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AGRONOMIC STRATEGIES FOR DROUGHT MITIGATION FOR RAINFED *RABI* SORGHUM

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Rainfed *rabi* sorghum is an important crop of India grown in the Deccan Plateau on area about 5.6 m ha in the states of Maharashtra (3.5 m ha), Karnataka (1.6 m ha), Telangana (0.30 m ha), and Andhra Pradesh (0.18 m ha) with a productivity of 0.85 t/ha grain and 3.4 t/ha fodder. It is largely sown on shallow Entisol and Vertisol soils during the months of September on monsoon rains and complete life cycle on residual soil moisture storage of monsoon rains and post monsoon rains that received on an average 100 mm during the months of October-December. Guhathakurta and Elijabeth, (2012) and Jain and Kumar, (2012) reported that the amount, timing and frequency of monsoon and post monsoon rains in the Deccan Plateau region is highly unpredictable and unreliable, that leads frequent drought situation in the region during the crop growing period. In majority cases *rabi* sorghum face terminal drought (Table 1) that cause 61 to 96 % loss in grain and 54 to 69 % in fodder yield (Kholova *et al.*, 2013). In addition to erratic rainfall behaviour, the unfavourable soil physical conditions of Vertisol soils preventing timely sowing and low water holding capacity of shallow Entisol soils leads moisture stress at different growth stages during cropping cycle that makes drought situation more venerable.

Table-1 Magnitude of yield losses in sorghum cultivar M-35-1 due to drought

Type of Droughts		**% yield losses due to drought in comparison to zonal potential**		**Pattern frequency (%)**	**Zone potential**
		Grain yield	Biomass yield		
Terminal droughts	Vegetative stress	95.8	68.6	07.0	3.1t grains ha^{-1} 8.3t biomass ha^{-1}
	Pre flowering stress	85.4	63.9	18.0	
	Post flowering stress	61.2	54.0	18.0	
Post flowering relieved stress		62.3	57.3	17.0	
Mild stress		63.2	61.4	40.0	

Source: Kholova *et al.*, (2013)

Rainfed *rabi* sorghum is the major source of food and fodder in the Deccan Plateau region, and as such, it greatly influences the economic wellbeing of the population in the region. In region, the productivity of rainfed *rabi* sorghum is far less than that the actual yield potential of available cultivars only due to drought problem. To meet the future food and fodder needs of the increasing human and animal population in the region, it is required to increase production and productivity of rainfed *rabi* sorghum.

Agronomic Strategies for Drought Mitigation

Since sorghum is drought tolerant, the 13 to 15 days moisture stress at any growth stage did not affect yield, but moisture stress more than 27 days significantly reduce yield (Eck and Musick, 1979). Data presented in Table-1 indicated that yield losses due to drought in rainfed *rabi* sorghum are highly variable, depending on magnitude and duration of moisture stress and crop growth stage at which moisture stress encountered the crop. Keeping these facts in view, we summarized the drought mitigation potential of different agronomic practices for different soils types and different type of drought situations.

Timely sowing

Sowing time is the foremost non-monetary input influencing crop growth, development and yield. Sowing at optimum time improves the productivity by providing suitable growing environment at all the growth stages. Rainfed *rabi* sorghum largely sown during the month of September on monsoon rains, and complete life cycle on residual soil moisture storage of monsoon rains and post monsoon rains that received on an average 100 mm during the months of October-December. In, Deccan Plateau region, timely sowing helps out the *rabi* sorghum by three ways. First, the timely sowing ensures good crop establishment. Second timely sowing facilitated crop for efficient utilization of rainwater received during monsoon and post monsoon periods because timing, frequency and amount of monsoon and post monsoon rains are highly unpredictable and unreliable in the region that leads frequent drought situation during the crop growing period. Third way, the flowering stage of rabi sorghum is highly sensitive to low temperature. If night temperature falls below 10^0C during flowering stage, it causes peculiar damage to fertilization process, that result partial or complete absence of seed setting (Reddy *et al.*, 2014; Mukri *et al.*, 2010). Hence, early sowing invites low night temperature problem, and late sowing invites crop establishment and moisture stress problem at later stages of crop. The different research

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findings also talk about the beneficial effect of optimum sowing time. Kalhapure and Shete, (2013) reported that *rabi* sorghum *cv*. Phule Anuradha gave highest grain (2179 kg) and fodder (4902 kg) yield ha^{-1}with sowing date 15th September in comparison to grain (1741 kg), fodder (4097 kg) and grain (942 kg), fodder (2485 kg) yield ha^{-1}with sowing dates 30th September and 15th October, respectively. Each week's delay in sowing after 12th May shortened the total growth cycle by 5·9 to 6·0 days, with 77 to 78 per cent in the vegetative phase, 7 to 8 per cent in the head development phase and 14 to 16 per cent in the grain filling phase in photosensitive sorghum cultivar.

Optimum plant population

Plant population is the second most important non-monetary input influencing crop growth, development and yield. Optimum plant population improves the productivity by providing suitable growing conditions at all the growth stages. Rainfed *rabi* sorghum largely growing on shallow Entisol and Vertisol soils during the months of September on residual soil moisture of monsoon rains. The water storage capacity of these shallow Entisol and Vertisol soils are low that results crop frequently face different type of terminal droughts depending on soil type at different growth stages of crop. Under these situations, optimum plant population act as a strategy which reduce intensity of drought stress by changing the timing of water use. The small plants planted at optimum distance in the field, will use all of the water that is in the immediate vicinity of where they are growing, but are not big enough (root system) to get to the water in the middle area when they are small. However, as they approach maturity, the plants are large enough to get to the reserve of water in the middle area. The key point here is the critical moisture demand period for sorghum development is heading. Because sorghum is sensitive to drought during flowering, the water reserve in the middle area tends to counteract the drought that commonly occurs during flowering in the Deccan Plateau region. In a close planting, where the plants are more closely distributed in the field, soil water is used as the plants grow and is depleted earlier in the season. The optimum plant population ensures that some water will still be left in the soil profile for the crop during that critical period at pollination. That extra soil moisture reserve then can result in better sorghum yields in shallow Entisol and Vertisol soils of the region. In addition to rationalizing crop water use, optimum plant population improves crop microclimate, which reduces disease and pest attack problems. The papers also talk about the beneficial effect of optimum plant population. The data of AICRPDA annual report (1981) indicated that increasing plant population from 45 (x 1000/ha) to 135 (x 1000/ha) increase mean grain yield of sorghum of three location (Bellary, Bijapur and Solapur) from 2035 to 2401 kg/ha but further increase in plant population decrease sorghum yield at all locations, it could be due to dance population consume store soil moisture at early growth stages which result crop encountered moisture stress at critical stages. Lamani *et al.,* (1997) reported that growth attributes viz., plant height, leaf area index (LAI), leaf area duration (LAD), leaf area ratio (LAR) absolute growth rate (AGR) relative growth rate (RGR) net assimilation rate (NAR) showed a decreasing trend with the increased plant density. Increased population affected all the growth attributes severely due to mutual shading and competition for water and nutrition, which is a result of decreased LAD and LAR.

Fig. 1 Farmers field photo, which indicates beneficial effect of optimum plant population.

Selection of cultivars

Rainfed *rabi* sorghum faced different degree of moisture stress at various growth stages every year, due to erratic rainfall behaviour and low water storage capacity of eroded shallow Entisol and Vertisol soils. Once in three-year, crop faces severe moisture stress, which leads total crop failure. Beside moisture stress unfavourable soil physical conditions preventing timely sowing that leads low night temperature, terminal heat stress, diseases and past incidence early crop establishment problems. Under these environments' performance of *rabi* sorghum cultivars controlled by traits such as tolerance to drought, matching with potential sowing dates, 110 to 130 days maturity duration, registrant to low night temperature stress, matching with different soil conditions, high seedling vigor for early crop establishment and registrant to disease and pests.

Among these traits, selection of cultivars based on soil condition is one of the most viable traits for the Deccan Plateau region. Because sorghum growing area of region characterized by different soil types ranging from shallow Entisol soils to medium to deep Vertisol soils. Under these situations, depth of soils determines the magnitude of yield losses due to moisture stress. In shallow soils shorter-season cultivars such as Selection 3 (Phule Anuradha) performs better than medium to longer-season cultivars such as M 35-1 (Phule Suchitra). It could be due to the shorter-season cultivars completed their flowering period before terminal moisture stress started in shallow soils and shorter-season cultivars consume less water than a medium to longer-season cultivars at all stages of growth.

Planting depth

In Deccan Plateau region rainfed *rabi* sorghum growing in different soil conditions ranging from shallow Entisol soils to deep Vertisol soils. Every soil condition has their own merits and demerits, such as Entisol soil shaving better germination and better crop establishment due to light texture, which facilitated timely tillage and sowing operations. Timely tillage and sowing operations increased the duration of moisture range which is suitable for seed germination and seedling emergence. But on the other side, Entisol soils having low clay content that reduces water storage capacity of soil, which leads moisture stress in crops earlier than Vertisol soils. The Vertisol soils having good water holding capacity due to high clay content and most suitable for dryland farming but germination and early crop establishment was poor in these soils due to heavy texture. The physical properties of Vertisol soils are greatly influenced by soil moisture content. Usually, these soils are too sticky and unworkable when wet and very hard when dry. These physical conditions of Vertisol soils narrow down the soil moisture range which is suitable for tillage and sowing operations. The delayed sowing operations affects moisture range which is suitable for seed germination and seedling emergence that resulted increased timing between sowing and seedling emergence, affects early season plant uniformity and plant stand.

Sorghum is a small seed, and it should be planted shallow for better crop establishment, but above-mentioned unfavourable soil physical conditions make planting depth/seed placement depth a critical factor for rainfed *rabi* sorghum. The shallower or deeper planting depths can affect the time between planting and emergence, affecting early-season plant uniformity. In Deccan Plateau region, planting/seed placement depthof rainfed *rabi* sorghum was determined by soil type and moisture availability. In medium to deep Vertisol soils, the planting depth should not be more than 2-3cm in normal moisture conditions, while in shallow Entisol soils, the planting depth should be up to 4-5cm. In irrigated conditions a planting depth of 2-3cm resulted better than shallower (<2cm) or deeper (>3cm) planting. Under dry conditions the seed should be planted deeper 4-5 cm in both soil types, but no more than 5 cm in any condition.

Planting direction

Solar irradiance is the primary source of energy that is converted into soil, sensible, and latent heat fluxes in the soil-plant-atmosphere continuum. The row orientation of agricultural crops relative to the sun's zenith angle determines the amount of solar irradiance reaching the plant and soil surfaces and its partitioning via absorption and reflection from soil and vegetation. Row orientation also affects soil heat flux and evaporation. Since soil evaporation may be considered as a non-productive water loss, minimizing soil evaporation improves water use efficiency. In Deccan Plateau region yield of rainfed *rabi* sorghum is primarily water-limited. In such conditions, unproductive water loss in the form of soil evaporation may also become a critical factor for crop yield. Steiner (1986) reported that water use efficiency, harvest index, grain yield and stover yield of sorghum was higher in the north-south row orientated crop in comparison to east-west row orientated crop with less evapotranspiration.

Nutrient Management

Low soil fertility status and submarginal availability of soil moisture are the major biophysical constraints of eroded shallow Entisol and Vertisol soils. Availability soil moisture in submarginal levels limits the effectiveness of fertilizers and increases the economic risk of fertilizer use. It is generally reported that adequately fertilized soils promote rapid root growth, leaf area expansion and more rapid ground cover, thus reducing evaporation. Better rooting and leaf area expansion enabled the plants to extract water from deeper soil profiles thus reducing moisture stress that resulting in increased crop productivity, nutrient use efficiency and water use efficiency. Singh and Das, (1995) reported that increased soil-moisture storage and its availability to crop plants at critical growth stages improve the fertilizers use efficiency. In drought prone areas of Deccan Plateau, higher yield of *rabi* sorghum was obtained in a deep soil having more stored water compared to a shallow soil, with a response up to 75 kg N ha^{-1} in the deep soil and only up to 25 kg N ha^{-1} in the shallow soil. Prasad, *et al.*, (2009) reported that balanced fertilization improves grain yield and agronomic nitrogen use efficiency of sorghum in rainfed areas. The agronomic N use efficiency of applied N was increased by applying P and K fertilizers, from 5.3 (N alone) to 12.0 kg sorghum grain kg^{-1} N and grain yield increased from 1.48t $ha^{-1}$with alone N to 1.75 t $ha^{-1}$with NPK in comparison to 1.27 t $ha^{-1}$with no fertilizers application. The standard fertilizer recommendation to rainfed crops in semiarid regions in India is to drill or place the basal application 5 to 10 cm deep in the root zone. In the rainy season, a portion of the N dose and all P and K are applied basally. During the dry season, when little or no rainfall is expected, full amounts of nutrients for the entire crop season are recommended to be applied basally. Venkateswarlu, (1987) found that grain yield can vary from 340 to 1,500 kg grain $ha^{-1}$by adopting the recommended fertilizer placement method in rainfed areas.

Timely weeding

In dryland areas, timely and effective weeding is the foremost agronomic practices that could bring immediate positive effects on crop growth and yield. Out of total yield losses caused by pests (insects, diseases and weeds) in crops, weeds alone account for one-third of the yield losses. The problem becomes more severe in rainfed areas, where soil moisture is the major yield limiting factor. Sorghum is particularly vulnerable to damage by parasitic weeds like *Striga lutea*, *S. asiatica* and *S. hermonthica*, two hands weeding are normally required, the first can be carried at thinning and another one at 35 to 45 day after sowing (Reddy *et al.*, 1976)

Conclusion

From the above, it could be inferences that:

1. In Deccan Plateau region yield of rainfed *rabi* sorghum is primarily water-limited.
2. Sowing time is the foremost critical factor which avoids and reduces moisture stress intensity through manipulating crop growing conditions at all crop growth sages.

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3. Plant population is the second most important critical factor which reduces moisture stress intensity through rationalizing, timing of water use of crop.
4. Selection of cultivars based on soil condition improves crop productivity through avoiding and reducing moisture stress intensity by utilizing water in efficient way.
5. Unfavorable soil physical conditions and moisture availability at sub marginal level makes planting depth a critical factor for rainfed *rabi* sorghum production in region.
6. Row orientation influence solar irradiance, soil heat flux and soil evaporation which affects water use efficiency.
7. Optimum fertilization enabled the crop plant to extract soil moisture from deeper soil profiles, thus reducing moisture stress and resulting in increased crop productivity
8. Timely weeding reduces water losses from soil profile that reducing moisture stress and resulting increased crop productivity

In conclusion, since all above revealed, agronomic strategies reduce moisture stress. But based on their drought mitigation potential, we ranked these practices as: - sowing time ≥ plant population> selection of cultivars based on soil conditions ≥ nutrient management>timely weeding≥planting depth> planting direction.

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