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Response of Sunflower to Rainwater Conservation and Nutrient Management in Semi-arid Conditions

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Abstract: Sunflower is an important oilseed crop grown throughout the year due to its short duration, day neutral, low photoperiod sensitivity and wider adoptability to agroclimatic conditions and soil types in Asian countries. Lower yields of sunflower in rainfed vertisols are attributed to lower soil moisture and nutrients availability. In this situation, we conducted field studies at research farm and farmers' fields to know the response of sunflower to rainwater conservation and nutrient management in vertisols of India. Compartmental bunding and ridges and furrows conserved more rainwater in profile, thus producing greater sunflower seed yields varying from 22% to 28% compared to farmers' practice of flat-bed sowing. Greater seed yield with resource conservation is attributed to higher head diameter with greater head weight and seed weight per plant over flat-bed sowing. Nutrient management as farmers practice INM_1 (15 kg N ha^{-1} + 15 kg P_2O_5 ha^{-1} + 1.0 t farmyard manure ha^{-1}) with *Azospirillum* seed treatment (INM_2) produced 5–6% higher seed yield, whereas recommended rate of nutrients (40 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} + 2.0 t farmyard manure ha^{-1}) with *Azospirillum* seed treatment (INM_3) produced 13–16% greater seed yield both at research farm and farmers' fields over INM_1.

Keywords: *Azospirillum*, nutrient management, rainwater conservation, sunflower, vertisols

Introduction

Vegetable oils are critical for nutrition, energy and economy of any country. The growth in vegetable oil supplies is limited due to cultivation of oilseed crops

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under the situation of shrinking resource base, input supplies and uncertain profitability, while the demand increases at an increasing rate due to increase in per capita income and increase in standard of living. Per capita demand for oil crops at the global level is expected to increase more rapidly than that of cereals due to the diversion of vegetable oils for energy and non-food uses (DOR, 2013). During 2010–11, India imported about 9.2 Mt of vegetable oils costing around Rs 38,000 crores, whereas export earnings were a little less than Rs 21,000 crores. Hence, the major thrust in oilseeds is to increase productivity and decrease the expenditure on imports. In India, with limited scope to bring additional area under oilseeds, bulk of the future increases in oilseed production have to come primarily from land-saving technologies, high-yielding varieties/hybrids, balanced and integrated crop nutrition, efficient crop management practices including rainwater conservation, protective irrigation, integrated pest management and selective farm mechanization (Hegde, 2012). It may not be difficult to achieve an average oilseeds productivity of about 1.5 t ha^{-1} by 2020 and 2.0 t ha^{-1} by 2050, if concerted efforts are made for effective dissemination of available improved technologies.

Among the oilseed crops, sunflower (*Helianthus annuus* L.) is an important oilseed crop being cultivated throughout the year under different agroclimatic regions owing to its thermo-photo-insensitivity and greater potentiality under favourable moisture and nutrient availability in different parts of the world. Globally sunflower is cultivated over an area of 23.71 Mha with a seed production of 32.39 Mt and productivity of 1,366 kg ha^{-1} that accounts for nearly 8.5% of total oilseeds production (Nayak *et al.*, 2010). The average sunflower productivity in India is low, i.e. around 607 kg ha^{-1} (Hegde, 2012). In India, sunflower is being cultivated in the states of Karnataka, Maharashtra and Andhra Pradesh of which Karnataka alone accounts for nearly 54% of cultivated area. In these states, it is mainly cultivated in rainfed regions where average annual rainfall is less than 650 mm with its uneven distribution. In low rainfall regions of semi-arid tropic (SAT) in South India, water is a critical and costly input for agriculture. Hence, effective use of rainwater through conservation measures at farmers' field is becoming important due to frequent droughts and predicted moisture deficits situations in future due to changing climatic situations (Deutsch *et al.*, 2010; Lal *et al.*, 2011). Though many factors contribute for increasing the potential yield of sunflower, soil moisture is considered to be vital as the crop response to all other inputs depends on the availability of soil water in the profile from sowing to harvest especially at critical stages of crop growth in drylands (Ardeshna *et al.*, 2013; Paulpandi *et al.*, 2009; Reddy *et al.*, 2005).

Under rainfed situations in south India, sunflower is cultivated in vertisols and associated soils. Majority of soils in the region are low in available N. Continuous use of inorganic fertilizers without organic amendments degrade soil properties and causes environmental pollution. Organic manures act both as a source of nutrients and organic matter and also improve soil properties and increases microflora of the soil (Albiach *et al.*, 2000; Nandini Devi *et al.*, 2013). Environmental degradation especially soil fertility loss is a major threat confronting the agriculture due to imbalanced use of fertilizers which reduces agricultural productivity. There is a growing realization that the adoption of ecological and sustainable farming practices can only reverse the declining trend in the global productivity and environment protection (Aveyard, 1988; Wani and Lee, 1992; Wani *et al.*, 1995; Spiertz, 2010). Use of organic manures alone or in combination of chemical fertilizers will help to improve soil physical and chemical properties. One such strategy to maintain soil fertility for sustainable production of sunflower is through efficient use of fertilizers (Bobde *et al.*, 1998) coupled with organic amendments as use of organic manures alone is not sufficient (Prasad, 1996). Further, to address the problems of chemical fertilizers demands the use of biofertilizers in crop production. *Azospirillum* has been used as biofertilizer for cereals and oilseeds since last two decades as it increases the N availability in the soil, minimizes production costs and mitigates environmental hazards (Galal *et al.*, 2001). Therefore, it is essential to apply N through appropriate combination of organic amendments, inorganic fertilizer along with biofertilizers that meet the crop nutrient requirements (Spiertz, 2010). In addition, *in situ* rainwater conservation increases water and nutrient availability besides improving soil health and sustaining sunflower productivity (Hegde and Sudhakara Babu, 2009; Madhurendra *et al.*, 2009; Maruthi Sankar *et al.*, 2008; Paulpandi *et al.*, 2009). Farmers in rainfed regions apply only 30% of the recommended farmyard manure (FYM) and fertilizers without biofertilizers at sowing even though sunflower responds to biofertilizers.

Keeping in view of these existing situations, field studies were initiated simultaneously both at research farm and farmers' fields to study the response sunflower to *in situ* rainwater conservation and integrated nutrient management in vertisols of SAT in South India.

Materials and methods

Soil and site characteristics

During winter season of 2008–09 under rainfed situations, field experiments were laid out on vertisols both at research farm (Bellary) and in six farmers' fields in six villages of Karnataka and Andhra Pradesh, India. The soils of the experimental plots both at research farm and farmers' fields were classified as Typic–Pellusterts. Soil at research farm belongs to Bellary series. These soils are derived from granite, gneiss and schist. Clay content of these soils increased with depth from 44% on surface to 50% at 0.90 m. Infiltration rate of these soils varied from 0.8 to 1.00 mm h^{-1} with bulk density varying from 1.22 to 1.28 mg m^{-3} (Black, 1965). These soils are alkaline in reaction with soil pH ranging from 8.5 to 8.9 (Piper, 1966) and electrical conductivity varied from 0.12 to 0.21 dS m^{-1}. Organic carbon content of these soils varied from 3.20 to 3.83 g kg^{-1} (Piper, 1966) with low available N that varied from 130 to 189 kg ha^{-1} (Subbaiah and Asija, 1956), available P was low to medium and ranged from 18 to 28 kg as P_2O_5 ha^{-1} (Jackson, 1967), whereas available K was high and varied from 520 to 630 kg as K_2O ha^{-1} (Muhr *et al.*, 1965). During winter season of 2007–08, chickpea (*Cicer arietinum*) was cultivated at study sites both at research farm and farmers' fields. Rainfall recorded at research farm and Agriculture Research Station, Hagari, was used as a reference rainfall for studies at research farm and all six farmers' fields in six villages, respectively.

Treatments details

A field study was conducted in a split-plot complete randomized block design with flat bed, compartmental bunding and ridges and furrows as main treatments and integrated nutrient management as subplot treatments. In these experimental plots, soon after summer plowing with mould board plow, fields were harrowed prior to third week of June. During second and fourth weeks of June, these fields were laid out into compartmental bunding (Figure 1), with the help of a bund former and ridges and furrows with ridger. At the research farm, the experiment was laid out in three replications, whereas in the farmers' fields each farmer was considered as replication. Individual experimental plot size was 6.8 × 5.4 m at the research farm, whereas in the individual farmers' fields each main plot treatment comprised 1 acre in which subplot measured one-third of an acre (approximately 1,350 m^2) with the total nine experimental plots. In the subplot, the treatments comprised integrated nutrient management, i.e. INM_1 = farmers' practice (15 kg N ha^{-1} + 15 kg P_2O_5 ha^{-1} + 1.0 t FYM ha^{-1}), INM_2 = farmers' practice (15 kg N ha^{-1} + 15 kg P_2O_5 ha^{-1} + 1.0 t FYM ha^{-1}) with *Azospirillum* seed treatment and INM_3 = recommended nutrient management (40 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} + 2.0 t FYM ha^{-1}) with *Azospirillum* seed treatment. FYM was applied as per the treatment during third week of August. The applied FYM nutrient content is (0.58% N, 0.29% P and 0.62% K). Prior to

Tractor-drawn bund former Compartmental bunding

Figure 1: Layout of compartmental bunding in the field.

sowing, all fields both at research farm and farmers fields' were harrowed during first week of September for covering the FYM and better seed bed preparation. Sunflower was sown at 60 × 30 cm spacing. Nitrogen as urea and phosphorus through single superphosphate was applied as per treatment specification in a line drawn by a ridger at 5 cm away from seed row at sowing. Prior to sowing seeds were treated with *Azospirillum* as per the treatments. The sunflower hybrid, i.e. Ganga Kaveri 2002 was sown on 26 September 2008 and harvested on 12 January 2009 at the research farm, whereas the sowing time varied from 20 to 30 September depending upon the rainfall and crop was harvested during second week of January 2009 in the farmers' fields.

Computation of soil water and water use efficiency

Soil water in the top 0.60 m soil depth was determined gravimetrically from sowing up to harvest (30 days interval) in all 27 study plots at research farm and 54 study plots at farmers' fields. Consumptive use of water (CUW) was determined by taking difference in values of soil moisture content (mm) in top 60 cm of soil between any two stages, by adding the rainfall and subtracting runoff during the relevant period (Patil, 2013). No drainage or deep percolation was observed at Bellary during the crop growth period and hence it was not accounted for calculation of CUW during 3 years of study period. Daily rainfall was measured by using standard ISI raingauge located in class A meteorological observatory situated about 10 m from experimental plot at research farm and Agricultural Research Station, Hagari, for farmers fields as all the farmers' fields were located in the vicinity of Hagri. Runoff from adjacent experimental plot was measured by using multi-slot device at the research farm and same was used in this experiment for all 27 study plots in three replications for assessing runoff from each treatment. Difference in soil water was added to arrive at CUW or soil water utilized for crop growth. The water use efficiency (WUE) was determined by dividing economic yield by CUW (mm) and expressed as kg ha^{-1} mm^{-1}.

Biometric observations

Plant height was 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. Head diameter (cm) was measured by placing the scale at the centre of the head and recorded measurement was expressed in cm. Five randomly selected plants from net plots were oven dried at 60–65°C for 48 h and recorded for head weight and seed weight per plant at physiological maturity after separation of seeds from the head. The 100 – seeds drawn from seed yield of each study plot was weighed and expressed in g. Seeds per head was calculated from the seed weight per head and 100 – seed weight using the equation (Patil, 2013),

$$\text{Seed number per head} = \frac{\text{Seed weight per head}}{100\ -\ \text{seed weight}} \times 100$$

From each plot the stover was sun dried for 15 days after harvest and weighed to express in kg ha^{-1}. After separation of seeds from the head of each plot the seeds were weighed and expressed as kg ha^{-1}. The seed yield of sunflower was divided by total above ground biological yield and was multiplied by 100 to arrive at harvest index (HI) and expressed in percentage (Donald, 1962).

Statistical data processing

All the data obtained of sunflower both at Research farm and farmers' fields of this study were statistically analysed using the *F*-test and the data were analysed using a computerized statistical MSTAT–C package (ANOVA no. 9) given by Gomez and Gomez (1984). The LSD values at $P = 0.05$ were used to determine the significance of differences between means. When analysis of variance indicated significant difference, LSD test was used to separate the treatment means for rainwater conservation techniques and nutrient management and for comparing across them. All significant year, main and subplot effects besides interactions were considered.

Results and discussion

Rainfall distribution and crop performance

The rainfall received during 2008 at research farm was 22% (i.e. 607.4 mm) higher compared to 54% (i.e. 729.2 mm) higher at farmers' fields than the mean annual rainfall of 498.9 and 474.1 mm, respectively (Figure 2). Both at research farm and at farmers' fields the higher rainfall over the normal rainfall was observed during March, May, June and August, thus resulting in closing of all the cracks completely and wetting the soil profile at sowing during 2008 (Figure 3). Normal rainfall (124.9 mm) at research farm and higher rainfall (190.2 mm) at farmers' fields during September resulted in

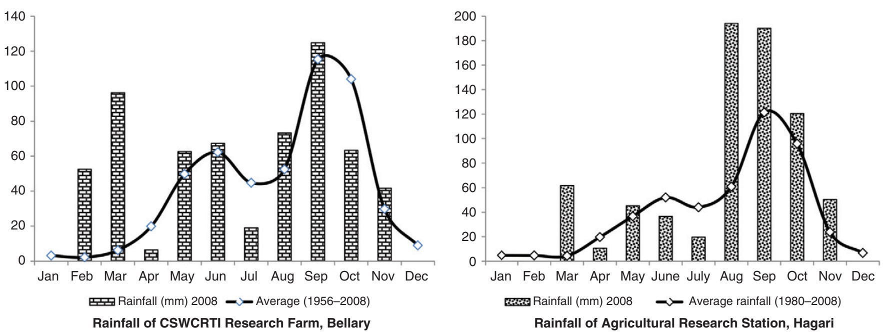

Figure 2: Average and 2008 rainfall (mm) at study site.

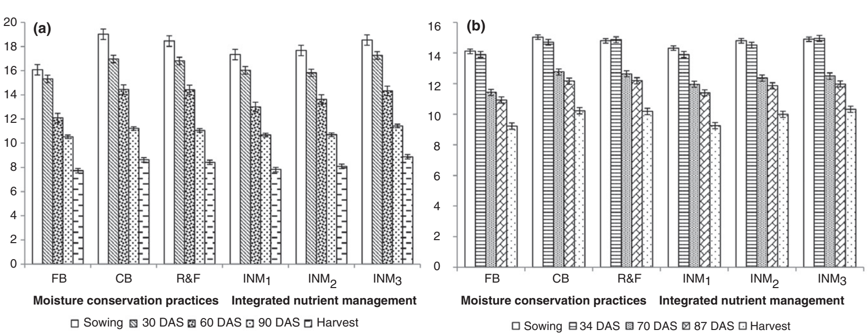

Figure 3: Soil moisture at different stages of crop at IISWC Research Farm (a) and farmers' fields (b).

sowing of sunflower on 26 September at research farm and early sowing from 15 to 18 September in different farmers' fields. In addition, the crop season rainfall of 105 mm in 8 rainy days and 181 mm distributed in 14 rainy days was observed both at research farm and farmers' fields, respectively. In general, sunflower yields both at research farm and farmers' fields were nearly 15–20% higher over the normal yields under normal rainfall situations and was attributed to higher rainfall received during 2008 both at research farm and farmers' fields. Interaction due to rainwater conservation practices and integrated nutrient management was not significant.

Rainwater conservation practices

Soil profile was completely wet at sowing and produced nearly 90% germination at Research farm and farmers fields' with good plant stand. In the early vegetative growth stages crop growth was better due to uniform wetting of soil profile. Higher rainfall that received at farmers' fields compared to research farm produced slightly higher sunflower yields at farmers' fields.

Higher rainwater conservation with compartmental bunding and ridges and furrows resulted in greater soil water availability in profile from sowing to harvest and thus producing higher dry matter in head (Figure 3). Layout of field with compartmental bunding and ridges and furrows produced 22% (1,079 kg ha^{-1}) and 21% (1,072 kg ha^{-1}) significantly higher sunflower seed yields at research farm, whereas the seed yield increased by 28% (1,169 kg ha^{-1}) and 24% (1,132 kg ha^{-1}) in farmers fields', respectively, over flat bed (886 and 915 kg ha^{-1}) (Tables 1 and 2). Response of sunflower to moisture conservation practices was higher at farmers fields' compared to research farm and it was attributed to more rainfall and more rainwater conservation at farmers' fields with a slope of 1–2.5% compared to $< 1\%$ slope at research farm (Shekhawat *et al.*, 2012). Higher yields in compartmental bunding and ridges and furrows over flat sowing were attributed to greater soil water availability from sowing up to physiological maturity in sunflower (Figures 2 and 3). Recommended moisture conservation practices in winter sorghum in clayey soils (Patil and Sheelavantar, 2004) and sandy clay to clayey soils (Reddy *et al.*, 2005), tillage operations in mustard (Shekhawat *et al.*, 2012) and ridge formation in potato (Vucajnk *et al.*, 2012), ridge and furrow method in sunflower (Maruthi Sankar *et al.*, 2008) conserved rainwater *in situ*, increased the soil moisture in the profile and crop yields. Greater water availability in soil profile in compartmental bunding and ridges and furrows could result in

Table 1: Crop growth and yield components of sunflower as influenced by rainwater conservation and integrated nutrient management practices at Research farm during 2008–09.

Treatments	Plant height (m)	Head diameter (cm)	Head weight (g $plant^{-1}$)	Seed weight (g $plant^{-1}$)	100 seeds weight (g)	Seeds per head	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Rainwater conservation practices								
Flat bed	110.7	14.6	68.78	39.00	5.44	722	1,120	886 –
Compartmental bunding	124.3	16.7	88.78	52.56	6.43	816	1,299	1,079 (22)
Ridges and furrows	121.0	16.1	87.11	51.89	6.22	832	1,298	1,072 (21)
S.Em. ±	3.9	0.14	2.58	2.04	0.09	38	110	30
LSD ($p < 0.05$)	ns[a]	0.55	10.14	8.01	0.34	ns	ns	119
Integrated nutrient management								
INM_1	112.0	14.7	76.89	41.55	5.74	726	1,128	954 –
INM_2	121.3	15.9	79.78	49.22	5.98	822	1,208	1,011 (06)
INM_3	122.7	16.8	88.00	52.67	6.37	823	1,379	1,071 (13)
S.Em. ±	3.5	0.30	2.45	1.84	0.19	29	76	44
LSD ($p < 0.05$)	ns	0.93	7.54	5.66	0.57	90	234	136

[a]Non-significant.

Table 2: Crop growth and yield components of sunflower as influenced by rainwater conservation and integrated nutrient management practices at farmers' fields during 2008–09.

Treatments	Plant height (m)	Head diameter (cm)	Head weight (g $plant^{-1}$)	Seed weight (g $plant^{-1}$)	100 seeds weight (g)	Seeds per head	Stover yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Rainwater conservation practices								
Flat bed	130.7	12.1	36.28	22.89	3.99	574	1,033	915 –
Compartmental bunding	144.7	13.8	48.47	29.23	4.58	638	1,218	1,169 (28)
Ridges and furrows	140.8	13.4	47.37	28.31	4.47	632	1,218	1,132 (24)
S.Em. ±	1.8	0.2	1.77	1.00	0.11	24	29	40
LSD ($p < 0.05$)	5.6	0.5	5.58	3.17	0.33	ns[a]	91	126
Integrated nutrient management								
INM_1	135.8	12.5	42.01	25.08	4.20	598	1,078	1,003 –
INM_2	138.3	13.1	44.07	26.34	4.36	603	1,177	1,054 (05)
INM_3	142.1	13.7	46.05	29.00	4.49	643	1,214	1,160 (16)
S.Em. ±	1.3	0.2	1.04	0.71	0.07	18	29	29
LSD ($p < 0.05$)	3.7	0.6	3.00	2.06	0.21	ns	84	82

[a]Non-significant.

better vegetative growth in earlier stages and greater dry matter translocation to head at physiological maturity.

Higher seed yield in plots laid out with compartmental bunding and ridges and furrows was attributed to production of greater head diameter with higher head weight and seed weight per plant and higher 100 seed weight over flat-bed sowing. At research farm sunflower sown in compartmental bunding plots produced 14% higher head diameter, 35% greater seed weight per head and 18% higher test weight compared to flat-bed sowing generally adopted by the farmers in the region. Higher number of seeds per head by 13% and 15% with compartmental bunding and ridges and furrows produced greater seed yield over flat-bed sowing (Tables 1 and 2). Among the rainwater conservation measures even at farmers fields' also compartmental bunding was more efficient in increasing sunflower seed yield per plant with higher values observed in yield attributes. The head diameter was 14% greater with head and seed weights per plant were higher by 34% and 28%, respectively, when sunflower was sown in compartmental bunded fields compared to farmers' practice of flat sowing. Even the 100 seeds weight and seeds per head also were higher by 15% and 11% with compartmental bunding, thus indicating that sunflower plants were better grown with higher dry matter translocation to head at physiological maturity when rainwater conservation practices were adopted compared to flat sowing.

Even the stover yield of sunflower was significantly higher by 16% (1,299 kg ha^{-1}) and 18% (1,218 kg ha^{-1}) in compartmental bunding and ridges and furrows plots both at research farm and farmers fields' compared to flat-bed sowing (1,120 and 1,033 kg ha^{-1}). Higher stover yield with rainwater conservation practices was attributed to higher soil water availability in the profile and greater plant growth that produced taller plants and greater stem diameter as compared to flat-bed sowing (Tables 1 and 2). Compartmental bunding produced 12% taller plants at research farm, whereas at farmers fields' plants were taller by 11% compared to farmers' practice of flat-bed sowing. The WUE was higher by 10% with compartmental bunding at research farm, whereas it was higher by 24% at farmers' fields over flat-bed sowing (Table 3). Conservation and efficient use of conserved rainwater in the profile by sunflower with compartmental bunding produced higher WUE both at research farm and farmers' fields. In compartmental bunding plots the WUE was higher by 24% at farmers' fields, whereas at research farm it was higher by 10% over flat-bed sowing and it was attributed higher rainwater conservation at >1% slope of farmers' fields as compared to < 1% sloped lands at research farm (Tolk and Howell, 2012; Amanullah and Stewart, 2013).

Table 3: Water use efficiency (kg ha^{-1} mm^{-1}) of sunflower.

Treatments	Research farm	Farmers' fields
Rainwater conservation practices		
Flat bed	3.33	2.72
Compartmental bunding	3.66	3.37
Ridges and furrows	3.70	3.29
S.Em. ±	0.11	0.12
LSD ($p < 0.05$)	ns[a]	0.46
Integrated nutrient management		
INM_1	3.43	2.96
INM_2	3.58	3.06
INM_3	3.68	3.35
S.Em. ±	0.16	0.08
LSD ($p < 0.05$)	ns[a]	0.25

[a] Non-significant.

Integrated nutrient management

Sunflower performance during winter season (postrainy) of 2008–09 was better both at research farm and farmers' fields with recommended nutrient management practice, INM_3 compared to INM_2 and INM_1 and it confirms with the reviews of Shekhawat *et al.* (2012) who indicated that the application of 10 t FYM + 90:45:45 NPK kg ha^{-1} with *Azotobacter* or *Azospirillum* inoculation produced higher *Brassica* yields, whereas in vertisols of Sholapur, optimal N ranged from 51 to 53 kg ha^{-1} and P varied from 26 to 27 kg ha^{-1} during rainy (*kharif*) season for higher sunflower yields (Maruthi Sankar *et al.*, 2008). Seed yield of sunflower was 5–6% higher with INM_2 and yield further increased significantly by 13–16% with INM_3 compared to INM_1 (Tables 1 and 2). Greater seed yield with INM_3 was attributed to higher rainfall by 21% at research farm and 31% at farmers' fields over normal rainfall during the year that resulted in greater soil water availability to the crop from sowing up to harvest as depicted in Figures 2 and 3 and in addition to higher N and P availability (Shekhawat *et al.*, 2012; Salih, 2013). The combined effect of greater soil water availability and nutrient availability throughout the crop season could produce better vegetative growth at the early stages of crop growth with greater dry mater translocation and its accumulation in head at the physiological maturity as indicated by higher values of head diameter with greater head weight per plant, seed weight per plant, 100 seed weight and more number of seeds per head. Favourable response of sunflower hybrids to fertilization in the presence of adequate moisture has been observed by Megur *et al.* (1993), Devidayal and Agarwal (1998), Reddy *et al.* (2005) and Subhas Babu *et al.* (2013). At research farm, greater plant growth with INM_3 produced significantly higher head diameter by 14%, greater seed weight per head by 27% and higher 100 seed weight by 11% over INM_1. Similar trend in yield component values was also observed at farmers' fields with head and seed weight per plant were 10–16% higher with 7% greater test weight and 8% more seeds observed per head with INM_3 compared to INM_1 as depicted in Tables 1 and 2. Stover yield also increased significantly by 22% at research farm and 13% at farmers' fields with INM_3 compared to INM_1. Better plant growth at research farm produced 10% taller plants with INM_3 compared to INM_1, whereas growth of plant was slightly lesser at farmers' fields with 5% greater plant height with INM_3 compared to INM_1 (Tables 1 and 2). In vertisols of Sudan increase in N and P application up to 80 kg ha^{-1} increased the plant height, dry matter weight per plant, seed and stover yields in sunflower (Salih, 2013). Recommended nutrient management with *Azospirillum* produced 7% higher WUE at research farm, whereas response was higher at farmers' fields, i.e. 13% over farmers' practice of nutrient management. The greater WUE with INM_3 over INM_1 was attributed to greater rainwater conservation and higher nutrient availability for sunflower crop (Table 3). The low-cost biofertilizers, i.e. *Azospirillum* produced economically higher yields over control and hence *Azospirillum* seed treatment needs to be popularized among the sunflower growers.

Conclusions

Rainwater conservation practices conserved the rainwater *in situ* and increased soil moisture availability from sowing till harvest, thus resulting in better plant growth with greater sunflower seed yield over flat sowing both at research farm and farmers' fields. Compartmental bunding and ridges and furrows produced higher sunflower seed yields by 22% and 21% at research farm and 28% and 24% in farmers' fields, respectively, over farmers' practice of flat-bed cultivation. Sunflower seed yield increased by 13% and 16% with application of 40 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} + 2.0 t FYM ha^{-1} and *Azospirillum* seed treatment at research farm and farmers' fields, respectively, over farmers nutrient management at 15 kg N ha^{-1} + 15 kg P_2O_5 ha^{-1} + 1.0 t FYM ha^{-1} that is generally adopted in this region. Adopting compartmental bunding with application of 40 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1} + 2.0 t FYM ha^{-1} and *Azospirillum* seed treatment conserves rainwater, top fertile soil and produces higher sunflower yields in vertisols of SAT in India.

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