Vol. 44, No. 2, pp 198-205, 2016
Indian Journal of Soil Conservation
Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Tillage and integrated nitrogen management: Does sustain sorghum productivity in Vertisols of Semi-Arid Tropics under varying rainfall situations?

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ARTICLE INFO

Article history :
Received : October, 2014
Revised : September, 2015
Accepted : October, 2015

Key words :
Conventional tillage,
Integrated nutrient management,
Low tillage,
Reduced tillage,
Sorghum

ABSTRACT

A field study was conducted for four years (2003-2007) to investigate the effect of tillage and integrated nutrient management practices on soil moisture conservation and sorghum yield under different rainfall situations in a rainfed SAT in India. Tillage treatments include conventional tillage, CT (1 ploughing + 2 harrowing + 2 hoeing + 1 hand weeding), reduced tillage, RT (2 harrowing + 1 hoeing + 1 hand weeding) and low tillage, LT (1 Harrowing + 1 hoeing + herbicide application). Nutrient management treatments were 50% recommended rate of nitrogen (RRN), 100% RRN and 150% RRN. Fifty percent N was applied through farmyard manure and 50% N through urea. The differences of rainfall during a year as well as cropping season had a marked effect on sorghum yield. Under varying rainfall situations, CT conserved greater rainfall and improved soil physical properties performed relatively better over RT or LT. We found that sorghum response to INM varied differently under different rainfall situations in all the 4 years of study. In drought year, 50% reduced N application served better whereas in nearly drought year RRN suits. In a good rainfall year, even 50% higher RRN application produced greater sorghum yield significantly over lower rates.

1. INTRODUCTION

Tillage is a primary land preparation activity which consumes most of the energy input in the farming practices (Khaledian *et al.,* 2012; Shamabadi, 2012). Any reduction in tillage saves resources, time and money to the farmers thereby improves farm profitability (Khaledian *et al.,* 2012; Mitchell *et al.,* 2012). In semi-arid regions, rainfed agriculture is to deal with major water-related challenges such as the extreme variability in rainfall (amount and distribution), characterized by few rainfall events, high-intensity storms, and high frequency of dry spells and droughts (Cantero-Martínez *et al*., 2003; Wani *et al*., 2009). In SAT region, Vertisols were conventionally tilled with a mould board plough usually done from February to May and two criss-crosses harrowing between July and September along with 2-3 inter-row cultivation and a hand weeding to control weeds (Patil, 2007). Weeds were controlled through tillage practices and/or hand weeding. Though conventional tillage, in general, controls weeds effectively and also accelerates oxidation of soil organic matter, weeds could also to be managed through combination of herbicides, inter-row cultivation and manual weeding to reduce the cost of tillage and human labour (Walker *et al*., 2005; Blaise, 2006) and thus application of herbicides results in reduced tillage (Blaise and Ravindran, 2003). There is overwhelming evidence that besides conserving soil moisture conventional tillage enhances runoff and soil erosion due to repeated tillage whereas RT in contrast restore and improve soil quality and lead to sustained food production and a healthy environment (Hulugalle and Entiwistle, 1997; Unger *et al*., 1997). On Vertisols, RT system has been reported to yield equal to or higher than CT system (Hulugalle *et al*., 2004; Blaise *et al*., 2005). Assefa *et al.* (2010) calls for designing techniques that could improve water availability in sorghum growing season to double the current dryland sorghum yield with the existing genetic potential. There is general opinion that wise farm planning with low or reduced tillage practices and efficient resource use are essential as a mitigation tool to fight global warming by reduced energy consumption otherwise it causes global climate change (Bonari *et al*., 1995; Spiertz, 2010). However, we found scarce informations are available on functioning of reduced tillage strategies under varying rainfall situations like nearly drought and drought.

Resource-use efficiency in agriculture has become a major global concern and particularly nitrogen (N)-use efficiency in developing production system requires research on different scales to match N demand in time and space on an integrated long term crop rotation (Spiertz, 2010). In drylands soil management through tillage and rational use of N fertilization can improve the performance of crops through improved use of available water and increased use efficiency (Cantero-Martínez *et al*., 2003). Nitrogen is generally considered to be a major limiting factor in the Vertisols, as these soils are low in N (< 250 kg N ha^{-1}) and immobilization as well. Nitrogen is usually applied in low amount to meet the crop needs, especially for sorghum during winter season. The RT system reduces mineralization thus lowers N availability to sorghum which aggravate N deficiency in already deficient soils. As reported from Louisiana, USA, RT system on silty-loams requires additional N as compared to CT systems (Boquet *et al*., 2004). Information is scanty on influence of N application through integrated approach by organic and inorganic materials (INM) under different tillage and varying rainfall situations for rainfed winter sorghum in SAT, India. In general, integrated approach of N application through organic materials and urea improves soil properties and enhances its use efficiency.

Sorghum is the fifth most important cereal and fodder crop grown largely under rainfed conditions in the SAT of Asia, Africa and Americas (Pandey and Roy, 2011; Kholova *et al*., 2013). Eighty per cent of sorghum production in the world is under dryland conditions (Assefa *et al*., 2010). In India, winter sorghum cultivation is confined to Deccan plateau (House *et al*., 2000; Murthy *et al*., 2007; Kholova *et al*., 2013) and in postrainy season 3 M t grain produced from 5.7 M ha which supports 5 million household's livelihood (Kholova *et al*., 2013). The existing large yield gap between attainable yield and farmers' practice as well as between the attainable and potential yield elucidates potential of rainfed agriculture in SAT region (Wani *et al*., 2009; Assefa *et al*., 2010). Productivity of winter sorghum in this region is generally low (<1 t ha^{-1}) and is mainly attributed to sowing crop on residual/receding soil water during postrainy season with low average annual rainfall of 497.2 mm and low soil fertility (Patil, 2007; Kholová *et al*., 2013). The study is based on the hypothesis that reduced tillage farming strategies would conserve greater soil moisture; improve soil quality and productivity. With this as the background we would like highlight functioning of reduced tillage farming strategies against conventional and integrated nutrient management strategies for resource conservation and sustainable crop productivity in semi-arid Vertisols of south India especially under varying rainfall situations.

2. MATERIALS AND METHODS

Study Area and Soil Characteristics

A field study was conducted during winter seasons from 2003 to 2007 at Research Farm of ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Ballari. This site is situated in the northern dry zone of Karnataka, India (15º09' N latitude, and 76º 51' E longitude) at an altitude of 445 m above msl. The chosen experimental site was a Vertisol belonging to Ballari series classified as Typic-Pellusterts. These soils are derived from granite gneiss and schist. The infiltration rate of soil is low (8 mm h^{-1}) and bulk density is 1.22 Mg m^{-3} (Black, 1965). These soils are alkaline in reaction with soil pH of 8.5 and electrical conductivity of 0.13 dS m^{-1} (Piper, 1966). The clay content increased with depth from 45% on surface to 51% at 0.9 m soil depth. The field capacity at 1/3 atmosphere varied from 36 to 47% and wilting point varied from 26 to 30% from top soil to 0.9 m soil depth, respectively. The soils at the experimental site are low in organic carbon (2.8 g kg^{-1}) (Piper, 1966), low in available N (155 kg ha^{-1}) (Subbiah and Asija, 1956), medium in available P (24 kg P_20_5 ha^{-1}) (Jackson, 1967) and high in available K (560 kg K_20 ha^{-1}) (Muhr *et al*., 1965).

Experimental Design and Treatments

To evaluate the impact of different tillage practices and integrated nutrient management system comprising of N supply through organic and inorganic materials on soil properties and winter sorghum yields, a field experiment was laid out in split plot design with three main plot treatments comprising of conventional tillage, CT (1 ploughing + 2 harrowing + 2 hoeing + 1 hand weeding), reduced tillage, RT (2 harrowing + 1 hoeing + 1 hand weeding) and low tillage, LT (1 harrowing + 1 hoeing + weedicide). Sub plot treatments comprising of three integrated nutrient management, INM, *i.e.,* INM_1=50% RRN (50% N through farmyard manure + 50% of N through urea), INM_2=100% RRN (50% N through farmyard manure + 50% N through urea) and INM_3=150% RRN (50% N through farmyard manure + 50% N through urea). All treatments were replicated thrice. The plot size was 6.8 × 5.4 m. Infiltration rate was recorded after harvest of crop in all 27 plots during March 2007 using double ring infiltrometer having 30 cm height and diameter of 20 and 40 cm for inner and outer rings, respectively as described by Richards (1954). Bulk density was measured in undisturbed soil cores collected from 0-0.15 and 0.15-0.30 m depths in all nine treatments in three replications (Black, 1965).

Taking corresponding bulk density values and standard particle density (2.65 Mg m^{-3}), the porosity of surface and sub soil thus calculated was used in discussion.

Crop Management and Yield Measurements

The winter sorghum (cv. M35-1) sown on different dates as influenced by seasonal rainfall (Table 1 and Fig. 1). Land was prepared with a tractor drawn mould board plough and harrow, followed by bullock drawn hoeing. Recommended plant protection chemicals were applied to control pests and disease during the experimental period. Yield of main and by-product was measured by harvesting 36.72 m^2 area in each plot at physiological maturity. Crop germination was better in all years, except during 2003-04 it was 30% at sowing and improved to 50% with 57.4 mm rainfall that fell during succeeding week. During 2005-06, all the growth and yield components *i.e.,* plant height, head length and head girth was measured by standard procedure. Five randomly selected plants from net plots were oven dried at 60 to 65°C for 48 hours and recorded for head weight and grain weight $plant^{-1}$ at physiological maturity after separation of grains from the head. The 1000-grains drawn from grain yield of each study plot was weighed and expressed in g. Grain number $head^{-1}$ was calculated from the grain weight per head and 1000-grains weight using the equation:

$$\text{Grain number head}^{-1} = \frac{\text{Grain weight per head}}{\text{1000-grains weight}} \times 1000$$

The grain yield of winter sorghum was divided by total biological yield and was multiplied by 100 to arrive at harvest index (HI) and expressed in percentage (Donald, 1962).

Soil Moisture, Water Use Efficiency and Soil Physical Properties

Soil moisture was measured gravimetrically from sowing to harvest (30 days interval) for 0-15, 15-30 and 30-60 cm depths in all 27 study plots (Jalota *et al*., 1998). Soil moisture utilized was computed as the difference of soil water at sowing, at different crop growth stages and at harvest. Consumptive use of water (CUW) was determined by taking difference in values of soil water content (mm) in top 0.60 m of soil between any two stages, by adding the rainfall and subtracting runoff during the relevant period. No drainage or deep percolation was observed at Ballari during the crop growth period and hence it was not accounted for calculation of consumptive use of water during four years of study period. Daily rainfall was measured by using standard ISI rain gauge located in class A meteorological observatory situated about 10 m away from experimental plot in the Research Farm. Runoff from adjacent experimental plot was measured by using multislot device and same was used in this experiment for all 27 treatments in three replications for assessing runoff from each treatment. Difference in soil water was added to arrive at CUW in mm (Patil and Sheelavantar, 2006). Water use efficiency (WUE) was determined by dividing economic yield by CUW (mm) and expressed as kg $ha^{-1}mm^{-1}$. Soil bulk density was measured by core method (Black, 1965), and water infiltration rate (IR) by double-ring infiltrometer (Bouwer, 1986).

Statistical Analysis

All data were statistically analyzed in split plot design for analysis of variance using a computerized statistical MSTAT-C package. When analysis of variance indicated significant difference, LSD test was used to separate the treatment means for tillage and INM practices, and for comparing across them at 5% level of probability. All significant main and sub plot effects besides interactions

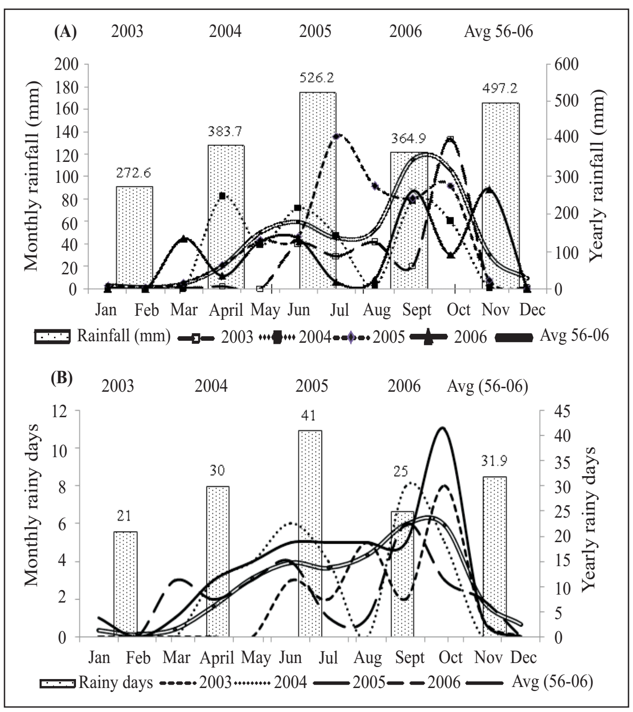

Fig. 1. Distribution of monthly and year rainfall (A) and monthly and year rainy days (B) during the study period

Table: 1
Rainfall and its distribution during study period

Year	Date of sowing	Date of harvest	Rainfall in the year till sowing	Rainy days in the year till sowing	Crop season rainfall (mm)	Rainy days during crop season
2003-04	10.10.2003	25.02.2004	209.0	16	63.6	5
2004-05	05.10.2004	21.02.2005	370.5	28	13.2	2
2005-06	17.10.2005	21.02.2006	466.2	35	60.0	6
2006-07	08.11.2006	03.03.2007	363.7	25	1.2	0

were considered and expressed with standard error bars in figures.

3. RESULTS AND DISCUSSION

Rainfall Distribution

Attributes of winter cropping season in the region are limited rainfall, cooler average temperature and shorter days which results in lower potential crop evapotranspiration. Further, occurrence of shallow black soils across the sorghum production area limits the moisture storage capacity often resulting in exhaustion of available soil moisture early in the crop cycle leading to limited grain and stover production (Murthy *et al*., 2007; Kassahun *et al.,* 2010). Recommended sowing time in the region is second fortnight of September. Winter sorghum (cv. M35-1) was sown on different dates as it was influenced by local rainfall. During 2003 and 2004 sorghum was sown in the first fortnight of October whereas during 2005 and 2006 crop sown during second fortnight of October and first fortnight of November, respectively due to late onset of northeast monsoon (Table 1 and Fig. 1). Rainfall during 2003, 2004 and 2006 was 45, 23 and 27% less than 50 years mean annual rainfall, respectively thus produced lower sorghum yields. Shifts in sowing time due to changes in spring water storage in soils which in turn caused by change in precipitation reported by Sepp and Tooming (1991). In normal rainfall year (2005), soil profile is fully charged with rainwater to produce acceptable sorghum grain and straw yields. In general, planting time of winter sorghum is important in Vertisols of south India thus recommends early planting during second fortnight of September to avoid heat effects and to have better yield and water use efficiency (Wylie, 2008). Thus key to avoid adversities of climate change is the adaptation of agriculture to the changed agro-climatic conditions through better resource management practices (Karing *et al*., 1999).

Interactions: Grain yield and WUE

Interactions due to tillage practices and INM were observed in grain yield and WUE during 2004-05 only. Conservation of higher moisture in soil profile with CT compared to RT and LT produced greater grain yield and WUE at all INM's. The year 2004-05 being a drought year, the response to INM under different tillage practices increased up to INM_2 and further due to negative interaction of INM at lower moisture level decreased the grain yield and WUE at INM_3. Significantly higher grain yield of 526 kg ha^{-1} and WUE of 2.70 kg ha^{-1} mm^{-1} was observed with CT and INM_2 (Table 2 and Table 3). Under water stress situation response of crop to higher N reduces due to negative interaction of limited soil moisture with greater N availability (Villar-Salvador *et al*., 2013).

Rainfall, Tillage and crop yields

Lower annual rainfall during 2003 (55%) and 2004 (77%) produced lower sorghum grain and straw yields, however, crop performed better under CT as it conserves higher soil moisture in top 0.60 m soil profile from sowing to harvest compared to RT and LT (Patil, 2007). During 2003-04 and 2004-05, CT produced nearly 9 and 26% higher grain yield and 21 and 5% greater straw yields over LT, respectively. Even though nearly 74% of mean annual rainfall was received during 2006, due to uneven distribution and late sowing on November 8 with low soil moisture at sowing leads to poor germination (30%). Among the germinated plants only 80% of the plants borne heads but seeds turned into chaffy due to low soil moisture in the profile up to harvest thus producing straw yield alone. Among the tillage practices due to better soil moisture availability in CT produced 41% higher straw yield (1.26 t ha^{-1}) over LT (Table 4). The water stress in the region is described as "terminal drought" occurs with varying timing of onset during the crop cycle and reduces the crop yields drastically (Kassahun *et al*., 2010; Sajjanar *et al*., 2011). Thus vagaries of nature demands for still better farming strategies to cope with extremes in the Vertisols region.

About 6% higher rainfall that fell during 2005 produced normal sorghum yields even though crop was sown late during second fortnight of October due to uneven distribution of rainfall (Table 1, Fig. 1). Even during good rainfall year also CT produced significantly higher grain yield by 8 and 15% and straw by 6 and 10% over RT and LT, respectively. Higher yields with CT are attributed to greater soil moisture availability from sowing to harvest compared to RT and LT (Fig. 2). Higher amount of soil water

Table: 2
Grain yield (kg ha^{-1}) of sorghum as influenced by tillage and INM interactions during 2004-05

Tillage practices	Integrated nutrient management			Mean
	INM_1	INM_2	INM_3	
CT	440	526	481	433
RT	350	481	250	386
LT	291	468	197	343
Mean	360	492	309	387
Comparing the means of		LSD (< 0.05)		
Tillage practices at same INM		101		
INM at same/different tillage practices		84		

Table: 3
Water use efficiency (kg $ha^{-1}mm^{-1}$) of sorghum as influenced by tillage and INM interactions during 2004-05

Tillage practices	Integrated nutrient management			Mean
	INM_1	INM_2	INM_3	
CT	2.32	2.70	2.42	2.21
RT	1.93	2.63	1.29	2.01
LT	1.52	2.41	1.05	1.87
Mean	1.92	2.58	1.59	2.03
Comparing the means of		LSD (< 0.05)		
Tillage practices at same INM		0.53		
INM at same/different tillage practices		0.44		

Table: 4
Grain yield, straw yield, water use efficiency and Harvest Index of winter sorghum as influenced by tillage practices and integrated nitrogen management

Treatment/ Years	Grain yield ($kg\ ha^{-1}$)			Straw yield ($t\ ha^{-1}$)				Water use efficiency ($kg\ ha^{-1}mm^{-1}$)			Harvest Index (%)		
	2003-04	2004-05	2005-06	2003-04	2004-05	2005-06	2006-07	2003-04	2004-05	2005-06	2003-04	2004-05	2005-06
Tillage practices													
CT	282	433	1953	1.70	2.02	2.66	1.26	1.71	2.21	7.24	14.4	21.6	41.3
RT	264	386	1815	1.54	1.81	2.52	1.00	1.59	2.01	6.95	14.6	21.6	41.8
LT	260	343	1703	1.41	1.93	2.43	0.89	1.57	1.87	6.79	15.6	17.4	42.2
LSD (< 0.05)	NS	22	130	0.14	NS	0.11	0.09	NS	0.11	NS	NS	2.8	NS
Integrated Nutrient Management													
INM_1	280	360	1742	1.69	1.88	2.46	1.12	1.51	1.92	6.75	15.6	19.8	41.4
INM_2	271	492	1811	1.59	2.00	2.55	1.09	1.65	2.58	7.01	14.6	24.7	41.5
INM_3	254	309	1917	1.37	1.88	2.60	0.94	1.71	1.59	7.23	14.4	16.1	42.3
LSD (< 0.05)	NS	58	154	0.16	NS	0.09	0.12	NS	0.31	NS	NS	4.2	NS

NS: Non Significant

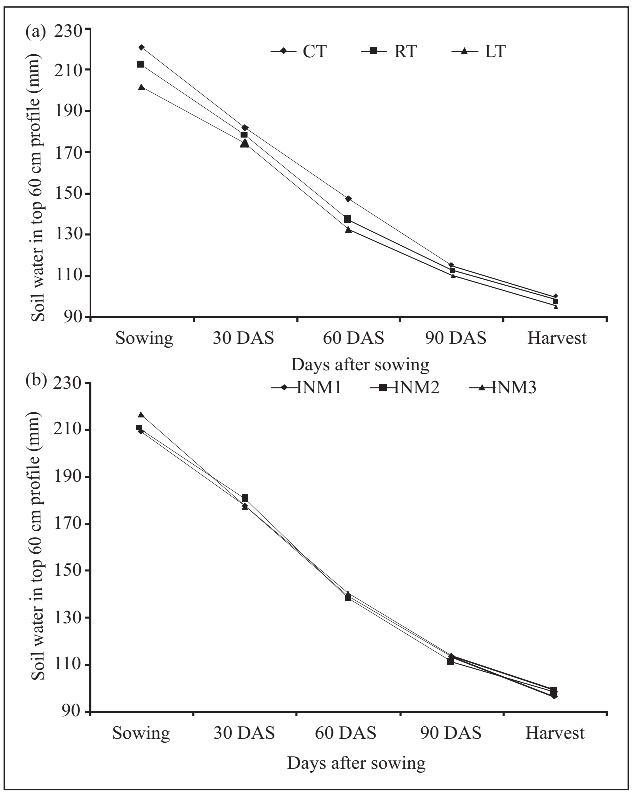

Fig. 2. Soil water content in top 60 cm soil profile at different stages of crop growth as influenced by tillage (a) and integrated nitrogen management (b) during 2005-06

conserved in CT is attributed to higher infiltration rate, reduced bulk density and increased porosity with greater opportunity time for rainwater infiltration (Figs. 3, 4, 5). Similar results were also observed with deep tillage compared to medium and shallow tillage in Vertisols of Bijapur, India (Patil and Sheelavantar, 2006). Infiltration rate was significantly greater in CT (9.0 mm h^{-1}) followed by RT (8.1 mm h^{-1}) while LT recorded significantly lower infiltration rate of 7.3 mm h^{-1}. Greater infiltration rate in CT is attributed to reduced bulk density in top soil (1.19 Mg m^{-3}) and sub soil (1.21 Mg m^{-3}) as compared to RT and LT (Figure 4). As the depth and number of tillage operations increased from LT to CT, the porosity increased from 52.5 to 55.2% in top soil and from 51.5 to 54.3% in subsoil as depicted in Fig. 5 and similar observations were also earlier recorded by Patil (1998).

Greater sorghum grain yield in CT compared to RT/LT is attributed to bigger head size*, i.e.,* head length and girth with higher dry matter accumulation in head thus producing greater grain weight per plant and 1000-grains weight (Table 5). Even, the grain numbers per head were significantly higher by 10% under CT compared to LT (Patil, 1998; Cantero-Martínez *et al*., 2003; Patil, 2007). Further straw yield also followed the similar trend of grain yield with CT recording greater

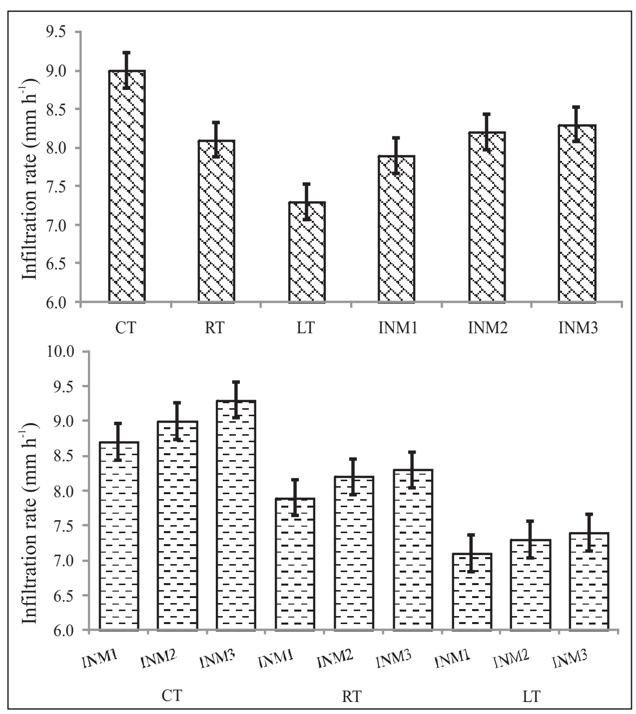

Fig. 3. Infiltration rate as influenced by tillage and integrated nitrogen management

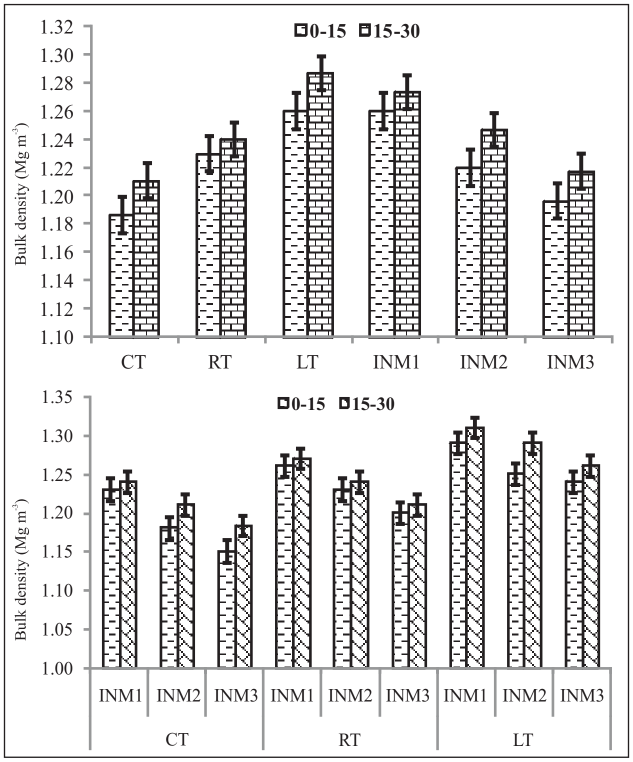

Fig. 4. Bulk density as influenced by tillage and integrated nitrogen management

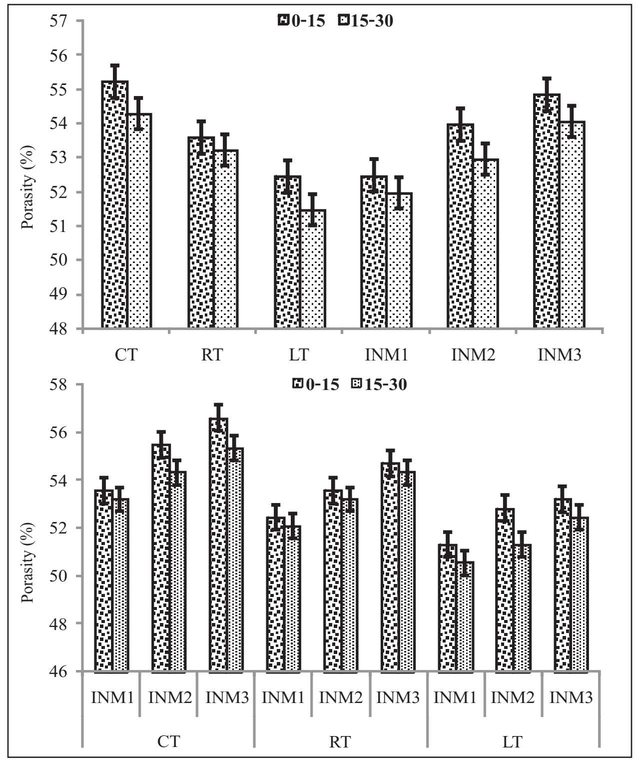

Fig. 5. Porosity as influenced by tillage and integrated nitrogen management

Table: 5
Crop growth and yield components of winter sorghum as influenced by tillage practices and integrated nitrogen management during 2005-06

Treatments	Plant height (cm)	Head length (cm)	Head diameter (cm)	Seed weight (g plant^{-1})	1000 seed weight (g)	Grains head^{-1}	Leaf weight (g plant^{-1})	Stem weight (g plant^{-1})	Head weight (g plant^{-1})	Dry matter production (g plant^{-1})
Tillage practices										
CT	183.6	17.7	14.6	30.64	29.52	1045	12.83	37.11	35.67	86.71
RT	179.8	16.9	13.4	27.79	27.50	1020	11.62	35.67	32.89	80.18
LT	176.5	15.7	13.0	25.50	26.86	951	10.64	33.44	30.67	74.75
LSD (< 0.05)	3.4	1.2	0.6	2.77	2.39	78.8	1.12	2.22	3.25	5.76
Integrated Nutrient Management										
INM_1	176.0	16.2	13.1	25.62	26.33	987	11.19	32.89	30.89	74.97
INM_2	180.8	16.8	13.7	28.39	28.41	1000	11.77	36.00	33.78	81.55
INM_3	183.1	17.3	14.2	29.92	29.15	1029	12.13	37.33	34.56	85.17
LSD (< 0.05)	3.7	0.5	0.9	2.77	NS	NS	NS	3.20	2.89	3.95

straw yield by about 10% over LT. Higher straw yield in CT was attributed to greater dry matter accumulation in leaf and stem per plant at harvest. Significantly greater harvest index of 21.6% was observed in CT and RT over lower HI of 17.4% produced under LT (Table 4).

Rainfall, Tillage and WUE

Greater grain yield with efficient utilization of soil moisture by sorghum produced higher WUE in CT compared to RT and LT during three years in this study. The CT improved WUE from 7% during 2005-06 to 18% during 2004-05 over LT indicating that optimum moisture utilization for grain production during marginally drought year as compared to drought or normal years of rainfall (Patil, 1998).

Rainfall, Integrated Nutrient Management and crop yields

Occurrence of 45% deficit rainfall during 2003 and uneven distribution of rainfall with late sowing during 2006 resulted in lower soil moisture availability from sowing to harvest. Under such circumstances winter sorghum responded to low fertilizer rate, *i.e.,* INM_1 by producing significantly higher grain and straw yields compared to INM_2 and INM_3. Thus it confirms that crop at water stress requires less nutrients as plants adjust osmotically and reduces nutrient uptake by roots (Alam, 1999). Reduction of grain and straw yield at INM_2 and INM_3 was attributed high N which reduces drought tolerance (Villar-Salvador *et al*., 2013). Even though 383.7 mm (77% of mean annual) rainfall was received during 2004 due to uniform rainfall distribution and greater soil moisture availability during crop period sorghum responded to recommended rate of fertilizer, INM_2 over INM_1 and INM_3. Sorghum responded significantly to higher N fertilizer, INM_3 compared to INM_2 and INM_1 during 2005 was mainly attributed to higher rainfall by about six per cent with its uniform distribution produced greater soil moisture throughout the crop growth (Patil and Sheelavantar, 2006).

Greater amount of organic materials added through farmyard manure in INM_3 compared to INM_2 and INM_1 could result in higher soil moisture in top soil and produced greater grain and straw yields during 2005-06 (Table 4, Fig. 2). Higher grain yield in INM_3 was attributed to larger head size with higher dry mater accumulation in head and greater 1000-grains weight. Dry matter accumulation in leaf, stem and its translocation to head and the total dry matter production per plant was significantly higher in INM_3 compared to INM_1 as observed in Table 5 (Patil, 1998). Application of organic amendments through *Leucaena* loppings, farmyard manure, vermicompost and sorghum stubbles recorded higher soil moisture in profile in Vertisols (Bellakki and Badnur, 1994; Patil and Sheelavantar, 2006). Marginal increase in soil moisture with greater amount of farmyard manure application was attributed to increased infiltration rate, reduced bulk density and increased porosity in top and sub soil as indicated in Figs. 3, 4, 5 comply with Venkateswarlu (1984) and Kuotsu *et al.* (2014). Marginal reduction in bulk density with increased farmyard manure in INM_3 over INM_2 and INM_1 was attributed to higher fine and coarse water stable aggregates. It was earlier reported by Mishra and Sharma (1997) that increased fine (0-0.25 mm) and coarse (1-8 mm) aggregates and reduced bulk density with farmyard manure + blue green algae (BGA) application. Application of greater amount of farmyard manure (INM_3) increased the macro- and micro-pores and resulted in marginal increase in porosity in topsoil (54.8%) and subsoil depths (54.1%) compared to lower porosity observed with INM_2 and INM_1 (Fig. 5). Even in black soils of Bijapur, India, Mastiholi (1994) recorded slightly higher infiltration rate and reduced bulk density with vermicompost application at 2.0 Mg ha^{-1} compared to 1.0 Mg ha^{-1} application.

Tillage, Integrated Nutrient Management and Soil Properties

Higher soil moisture in top 0.60 m soil from sowing to harvest was observed in CT with INM_3 and it was attributed to significantly lower bulk density in top (1.15 Mg m^{-3}) and sub soil (1.18 Mg m^{-3}) with greater infiltration rate (9.3 mm h^{-1}) and higher porosity of 56.6% and 55.3% in top and subsoil, respectively (Figs. 2, 3, 4, 5) (Patil and Sheelavantar, 2006; Kuotsu *et al.,* 2014).

Rainfall, Integrated nutrient management and WUE

During a severe drought year of 2003, INM_1 produced 10% higher WUE over INM_3 and during slightly drought year recommended N application through INM_2 produced nearly 63% higher WUE over INM_3, whereas during normal rainfall situation INM_3 produced higher WUE of 7.23 kg ha^{-1} mm^{-1} due to higher moisture availability and better utilization of N resulted in 7% better WUE over INM_1 (6.75 kg $ha^{-1}mm^{-1}$). This clearly indicates soil moisture level and N interact either positively or negatively in terms of WUE (Table 4).

4. CONCLUSIONS

Conventional tillage under varying rainfall situations performed relatively better over RT or LT in SAT region. The RT or LT strategies not efficient in conserving soil moisture compared to CT. Sorghum production during drought years may not be a profitable venture. Among the integrated nutrient management system we found varying response of crop under different rainfall situations. In drought year 50% reduced N application through farmyard manure (50%) and urea (50%) serves better whereas in nearly drought year recommended rate suits. In slightly above rainfall year, even 150% RRN application produces significantly greater winter sorghum yield and its parameters.

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