treatments on Monetary Returns from Sorghum and Pigeonpea

The effect of fertilizer treatments on gross returns, net returns and B:C ratio are given in Table 4. The gross returns from sorghum ranged from ₹ 8751 ha^{-1} under T_1 to ₹ 17656 ha^{-1} under T_6 with mean of ₹ 14313 ha^{-1} and variation of 17.6%, while gross returns from pigeonpea ranged from ₹ 18064 ha^{-1} to ₹ 24635 ha^{-1} under the respective treatments with mean of ₹ 21182 ha^{-1} and variation of 9.0%. The total gross returns from both crops ranged from ₹ 26815 ha^{-1} under T_1 to ₹ 42291 ha^{-1} under T_6 with mean of ₹ 35495 ha^{-1} and variation of 12.2%, while total net returns ranged from ₹ 16283 ha^{-1} to ₹ 25416 ha^{-1} under the respective treatments with mean of ₹ 20486 ha^{-1} and variation of 14.3%. The B:C ratio from sorghum and pigeonpea ranged from 2.07 under T_9 green leaf to 2.65 under T_6 with mean of 2.38 and variation of 8.9%.

Effect of Fertilizer Treatments on Soil Fertility of Nutrients

The effect of treatments on organic carbon, N, P and K are given in Table 5. There was an increasing effect of all treatments over T_1 on soil N, P_2O_5 and K_2O. The initial organic carbon was 5.2 g kg^{-1}, while N, P_2O_5 and K_2O were 210, 22.5 and 345 kg ha^{-1}, respectively. After 11 years, T_1 showed improvement in N, P and organic carbon over initial fertility, indicating that there was no soil degradation. This was due to the fact that black soils developed on basaltic parent material are rich in plant nutrients except N and legumes

Table: 3
Effect of treatments on harvest index, productivity rating index, rainwater use efficiency and sustainability yield index

Treatments	Harvest index (%)		PRI (%)		RWUE (kg ha^{-1} mm^{-1})	SYI (%)
	Sorghum	Pigeonpea	Sorghum	Pigeonpea		
T_1: Control	17.8	20.5	16.0	45.5	3.58	38
T_2: 100% recommended N	27.8	19.7	34.9	54.0	5.59	53
T_3: 50% recommended N	25.4	20.0	29.0	49.8	4.80	46
T_4: FYM @ 4 t ha^{-1}	24.8	20.2	28.1	50.0	4.73	48
T_5: FYM @ 4 t ha^{-1} + 10 kg N ha^{-1}	29.0	21.3	35.1	54.8	5.69	47
T_6: FYM @ 4 t ha^{-1} + 20 kg N ha^{-1}	29.5	23.2	39.5	62.6	6.47	53
T_7: 2 t ha^{-1} green leaf + 10 kg N ha^{-1}	24.1	21.0	27.6	51.4	5.18	51
T_8: 2 t ha^{-1} green leaf + 20 kg N ha^{-1}	28.7	21.6	34.1	56.3	5.61	57
T_9: FYM @ 4 t ha^{-1} + 2 t ha^{-1} green leaf	28.9	22.1	33.2	56.8	5.58	51
Minimum	17.8	19.7	16.0	45.5	3.58	38
Maximum	29.5	23.2	39.5	62.6	6.47	57
Mean	26.2	21.1	30.8	53.5	5.25	49
SD	3.7	1.1	6.8	5.0	0.8	5.5
CV (%)	14.3	5.3	22.0	9.3	15.5	11.1
LSD (P < 0.05)	2.4	0.7	4.4	3.2	0.53	3.6

Table: 4
Profitability of nutrient management treatments in sorghum+pigeonpea system

Treatment	Sorghum grain yield (kg ha^{-1})	Sorghum fodder yield (kg ha^{-1})	Gross returns (₹ ha^{-1})	Pigeonpea grain yield (kg ha^{-1})	Pigeonpea stalk yield (kg ha^{-1})	Gross returns (₹ ha^{-1})	Total gross returns (₹ ha^{-1})	Total net returns (₹ ha^{-1})	B:C ratio
T_1	720	3315	8751	546	2113	18064	26815	16283	2.53
T_2	1570	4082	15936	648	2645	21508	37443	23304	2.65
T_3	1306	3827	13687	597	2395	19794	33481	20309	2.54
T_4	1264	3838	13381	600	2369	19875	33256	17269	2.08
T_5	1578	3867	15781	657	2426	21679	37459	20928	2.27
T_6	1777	4240	17656	751	2482	24635	42291	25416	2.51
T_7	1241	3915	13285	617	2325	20382	33667	18966	2.29
T_8	1535	3814	15403	675	2457	22255	37658	22567	2.50
T_9	1492	3676	14941	682	2404	22446	37387	19333	2.07
Min	720	3315	8751	546	2113	18064	26815	16283	2.07
Max	1777	4240	17656	751	2645	24635	42291	25416	2.65
Mean	1387	3842	14313	641	2402	21182	35495	20486	2.38
SD	305	257	2520	60	141	1905	4328	2925	0.21
CV	22.0	6.7	17.6	9.3	5.9	9.0	12.2	14.3	8.9

SD: Standard deviation; CV: Coefficient of variation (%)

Table: 5
Effect of fertilizer treatments on soil fertility of nutrients in sorghum+pigeonpea over years

Treatments	OC (g kg^{-1})	Soil N (kg ha^{-1})	Soil P_2O_5 (kg ha^{-1})	Soil K_2O (kg ha^{-1})
T_1: Control	5.5	212	19.6	316
T_2: 100% recommended N	6.0	252	26.0	329
T_3: 50% recommended N	5.9	230	25.2	324
T_4: FYM @ 4 t ha^{-1}	6.2	232	27.3	328
T_5: FYM @ 4 t ha^{-1} + 10 kg N ha^{-1}	6.4	247	27.9	331
T_6: FYM @ 4 t ha^{-1} + 20 kg N ha^{-1}	6.7	255	28.9	339
T_7: 2 t ha^{-1} green leaf + 10 kg N ha^{-1}	6.5	238	27.4	330
T_8: 2 t ha^{-1} green leaf + 20 kg N ha^{-1}	6.3	252	28.7	336
T_9: FYM @ 4 t ha^{-1}+2 t ha^{-1} green leaf	6.2	241	27.9	331
Initial value	5.2	210	22.5	345
LSD ($p < 0.05$)	0.3	14	2.1	7

may full-fill the N requirement through symbiotic fixation of atmospheric N. There was a build-up of organic carbon in all treatments over initial status. It ranged from 5.5 to 6.7 g kg^{-1} with mean of 6.2 g kg^{-1} and variation of 5.7%. Maximum organic carbon of 6.7 g kg^{-1} was observed in T_6. Similar observations were made by Tolanur and Badanur (2003). Soil nitrogen ranged from 212 to 255 kg ha^{-1} with mean of 240 kg ha^{-1} and variation of 5.8%. Maximum soil N of 255 kg ha^{-1} was observed in T_6, while lowest N of 212 kg ha^{-1} was observed in T_1, which was marginally higher compared to initial N of 210 kg ha^{-1}. Being a legume, pigeonpea would shed its senescing leaves from flowering onwards. The N by fallen leaves and flower parts would add about 40 to 60 kg N ha^{-1} to the soil (Sheldrake and Narayanan, 1979).

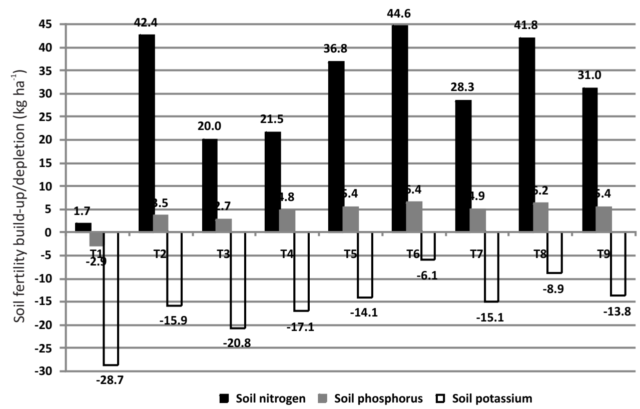


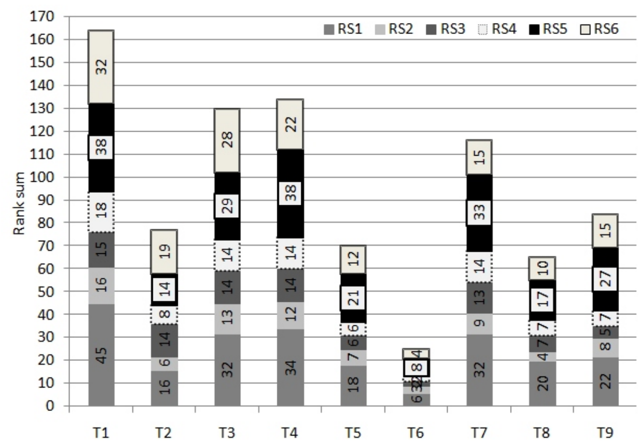
Fig. 2. Soil fertility build-up/depletion of nutrients over years

Soil phosphorus ranged from 19.6 to 28.9 kg ha^{-1} with mean of 26.5 kg ha^{-1} and variation of 10.8%. Maximum phosphorus of 28.9 kg ha^{-1} was observed in T_6, while lowest of 19.6 kg ha^{-1} was observed in T_1, which was marginally lower compared to initial P_2O_5 of 22.5 kg ha^{-1}. T_6 and T_8 which received 40 kg P_2O_5 ha^{-1} through single super phosphate along with FYM/Leucaena attained higher soil phosphorus. There was a gain of phosphorus in all treatments except T_1. To minimize the conversion of plant available phosphate to unavailable form due to calcareous nature of black soil as well as about 21% calcium in SSP fertilizer, addition of FYM together with fertilizers would be necessary. Soil potassium ranged from 316 to 339 kg ha^{-1} with mean of 329 kg ha^{-1} and variation of 2%. Maximum potassium of 339 kg ha^{-1} was observed under T_6. T_1 had lowest K_2O of 316 kg ha^{-1}, which was significantly lower compared to initial K_2O of 345 kg ha^{-1}.

There was a depletion of potassium in all treatments. Since FYM contained about 0.5% K_2O, T_5, T_6, T_7 and T_8 which received FYM/Leucaena together with fertilizers were superior for potassium. The humus part of FYM after mixing with soil would also reduce the swelling and shrinkage capacity of soil through improvement in soil structure. The P balance indicated its gain in all treatments except T_1, while higher gain was observed in T_6. Similar positive balance of N and P in cotton under Vertisols was observed by Rego *et al.* (2003). An increase in soil N under pigeonpea which indicated positive N balance was observed by Rego and Seeling (1996). The potassium balance indicated its depletion in all treatments, while minimum loss was observed in T_6.

Ranking and Selection of Superior Fertilizer Treatments

Ranks were assigned to mean values of parameters over years and rank sums (RS) were derived under 6 groups *viz.,* RS1, RS2, RS3, RS4, RS5 and RS6. RS1 comprised of ranks of sorghum grain, pigeonpea grain, sorghum straw, pigeonpea stalk and sorghum grain equivalent yield, while RS2 comprised of SYI and RWUE parameters. RS3 comprised of ranks of harvest index, while RS4 comprised of PRI parameters. RS5 comprised of ranks of gross returns of sorghum, pigeonpea, sorghum+pigeonpea; net returns of sorghum+pigeonpea and B:C ratio, while RS6 comprised of organic carbon, soil N, P_2O_5 and K_2O. The rank sums of treatments under different groups are depicted in Fig. 3. T_6 was superior with lowest rank sum of 25. Our results are in concurrence with the findings on maize+soybean under semi-arid Vertisols (Sharma *et al.,* 2014), soybean under semi-arid Vertisols (Sanjay Sharma *et al.,* 2016); cotton under semi-arid Vertisols (Maruthi Sankar *et al.,* 2014); green gram-finger millet rotation under semi-arid Alfisols (Shankar *et al.,* 2013).



Rs1: Rank sum of sorghum grain, pigeonpea grain, sorghum straw, pigeonpea stalk & sorghum grain equivalent yield; RS2: Rank sum of SYI & RWUE; RS3: Rank sum of harvest index of sorghum & pigeonpea; RS4: Rank sum of productivity rating index of sorghum & pigeonpea; RS5: Rank sum of gross returns of sorghum, pigeonpea, sorghum+pigeonpea; net returns of sorghum+ pigeonpea; & benefit-cost ratio; RS6: Rank sum of organic carbon, N, P_2O_5 & K_2O nutrients

Fig. 3. Rank sum of treatments for different parameters

4. CONCLUSIONS

Based on experiments on sorghum and pigeonpea conducted at Akola during 1998 to 2008, a superior treatment was identified for attaining maximum yield, RWUE, monetary returns and soil fertility over years. Application of T_6 to sorghum along with recommended phosphorus @ 40 kg ha^{-1} through SSP was found to be efficient. This treatment gave significantly higher grain yield of 1777 kg ha^{-1}, fodder yield of 4240 kg ha^{-1}, gross returns of ₹ 17656 ha^{-1} from sorghum; grain yield of 756 kg ha^{-1}, stalk yield of 2482 kg ha^{-1} and gross returns of ₹ 24635 ha^{-1} from pigeonpea. Maximum total gross returns of ₹ 42291 ha^{-1}, net returns of ₹ 25416 ha^{-1}, B:C ratio of 2.51 and RWUE of 6.47 kg ha^{-1} mm^{-1} were attained by T_6. This treatment maintained maximum organic carbon (6.7 g kg^{-1}), N (255 kg ha^{-1}), P (28.9 kg ha^{-1}) and K (339 kg ha^{-1}) over years. It gave SYI of 53% with lowest rank sum of 25 for different parameters. We recommend T_6 for sustaining sorghum and pigeonpea yield, attaining high RWUE and monetary returns, apart from maintaining maximum soil fertility under semi-arid Vertisols.

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