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Assessment of Suitability of Rabi Sorghum Crop in Ahmednagar District of Maharashtra, India

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Abstract

Water availability is an important aspect in the crop production mainly in winter (rabi, rest rainy season) season. Soil type and rainfall plays an important role in the crop productivity. In this study, Ahmednagar district, Maharashtra, has been chosen for the suitability assessment of rabi sorghum (Sorghum bi-colour L. Moench). The water budget model adopted by FAO (1990) has been used for 13 meteorological stations. The data were analyzed for the computation of reference evapotranspiration (ET0), crop water requirement (WR), soil moisture holding capacity (RS), water surplus and water deficit. Finally the index of Water Requirement Satisfaction Index (WRSI).

WRSI based suitability shows that deep soils of Ahmadnagar, Jamkhed, Karjat and Akola are highly suitable for rabi sorghum production. Deep soils in Nevasa, Parner, Pathardi, Shevgaon and Shrigonda tehsils are moderately suitable and deep soils of Rahuri and medium soils of Jamkhed are less suitable.

Introduction

Sorghum (Sorghum bi-colour L. Moench) is the fourth most important world cereal, following wheat, rice and maize. It is a staple food in the drier parts of Tropical Africa, India and China. It stands stress conditions and to some extent water logging. In developing countries, sorghum is used as feed for livestock. In the developed countries as well as in some parts of Africa, grains are used for brewing. In India grain is mainly used as human food either in the form of *roti* (unleavened bread) or for making *soji*, while the *kadbi* (dried fodder) forms forage for cattle.

Sorghum belt receives a mean annual rainfall of 700 mm, ranging from 500 to 900 mm, most of which is received during south-west monsoon (June to September). Nearly 96% of sorghum in India is rainfed. At lower rainfall, millets become competitive with sorghum and at higher rainfall sorghum in turn competes with maize and upland rice. It is an important crop for sustenance of the rural farmers with limited resources and the poor urban consumers with limited purchasing power. The high biomass productivity potential of sorghum under moisture stress gives it an edge over other crops, as fodder supply is critical during dry seasons.

In Maharashtra sorghum is grown in both seasons. The average yield of sorghum in the State is about 7.61 quintals per hectare with average kharif and rabi yields of 11.6 q/ha and 5.47 q/ha respectively. Rabi sorghum is grown predominantly in five districts of Maharashtra viz. Solapur, Ahmednagar, Beed, Osmanabad and Aurangabad. Rabi sorghum (Sorghum bi-colour L. Moench) is sown in September, when the soil moisture from the rainfall is adequate. Peak

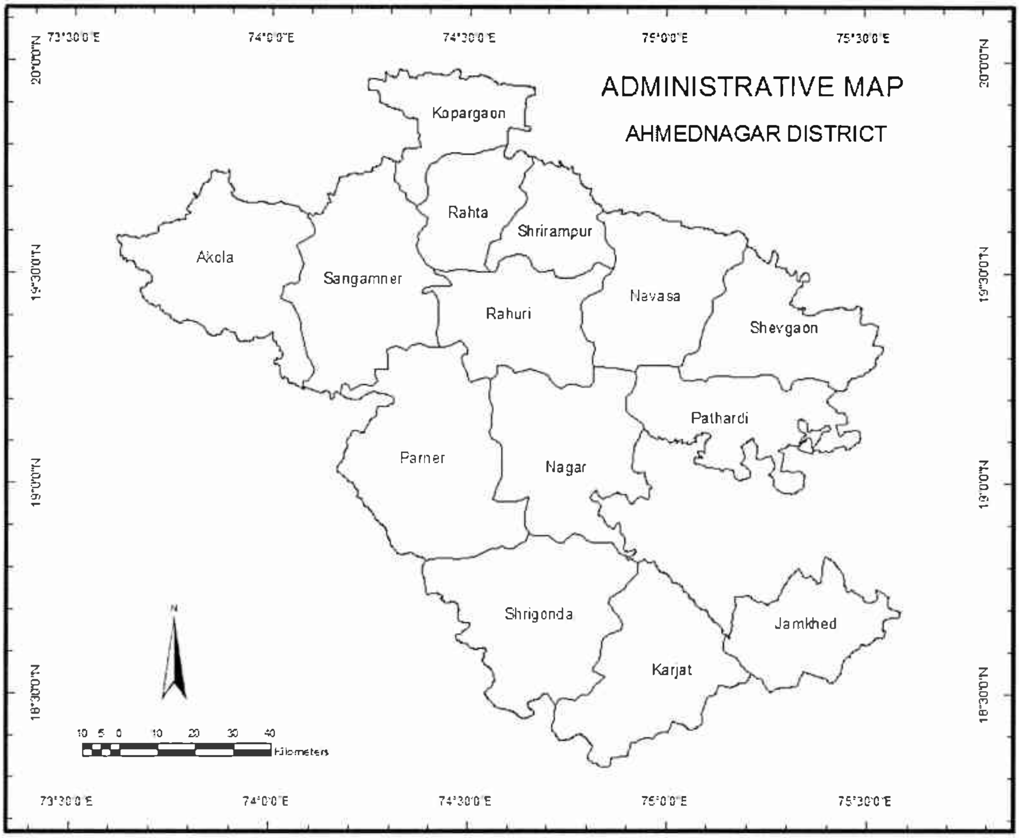


Fig.1: Administrative map of Ahmednagar district

vegetative growth is reached in the middle of December to first week of January. Grain filling lasts until middle to late January. The grain is harvested in February and March.

The yield of grain sorghum cultivated in dry-land regions in India fluctuates widely in relation to its critical growth phases depending on the weather conditions. *Rabi* sorghum yields in the study area have been low and stagnant over the period. (Deosthali, 1996). Rabi sorghum was ignored all the time, and did not receive adequate attention. Therefore, the rabi hybrid program has not made much dent (Singh *et al* 2004).

Stored moisture in the soil plays an important role in the growth of rabi crops. Water scarcity directly affects the final yield of crop; therefore, there is a need to study soil water dynamics during crop growth.

In this context, the present study makes an attempt to evaluate the performance and suitability of rabi (post-rainy season) sorghum crop in Ahmednagar district, Maharashtra.

This study assesses suitability of *rabi* sorghum in varying soil-rainfall environment in different tehsils of Ahmednagar district. This will be achieved by

- Characterizing rabi sorghum growing season
- Examining the water surplus / deficit episodes during the crop growing season

through soil-climate-crop interaction in the *rabi* sorghum in varying depths of vertisols
- Assessing crop performance in spatio-temporal frame

Data Used

Climatic data: Weekly rainfall data for 30 year-period for 13 *tehsil* staions and surface meteorological data for Ahmednagar were obtained from IMD, Pune. Soil map with attribute data is obtained from National Bureau of Soil Survey and Land Use Planning, Nagpur. Area (1981-2000) and yield (1967-2000) of Rabi sorghum in 13 tehsils was collected from the Directorate of Agriculture, Government of Maharashtra. Information on sowing date, agronomic practices, variety, and phenological stages of *Rabi* sorghum were collected in the field, through literature and discussion with scientists at Mahatma Phule Agricultural University, Rahuri.

Study area

Ahmadnagar district is located in the western Maharashtra to the east of Sahaydri range between 18°2' north to 19°9' north latitudes and 73° 9' east to 75°5' east longitude covering a total geographical area of 17,048 km^2. The district is divided into 13 *tehsils* with its headquarters at Ahmednagar (Fig 1).

The region is entirely covered by the vertisols also known as black cotton soils of varying depth. These are characterized by high proportion of clay which swell when wet and shrink on drying producing deep cracks. Soils are grouped according to the depth as shallow (< 30 cm), medium (30 to 60 cm) and deep soils (>60cm). Vertisols are moisture retentive soils. Available water capacity of deep, medium and shallow soils is 120, 60 and 30 mm respectively. Ahmadnagar district entirely falls in the Western Maharashtra Scarcity Zone and suffers from very low rainfall (Fig. 2) i.e. mean annual rainfall <750 mm distributed in about 45 days, with uncertainty and uneven distribution.

The occurrence of drought is noted once in three years. The drought prone area suffers from the twin problems of low productivity and high instability, as a result of inadequate and undependable rainfall. Two peaks of rainfall are observed, 1st during June/July and 2nd during September resulting in bi-modal pattern of rainfall distribution.

Methodology

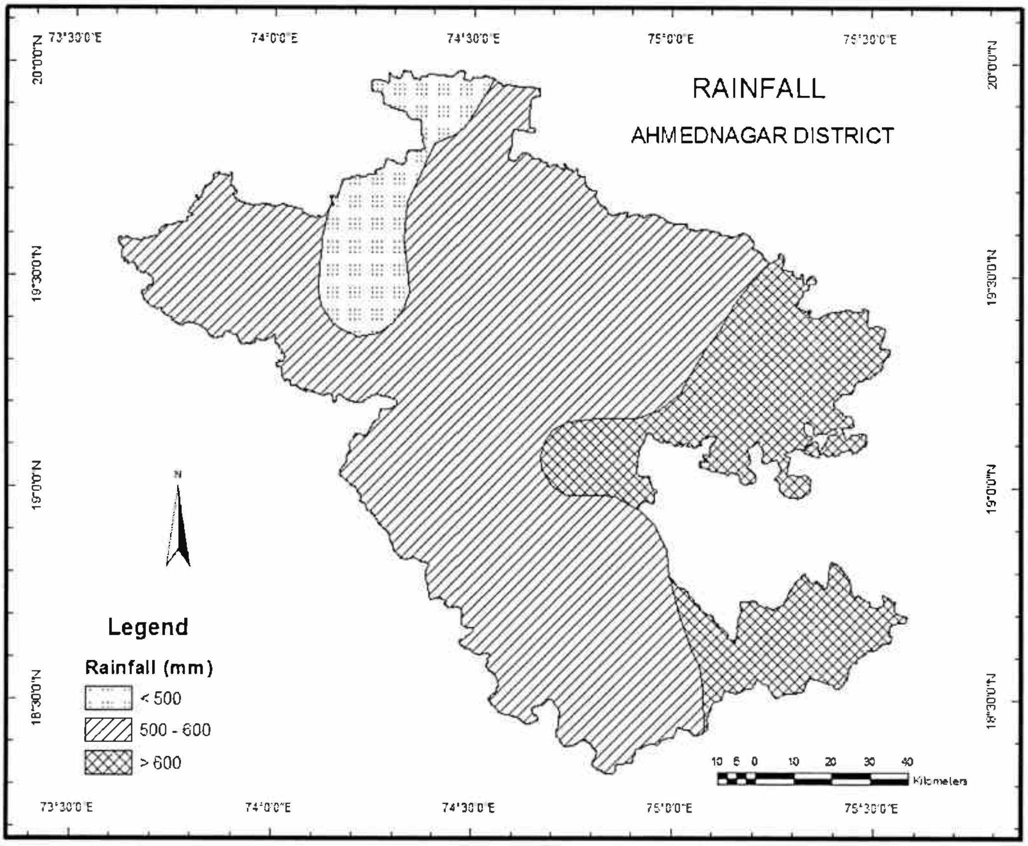
Micro-climates in a plant canopy keep on changing throughout the crop growth season. These variables make water balance complex and dynamic over time and space.

Growing season

The growing season (GS) is estimated using weekly normal ETo and rainfall data for 11 tehsil stations of Ahmadnagar district following Higgins and Kasam (1981) method. According to this method, sowing may be carried out when weekly normal precipitation exceeds 0.5 ETo for that week. When rainfall is below 0.5 ETo, it is taken as the end of the GS. For this, the weekly graphs of mean precipitation, mean ETo and 0.5 ETo for the rainy season are super imposed to determine the start of GS.

Present study uses Cumulative Water Balance Model proposed by Frere and Popov (1979) as this model is basically developed

Fig.2: Rainfall Map of Ahmadnagar District



for regions where amount and distribution of rainfall is inadequate. The model identifies water availability periods and presents 'Water Requirement Satisfaction Index' (WRSI) which indicates the extent to which water requirements of the annual crops have been satisfied in a cumulative way at any stage of the crop-growing season. This technique of water balance represents an environmental systems approach to the hydrological cycle with an emphasis on the income, outgo and storage of water at various places which is stated by the following equation (Slatyr, 1968)

$$\mathbf{P - O + U + ET + W = 0}$$

Where,

P = *Precipitation*
O = *Runoff*
ET = *Evapotranspiration*
U = *Deep Drainage*
W = *Change in soil water storage during a period.*

All the parameters are in mm. If the moisture capacity of the soil is known; the water balance equation can be solved by comparing rainfall and irrigation water with ET rate. In this study, cumulative water balance is applied for the entire growing season of rabi sorghum crop, through successive meteorological weeks following the procedure given by FAO, Publication number 73 (1980). The analysis is carried out for varying soil types using 30 year weekly rainfall data for 11 tehsil stations of Ahmadnagar district.

Water balance parameters for this model	
Input data required Precipitation (P) Reference crop evapotranspiration (ETo) Crop coefficient (kc) Crop evapotranspiration – Etcrop (WR) Soil water reserve (RS)	Outpurt Parameters Water surplus (WS) Water deficit (WD) Water requirement satisfaction index (WRSI)

Reference Crop Evapotranspiration (ETo)

Hargreaves (1985) method is used for estimating ETo. The equation is as follows:

$$ETo = 0.0033Ra * T\,^0c * TD^{0.5}$$

Where,

$T\,^0C$ = Mean air temperature for a week

TD = Difference between mean maximum and mean minimum temperature

Ra = Extraterrestrial radiation expressed in equivalent evaporation mm/day

Table 1: Duration of Rabi Sorghum Growth Stages

Growth Stage	No. of Weeks
Establishment	1
Vegetative Development	4
Flowering	4
Grain Formation	6
Maturity	3
Total	18

The Kc depends upon the rate and stage of growth of a crop. For the computation of K_C, the crop growing season is divided into four stages as indicated below:-

1. Initial stage – germination period and early growth of the crop when the soil cover by the crop is <10%.
2. Crop development stage – From the end of initial stage fill the attainment of soil cover by the crop about 70-80%.
3. Mid season stage – From the end of crop development stage to the start of maturity.
4. Late-season stage – From the end of mid-season stage to the harvest.

Doorenbos and Kasam (1979) have reported the K_C values for the above growth stages of sorghum crop

Table 2: Crop Coefficients for Rabi Sorghum

Initial Stage	Mid Season Stage	Late season Stage
0.3 – 0.4	1.05 – 1.18	0.5 – 0.55

Water deficit (WD) and Water surplus (WS)

Water deficit (WD) refers to quantity that lies below the zero level of water retention capacity. While the water surplus (WS) refers to any quantity that lies above the capacity.

$$WSn/\ WDn = (RS\ (n-1) + Pn) - WRn$$

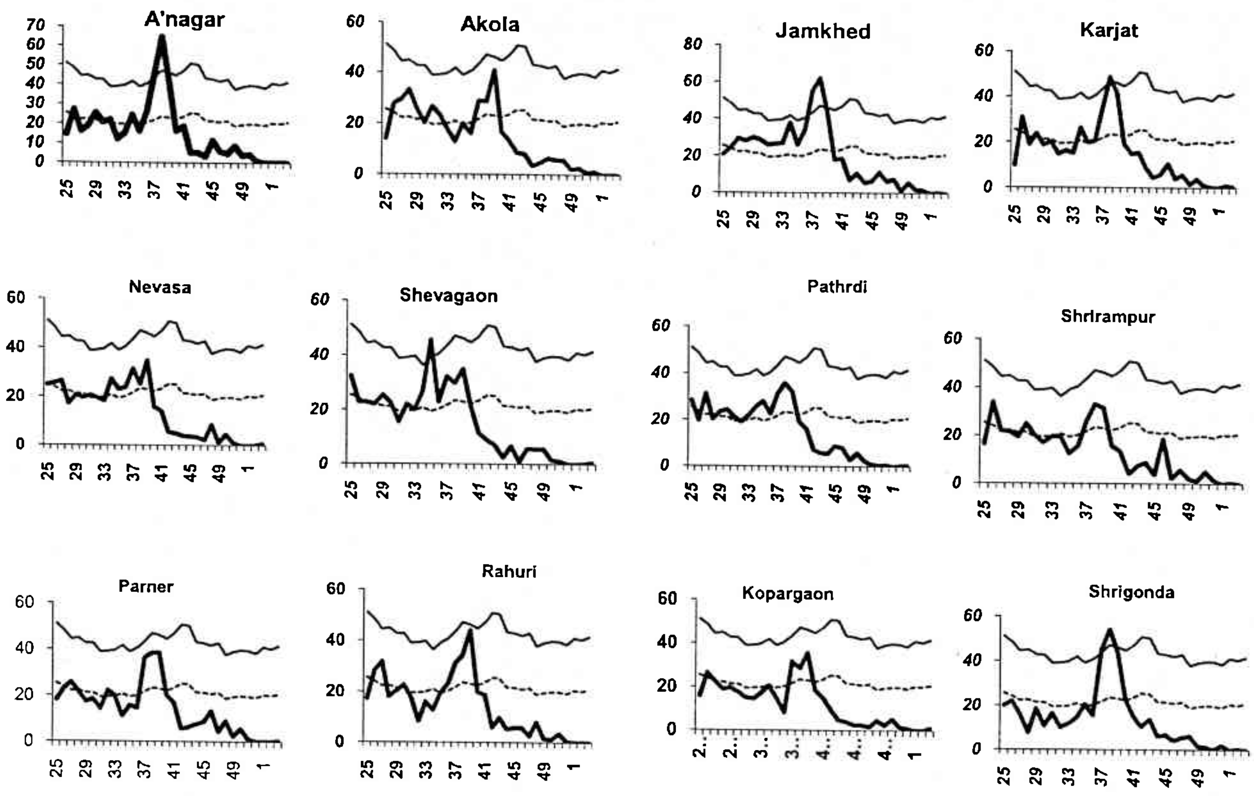
Where,

RS (n-1) = the soil moisture reserve in a previous week

Pn = precipitation of the given week

WRn = crop water requirement of the given week.

Fig. 3:Rabi sorghum growing season using weekly rainfall and Eto data from year 1961-62 to 1988-89



X' Axis - Meteorological weeks
Y' Axis - Rainfall, Eto, 0.5 Eto(mm)

Water Requirement Satisfaction Index (WRSI)

Water requirement Satisfaction Index is the significant output parameter of this model. It is indicated in percentage as the extent to which the water requirement of a crop has been satisfied in a cumulative way at any stage of its growth. In the event of water deficit, the index decreases as under,

WRSIn = WRSI (n-1) – [(WDn/ TWR)*100]

Where,

WRSI (n-1) = index of the previous week,

WDn = the water deficit (mm) of the given week,

TWR = the total water requirement of the crop season (mm)

Assessment of crop performance

On the basis of WRSI, qualitative agro-meteorological crop assessment can be carried out by using the scale below:

In the present study, the index at the end of grain formation stage (IV stage) is used for the assessment of a sorghum crop. The index reduced due to water deficit during the maturity stage is ignored as the crop needs dry weather during the ripening period.

Results and Discussion

Growing Season

Growing season is estimated by using Higgins and Kasam (1981) method using weekly mean rainfall and ETo based on 30 years data. It is observed that weekly rainfall has not exceeded 0.5 ETo of the respective weeks at most of the stations except for Jamkhed, Ahmednagar, Shrigonda, Shevgaon and Karjat. The latter stations lie in the relatively higher rainfall zone i.e. between 450 to 600 mm.

Table 3: Crop Performance Categories According to WRSI

Index (%)	Description
≥ 70	Good
60-69	Fair
50-59	Average
≤ 49	Poor

It is noted that in 38th Meteorological Week (MW) (17 – 23 September) the weekly rainfall is greater than weekly ETo. Late commencement of sowing rains in this district has resulted in cultivation of sorghum in rabi season. It was observed that the farmers tend to sow the crop in this week (MW 38) only.

After MW 41 the rainfall curve at all stations rapidly falls far below 0.5 ETo curve, indicating thereby shortage of moisture during the critical growth stages like flowering and grain formation.

Water Balance for Sorghum Crop

Reference crop evapotranspiration (ETo)

Crop water requirement is influenced by climatic condition which is accounted for by computation of ETo. This indicates maximum atmospheric water demand for grass which is a reference crop. Table 4 shows the weekly average ETo during growing season obtained for Ahmednagar station using weather data for 30 years period following Hargreave`s method. Weekly ETo at establishment stage (1 week) is 47 mm. It increases during the vegetative development stage (4 weeks) which coincides with October when ETo influencing factors like temperature and sunshine increase. Weekly ETo decreases during the flowering (4 weeks) and grain formation stages (6 weeks) because daily mean temperature also decreases with the onset of winter.

Table 4: Weekly normal ETo at Ahmadnagar

MW	ETo (mm)	MW	ETo (mm)
38	47.2	47	43
39	43.2	48	37.8
40	44.7	49	39.2
41	47.1	50	39.8
42	51	51	39.6
43	50.4	52	38.5
44	43.4	1	41
45	43	2	40.4
46	42	3	41.6

Crop Coefficient (kc)

Crop water requirement is also influenced by crop characteristics which are accounted for by crop coefficient. Weekly kc values are obtained from crop coefficient curve (fig. 4). The kc values are low at establishment stage and progressively increase during vegetative development stage. This indicates that actual evapotranspiration (AET) is lower than the maximum evapotranspiration (ETo) at initial stage and vice versa conditions at vegetative stage. It is the indication of more losses of moisture at initial stage from soils as the canopy is sparse and low. During vegetative stage water loss from canopy is higher than that from the soils as canopy is established covering the soils.

During flowering stage kc values are high and more or less constant; grain formation and maturity stages indicate decreasing kc values and in turn crop water need as crop experiences senescence.

Crop water requirement (ETcrop)

Crop water need is obtained as a product of atmospheric water need and crop characteristics. Normal ETcrop values for

Fig. 4 : Crop Coefficient Curve (kc) for Rabi Sorghum

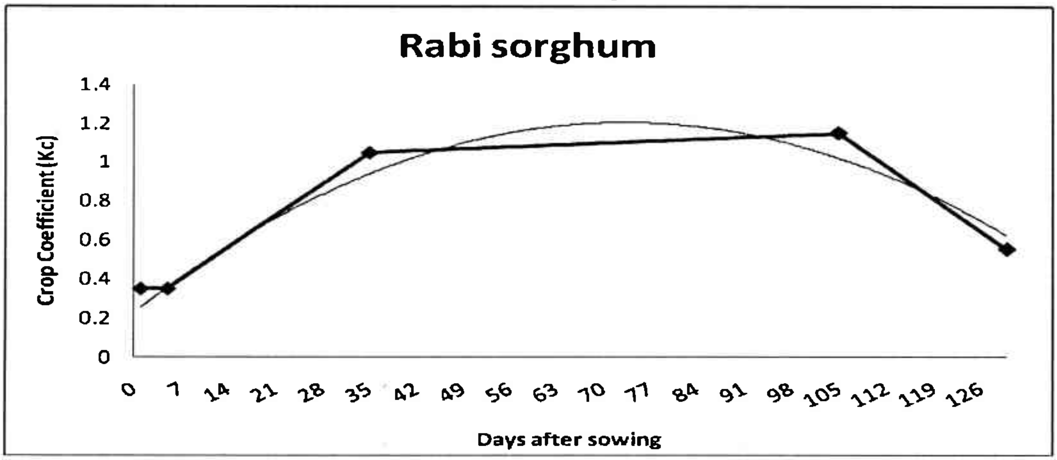


Table 5: Total Water Need (mm) during Crop Growth Stages

Establishment	Vegetative Develop-ment	Flowering	Grain Formation	Maturity
11	105	175	251	69

establishment, vegetative growth, flowering, grain formation and maturity stages of rabi sorghum crop are given in table 5.

Water Requirement Satisfaction Index (WRSI)

Water budget analysis for all the years (1961-62 to 1988-89) was carried out for 12 tehsils in study region from the MW 25 (June 18- 24) to MW 3 (January15-21). The Water Requirement Satisfaction Indices at sowing week and at grain formation stages were obtained for sorghum crop cultivated in all the three soil depths at all stations. Similarly, WRSI at the IV stage (Anne. 3) is evaluated for the crop performance as during the V stage i.e. maturity, grains are in hardening stage and water requirement and its satisfaction become insignificant.

It is observed that the WRSI at sowing stage during the study period in the district is varying from 66 to 100% for deep soils, 61 to 95% for medium soils and 58 to 90% for shallow soils. This indicates that the region displays extremely variable climatic conditions with respect to the amount and distribution of weekly rainfall during the monsoon season. WRSI less than 100% at MW 38 which is a sowing week indicates that moisture storage capacity of soils is not fulfilled even in the sowing week (when rainfall exceeds ETo).

WRSI at the end of grain formation stage varies from 32 to 69% for deep soils, 25 to 60% for medium soils and 23 to 52% for shallow soils. It is important to note that one could expect a logical relationship between WRSI at sowing and WRSI at growth stage IV, however there is no one-to-one relationship between them. This is attributed to the occurrence of rainfall during October and November. If the normal rainfall of October/ November is received the final index may be high in spite of low sowing index.

Water deficit

Sorghum crop is a drought tolerant crop recommended for regions where rainfall is inadequate and ill-distributed. The water deficit tolerated by the crop obtained through several experiments conducted in various agro-ecological zones reported in FAO Irrigation and Drainage Paper 24 (1975) is 0.65 which indicates that sorghum crop can tolerate 65% deficit of its total water need during the entire growing season.

Total water need during the critical growth stages of flowering and grain formation is 425 mm; thus probability of the occurrence of >275 mm deficit in these critical stages was worked out. In deep soils probability is varying from 60% for Parner to 89% for Nevasa, in medium soils 74% for Ahmednagar to 96% for Karjat and in shallow soils 84% for Parner to 100% for Shevgaon and Nevasa. For the same station it is increasing from deep to shallow soils. It is extremely important to note that large deficits in critical growth stages of sorghum crop are omnipresent.

Water surplus

During establishment and vegetative development stages water surplus in deep soils ranged from 40 to 60 mm, in medium soils from 50 to100 mm and in shallow soils from 100 to 110 mm during 1 out of 3 years. This surplus water needs to be conserved to ameliorate adverse effects of severe deficits in the following flowering and grain formation stages. Thus application of dryland farming technology in sorghum management may improve suitability of the region for the crop.

Suitability of sorghum crop

The WRSI at the end of grain formation stage obtained for 30 years period (1961-62 to 1988-89) is used to assess the performance of rabi sorghum crop in deep, medium and shallow soils in all tehsils of Ahmadnagar district. The index is grouped to qualitatively characterize the growth and yield potential of sorghum as good (>70%), average (60 to 69%), fair (50 to 59%) and poor (<50%). Probability of the occurrence of the WRSI in each of the above 4 groups is worked out for each station to determine agro-ecological (rainfall-soil) suitability of tehsil for cultivation of rabi sorghum.

Performance of rabi sorghum on deep soils

Deep soils which are more than 1 meter deep are moisture retentive and therefore are able to support rainfed sorghum growth sown during post-rainy season. Figure 5 denotes the tehsil wise distribution of sorghum performance. Kopargaon, Shrirampur and Nevasa tehsils do not report a single season performing in a good category even in deep soils as annual average rainfall is very low varying between 350 and 450 mm. Crop failure (poor category) is a recurrent feature (40 to 60%) in these tehsils. Sorghum production potential in these tehsils is less, larger areas under deep soils notwithstanding.

Akola, Rahuri, Shevgaon, Ahmadnagar, Parner and Karjat in the rainfall zone of 450 to 500 mm experience about 10% of the years good sorghum crop performance in deep soils. However, the occurrence of poor performance is also significant ~40%. The analysis, thus, reveals that in 6 out of 10 years sorghum growth and its yield potential is between average to good category.

Pathardi and Jamkhed located in rainfall zone of above 500 mm indicate good sorghum performance in 15 out of 100 years. It is important to note that probability of poor performance at Jamkhed is low as annual mean rainfall is more than that of Pathardi (35%). However, having the larger coverage of deep soils, Pathardi tehsil has higher production potential of rabi sorghum than that of Jamkhed.

Performance of rabi sorghum in medium soils

Kopargaon, Shrirampur and Nevasa tehsils indicate poor sorghum performance in medium soils in about 80% of the years under study while the rest of tehsils do not experience a single season of good sorghum crop (Figure 5). Tehsils in the middle part of the district indicate 60% probability of occurrence of poor performance.

At least average crop potential is 50% in Jamkhed tehsil which is located in the relatively wetter zone and having large coverage of medium soils. Thus medium soils of Jamkhed tehsil indicate large sorghum production potential in the district.

Performance of rabi sorghum in shallow soils

Shallow soils with less than 30 cm root depth have low moisture storage capacity and therefore are least productive for post-rainy season dryland agriculture. It highlights absence of good and fair sorghum crop season in the district and poor crop growth is noted in 9 out of 10 events (figure 5).

Again shallow soils in Pathardi and Jamkhed tehsils can support average crop performance in 2 out of 10 years. Pathardi having large shallow soil coverage and

20% probability of average performance ensures relatively large sorghum production potential from shallow soils among all tehsils of the district.

Comparative assessment

The comparative assessment illustrates probability of rabi sorghum performance in 3 soils depths according to tehsils. A threshold of 70% of probability of at least average performance of sorghum crop in a given soil depth is considered high suitability, 60 to 70% probability as moderate suitability, 50 to 60% probability as less suitability and < 50% probability as not suitability of a tehsil for cultivation of rabi sorghum under dryland condition. Table 6 given below indicates the suitability of soil depth according to tehsils for sorghum cultivation using the above criteria.

1 – Highly suitable
2 – Moderately suitable
3 – Less suitable
4 – Not suitable

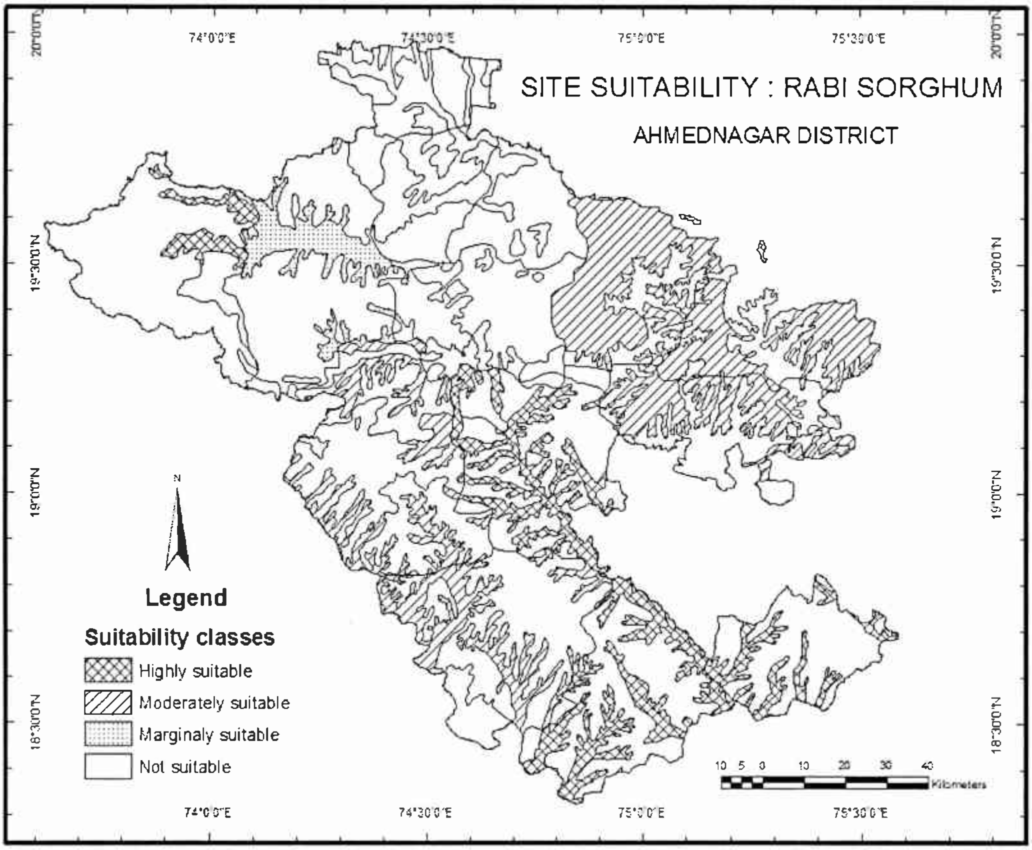
Summary and Conclusions

In this study an attempt is made to analyze performance of rabi sorghum crop in varying soils depths in 12 tehsils of Ahmadnagar district. A water balance approach was adopted using weekly rainfall data for 30 years (1961 to 1989) of all tehsil places. The Water Requirement Satisfaction Index, an outcome of water balance analysis was used to evaluate crop performance in shallow, medium and deep soils. Probability of crop performance in a given tehsil for a given soil depth was evaluated to determine their suitability for cultivation of post-rainy season sorghum crop under dry land condition.

Table 6: Suitability of Soils for Rabi Sorghum

S.N.	Tehsil	Deep	Medium	Shallow
1	Ahmadnagar	1	4	4
2	Akola	1	4	4
3	Jamkhed	1	3	4
4	Karjat	1	4	4
5	Kopargaon	4	4	4
6	Nevasa	2	4	4
7	Parner	2	4	4
8	Pathardi	2	4	4
9	Rahuri	3	4	4
10	Shevgaon	2	4	4
11	Shrigonda	2	4	4
12	Shrirampur	4	4	4

Figure 5: WRSI based Site Suitability of Rabi Sorghum in Ahmednagar District



The salient findings of the study are presented in this section.

- It is observed that weekly rainfall has not exceeded 0.5 ETo of the respective weeks at all the stations except for Jamkhed, Ahmednagar, Shrigonda, Shevgaon and Karjat. These stations lie in the relatively higher annual mean rainfall zone i.e. between 450 to 600 mm.
- WRSI less than 100% at MW 38 which is a sowing week indicates that moisture storage capacity of soils is not fulfilled even in the sowing week at any place in the district.
- There is no one-to-one relationship between WRSI at sowing and WRSI at growth stage IV which could be attributed to the occurrence of rainfall during October and November. If there is rainfall in October/ November, the final index is high in spite of low sowing index.
- Large deficits in critical growth stages (>275 mm) of sorghum crop are omnipresent.
- Having the larger coverage of deep soils which gives 65% probability of at least average crop performance, Pathardi tehsil has higher production potential

of rabi sorghum from deep soils in the district. Having large coverage of medium soils with 50% probability of at least average crop potential, Jamkhed tehsil indicates large sorghum production potential from medium soils in the district. Pathardi having significant shallow soil coverage and 20% probability of at least average performance ensures relatively large sorghum production potential from shallow soils among all tehsils of the district.

- WRSI based suitability shows that deep soils of Ahmadnagar, Jamkhed, Karjat and Akola are highly suitable for rabi sorghum production. Deep soils in Nevasa, Parner, Pathardi, Shevgaon and Shrigonda tehsils are moderately suitable and deep soils of Rahuri and medium soils of Jamkhed are less suitable. Rest of the region of Ahmadnagar district is not suitable for rabi sorghum production under dryland conditions.

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