Management strategy to improve input use efficiency and enhance sorghum productivity per stored rain drop in vertisols during *rabi* season

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Crop developmental process and in turn its growth phases (vegetative and reproductive) are influenced by environmental factors, i.e. temperature and photoperiod in field crops like sorghum. Crop growth and biomass production is a function of genotype by environment interaction, which is optimized through management strategies. Crop grain yield is determined as a product of its yield components like the grain numbers per plant and the average kernel weight at maturity. Grain numbers set at the panicle initiation phase can be enhanced by best matching the supply of nitrogen with its demand in the crop. Grain growth dynamics, a function of genotype by environment by management interaction is an important feature that enhances sorghum productivity.

Rabi **sorghum growing environment presents a challenge through a receding soil moisture front which decreases its response to applied external inputs like nitrogen (N) fertilizer. Deep placement of top dressed nitrogen fertilizer treatments increased *rabi* sorghum grain yield by about 630–930 kg ha^{-1} over farmers, practice of no fertilizer application. A management strategy helped enhance the agronomic nitrogen use efficiency to 16 kg grain per kg applied N, and the rain water use efficiency to 15 kg ha^{-1} mm. Thus, the hypothesis of increased *rabi* sorghum productivity per rain drop through improved management intervention in vertisols was validated.**

Keywords: Management, nitrogen use efficiency, productivity, *rabi* sorghum, vertisols.

IN India, sorghum is grown during *kharif* (rainy), *rabi* (post-rainy) and summer seasons across different states. The Indian Institute of Millets Research (IIMR) has a national mandate of improving sorghum productivity in these three different seasons[1]. The *kharif* (June–October) and summer (January–May) seasons are typically characterized by longer photoperiod, while during *rabi* (October–February) season, shorter photoperiod (<12 h) commences with the annual phenomenon of equinox falling on 21 September[2]. Another distinguishing feature of *rabi* season is the dependence of sorghum growth and development on receding stored soil moisture grown in vertisols.

Sorghum improvement in India historically commenced with the national release of CSH-1 as the first hybrid and followed with the spread of high yielding seeds across the rainfed sorghum-based cropping systems. A number of hybrids and open pollinated varieties have been released till date, for cultivation, specifically to suit different seasons, both nationally (ICAR) and at the state level by state agricultural universities (SAUs). Sorghum genotypes based on their photoperiod responses have been bred for longer and shorter photoperiods, so as to exploit the prevailing environmental conditions. Some of the prevalent sorghum hybrids adapted to longer photoperiod (*kharif* and summer seasons) include CSH-9, CSH-14, CSH-16 and CSH-25, while cultivars that adopted to shorter photoperiod (*rabi* season) include CSH-15R, CSH-19R, CSV-14R, CSV-216R, CSV-22R and M 35-1. The only sorghum cultivar that shows improved productivity across all three seasons is the hybrid CSH-13 K&R[3].

Management of sorghum that starts with creating a soil environment to establish a seedling, continues through optimizing inputs, enhancing resource use efficiency and minimizing biotic and abiotic stresses until the last grain forms a black layer. Seasonal management comes to an end with harvest of both grain and fodder. In a rainfed environment, management plays an important role not only in improving infiltration and retention of rain water, but also water use efficiency through optimal fertilizer input. Nitrogen (N), an essential macro element for plant growth, is deficient in Indian soils which limits sorghum productivity more than any other element. External application of N fertilizer increased biomass and grain yield of sorghum[4]. High sorghum yield was mainly associated with improving panicle number, grain number per panicle and grain weight[5].

Interaction of soil moisture and essential nutrient facilitates root uptake by crops and is an important feature of the rainfed production system. Response to fertilizer input is a function of soil moisture content which is replenished with every rainfall, especially during *kharif* season, that is frequented by south-west monsoon. But during *rabi* season, the receding soil moisture limits the response, as the top soil layer dries up by the time the crop completes first growth phase (emergence to panicle initiation (PI)). In most annual crop systems, uptake of N from soil at significant rates lasts for only 8–12 weeks, and matching of N availability with crop needs is probably the biggest contributor to increased N use efficiency[6]. Hence, top dressing of N fertilizer is an important management intervention that helps attain the potential yield, both in rainfed and irrigated sorghum.

Cereal nitrogen use efficiencies (NUEs) are 42% and 29% in developed and developing countries respectively, and based on the present fertilizer use, a 1% increase in N

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use efficiency for cereal production worldwide, would lead to a \$234,658,462 savings in N fertilizer costs[7]. The present study was designed to address the objective of improving *rabi* sorghum response to applied N fertilizer as well as increase the resource use efficiency in a rainfed environment.

The two-year experimentation was conducted in Solapur, Maharashtra, India located at 17.04°N and 75.54°E, which has the largest *rabi* sorghum area. The soil represents different orders like vertisol, inceptisols and entisol, derived from basic igneous rock namely basalt. Soils are base-saturated, with calcium as the predominant cation in the exchange complex and are low in nitrogen, low to medium in phosphorus and high in available potash (three macro nutrients). Vertisols and associated group of soils have adverse physical properties like high swelling (when wet) and shrinkage (when dry), with moderate rate of infiltration.

The field experiment consisted of six treatments, wherein a basal fertilizer of 30 kg N and 30 kg P_2O_5 was applied to all treatments except the control where no fertilizer was applied. The four test treatments included D1: placement of top dressed N fertilizer (@ 30 kg N/ha) at 15 cm depth at PI stage, D2: placement of top dressed N fertilizer at 30 cm depth at PI stage, D3: top dressing of N fertilizer (@ 15 kg N/ha) twice at 15 cm at PI stage and at 30 cm depth at boot leaf stage, D4: 2% urea was sprayed twice at PI and boot leaf stages. The two check treatments for comparison included D5: band placement of basal fertilizer (@ 30 kg N/ha) at sowing and D6 which was farmer's practice (no fertilizer). All the six treatments were laid out in a randomized block design, with four replications. Sorghum cultivar CSV-22R was grown across two years (October 2012–March 2013 and September 2013–March 2014) of experimentation on 9 October and 27 September during respective years. The spacing adopted was 45 cm between rows and 10 cm between plant to plant. The plot size of each treatment was 3.6 m × 4 m. Recommended set of practices were followed uniformly during crop growth period across all treatments. The grain and fodder yields were recorded after harvesting the crop from a net plot size of 2.7 m × 3.0 m. A sub-sample of five earheads were drawn from each treatment across four replications to count the spikelet number and individual weights. Spikelet number one starts at the base and progressively increases to the tip of the earhead.

Indian rain-fed agriculture relies on two different monsoonal events in any given year, the south-west (SW) monsoon that commences on the Kerala coast around June and spreads through south, central, eastern and ultimately the western region of mainland. Northeast monsoon (NE) season is the major period of rainfall activity over south peninsula which commences with the withdrawal of SW monsoon around end of October. Rainfall is particularly active in the eastern half, comprising meteorological subdivisions of Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu–Puducherry. The 30 years long term average rainfall at Solapur (Figure 1) indicates that most rainfall events are less than 40 mm during the first three months of June, July and August (24th–35th standard week) of SW monsoon. Later from 36th to 40th week there are one or two rainfall events that reach 60 mm which helps fill the soil profile facilitating sowing of *rabi* season crops. During the first year of experimentation there was a peak in rainfall with 130 mm at 40th week, while during the second year it was 67 mm at 38th week (Figure 1).

The total annual rainfall received during the first year (2012) was 632 mm, while during the second year (2013) it was 493 mm (Table 1), but the seasonal rainfall was much higher during the second year (169 mm) as compared to the first year (100 mm). Seasonal rainfall has greater importance during *rabi* season and improving the rain water use efficiency through nutrient management strategy would be essential for optimizing the benefit of *in situ* water harvested[8]. Meagre rainfall at later stages of flowering and grain fill clearly indicates the total dependence of *rabi* sorghum on *in situ* stored soil moisture.

The two years' data for 2012–13 and 2013–14 were pooled and statistically analysed. The results (Table 2) indicate that all the three deep placement treatments of top dressed N fertilizer improved grain yield of *rabi* sorghum to an extent of 60% (mean of D1, D2 and D3) over basal band placement of fertilizer (D5). Similarly fodder yield increase from the three deep placement treatments was 34% over D5 treatment. In *rabi* sorghum, application of 50 kg N ha^{-1} produced significantly (8%) higher dry matter in earhead (42.86 g $plant^{-1}$) over 25 kg N ha^{-1} (39.81 g $plant^{-1}$) and 25% higher (33.91 g $plant^{-1}$) over control at harvest[9]. While in *kharif* sorghum, application of 80 kg N ha^{-1} increased the grain yield over control in vertisols at Dharwad, Karnataka, India[10]. Seasonal availability of soil moisture during a given season is the key to N response and management practice should improve

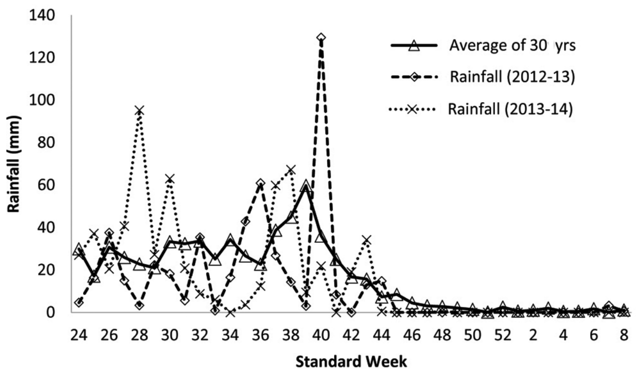

Figure 1. Long term mean rainfall over thirty years in comparison with rainfall during the two years of experimentation (2012–13 and 2013–14).

Table 1. Rainfall distribution pattern during the years of experimentation, 2012–13 and 2013–14

Growth stages	2012–13 (mm)	2013–14 (mm)	Mean
Early establishment stage (0–30 days)	64.7	140.9	102.8
Panicle initiation to boot leaf stage (30–55 days)	18.9	27.8	23.35
Boot leaf to 50% flowering stage (55–70 days)	6.1	0	3.05
Grain filling stage (70–90 days)	6.1	0	3.05
Grain maturity stage (90–110 days)	3.8	0	1.9
Crop seasonal rainfall (mm)	99.6	168.7	134.15
Annual rainfall (mm)	631.9	492.9	574.5

Table 2. *Rabi* sorghum fodder and grain yield response to deep placement of top dressed N fertilizer (mean of two years)

Treatment	Fodder yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Rainwater use efficiency (kg ha^{-1} mm)
D1 = 30 kg N Basal + 30 kg N Top dressing at 15 cm depth	5008	1689	13
D2 = 30 kg N Basal + 30 kg N Top dressing at 30 cm depth	5217	1991	15
D3 = 30 kg N Basal + 15 kg N at 15 cm + 15 kg N at 30 cm	4936	1770	13
D4 = 30 kg N Basal + 2% urea spray at PI and boot leaf	4446	1470	11
D5 = Check 1 30 kg N Basal	3780	1137	9
D6 = Check 2 No fertilizer	3322	1060	8
CD (5%)	1158	441	

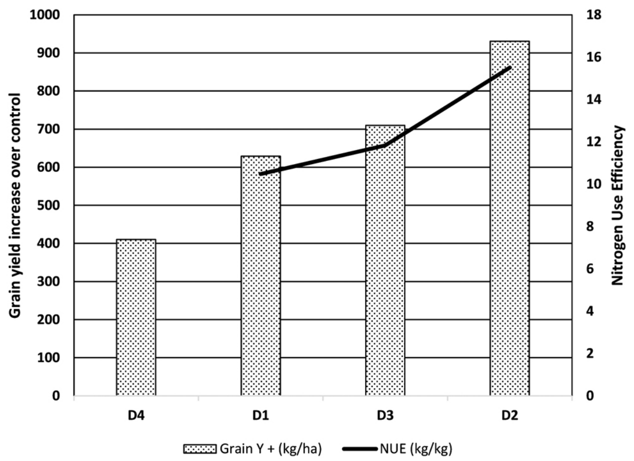

Figure 2. Increasing trends in grain yield due to deep placement of fertilizer and relative improvement in nitrogen use efficiency in *rabi* sorghum (mean of 2012–13 and 2013–14).

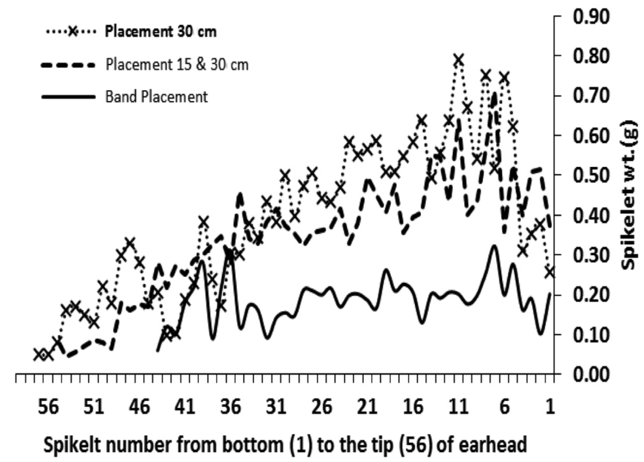

Figure 3. Spikelet number and weight distribution across the panicle (base to tip) as influenced by placement of N fertilizer in *rabi* sorghum.

nitrogen use efficiency at a given rate of input application.

The two years grain yield increase and related nitrogen use efficiency (NUE) data were summarized for the five treatments and the results are presented in Figure 2. Among the three test treatments (D1–D4), deep placement of top dressed N fertilizer at 30 cm depth (D2) gave the highest NUE of 15.5 kg grain per kg N applied. Similarly, increase in grain yield was in the range of 630–930 kg across the three deep placement treatments, when compared to no fertilizer application. The best hope for reducing the fertilizer needs is through increasing its usage efficiency on crops[11].

Major increase in NUE was reflected in the improvement in spikelet weights due to deep placement of top dressed N fertilizer. Both deep placement treatments, i.e. placement at 30 cm depth at PI stage and two split applications, at 15 cm at PI stage and 30 cm at flag leaf emergence stage, had influence on spikelet number and weights (Figure 3). The spikelet number increase was in the range of 11–13, while the average spikelet weight increase was in the range of 0.2–0.4 g across the panicle especially at its base. The potential yield in grain sorghum occurred early in the plant life cycle through number of kernels per panicle at the PI stage[12].

Thus, the interaction of applied fertilizer with available soil moisture through deep placement management strategy improved the spikelet number and weight. Improvement in yield components increased the grain yield and in turn the agronomic nitrogen use efficiency. Annual and seasonal rainfall which replenish the stored soil moisture could be utilized efficiently through proper N management intervention. The hypothesis that the improved water use efficiency in a rainfed *rabi* environment characterized by receding stored soil moisture can be brought about by deep placement of N fertilizer in *rabi* sorghum was validated.

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Can cold tolerance bring in hybrids on commercial front in winter sorghum?

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Studies on early-season and mid-season cold temperature stress on growth and yield components in diverse classes of winter sorghum are essential for targeting hybrid development that is otherwise confined only to rainy season-grown sorghum. The results showed that from among the 194 winter sorghum genotypes belonging to 5 groups – varieties, B-lines, R-lines, hybrids and germplasm lines, 81% of the genotypes were correctly placed in their respective groups based on discriminant analysis. Principal component analysis showed that most of the traits involved in the study are important and variability cannot be explained by a few traits and the traits recorded at seedling and maturity stages were explained by different principal components. Most of the traits recorded under cold stress at seedling stage did not correlate with those recorded under cold stress at anthesis. There is scope for improvement of individual groups for seedling dry fodder yield and grain yield, more so in the case of hybrids and female parental lines. Breeding for cold tolerance at seedling as well as anthesis stages has to be separately targeted. Thus, for developing new winter sorghum hybrids, female parental lines have to be diversified and improved for grain yield and percentage of seed set by crossing with promising germplasm lines identified in the study.

Keywords: Cold tolerance, germplasm, hybrids, winter sorghum.

SORGHUM is the fifth important cereal crop grown across the world for diverse uses – such as food, feed, fodder, fuel and fibre crop. Due to its African origin, the crop has adapted to hot and dry ecologies; however, due to gradual introduction to semi-arid tropics and temperate regions across the world, it has developed variants to suit new ecologies[1]. Due to its inherent ability to adapt to a wide range of climatic conditions, sorghum occupies a special niche in the current scenario of rapid climate change. However, being a crop of the tropics, it is considered as a cold susceptible species, though cold-tolerant germplasm has been identified. It suffers from chilling injury during the seedling stage and poor seed set during the reproductive stage when exposed to temperatures below 15°C. Cold temperature at flowering seems to be more detrimental to the yield of sorghum. All yield components, including panicle weight, number of seeds per panicle, grain yield and seed size are severely affected by mid-season cold stress[2].

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