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ABSTRACT

Soil erosion, low nitrogen availability and soil moisture stress during winter season are among the major limitations to high crop production and sustainable land management in a rainfed Semi-Arid Tropics (SAT) in India. We conducted three years field study (2000-01 to 2002-03) on a Vertisol to study the impact of land configuration and nitrogen management on winter sorghum productivity under different rainfall situations. Greater quantity soil moisture availability in the profile with rainwater conservation techniques (RCT), *viz;* compartmental bunding (CB) and ridges and furrows (RF) from sowing to harvest produced 17 to 22% higher sorghum grain yields over flat bed (FB) sowing. Sorghum grain yields and water use efficiency (WUE) were higher during mild moisture stress year compared to normal rainfall year with rainwater conservation techniques. In the sub plot, application of 20 kg N ha^{-1} produced 19% higher grain yield during a drought year. Further increase in N application to 40 kg ha^{-1} produced 22% higher yield during normal rainfall year. Mean sorghum yield during study period was 19% higher with 40 kg ha^{-1} compared to 0 kg N ha^{-1}. The CB and RF with application of 40 kg N ha^{-1} produced greater winter sorghum yields in Vertisols of south India under rainfed situations.

1. INTRODUCTION

The change and increase of energy prices will increase cost of agricultural inputs, such as land management, fertilizer and fuel, and make future food security a major concern (Delgado *et al.,* 2011). Further, climate change threatens to increase erosion, reduce soil quality, soil depth and soil nutrient availability resulting in 10 to 20% lower agricultural productivity, making it one of the most severe challenges to be faced in 21st century (Deutsch *et al.,* 2010; Lal *et al.,* 2011).

Farmers in the high potential regions of developed countries have increased crop yields by around 5% annually while agricultural growth is less than one per cent in the Semi-Arid Tropics (SAT) of Asia including India during recent years. Crop yields range from one to two t ha^{-1} in almost all rainfed areas (Falkenmark *et al.,* 2001), indicating that productivity can be improved in the rainfed areas. Though India is currently self sufficient in food production, it needs to produce at least 281 Mt food grains, 53.7 Mt oilseeds, 22 Mt pulses, 127 Mt vegetables and 86 Mt fruits by 2020-21 (Singh, 2014).

In Vertisols of south India, nearly 10-20% of rainfall goes as runoff from the agricultural fields and only small amount of water is the green water (Mishra *et al.,* 2006; Lal, 2013; Schneider, 2013) for crop production system (Saha *et al.,* 2007). Thus crop production in rainfed Vertisols is prone to sever drought stress during post monsoon from September to January (Mishra and Patil, 2011). Adopting *in-situ* rainwater conservation techniques during rainy season (June to September) conserves rainwater reduces runoff and increases soil moisture storage in the profile (Das *et al.,* 2013; Kuotsu *et al.,* 2014; Takate *et al.,* 2014). Bellary region, Karnataka receives lower mean annual rainfall of 511.9 mm, due to low infiltration rate (0.8 mm h^{-1}) coupled with high intensity of rainfall results in 6 to 15 t ha^{-1} soil loss every year (Mishra *et al.,* 2006). This results in lower N content (< 250 kg N ha^{-1}) in the Vertisols. Farmers in this Vertisols region apply only 10 to 20 kg N ha^{-1} with small quantities of organic amendments (Patil, 2013). In addition, farmers rarely adopt rainwater conservation techniques. This ultimately results in lower soil moisture and nutrient availability to the crops during growth period resulting in frequent failure of crops or decline in productivity (Patil and

Sheelavantar, 2004; Jat *et al.,* 2008; Delgado *et al.,* 2011). Among the cereals, sorghum is one of the major staple food crop cultivated under receding soil moisture conditions during winter season under rainfed situations in Vertisols of Bellary region, Karnataka India (Patil and Basappa, 2004). Lower productivity of winter sorghum is attributed to low soil moisture with application of lower fertilizer especially N (Patil, 2013).

In view of this, present field study was conducted to evaluate the effect of rainwater conservation techniques and N application on water use efficiency and yield of sorghum during winter season with the altered land configuration would conserve rainwater and application of N through urea would efficiently utilize the conserved rainwater and increase sorghum productivity during winter season.

2. MATERIALS AND METHODS

Site and Soil Characteristics

The experimental site (latitude15°09´N; longitude 76° 51´E; altitude 445 m amsl) is classified as Typic- Pellusterts, Bellary series (Vertisol) located at the Indian Institute of Soil and Water Conservation Research Farm, Bellary, Karnataka, India. The infiltration rate of soil is 0.8 mm h^{-1} and 1.23 Mg m^{-3} is the bulk density (Black, 1965). These soils are alkaline in reaction with 8.6 soil pH (Piper, 1966), electrical conductivity is 0.14 dS m^{-1}; clay content increased with depth from 44% at surface to 50% at 0.90 m depth, low in organic carbon (3.8 g kg^{-1}) (Piper, 1966), available N (159 kg ha^{-1}) (Subbaiah and Asija, 1956), available P (21 kg as P_2O_5 ha^{-1}) (Jackson, 1967) and high in available K (550 kg as K_2O ha^{-1}) (Muhr *et al.,* 1965). During winter season of 1999-2000, chickpea was cultivated with application of recommended fertilizer (25:50:0 N:P_2O_5:K_2O) and adopting suitable crop protection practices.

Treatments

The experiment was conducted during 2000 to 2003 and was laid out in a split plot design with land configuration as main treatments and nitrogen dose as sub treatments with three replications. Each sub plot measured 36.72 m^2. Rainwater Conservation Techniques (RCT), *i.e.,* compartmental bunds (CB) of size 3.4 x 2.7 m were formed with bullock drawn bund former along and across the plot. Ridges and furrows (RF) were imposed at 0.60 m interval by bullock drawn ridger. Both CB and RF were imposed in the first week of July during all the three years of study. Nitrogen was applied at 0, 20, 40 and 60 kg ha^{-1} through urea along with recommended rate of phosphorus at 40 kg ha^{-1} through single super phosphate. The fertilizers were applied as per treatments in a line drawn by a ridger at 5 cm away from seed row at sowing. *Rabi* sorghum cv. Maldandi (M35-1) was sown at a depth of 5 cm on 15th October, 27th September and 21st October during 2000, 2001 and 2002, respectively. The spacing was 15 cm apart in rows and 60 cm between rows and the crop was harvested on 16th February 2001, 29th January 2002 and 20th February 2003 (Table 1).

Soil Water and Water Use Efficiency

Soil water was gravimetrically measured at 30 days interval for 0-15, 15-30 and 30-60 cm depths in each treatment from sowing to harvest (at) in all 36 treatments (Jalota *et al.,* 1998; Patil and Sheelavatar, 2006). Soil water utilized was computed as the difference in soil moisture at sowing, at different crop growth stages and at harvest. Consumptive use of water was determined as difference in soil water content (mm) at 60 cm soil depth between any two stages and by adding the rainfall and subtracting runoff during the relevant period (Patil, 2013). Runoff from adjacent experimental plot was measured by using multi-slot device and used for 36 treatments for assessing runoff from each treatment. No drainage or deep percolation was observed during the crop growth period and hence it was not accounted for calculation of consumptive use of water. Daily rainfall was measured by using standard ISI rain gauge located in class A meteorological observatory situated about 10 m from experimental plot. Difference in soil water was added to arrive at consumptive use of water in mm by using the formula:

$$CUW = \sum_{i=1}^{n} (SMa-SMb)+Rainfall-Runoff$$

Where, CUW = Consumptive use of water (mm), SMa = Soil water content in top 60 cm soil at stage a, SMb = Soil water content in top 60 cm soil at stage b, Rainfall and Runoff as recorded between stage a and stage b.

Table: 1
Rainfall and its distribution at the experimental site during (2000-2003)

Particulars	Year		
	2000-01	2001-02	2002-03
Antecedent rainfall (mm)	196.7 (5 to 14 October 2000)	189.0 (17 to 26 September 2001)	125.7 (8 to 17 October 2002)
Crop season rainfall (mm)	33.2	248.5	9.8
Rainy days (Cropping season)	2	14	1
Date of sowing of sorghum	15 October 2000	27 September 2001	21 October 2002
Date of harvest of sorghum	16 February 2001	29 January 2002	20 February 2002
Annual rainfall (mm)	550.9	566.6	432.6
Total number of rainy days	34	31	32
Percentage of mean annual rainfall during the year	107.6	110.7	84.5

Sorghum grain yield (kg) was divided by CUW (mm) to obtain the water use efficiency (WUE) and is expressed in kg ha^{-1} mm^{-1}.

Biometric Observations in Winter Sorghum

Plant height is measured from the base of the plant to the tip of the head from five randomly selected plants from each plot prior to harvest. Average plant height was calculated and expressed in m. Five randomly selected plants were harvested from each plot for measurement of head length and head girth. These plants were oven dried at 60 to 65°C for 48 hours before recording head weight and grain weight per plant after separation of grains from head. Head length was measured from the base to the tip of the head and expressed in cm. Head girth was measured by placing a thread at middle portion around the head and the measured thread was placed on a scale to record head girth in cm. The weight of 1000 grains drawn from grain yield of each plot was weighed and expressed in g.

Harvest index (HI) is the ratio of economic yield to the total biomass yield and multiplied by 100 and expressed in percentage (Donald, 1962).

Statistical Analysis

Data were analyzed using a computerized statistical MSTAT-C package (Gomez and Gomez, 1984). Year was considered as a first factor, rainwater conservation techniques as second factor and N application as third factor for pooled analysis of data over three years. When analysis of variance indicated significant difference, LSD test was used to separate the treatment means for year, rainwater conservation techniques and N application, and for comparing across them. All significant data for year, main and sub plot effects besides interactions were considered at 5% level of significance.

3. RESULTS AND DISCUSSION

Interactions

The interaction effect of rainwater conservation techniques/N application rates was noticed in respect of straw yield, HI and 1000 grains weight for pooled data. Rainfall during June to sowing (September/October) was conserved in CB and RF treatments thus resulting in higher soil moisture availability in the soil profile from sowing to harvest. This produced better plant growth with higher straw yields by 18 and 28% with CB and 26 and 28% with RF during 2000-01 and 2001-02, respectively compared to FB as depicted in Table 3 and Fig. 1 (Patil and Sheelavantar, 2004).

Even though rainfall during 2000 was slightly higher than the normal, due to uneven distribution with only 33.2 mm of crop season rainfall resulted in low soil moisture availability from ear emergence to harvest. Under such situation, sorghum straw yield increased only up to 40 kg N ha^{-1} thus producing 22% higher straw yield over 0 kg N ha^{-1} (Table 3). Lower rainfall during a drought year of 2002 resulted in lower soil moisture availability in profile and increased straw yield only up to 20 kg N ha^{-1}. Under water stress situation, the response of crop to higher N reduces due to negative interaction of limited soil moisture with greater N availability (Villar-Salvador *et al.,* 2013). Response to N application was quadratic and was significant only up to 25 kg N ha^{-1} with scarce water in profile in a mild to severe drought year (Umrani and Bhoi, 1982).

Higher annual rainfall of 566.6 mm that fell during 2001 with higher rainfall prior to sowing (189.0 mm) and during crop season (248.5 mm) resulted in uniform wetting of soil profile at sowing thus leading to higher soil moisture availability during crop growing period. Thus, the higher soil moisture availability produced 14 to 39% higher straw yield with application of 20 to 60 kg N ha^{-1} over 0 kg N ha^{-1}. In Vertisols of Solapur, India, grain yield of setaria (*Setaria italica*) increased with increase in N application to 75 kg ha^{-1} with higher soil water stored in profile in a normal to above normal rainfall situations and response was linear (Umrani and Bhoi, 1982).

Higher soil moisture availability at physiological maturity due to higher rainwater conservation through CB during 2002 and RF during 2000 produced higher dry matter in head thus resulting in 5 and 13% higher HI, respectively compared to FB (Table 3). During mild drought (2000) and severe drought (2002) rainfall situations, rainwater conservation techniques conserved greater

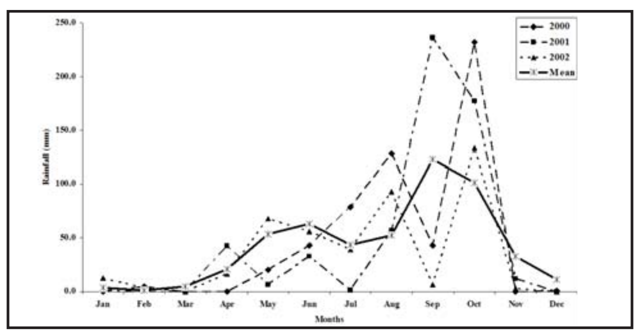

Fig. 1. Rainfall at experimental site during the study period

Table: 2
Water use efficiency (kg ha^{-1} mm^{-1}) as influenced by rainwater conservation techniques (RCT) and nitrogen application (NA) during 2001-02

Rainwater conservation techniques	Nitrogen application (kg ha^{-1})				
	0	20	40	60	Mean
Flat Bed	6.21	7.05	7.33	8.36	7.24
CB	6.82	8.15	8.89	8.91	8.20
RF	7.11	7.76	8.36	8.21	7.86
Mean	6.71	7.67	8.19	8.49	7.77
Interactions	LSD (P< 0.05)				
RCT x NA	0.59				

Table: 3
Straw yield (t ha^{-1}), Harvest index (%) and 1000 grains weight (g) as influenced by year and rainwater conservation techniques/nitrogen application (Pooled)

Year	Rainwater conservation techniques												Nitrogen application (kg ha^{-1})				
	Straw yield (t ha^{-1})				Harvest index (%)				1000-grains weight (g)				Straw yield (t ha^{-1})				
	FB	CB	R&F	Mean	FB	CB	R&F	Mean	FB	CB	R&F	Mean	0	20	40	60	Mean
2000-01	1.83	2.34	2.30	2.16	41.2	41.6	43.3	42.0	25.60	28.12	28.90	27.54	1.89	2.11	2.31	2.32	2.16
2001-02	4.29	5.05	5.51	4.95	39.8	38.7	37.4	38.6	30.11	32.55	33.54	32.07	4.15	4.72	5.15	5.77	4.95
2002-03	2.80	2.69	2.98	2.82	32.5	36.6	35.0	34.7	24.25	25.62	26.08	25.32	2.58	2.85	2.84	3.03	2.82
Mean	2.97	3.36	3.60	3.31	37.8	39.0	38.6	38.5	26.65	28.77	29.51	28.31	2.87	3.23	3.43	3.71	3.31
Interactions		LSD (P<0.05)				LSD (P<0.05)				LSD (P<0.05)				LSD (P<0.05)			
Year x RCT		0.29				2.00				2.00				0.32			

Note: FB: Flat bed; CB: Compartmental bunding; R&F: Ridges and furrows, RCT: Rainwater conservation techniques

Table: 4
Grain yield, straw yield, harvest index and water use efficiency of winter sorghum as influenced by Rainwater Conservation Techniques (RCT) and Nitrogen Application (NA)

Treatments	Grain yield (kg ha^{-1})				Straw yield (t ha^{-1})				Harvest index (%)				Water use efficiency (kg ha^{-1} mm^{-1})			
	2000-01	2001-02	2002-03	Pooled	2000-01	2001-02	2002-03	Pooled	2000-01	2001-02	2002-03	Pooled	2000-01	2001-02	2002-03	Pooled
LSD (P< 0.05)		138				0.33				2.4				0.92		
Rainwater Conservation Techniques																
FB	1290	2816	1339	1815	1.83	4.29	2.80	2.97	41.3	39.7	32.3	37.8	8.57	7.24	6.20	7.34
CB	1648	3169	1548	2122	2.34	5.05	2.69	3.36	41.6	38.6	36.5	38.9	9.86	8.20	6.71	8.25
RF	1756	3256	1605	2206	2.30	5.51	2.98	3.60	43.3	37.1	35.0	38.6	10.77	7.86	6.82	8.48
LSD (P< 0.05)	327	215	180	113	0.34	0.33	NS	0.17	1.6	NS	2.7	NS	2.11	0.53	NS	0.61
Mean value	1565	3080	1498	2048	2.16	4.95	2.83	3.31	42.0	38.6	34.7	38.4	9.73	7.77	6.58	8.03
Nitrogen Application (kg ha^{-1})																
0	1373	2743	1305	1807	1.89	4.15	2.58	2.88	42.1	39.8	33.6	38.5	9.02	6.71	5.65	7.13
20	1517	3036	1550	2034	2.11	4.72	2.85	3.23	41.8	39.1	35.3	38.7	9.56	7.67	6.72	7.98
40	1679	3215	1568	2154	2.31	5.15	2.84	3.43	42.4	38.4	35.6	38.8	10.39	8.19	7.03	8.54
60	1689	3328	1568	2195	2.32	5.77	3.03	3.71	42.1	36.6	34.1	37.7	9.96	8.49	6.90	8.45
LSD (P< 0.05)	111	112	146	68	0.27	0.42	0.29	0.18	NS	2.0	NS	NS	0.71	0.29	0.62	0.32
Interactions:																
RCT × NA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.59	NS	NS
Year × RCT				NS				0.29				2.0				NS
Year × NA				NS				0.32				NS				NS
Year × RCT × NA				NS				NS				NS				NS

NS: Non significant

rainwater and increased soil moisture availability in profile thus resulting in greater dry matter translocation to head as well as individual grains thus producing bolder seeds. This produced nearly 6% higher 1000grains weight with CB during 2002-03 and 13% higher 1000 grains weight with RF during 2000-01 compared to FB (Table 3).

Interaction due to rainwater conservation techniques and N rates is observed for WUE during 2001-02 (Table 2). Higher rainfall with uniform distribution during 2001 produced greater soil moisture availability from sowing to harvest thus resulting in 18 and 30% higher WUE with RF and CB, respectively with 40 kg N ha^{-1}compared to 0 kg N ha^{-1}. Further, increase in N application at 60 kg ha^{-1} produced 35% higher WUE in FB compared to 0 kg N ha^{-1} clearly indicating that higher N is required at lower soil moisture availability in FB (Jain and Lidder, 1999). Similarly lower WUE under FB were reported in canola under irrigated and rainfed systems (Tesfamariam *et al.,* 2010).

Year

In Vertisols of SAT in India, growth and yield of sorghum cultivated during postrainy season depends on annual rainfall and its distribution in a year and rainwater conservation techniques adopted during rainy season (Nalatwadmath *et al.,* 2008). Grain yield of 3080 kg ha^{-1} and straw yield of 4.95 t ha^{-1} produced during 2001-02 was significantly higher compared to lower grain yield of 1565 kg ha^{-1} and straw yield of 2.16 t ha^{-1} during 2000-01. Higher yields during 2001-02 were attributed to timely sowing on 27 September 2001, higher crop season rainfall of 248.5 mm that fell in 14 rainy days resulting in uniform wetting of soil profile at sowing and greater soil water availability in profile from sowing to harvest. Lower yields during 2001-02 were attributed to late sowing on 15 October 2000, low crop season rainfall of 33.2 mm that was distributed in two rainy days resulting in lower soil moisture availability and occurrence of drought especially from boot leaf stage to physiological maturity (Fig. 2, Table 1 and Table 4). Higher straw yield with lower grain yield during 2002-03 compared to 2000-01 was attributed to better vegetative growth in early stages of crop growth whereas, in later reproductive stages, occurrence of drought resulting in lower dry matter translocation to head at harvest. Higher dry matter translocation to head producing greater grain yield with lower straw yield resulting in higher HI of 42% during 2000-01 and it was higher by 9% and 21% compared to 2001-02 and 2002-03, respectively (Table 4). Higher grain yield during 2001-02 compared to 2000-01 and 2002-03 were attributed to greater panicle length and diameter with higher head weight, higher 1000 grains weight and more grains per head (Table 5). Greater straw yield (4.95 t ha^{-1}) during 2001-02 is attributed to production of 2.03 m taller plants and these plants were taller by 22 and 23% compared to 2000-01 and 2002-03, respectively with more leaves and

Table: 5
Yield components in winter sorghum as influenced by Rainwater Conservation Techniques (RCT) and Nitrogen Application (NA)

Treatments	Head weight (g plant^{-1})				Grain weight (g plant^{-1})				1000 grain weight (g)				Head girth (cm)			
	2000-01	2001-02	2002-03	Pooled	2000-01	2001-02	2002-03	Pooled	2000-01	2001-02	2002-03	Pooled	2000-01	2001-02	2002-03	Pooled
LSD (P< 0.05)		2.10				2.07				1.75				0.8		
Rainwater conservation techniques																
FB	31.92	40.83	35.25	36.00	27.09	35.95	28.71	30.58	25.60	30.11	24.25	26.65	15.3	13.5	12.2	13.6
CB	36.30	45.42	41.50	41.07	31.49	39.34	32.81	34.55	28.12	32.55	25.62	28.77	16.9	14.8	13.3	15.0
RF	36.60	48.75	42.00	42.45	31.83	40.94	33.36	35.37	28.90	33.54	26.08	29.51	17.9	15.3	13.4	15.5
LSD (P< 0.05)	3.75	2.62	2.146	1.32	3.64	3.41	2.68	1.48	1.41	1.66	0.82	0.61	0.9	0.5	0.80	0.3
Mean value	34.94	45.00	39.58	39.84	30.14	38.74	31.62	33.50	27.54	32.07	25.32	28.31	16.7	14.5	13.0	14.7
Nitrogen application (kg ha^{-1})																
0	31.53	40.11	34.89	35.51	27.21	34.83	28.56	30.20	24.71	30.13	24.22	26.36	15.4	13.3	12.2	13.6
20	35.10	44.67	41.11	40.29	30.49	37.25	32.64	33.46	27.46	32.01	25.66	28.38	16.6	14.5	13.3	14.8
40	36.42	46.78	41.67	41.62	31.77	40.97	32.88	35.21	29.06	32.81	25.46	29.11	17.2	15.0	13.5	15.2
60	36.70	48.44	40.67	40.94	31.07	41.93	32.42	35.14	28.93	33.32	25.93	29.39	17.5	15.3	12.9	15.2
LSD (P< 0.05)	2.71	4.11	3.52	1.92	2.97	3.65	3.123	1.79	2.28	1.03	NS	0.92	1.1	0.6	0.7	0.5
Interactions:																
RCT × NA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year × RCT			NS				NS				2.0				NS	
Year × NA			NS				NS				NS				NS	
Year × RCT × NA			NS				NS				NS				NS	

NS: Non significant

greater dry matter accumulation in leaves and stem. Lower grain yield and WUE during 2002-03 is attributed to lower rainfall with low soil moisture availability for sorghum growth (Table 4).Even though higher grain yield (3080 kg ha^{-1}) was observed during 2001-02, it was due to higher rainfall during 2001 produced more consumptive use of water, thus resulting in lower WUE of 7.77 kg $ha^{-1}mm^{-1}$. The WUE of 9.73 kg $ha^{-1}mm^{-1}$ produced during 2000-01 was 48% higher compared to 2002-03. Higher WUE during 2000-01 is attributed to lower consumptive use of water due to low crop season rainfall (33.2 mm) with normal plant growth and higher grain yield produced for lesser water utilized (Schindler and Donahue, 2006).

Rainwater Conservation Techniques

In this study, adopting rainwater conservation techniques between the bunded areas during rainy season (June-September) reduced soil and water losses and increased soil moisture and nutrient availability in the soil profile thus producing higher sorghum grain yields (Fig. 2 and Table 4). Sorghum grain yield increased from 13 to 28% with CB and 13 to 36% with RF during three years of study compared to FB. Adoption of rainwater conservation techniques between the bunded areas conserved the rainwater *in-situ* and increased the soil moisture availability to the crops resulting in higher yields (Radder *et al.,* 1991; Patil and Sheelavantar, 2004; Kalhapure and Shete, 2013; Takate, *et al.,* 2014). Conserved rainwater through rainwater conservation techniques was efficiently utilized for higher grain production especially during a drought year (2002) compared to above normal rainfall year (2001). Higher grain yield with rainwater conservation techniques was attributed to higher dry matter accumulation in head by 14 and 18% with greater grain weight per plant by 13 and 16% with CB and RF compared FB in the pooled data (Table 5). Even the 1000 grains weight was also higher in plots laid out with CB and RF compared to flat sowing. Higher grain yield with rainwater conservation techniques was also attributed to production of bigger head as indicated by higher values of head girth compared to FB (Table 5). In the pooled data, straw yield was higher by 13 and 21% in CB and RF laid out plots compared to FB and it was attributed to better plant growth that produced 1.81 and 1.82 m taller plants with greater dry matter accumulation in leaves and stem (Nalatwadmath *et al.,* 2008; Robinson *et al.,* 1986).

Efficient utilization of conserved rainwater through rainwater conservation techniques by winter sorghum during a drought year (2002) produced 8 and 10% greater WUE by CB and RF compared to FB (Table 4). This clearly indicated that rainwater conservation techniques were more effective during a drought year compared to normal rainfall situations with similar observations were also earlier noticed by (Kuotsu *et al.,* 2014) in rapeseed mustard and groundnut. Moisture content in the soil profile in FB

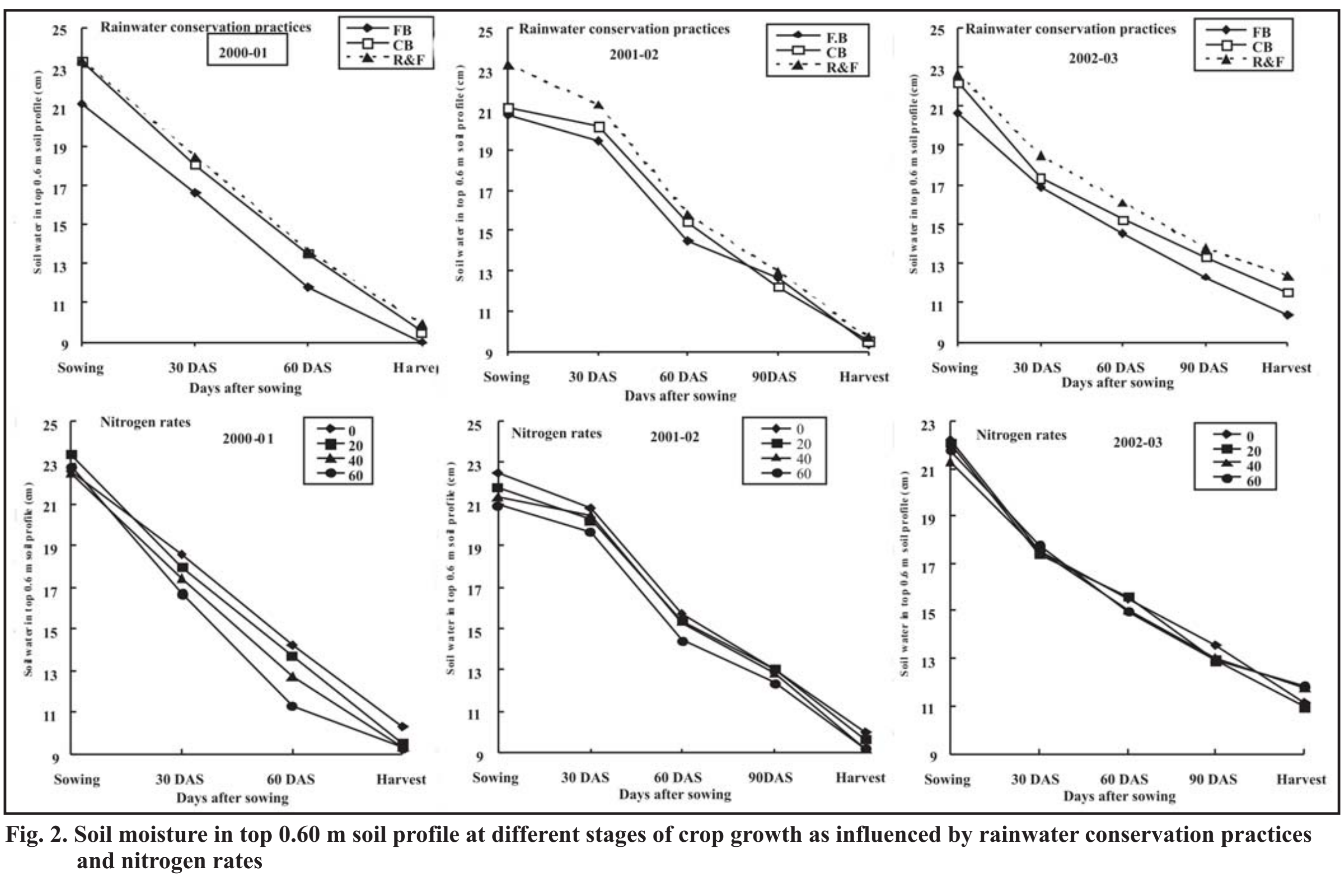

Fig. 2. Soil moisture in top 0.60 m soil profile at different stages of crop growth as influenced by rainwater conservation practices and nitrogen rates

depleted faster compared to rainwater conservation treatments, and low crop yield in FB reduced WUE. Better crop growth and root proliferation in the rainwater conservation treatments might have resulted in the better absorption and effective use of soil moisture by sorghum crop. Lower WUE of 7.77 kg ha^{-1} mm^{-1} during 2001-02 was attributed to higher consumptive use of water whereas lower consumptive use of water during 2000-01 produced higher WUE of 9.73 kg ha^{-1} mm^{-1}. Even the increase in WUE was only 13 and 9% with CB and RF, respectively during 2001-02 compared to greater increase in WUE by 15 and 26% with CB and RF over FB during 2000-01(Tables 1 and 4). Wang (2009) also observed rainwater conservation treatments increased crop yields, and enhanced WUE.

Nitrogen Application

Grain yield of winter sorghum in Vertisols of SAT, India depends on the rainfall and N availability in soils as these soils are not only thirsty but also hungry and N availability in these soils is low (Rao *et al.,* 1995; Patil *et al.,* 2001; Patil and Sheelvantar, 2009). The response of winter sorghum to N application was only to 20 kg ha^{-1} during a drought year of 2002 with low crop season rainfall due to lesser soil moisture availability to the crop. Further, increase in soil moisture availability during 2002 resulted in significant increase in grain yield up to 40 kg N ha^{-1}. Whereas during 2001 with higher annual (566.6 mm), antecedent, *i.e.,* prior to sowing (189.0 mm) and crop season rainfall of 248.3 mm could wet the soil profile completely at sowing and greater soil moisture availability during crop season increased the winter sorghum grain yields significantly up to 60 kg N ha^{-1} (Tables 1, 4 and Fig. 2). Grain yield was higher by 13, 19, and 21%, with application of 20, 40 and 60 kg N ha^{-1}, respectively compared to 0 kg N ha^{-1} in the pooled data. Increase in sorghum grain and straw yields with increase in N application to 60 kg ha^{-1} was attributed to increased availability of nutrients especially N. This in turn improved the root growth and increased N uptake further resulting in higher photosynthesis rate with greater dry matter accumulation in head thus producing higher grain yield (Itnal *et al.,* 1986; Patil *et al.,* 1989; Patil *et al.,* 2001). The WUE increased significantly by 9, 24 and 20% with 40 kg N ha^{-1} during 2000-01, 2002-03 and in the pooled data, respectively, whereas, WUE increased by 27% with 60 kg N ha^{-1} during 2001-02 compared to 0 N kg ha^{-1} (Table 4). The WUE increased to 60 N ha^{-1} during 2001-02 and is attributed to higher soil moisture availability to sorghum from sowing to harvest. Application of N in the conservation treatments enhanced soil fertility, improved yield, and enhanced WUE.

Higher sorghum grain yield with increase in N application to 60 kg ha^{-1} was attributed to production of greater head length (17.3 cm) and head girth (15.2 cm) compared to 0 N kg ha^{-1} over years (Table 5). Higher grain yield with application of 40 kg N ha^{-1} is attributed to higher head weight by 17% compared to 0 N kg ha^{-1}. Increased head weight at 40 and 60 kg N ha^{-1} was attributed to greater 1000 grains weight. This is depicted by 11, 17 and 16% more grain weight $plant^{-1}$ with application of 20, 40 and 60 kg N ha^{-1} compared to 0 N kg ha^{-1} over years. Taller plants with more dry matter accumulation in leaves and stem with application of 20 to 60 kg N ha^{-1} increased the straw yield from 12 to 29% compared to 0 kg N ha^{-1} (Table 4).

4. CONCLUSIONS

Compartmental bunding and ridges and furrows (rainwater conservation techniques) conserved more rainwater in profile from July to September and increased the soil moisture availability during crop growing season thus producing higher winter sorghum grain yield by 17 and 22%, respectively compared to flat bed sowing. More effect of rainwater conservation techniques on winter sorghum productivity in Vertisols is observed during drought years compared to normal and above normal rainfall situations. If winter sorghum is sown during September 2nd fortnight, apply 40 kg N ha^{-1} at sowing and additional 20 kg N ha^{-1} after 30 days of sowing in normal to above normal rainfall years. Sorghum sown during 1st fortnight of October, apply 40 kg N ha^{-1} in normal to above normal rainfall years. During below normal rainfall years when sorghum is sown after 15th October, apply only 20 kg N ha^{-1} (50% of recommended N rate) at sowing for higher sorghum productivity. The WUE is greater during a normal year compared to either drought or above normal rainfall situations.

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