academicJournals

Vol. 9(23), pp. 1761-1769, 5 June, 2014
DOI: 10.5897/AJAR2014.8476
Article Number: AE9BFD645221
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Azosprillium based integrated nutrient management for conserving soil moisture and increasing sorghum productivity

S. L. Patil

Central Soil and Water Conservation Research and Training Institute, Research Centre, Bellary, 583 104, Karnataka, India.

Received 6 January, 2014; Accepted 19 May, 2014

In this field study, we evaluated the utilization of *Azosprillium* with organic amendments and urea in winter sorghum productivity in order to achieve the best results with minimum nitrogen utilization in Vertisols under different rainfall situations of SAT, India. Results showed that the organic materials application conserved more rainwater in top 0.60 m soil profile. Across three years of study, *Azospirillum* seed inoculation had a positive effect on sorghum production and produced 13% more sorghum grain and straw yields compared to 0 kg N ha^{-1}. Sorghum grain yields were 44% higher when seeds were treated with *Azospirillum* and applied with 50% recommended rate of nitrogen (RRN) through urea and 50% RRN through organic materials (50:50 ratio of *Leucaena* loppings and farm yard manure) compared to control. Water use efficiency (WUE) was 42% greater with *Azospirillum* seed treatment and application 50% RRN through organic materials and 100% RRN through urea over control. Interference drawn in this study clearly indicates that low cost technology of *Azospirillum* seed treatment has to be adopted for higher sorghum grain yields. However, it is recommended to apply N through organic and fertilizer N in the ratio of 50:50 RRN along with *Azospirillum* seed treatment for sustainable sorghum yields and greater water productivity in the Vertisols of SAT, India.

Key words: *Azospirillum,* nitrogen, rainwater conservation, Vertisols, winter.

INTRODUCTION

The global human population will reach around 10 billion by 2050. To meet the needs of growing population, the pressure on the reduced land area will increase to produce more food, fibre and fuel by greater use high yielding crop cultivars, fertilizers and employing new production technologies at farm level (Johri et al., 2003). In India, nearly 60% of cultivated area is rainfed that contributes for 45% of agricultural production (Venkateswarlu, 2008a, b). Vertisols are major soils in rainfed eco–system of SAT in south India. These soils are sometimes more hungry than thirsty as low soil fertility is one of the major factor limiting crop productivity. These Vertisols are universally deficient in N and nearly 40% in P thus requires proper management to sustain productivity. Low rainfall (508 mm average of 56 years) and its uneven distribution; poor economic status of

* E-mail: slpatil64@gmail.com; slpatil101@yahoo.co.in

dryland farmers, high costs and timely unavailability of fertilizers and organic amendments in recent years resulting in lesser application than the recommended rate. This practice leads to higher rate of nutrients depletion than their replenishment that declines the soil health and consequently reduces crop productivity over the years (Math and Patil, 2013). Decreased availability of organic amendments, increased cost of chemical fertilizers and organic amendments farmers are forced to pay nearly double the cost of fertilizers during 2012 to 2013 alone in India. Frequent droughts due to greater variation in rainfall as a result of climate change resulting in higher cost of production and decreased net returns per unit area. Adverse effect of water stress on productivity of rainfed crops especially during drought years can be minimized by use of organic materials as soil amendments. These amendments conserve rainwater in situ; enhance nutrients supply and increase N use efficiency of applied fertilizers (Reddy et al., 2004; Patil and Sheelavantar, 2009). To meet crop nutrient requirements exclusively through organic amendments alone requires large quantity of materials which is uneconomical due to its high cost and low availability. Application of chemical fertilizers alone does not bring significant increase in crop yields on sustainable basis over the years as these fertilizers supply only limited nutrients.

In addition, continued use of chemical fertilizers causes health and environmental hazards such as ground and surface water pollution by nitrate leaching. So reducing the amount of nitrogen fertilizers applied to the field without a nitrogen deficiency will be the main challenge in field management. One of the possible options to reduce the use of chemical fertilizer could be using of organic materials. It is generally acknowledged that organic materials play an important role in maintaining a high level of soil fertility. The positive influence of organic fertilizers on soil fertility, on crop yield and quality has been demonstrated in the works of many researchers (Suresh et al., 2004; Naeem et al., 2006; Dauda et al., 2009). Increase in price of chemical fertilizers and organic amendments forcing the farmers in the region to use alternative low cost inputs like biofertilizers.

Biofertilizers play an important role in plant nutrient management, particularly in rainfeds where farmers wants to reduce the fertilizer application through biofertilizers that costs them low. Applications of biofertilizers improves soil organic matter content, enzymes, microbial population and decrease the negative effect of chemical fertilizer and also increase yields of crops on sustainable basis (Alizadeh and Ordookhani, 2011; Jala-Abadi et al., 2012). Among the plant growth promoting *rhizobacterium* (PGPR) species, *Azospirillum* spp. is well known for its ability to excrete. Earlier research indicates that cereal crops in general, and sorghum and pearlmillet in particular have a variety of N fixing bacteria in its rhizosphere, including *Azospirillum* and *Azotobacter* which releases growth promoting substances like phytohormones such as indole acetic acid, gibberellins, cytokinins and auxins. For instance, these phytohormones fixes nearly about 10 to 25 kg N ha^{-1} thus increasing root biomass and grain yield (Kumar and Gautam, 2004; Fuentes-Ramirez and Caballero-Mellado, 2005).

In view of the present existing situation,it is more essential to adopt Integrated plant nutrient supply system (IPNS) system for sustainable crop productivity by the farmers who have greater concerns on soil health. Under IPNS, balanced use of organic amendments along with chemical fertilizers including micronutrients and biofertilizers results in improved soil fertility and crop productivity through fertilizer use efficiency (Singh et al., 2004; Guggari and Kalghatagi, 2005; Jala-Abadi et al., 2012).

Sorghum is one of the major rainfed cereal crop cultivated in 41 Mha that produces 64.20 Mt, with a productivity hovering around 1.6 tons per ha. Unlike in other parts of world, sorghum is cultivated in both rainy and postrainy seasons in India. In India sorghum is cultivated in 7.69 Mha that produces around 7.29 Mt with a low productivity of 948 kg ha^{-1} (Tonapi et al., 2011). Quality of rainy season sorghum is poor and is mainly used for animal and poultry consumption. Postrainy season sorghum grain is mostly consumed by human beings and is a staple food of dryland dwellers in central and south India. Sorghum is cultivated on stored soil water in profile during winter season. Deficit soil moisture and low availability of required quantity of nutrients at critical crop growth stages of sorghum reduces crop yields in Vertisols of Deccan Plateau region in India. To enhance winter sorghum productivity, various agronomic management practices have been designed and evaluated, however the information on IPNS with biofertilizers is scarce under different rainfall situations.

In view of this situation, the present field study aims to explore the effect of bio-organic and organic materials and chemical fertilizers on rainwater conservation, water use efficiency and sorghum productivity during winter season.

MATERIALS AND METHODS

Soil and site characteristics

A field study was conducted for three years (2000 to 2001 to 2002 to 2003) at CSWCRTI's Research farm, Bellary, India (15°09' N latitude, 76°51' E longitude, and at an altitude of 445 m above msl). Experimental soils were classified as Typic–Pellusterts of Bellary series derived from granite, gneiss and schist. Clay content increased with depth from 44% on surface to 50% at 0.90 m. Infiltration rate of these soils is 0.8 mm h^{-1} with bulk density of 1.25 Mg m^{-3} (Black, 1965). These soils pH is 8.6, electrical conductivity is 0.14 dS m^{-1} and organic carbon content is 3.83 g kg^{-1} (Piper, 1966). The available N of these soils is low 159 kg ha^{-1} (Subbaiah and Asija, 1956), medium available P of 21 kg as P_2O_5 ha^{-1} (Jackson, 1967) and high available K of 550 kg as K_2O ha^{-1} (Muhr et al., 1965). Chickpea was cultivated at study site during 1999 to 2000.

Table 1. Nutrient content of organic materials.

Organic materials	N (%)	P (%)	K (%)
Leucaena loppings	2.50	0.79	1.50
Farmyard manure	0.66	0.38	0.84

Treatment details

A field study was conducted with 10 treatments combinations of N applied through organic materials, urea and PGPR *Azospirillum brasilense.* The treatments details includes, that is, T_1–0 kg RRN ha^{-1} (Control), T_2–*Azospirillum*, T_3–50% recommended rate of nitrogen (RRN) through organic material, T_4–50 RRN through organic material + *Azospirillum,* T_5–50% RRN through urea, T_6–50% RRN through urea + *Azospirillum,* T_7–100% RRN through urea, T_8–100% RRN through urea + *Azospirillum,* T_9–50% RRN through urea +50% RRN through organic material + *Azospirillum* and T_{10}–100% RRN through urea + 50% RRN through organic material + *Azospirillum.* This study is conducted in a randomized block design with three replications. The organic N is applied through Leucaena loppings and farmyard manure (50% each) on N content basis (Table 1). Leucaena loppings and farmyard manure were incorporated in soil during second and third week of August, respectively in top 10 cm soil depth as per the treatments. Seeds were treated with PGPR *A. brasilense* prior to sowing and N was applied through urea as per treatments at sowing along with recommended rate of P_2O_5, that is, 40 kg ha^{-1}. Sorghum (*Sorghum bicolor* (L.) Moench) during winter season was sown at 5 cm depth with seeds spaced at 15 and 60 cm in rows apart during 2000 to 2001 and 2001 to 2002, while during 2002 to 2003; sorghum was sown at 5 cm depth with plant to plant spaced at 17.5 cm in 60 cm rows apart. During 2000 to 2001, sorghum cultivar SPV–86 and during 2001 to 2002 and 2002 to 2003 sorghum cultivar Maldandi (M35–1) were sown. Each smallest plot measured 5.4 m wide and 6.0 m long. At harvest, head and straw from individual plots were harvested; sun dried for 10 days and after separation of grains from head; the grain and straw weights were recorded.

Computation of soil water and water use efficiency

Profile soil moisture was gravimetrically recorded at every 0.15 m soil depth up to 0.60 m soil depths in each treatment prior to sowing and at 30, 60 and 90 days after sowing (DAS) and at harvest. Soil moisture utilized was computed as the difference of soil moisture at sowing, at 30, 60 and 90 DAS and at harvest. Consumptive use of water was determined by recording difference in values of soil moisture content (mm) in top 0.60 m of soil between any two stages, by adding rainfall and subtracting runoff during the relevant period (Patil, 2013; Patil and Sheelavantar, 2006). No drainage or deep percolation was observed at Bellary during the crop growth period and hence it was not accounted for calculation of consumptive use of water during three years of study period. Runoff that was measured by using multi–slot device from adjacent study plot was used for this study in 10 treatments of 3 replications, that is, total 30 treatments for assessing each treatment runoff. Difference in soil water was added to arrive at consumptive use of water in mm by using the formula,

$$CUW = \sum_{i=1}^{n} (SM_a - SM_b) + \text{Rainfall} - \text{Runoff},$$

Where CUW = Consumptive use of water (mm),
SM_a = Soil moisture content in top 0.60 m soil at stage a,
SM_b = Soil moisture content in top 0.60 m soil at stage b,
Rainfall and Runoff as recorded between stage a and b. The stages a and b are sowing, 30 days after sowing (DAS), 60 DAS, 90 DAS and harvest.

The economic sorghum yield, i.e., grain yield was divided by CUW (mm) to work out the water use efficiency (WUE). The WUE is expressed in kg ha^{-1} mm^{-1}.

Growth and yield components of sorghum

Average plant height (base to the tip of the head) is computed from five randomly selected plants from each plot and expressed in meter. Biometric characterization of sorghum head was computed by measuring head length (base to tip) and head girth (perimeter at the centre of the head) of five randomly selected plants from each plot and expressed in centimeter. Weight of the head and grain yield per plant were recorded after drying for 10 days. The sample of 1000 grains were randomly drawn from individual treatment in all three replications were weighed and expressed in grams. The grains per head was estimated using the formulae,

$$\text{Number of grains per head} = \frac{\text{Grains weight per head}}{\text{1000–grains weight}} \times 1000$$

The Harvest index (HI) is computed using the formulae (Donald 1962).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Total biological yield}} \times 100$$

Statistical analysis

All the field data in this study was analyzed using MSTAT–C statistical package (Gomez and Gomez, 1984). When analysis of variance indicated significant difference, LSD test was used for comparing the differences between the treatments.

RESULTS AND DISCUSSION

Years

During 2001 the rainfall of 566.6 mm that fell in 31 rainy days was 12% higher. In addition, the antecedent rainfall of 184.0 mm that fell from 16 to 25 September 2001 resulted in timely sowing of winter sorghum on 27 September 2001 with uniform wetting of top 60 cm soil depth at sowing. Apart from timely sowing, uniform distribution of 248.5 mm rainfall in 14 rainy days during cropping season resulting in higher soil moisture in profile from sowing till physiological maturity thus produced better plant growth and increased the winter sorghum grain yields by nearly 70 and 53% during 2001 to 2002 compared to 2002 to 2003 and 2000 to 2001, respectively (Figure 1, Tables 2 and 3). Ghanbari et al. (2013) also reported increased maize yield with application of PGPR rhizobacteria and Zinc under favourable soil moisture as compared to stress situations. Late sowing of sorghum on 13 and 21 October with lower crop season rainfall of 45.6 and 9.8 mm that fell during 2000 to 2001 and 2002 to 2003, respectively produced lower yields. Higher grain yield during 2001 to 2002 compared to 2000 to 2001 and 2002 to 2003 was attributed to greater head weight, grain weight per plant, 1000 grains weight and greater head length and head girth (Table 4). Even the trend in straw production was similar to grain and is attributed to production of taller plants with more leaves higher dry matter production in both leaves and stem (Table 4). More dry matter translocation from leaves and stem to head at maturity during 2000 to 2001 produced higher HI by 15 and 24% compared to 2001 to 2002 and 2002 to 2003, respectively. The harvest index in maize was greater under favorable soil moisture conditions and decreased with water deficit stress conditions (Hagbabayi et al., 2011; Ghanbari et al., 2013). Lower consumptive use with more grain production per each unit of water utilized during 2000 to 2001 produced greater WUE of 8.53 kg ha^{-1} mm^{-1} and it was higher by 23 and 14% compared to 2002 to 2003 and 2001 to 2002, respectively (Table 4). In arid and semi arid regions abiotic stresses such as water stress, salinity, high light, temperature, flooding, toxic metals, wounding and biotic stresses including pests and pathogens reduced plant growth and yield (Glick et al., 2007; Ghanbari et al., 2013). Grain yield of maize reduced due to water stress (Sajedi et al., 2009; Habibi et al., 2010; Farajzadeh et al., 2011; Ghanbari et al., 2013).

Treatments

Azospirillum seed treatment produced 7% more grain yield compared to control during 2001 to 2002 with higher rainfall and its uniform distribution. During 2000 to 2001 with a higher rainfall of 550.9 mm and its uneven distribution, sorghum grain yield was higher by 13%, while in a drought year with lower annual rainfall of 432.6 mm during 2002 the sorghum grain yield was 23% higher with *Azospirillum* seed treatment compared to 0 kg N ha^{-1} during 2002 to 2003. Across three years, sorghum grain and straw yields were higher by 13% with *Azospirillum* seed treatment over control (Table 4). These results indicate that a simple low cost technology of seed treatment with *Azospirillum* is more beneficial during drought years with less soil water availability at different stages of sorghum compared to normal and higher rainfall years. Seed inoculation of wheat varieties with biofertilizers showed a significantly increased vegetative growth and grain yield (Narula et al., 2001; Jala-Abadi et al., 2012). Higher sorghum yields with *Azospirillum* inoculation was probably attributed to the biosynthesis and secretion of bacterial Indole–3–Acetic Acid (IAA) (Johri et al., 2003; Fuentes-Ramirez and Caballero-Mellado, 2005). Bacterial IAA stimulates plant root production, especially lateral roots with greater root hairs and improves their development (Meunchang et al., 2004). Okon and Kapulnik (1986) also pointed out that colonization of plant root by *Azospirillum* might enhance permeability of N, P, and K ions into roots. The plant growth promoting *rhizobacterium* (PGPR) enhances uptake of soil nutrients by host plant (Salamone et al., 1997; Fuentes-Ramirez and Caballero-Mellado, 2005). Higher grain yield of winter sorghum with *Azospirillum* inoculation compared to 0 kg N ha^{-1} was attributed to production of greater dry matter in head due to greater head and grain weight per plant, higher values of 1000 grains weight and higher head length and head girth (Table 4).

The sorghum grain yield enhanced from 13 to 38% with application of 50% RRN through organic material along with *Azospirillum* (T_4), while increase was higher and varied from 33 to 47% with application of 50% RRN through urea along with *Azospirillum* (T_6) during different years of study. Further, increase in N application from 50% to 100% through urea along with *Azospirillum* (T_8) increased grain yield marginally compared to control during all the three years of study (Table 3 and Figure 1). In pooled data, mean grain yield of three years in T_8 was 40% higher compared to control (Reddy and Sudhakarbabu, 1996). In addition to N fixation, *Azospirillum* improves plant growth through production of phytohormones leading to better plant growth with greater photosynthate production and its translocation to reproductive parts (Fuentes-Ramirez and Caballero-Mellado, 2005; Arbad et al., 2008; Prasad, 2008; Khan et al., 2010). Higher head and grain weight per plant with higher values of head length, head girth and 1000–grains weight produced higher grain yield in T_4, T_6 and T_8 treatments compared to control during all three years of this study. Application of bacterial inoculants at higher soil moisture with zinc sulphate increased maize cob weight (Ghoorchiyani et al., 2011; Mostafavi et al., 2012; Ghazvineh and Yousefi, 2012).

Applying 50% RRN through urea and 50% RRN through organic materials and seed treatment with *Azospirillum* (T_9) produced significantly higher grain yield varying from 32 to 66%, while increase in N application through urea to 100% (T_{10}), sorghum grain yield was 37 to 67% higher compared to 0 kg N ha^{-1} during study period and in pooled data (Table 3 and Figure 1). These results indicates that *Azospirillum* seed inoculation fixes around 10–25 kg N ha^{-1} and could save nearly 50% of recommended rate of N through urea in winter sorghum (Prasad, 2008). Occurrence of moisture stress from flower initiation to maturity due low soil water availability in profile and higher N through urea negatively interacted during a drought year of 2002 to 2003 thus marginally

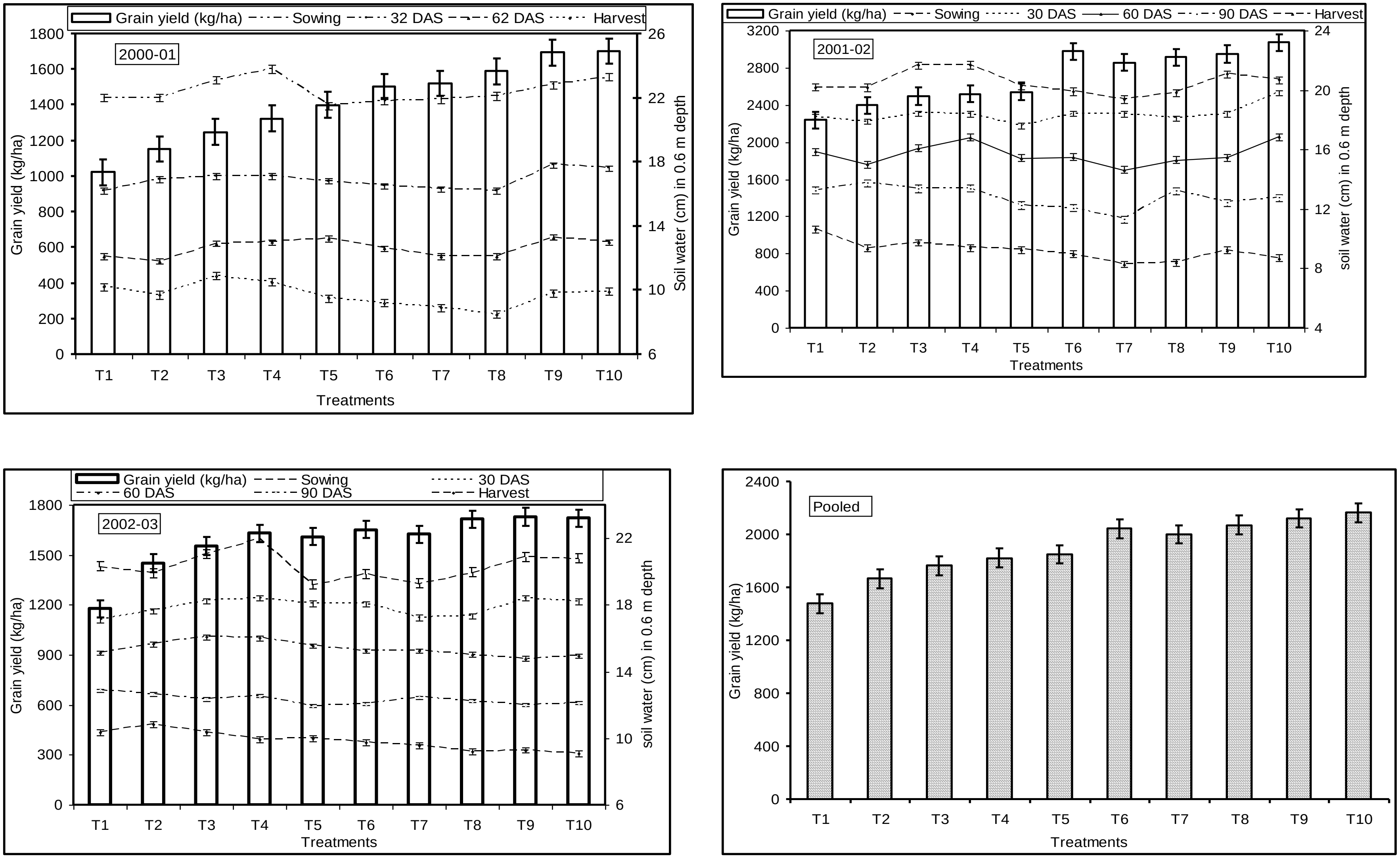

Figure 1. Grain yield (kg ha^{-1}) and soil water (cm) in 0.60 m soil profile as influenced by integrated nutrient supply system in winter sorghum in Vertisols of Bellary, India.

Table 2. Annual rainfall (mm), crop season rainfall and antecedent rainfall, number of rainy days during different years, date of sowing and date of harvest of sorghum.

Particulars	Years		
	2000 to 2001	2001 to 2002	2002 to 2003
Annual rainfall (mm)	550.9	566.6	432.6
Crop season rainfall (mm)	45.6	253.5	9.8
Antecedent rainfall	187.1 (3 to 12 October)	184.0 (15 to 25 September)	122.7 (8 to 17 October)
Number of rainy days during the year	34	31	32
Number of rainy days during crop season	3	14	1
Date of sowing	13.10.2000	25.09.2001	21.10.2002
Date of harvest	13.02.2001	30.01.2002	28.02.2003
Classification of years	Above normal year with uneven distribution	Above normal year with uniform distribution	Drought year

Table 3. Grain yield, straw yield, harvest index, water use efficiency and plant height of winter sorghum as influenced by integrated plant nutrient supply system.

Treatment	Grain yield (kg ha^{-1})			Straw yield (t ha^{-1})			Harvest Index (%)			WUE (kg ha^{-1} mm^{-1})			Plant height (m)		
	2000 to 2001	2001 to 2002	2002 to 2003	2000 to 2001	2001 to 2002	2002 to 2003	2000 to 2001	2001 to 2002	2002 to 2003	2000 to 2001	2001 to 2002	2002 to 2003	2000 to 2001	2001 to 2002	2002 to 2003
Year	1414	2693	1586	2.06	4.91	3.23	40.6	35.4	32.8	8.53	6.95	7.46	1.61	1.87	1.66
LSD (*P*< 0.05)		147			0.25			0.5			0.72			0.06	
T_1–0 kg RRN ha^{-1}	1020	2234	1176	1.62	4.15	2.52	38.8	34.9	31.8	6.94	5.81	5.34	1.47	1.71	1.54
T_2–*Azospirillum*	1152	2395	1449	1.70	4.67	3.02	40.3	33.9	32.4	7.11	6.23	6.95	1.49	1.77	1.62
T_3– 50% RRN through organic material	1246	2493	1553	1.82	4.67	3.18	40.8	34.9	32.9	7.74	6.23	7.10	1.54	1.79	1.62
T_4–50 RRN through organic material + *Azospirillum*	1323	2516	1629	2.33	4.85	3.40	35.9	34.1	32.4	7.69	6.29	7.98	1.59	1.87	1.63
T_5–50% RRN through urea	1398	2539	1609	1.99	4.84	3.30	41.3	33.0	32.9	8.79	6.58	7.95	1.62	1.79	1.66
T_6–50% RRN through urea + *Azospirillum*	1502	2976	1652	2.04	5.05	3.40	42.3	37.1	32.7	9.10	7.77	7.95	1.66	1.95	1.70
T_7–100% RRN through urea	1520	2854	1623	2.04	4.97	3.05	42.5	36.5	34.8	8.79	7.58	8.03	1.66	1.85	1.68
T_8–100% RRN through urea + *Azospirillum*	1588	2910	1714	2.21	5.19	3.33	41.8	36.1	34.1	9.29	7.64	8.21	1.68	1.94	1.70
T_9–50% RRN through urea +50% RRN through organic material + *Azospirillum*	1694	2945	1728	2.21	4.92	3.62	43.4	37.5	32.4	10.02	7.48	7.91	1.69	1.95	1.74
T_{10}–100% RRN through urea+ 50% RRN through organic material + *Azospirillum*	1701	3071	1719	2.61	5.49	3.50	39.5	36.0	32.9	9.83	7.88	7.91	1.71	2.04	1.70
LSD (*P*< 0.05)	376	254	176	0.50	0.66	0.37	n.s.	n.s.	2.5	0.79	0.65	0.81	0.13	0.18	n.s.

decreased sorghum grain yields from 1728 kg ha^{-1} under T_9 to 1719 kg ha^{-1} in T_{10}.

Straw yield during study period and in pooled data was higher and it varied from 32 to 61% in T_{10} compared to control (Table 3 and Figure 1). Higher grain and straw yield in T_9 and T_{10} were attributed to more rainwater conservation and its availability in soil profile from sowing to 60 days after sowing and increased the use efficiency of applied N fertilizer either through organic/inorganic materials/*Azospirillum* (Figure 1). Higher soil water and nutrient availability at different stages of sorghum produced better plant growth with greater dry matter translocation to head from leaf and stem during physiological maturity thus

Table 4. Yield components of winter sorghum as influenced by integrated plant nutrient supply system.

Treatment	Head weight (g plant^{-1})			Grain weight (g plant^{-1})			1000-Grain weight (g)			Head length (cm)			Head diameter (cm)		
	2000 to 2001	2001 to 2002	2002 to 2003	2000 to 2001	2001 to 2002	2002 to 2003	2000 to 2001	2001 to 2002	2002 to 2003	2000 to 2001	2001 to 2002	2002 to 2003	2000 to 2001	2001 to 2002	2002 to 2003
Year	34.65	47.90	41.00	28.48	40.71	29.72	26.34	32.28	27.11	14.4	16.9	16.5	13.7	13.7	14.0
LSD (*P*< 0.05)		5.87			4.15			1.82			0.60			n.s.	
T_1–0 kg RRN ha^{-1}	29.67	42.33	36.33	23.50	34.90	24.59	23.90	29.36	24.73	12.9	14.9	14.8	12.7	12.0	12.2
T_2–*Azospirillum*	31.33	44.00	37.00	24.90	35.91	25.91	24.70	30.60	26.21	13.4	15.7	15.2	12.2	12.9	13.3
T_3–50% RRN through organic material	31.70	45.00	37.67	25.40	36.90	27.07	24.76	31.40	26.57	14.0	16.3	15.8	12.4	13.0	13.9
T_4–50 RRN through organic material + *Azospirillum*	32.67	46.67	39.33	26.40	38.13	26.89	25.41	31.77	27.57	13.9	16.6	16.7	12.8	13.4	14.2
T_5–50% RRN through urea	33.33	47.33	39.67	27.00	41.54	30.62	25.92	31.89	26.31	14.2	16.8	16.7	13.0	13.6	14.2
T_6–50% RRN through urea + *Azospirillum*	36.07	51.33	41.00	29.40	43.94	30.98	27.06	34.37	28.04	14.3	17.7	17.0	14.1	14.0	14.8
T_7–100% RRN through urea	36.70	50.67	42.67	30.70	44.01	32.41	27.39	33.39	26.81	14.8	17.3	16.7	14.5	14.1	14.6
T_8–100% RRN through urea + *Azospirillum*	37.33	50.00	45.00	30.93	43.13	33.04	27.79	32.26	27.36	15.1	17.2	17.1	14.8	14.3	14.5
T_9–50% RRN through urea +50% RRN through organic material + *Azospirillum*	38.70	50.67	47.00	32.73	43.96	32.41	28.22	33.13	29.00	15.7	17.9	17.5	15.1	13.9	14.7
T_{10}–100% RRN through urea+ 50% RRN through organic material + *Azospirillum*	39.00	51.00	44.33	33.83	44.64	33.33	28.29	34.62	28.51	16.0	18.0	17.2	15.4	14.7	14.4
LSD (*P*< 0.05)	5.73	n.s.	6.37	6.07	5.87	5.09	2.72	1.85	2.24	n.s.	1.61	0.97	2.24	1.40	1.41

producing greater head weight plant^{-1}, grain weight plant $^{-1}$, 1000–grains weight, head length and diameter in T_9 and T_{10} (Kundu et al., 2009;Thakur et al., 2009). Greater grain and straw yields in T_9 and T_{10} were also attributed to balanced supply of nutrients through organic and inorganic materials with increased N use efficiency as reported earlier by Singh and Agarwal (2005), Kumar et al. (2005), Laddha et al. (2006) and Jala-Abdi et al. (2012). In Vertisols of Bijapur, India, adoption of moisture conservation practices with increased N application up to 50 kg ha^{-1} produced greater dry matter accumulation plant^{-1} resulting in higher grain and straw yield in sorghum (Math and Patil, 2013; Patil et al., 2011). Application of farmyard manure at 5 t ha^{-1} and 30 kg N ha^{-1} along with *Azospirillum* seed inoculation resulted in greater pearlmillet yield over other treatments as reported by Kumar and Gautam (2004). Results of this study clearly indicate that N application through either organic, inorganic or microbial cultures alone were not beneficial compared to their combination in increasing cereals yields and was attributed to soil and rainwater conservation and supply of all nutrients at required rates at different sorghum growth stages. In corn and sorghum also biological fertilizer was not sufficient but integrated application of biological and chemical fertilizers produced significant increase in yield (Amujoyegbe et al., 2007; Rizwan et al., 2008; Haghighi et al., 2010).

Greater dry matter translocation from leaves and stem to head at physiological maturity producing 7% higher HI with application of 50% RRN through urea, 50% RRN through organic materials and *Azospirillum* seed treatment compared to control during all three years of study and in the pooled data. Conserved rainwater in soil profile was better utilized for grain production thus producing higher WUE during 2000–01 compared to 2001 to 2002 and 2002 to 2003. In pooled data, WUE was 12% higher with *Azospirillum* seed inoculation over control. The WUE across three years of study increased from 16% (T_3) to 21% (T_4), 29% (T_5) to 37% (T_6) and 35% (T_7) to 39% (T_8) with *Azospirillum* seed treatment compared to application of organic or inorganic materials at same rate. The water use efficiency (WUE) was also greater by 41 and 42% with application of 50% RRN through urea, 50% RRN through organic materials and seed treatment with *Azospirillum* (T_9) and application of 100% RRN through urea, 50% RRN through organic materials with *Azospirillum* seed treatment (T_{10}), respectively compared to control (Table 3 and Figure 1). Higher WUE with urea alone compared to application of same quantity of N through organic materials or in combination of urea and organic materials was attributed to lower consumptive use of water with application of urea alone. Organic materials conserved more rainfall with higher soil water in profile resulting in higher consumptive use with lower WUE.

Conclusions

Organic materials conserved rainwater in-situ. *Azospirillum* seed inoculation produced 13% greater sorghum yields and was economically more beneficial during drought years compared to normal rainfall situations. Poor farmers with animal components apply available organic amendments with low cost *Azospirillum* for greater winter sorghum yields. Resourceful farmers apply available organic amendments at farm along with 50% RRN through urea during normal rainfall years and top dress 20 kg N ha^{-1} with urea during October second fortnight during above normal rainfall situations with better soil fertility and sustained sorghum yields in Vertisols of SAT, India. *Azospirillum* seed inoculation alone increased the WUE by 12% and further integrated nutrient management improved the water productivity in winter sorghum up to 41%.

Conflict of Interests

The author(s) have not declared any conflict of interests

ACKNOWLEDGEMENTS

Author thank late H. Basappa, Mr. B.N. Seshadri and Mr. S.M. Manikatti for kind help rendered by them during this study in data collection, Mr. Basavaraj Birakul for statistical analysis and Mr. S.K. Srivastava for editing research paper.

REFERENCES

Alizadeh O, Ordookhani K (2011). Use of N_2-fixing Bacteria, Azotobacter, Azosprilium in optimizing of using nitrogen in sustainable wheat cropping. Adv. Environ. Biol. 5(7):1572-1574.

Amujoyegbe BY, Opbode JT, Olayinka A (2007). Effect of organic and inorganic fertilizer on yield and chlorophyll content of Zea mays and Sorghum bicolor. Dept. Plant Sci. 46:186-174.

Arbad BK, Ismail S, Shinde DN, Pardeshi RG (2008). Effect of integrated nutrient management practices on soil properties and yield in sweet sorghum (*Sorghum bicolor* (L.) Moench) in Vertisol. An Asian J. Soil Sci. 3:329-332.

Black CA (1965). Methods of analysis, Part II. Chemical and microbial properties. American Soc. Agron. Incorporation, Madison Wisconsin, United States of America, 9:1569.

Dauda SN, Ajayi FA, Ndor E (2009). Growth and yield of water melon (Citrullus lanatus) as affected by poultry manure application. J. Env. Agric. Food. Chem. 8(4):305-311.

Donald CM (1962). In search of yield. J. Aust. Inst. Agric. Sci. 28:171-178.

Farajzadeh MTE, Yarnia M, Ahmadzadeh V, Farajzadeh N (2011). Priming effect of different times of maize seeds with nutrient elements in water stress on corn yield. Ann. Biol. Res. 2(3):419-423.

Fuentes-Ramirez LE, Caballero-Mellado J (2005). Bacterial biofertilizers, In: Siddiqui (Eds.), PGPR*:* Biocontrol and Biofertilization, Springer, Dordrecht, The Netherlands, pp.143-172.

Ghanbari ZS, Moosavi SG, Zabihi HR, Seghateslami MJ (2013). The effect of plant growth promoting rhizobacteria (PGPR) and zinc fertilizer on forage yield of maize under water deficit stress conditions. Tech. J. Eng. App. Sci. 3(23): 3281-3290.

Ghazvineh S, Yousefi M (2012). Study the effect of micronutrient application on yield and yield components of maize. American-Eurasian J. Agric. Environ. Sci. 12(2):144-147.

Ghoorchiyani M, Akbari GA, Alikhani HA, Dadi IA, Zareai M (2011). Effect of AM and Pseudomonas fluorescence on ear triats, amount of chlorophyll and yield of maize in water stress condition. Iranian J. Water Soil Sci. 1(21):97-114.

Glick BR, Cheng Z, Czarny J, Duan J (2007). Promotion of plant growth by ACC deaminase-producing soil bacteria. Eur. J. Plant Pathol. 119:329-339. http://dx.doi.org/10.1007/s10658-007-9162-4

Gomez KA, Gomez AA (1984). Statistical Procedures for Agricultural Research, 2nd Edition, A Wiley–Interscience Publication, New York, P. 657.

Guggari AK, Kalaghatagi SB (2005). Effect of fertilizer and biofertilizer on pearlmillet (*Pennisetum glaucum*) and pigeonpea (Cajanus cajan) intercropping system under rainfed conditions. Indian J. Agron. 50:24-26.

Habibi D, Moslemi Z, Ardakani MR, Mohammadi A, Asgharzadeh A (2010). Effects of super absorbent polymer and plant growth promoting rhizobacteria (PGPR) on yield and oxidative damage of maize under drought stress. Chemistry and Chemical Engineering (ICCCE), International Conference on 1-3 Aug. P.253-257.

Hagbabayi M, Azizi F, Zargari K (2011). Effect of drought stress on silage yield and agronomic traits of maize´s hybrids. Scientific Res. J. Plant Ecol. 7(25):45-57.

Haghighi BJ, Yarmahmodi Z, Alizadeh O (2010). Evaluation the effects of biological fertilizer on physiological characteristic and yield and its components of corn (*Zea mays* L.) under drought stress. American J. Agric. Biol. Sci. 5(2):189-193. http://dx.doi.org/10.3844/ajabssp.2010.189.193

Jackson UL (1967). Soil Chemical Analysis. Prentice–Hall of India Private Ltd, New Delhi, P.498.

Jala-Abadi AL, Siadat SA, Bakhsandeh AM, Fathi G, Alemi Saied KH (2012). Effect of Organic and Inorganic Fertilizers on Yield and Yield Components in Wheat (*T. aestivum* and *T. durum*) genotypes. Adv. Environ. Biol. 6(2):756-762.

Johri BN, Sharma A, Virdi JS (2003). Rhizobacterial Diversity in India and Its Influence on Soil and Plant Health. Advances Biochemical Engg/Biotech. 84:49–89.

Khan AMA, Rajmani K, Reddy PKA (2010). Effect of integrated nutrient management on yield, quality, nutrient content and uptake of sweet sorghum in Pongamia based Agrisilviculture system. Indian J. Dryland Agric. Res. Develop. 25:95–99.

Kumar N, Gautam RC (2004). Effect of moisture conservation and nutrient management practices on growth and yield of pearlmillet (*Pennisetum glaucum*) under rainfed conditions. Indian J. Agron. 49:182-185.

Kumar S, Rawat CR, Dhar S, Rai SK (2005). Dry matter accumulation, nutrient uptake and changes in soil fertility status as influenced by different organic and inorganic sources of nutrients to forage sorghum (*Sorghum bicolor*). Indian J. Agric. Sci. 75:340-342.

Kundu SPN, Gajbhiye PN, Ch Srinivas Rao, Bheemaiah G (2009). Effect of integrated nutrient management on yield attributes, yield, nutrient uptake and economics of growing maize in tamarind based cropping system. Indian J. Dryland Agric. Res. Develop. 24:81-86.

Laddha KC, Sharma RK, Sharma, SK, Jain PM (2006). Integrated nitrogen management in maize and its residual effect on blackgram under dryland conditions. Indian J. Dryland Agric. Res. Develop. 21:177-184.

Math SKN, Patil SL (2013). Winter sorghum productivity as influenced by resource conservation and nutrient management–A farmer participatory approach. Indian J. Soil Conserv. 41(2):163-169.

Mostafavi K, Golbashi M, Khavari-Khorasani S (2012). Study response of corn S.C hybrids to drought stress using multivariate statistical analysis. Crop Grow. Breed. J. 7(1):117-132.

Meunchang S, Panichsakpatana S, Ando S, Yokoyama T (2004).Phylogenetic and Physiological Characterization of indigenous *Azospirillum* isolates in Thiland. Soil Sci. Plant Nutritn. 50:413-421.
Muhr GR, Datta NP, Shankaranbramoney H, Lely VP, Donahaue RL (1965). Soil testing in India. USAID, New Delhi, India. Pp.39-41.
Naeem M, Iqbal J, Bakhsh, MAA (2006). Comparative study of inorganic fertilizers and organic manures on yield and yield components of mungbean (*Vigna radiat* L.). J. Agric. Soc. Sci. 2:227-229.
Narula N, Kumar V, Behl RK (2001). Effect of phosphate-solubilizing strains of Azotobacter chroococcum on yield traits and their survival in the rhizosphere of wheat genotypes under field conditions. Acta Agronimica Hungarica. 49:141-149. http://dx.doi.org/10.1556/AAgr.49.2001.2.4
Okon Y, Kapulnik Y (1986). Development and function of *Azospirillum*-inoculated roots. Plant Soil 90:3-6. http://dx.doi.org/10.1007/BF02277383
Patil SL (2013). Winter sorghum (*Sorghum bicolor*) productivity as influenced by tillage practices and nitrogen management in Vertisols of SAT, India. Soil Till. Res. 126:183-192. http://dx.doi.org/10.1016/j.still.2012.07.015
Patil SL, Sheelavantar MN (2006). Soil water conservation and yield of winter sorghum (*Sorghum bicolor* L. Moench) as influenced by tillage, organic materials and nitrogen fertilizer in Semi-Arid Tropical India. Soil Till. Res. 89:246-257. http://dx.doi.org/10.1016/j.still.2005.07.013
Patil SL, Sheelavantar MN (2009). Effects of tillage depths, organic amendments and nitrogen on yield of winter sorghum on a vertisol in South India. J. Sustain. Agric. 33:28-50. http://dx.doi.org/10.1080/10440040802395106
Patil SL, Sheelavantar MN, Shashidhar KC (2011). Growth and yield of winter sorghum (*Sorghum bicolor* (L.) Moench) as influenced by rainwater conservation practices, organic materials and nitrogen application in Vertisols of SemiArid Tropical India. Indian J. Soil Conserv. 39:50-58.
Piper CS (1966). Soil and plant analysis. Academic Press, New York, USA. pp.47-77.
Prasad R (2008). Integrated plant nutrient supply system (IPNS) for sustainable agriculture. Indian J. Fertilizers 4:71-90.
Reddy BN, Sudhakarbabu SN (1996). Production potential, land utilization and economics of fertilizer management in summer sunflower (*Helianthus annus*) based crop sequences. Indian J. Agric. Sci. 66:16-19.
Reddy SG, Maruthi V, Rekha SM (2004). Assessing the method of application of farmyard manure on dryland crops. Indian J. Agron. 49:104-107.
Rizwan A, Arshad M, Khalid A, Zahir A (2008). Effectiveness of organic bio-fertilizer supplemented with chemical fertilizer for improving soil water retention. Aggregate stability, growth and nutrient uptake of maize (*Zea mays*). J. Sustain. Agric. 34:57-77.
Salamone IEG, Nelson L, Brown G (1997). Plant growth promotion by Pseudomonas PGPR cytokinin producers, Proceedings of the Fourth International Workshop on Plant Growth-Promoting Rhizobacteria., Ed. A Ogoshi, K Kobayashi, Y Homma, F Kodoma, N Kondo and S Akino, Sopporo, pp. 316-319.
Sajedi NA, Ardakani MR, Naderi A, Madani H, Mashhadi ABM (2009). Response of maize to nutrients foliar application under water deficit stress conditions. American. J. Agric. Biol. Sci. 4(3):242-248. http://dx.doi.org/10.3844/ajabssp.2009.242.248
Singh BP, Mundra MC, Gupta SC, Singh RP (2004). Integrated nutrient management in predominant cropping systems in Haryana through participatory approach. Indian J. Agron. 49:135-139.
Singh R, Agarwal SK (2005). Effects of farmyard manure and nitrogen fertilization on grain yield and use efficiency of nutrients in wheat (*Triticum aestivum).* Indian J. Agric. Sci. 75:408-413.
Subbaiah BV, Asija GL (1956). A rapid procedure for the estimation of available nitrogen in soils. Current Sci. 25:259-260.
Suresh D, Goyala S, Kapoora K, Mundrab M (2004). Microbial biomass carbon and microbial activities of soils receiving chemical fertilizers and organic amendments. Archives Agron. Soil Sci. 50:641-647. http://dx.doi.org/10.1080/08927010400011294
Thakur NS, Kushwaha BB, Sinha NK, Upadhya SN (2009). Effect of plant density and nitrogen levels on growth, yield attributes and yield of sweet sorghum (*Sorghum bicolor* (L.) Moench) genotypes. Indian J. Dryland Agric. Res. Develop. 24:34-38.
Tonapi VA, Patil JV, Rao DB, Elangovan N, Bhat VB, Rao RKV (2011). Sorghum: Vision 2030. Directorate of Sorghum Research, Rajendranagar, Hyderabad 500 030 (AP), India, P.38.
Venkateswarlu B (2008a). Organic Farming in Rainfed Agriculture: Prospects and Limitations, In: Venkateswarlu B, Balloli SS, Ramakrishna YS. (Eds.), *Organic Farming in Rainfed Agriculture: Opportunities and Constraints,* Central Research Institute for Dryland Agriculture, Hyderabad, pp. 7-11.
Venkateswarlu B (2008b). Role of Biofertilizers in Organic Farming, In: Venkateswarlu B, Balloli SS, Ramakrishna YS (Eds.), *Organic Farming in Rainfed Agriculture: Opportunities and Constraints,* Central Research Institute for Dryland Agriculture, Hyderabad, pp. 84-95.