AGRICULTURAL DROUGHT MANAGEMENT IN RAINFED AREAS OF SEMI-ARID REGIONS OF SOUTH INDIA

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ABSTRACT *In the semi-arid regions of South India, droughts are more common and occur either due to failure of South-West or North-East monsoon. Drought impacts on agriculture are managed by taking appropriate preventive measures through massive resource conservation like watershed programme. The effects of droughts are mitigated through conservation of rainwater both at terrace and inter-terrace level through different soil and moisture conservation measures by improving crop yields as well as water use efficiency. Adoption of different agronomic measures like selection of suitable crops, crop varieties, sowing time including mid-seasonal corrections and use of microbes that benefit the crop to combat drought can improve the crop yields and water use efficiency on sustainable basis. The runoff can be harvested in situ through farm ponds and used for crop irrigation to increase the crop productivity besides recharging groundwater as well. Site specific drought analysis to help the farmers is not being attempted at research and development level. There is a need for integrated intervention in a participatory mode to combat the drought situation by stabilizing production.*

Key words Drought management; moisture conservation; resource conservation; semi-arid region; water balance; water harvesting.

INTRODUCTION

Drought is a combination of complex biophysical and social processes of widespread significance. It is the least understood of all natural hazards; affecting more people than any other natural hazard (Hagman, 1984). Drought is caused by either the delay in the onset and early withdrawal of monsoon or both, failure of seasonal and total rainfall and prolonged period of rainless days (dry spells). Although drought seldom causes structural damage in contrast to floods, earthquake and cyclones, it results in crop failure and associated social and economic problems. Because of this, the quantification of impact and the provision of relief are far more difficult task for drought related disasters compared to other natural disasters (Wilhite, 2000). Almost all parts of the world including India experience drought every year. However, the intensity of drought varies from year to year. During the period 1891 to 2002, India has experienced 22 intense droughts. Despite all the advances in science, the mechanisms, which cause the year to year variations in the monsoon, are still poorly understood (Raj, 2002). The drought of 2002 is recognized as one of the worst in the last 100 years. Drought brings untold miseries to human beings, livestock and other living organisms besides degrading quality of the natural resources. It has a long lasting impact on agrarian economy and bio-diversity.

In India, droughts occur due to failure of South-West or North-East monsoon. Also, there seems to be a clear association between EL Nino and La Nina events and weak monsoons. The El Nino phase of the Southern Oscillations (ENSO) have a direct impact on drought in India. The Intergovernmental Panel on Climatic Change (IPCC) of the World Organisation projected an increase of 0.1 to 0.3°C in temperature by 2010 and 0.4 to 2°C by 2020 in South Asia that may have serious implications for rainfall distribution and agricultural production (Singh, 2006). In the past, Government of India took up several initiatives/programmes such as rural work programme, drought prone area programme, desert development programme, crop-weather watch group, technology mission on drought, integrated watershed management etc. to combat drought and provide employment opportunity to rural mass (Masood, 2006).

On the technological front, scientists have generated vast information on weather forecast, choice of crops and varieties, water harvesting, moisture conservation, crop management practices, soil management, contingent crop planning, animal husbandry and farming systems etc., for different regions to combat drought. However, the prediction of drought – its nature, duration and intensity is so complex and variable that management practices of short term contribute a little to avert losses caused by drought especially when it is intense. Therefore, reliable weather forecast and precise region specific technologies need to be developed for drought of different intensities and nature.

The losses caused by drought can be considerably minimized if appropriate preventive measures and mid-season corrections are taken up whenever necessary. All the rainfed crops are prone to drought. In rainfed farming, information on rainfall pattern and moisture deficits over time is very helpful in crop planning, rain water management and other hydrological studies related to agriculture. The frequency and probability analyses already attempted at Central Soil and Water Conservation Research and Training Institute at Bellary, have revealed that the rainfall pattern in this region is very erratic. Semi-arid black and red soil regions of India experience very low rainfall varying between 500 to 750 mm and a major part of it occurs as intense precipitation. Besides ill distribution, the rainfall is often inadequate for sowing within the crop growing period because of unfavourable soil condition such as poor aggregation and stability, high swelling and shrinkage (45-60%), lack of vegetation, undulating topography with long lengths of slopes and inadequate moisture besides improper and unscientific management of land and water resources. This region also experiences severe erosion, high-unchecked runoff and low productivity. Therefore, a need arises for long-term conservation planning for drought management with equitable distribution of water. This is sought to be achieved by investigating the hydrological aspects of the region such as rainfall, runoff and soil loss and also water balance of the area. This data base is useful not only for soil and water conservation and crop management but also for optimum design and planning of water harvesting system, to mitigate drought situations. Mishra et al. (2004) have compiled the experiences of researchers on rainfed agriculture technology for different agro-ecological regions of Andhra Pradesh with specific recommendation for drought prone areas based on appropriate resource conservation and management options.

In this paper some of the work and experiences on drought analysis, drought proofing and management mechanisms through climatic and hydrological interpretation, resource conservation techniques at terrace and inter-terrace level, tillage practices, agronomic measures including water harvesting and reuse have been discussed.

CLIMATIC WATER BALANCE

Rainfall analysis and climatic water balance studies at Bellary and Chitradurga in Karnataka and Kurnool in Andhra Pradesh in semi-arid region of South India indicates that this region receives low mean annual rainfall from 500 to 650 mm with erratic distribution. Monthly average climatic water balance of the watershed falling under Bellary, Chitradurga and Kurnool region has been calculated using the following formula and is presented in Fig. 1.

$$WD = PE - (RF - RO) \quad (1)$$
$$WS = (RF - RO) - PE \quad (2)$$

where WD is water deficit; PE is potential evapotranspiration; RF is rainfall; RO is runoff; and WS is water surplus.

Bellary region receives rainfall mostly from North-East monsoon and the crops are grown with the conserved moisture during post rainy season. The region experienced 13 meteorological drought years in last 50 years in terms of annual rainfall. As it is post rainy season cropped area (September to November), the seasonal rainfall analysis indicates the occurrence of droughts in 22 years in the last 50 years with 10 severe drought years.

RESOURCE CONSERVATION

Soil and Water Conservation Measures at Terrace Level

Contour and graded bunds are most commonly adopted conservation measures at terrace level.

Contour Bunds

Contour bunds are laid across the major land slope along the contour lines in the areas having 1.5 to 6% land slope and having less than 600 mm annual rainfall. The minimum height of contour bund is 50 cm with a cross section of 1.61 m^2 having a vertical interval of 0.9 m and the horizontal interval between the bunds may vary from 50 to 70 m depending on the land slope. Bunds are stabilized in 2 to 3 years by growing local grasses on them and are particularly recommended for red soil areas. The surplus runoff is safely disposed through waste weirs.

Graded Bunds

The graded bunds are constructed with a longitudinal grade of 0.2 to 0.4% having a vertical interval of 0.75 m to divert the run off from the fields. The cross section area of the bund is 0.83 m^2. The horizontal distance is 60 to 70 m. These

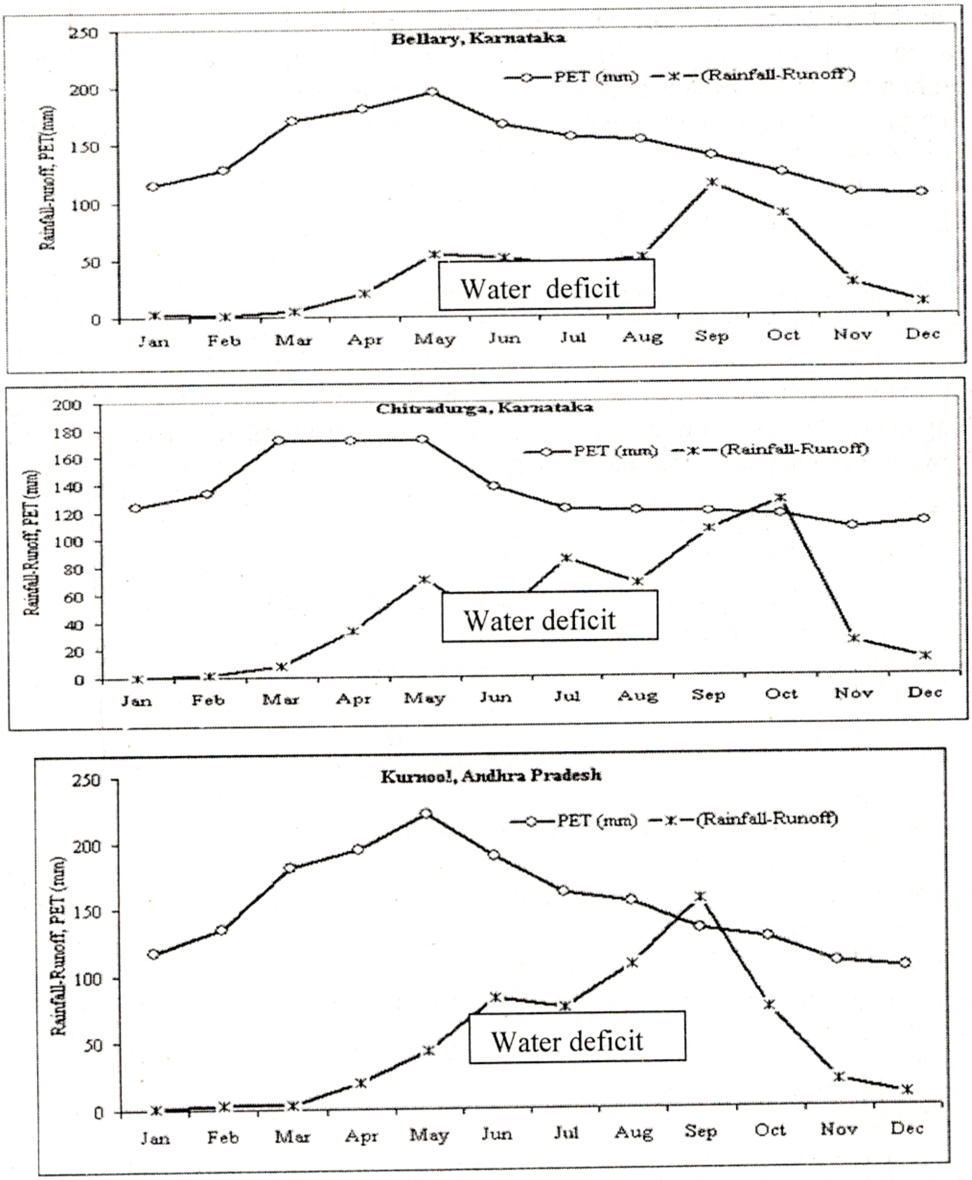

Fig. 1 Climatic water balance of Bellary, Chitradurga and Kurnool (semi-arid region).

bunds are more suitable for black soils with greater water logging in the periods of intense rainfall. With adequate vegetation the height of the bunds can be reduced to 50 cm. These bunds are recommended for the soils having less than 6% land slope. The graded bunds are connected to the water ways or water harvesting structures with waste weirs.

Different resource conservation measures were evaluated at a research farm in Bellary (vertisols) and in the watersheds viz., GR Halli (alfisols) and Joladarasi (vertisols) in Karnataka and Chinnatekur (black, red and mixed soils) in Andhra Pradesh. The performance of different conservation measures like contour bunds and graded bunds in conserving soil and rainwater and improving crop yields is presented for normal and drought years for *rabi* sorghum (Table 1). The percent increase in sorghum yields was higher in drought years (47%) as compared to normal years (25%). The magnitude of increase in crop yields was higher in graded bund (64% and 40%) as compared to contour bund (31% and 11%) during both drought and normal rainfall years, respectively over control.

Table 1 Grain yield of winter sorghum (kg ha^{-1}) as influenced by terrace level treatments under different rainfall situations in vertisols of Bellary.

Treatment	Normal years			Average	Percent increase over control	Drought years				Aver-age	Percent Increase over control
	I	II	III			IV	V	VI	VII		
Contour bund	1354	1348	2041	1581	11	163	769	508	627	517	31
Graded bund	1634	1888	2456	1993	40	224	857	643	872	649	64
Control	1367	1148	1765	1427	-	55	446	446	618	396	-

Note: I-1981-82; II-1982-83; III-1983-84; IV-1987-88; V-1988-89; VI-1989-90; VII-1990-91.

The adopted watersheds soil conservation measures (bunding, trenching, drop structures, farm pond, nala bund, check dams, etc.,) have reduced runoff and soil loss (Table 2). At GR Halli runoff is reduced from 9 to 2.3%, at Chinnatekur from 12.8 to 6.8%, and, in Joladarasi from 15 to 7.5%. Graded bunds were found to increase sorghum yields by 21% and 12% in GR Halli and Joladarasi, respectively, while it was 14% for groundnut at Chinnatekur (Table 3). The increase in yield with graded bunds during the normal years ranged from 5% for bajra to 32% for groundnut, whereas during the drought years the increase in yield was of greater magnitude with 14% for groundnut to 32% for *ragi* (Table 4). The resource conservation (adoption of moisture conservation practices) through watershed programme clearly indicates that the yields have been stabilized even in drought years and are comparable to those of normal years (Table 5) (Rama Mohan Rao et al., 2000a).

Table 2 Impact of conservation measures on runoff, soil loss and groundwater recharge.

	GR Halli watershed		Chinnatekur watershed		Joladarasi watershed	
	Pre-project Untreated	Post project	Pre-project Untreated	Post project	Pre-project Untreated	Post project
Annual rainfall (mm)	569		654		517	
Runoff %	9	2.3	12.8	6.8	15	7.5
Soil loss (t ha^{-1})	7.5	1.0	12.0	1.2	12.5	3
Groundwater recharge %		14		13		14

Table 3 Increase in crop yields (kg ha^{-1}) due to conservation measures.

Treatments	Watersheds		
	GR Halli	Chinnatekur	Joladarasi
	Sorghum	Groundnut	Sorghum
Graded bund	870	640	830
Control	720	560	740
% increase	20.8	14.3	12.2

Table 4 Impact of conservation measures on grain yield (kg ha^{-1}) of crops in GR Halli watershed.

Crops	Normal season			Drought season		
	With graded bunds	Without graded bund	% increase with bund	With graded bund	Without graded bund	% increase with bund
Sorghum (CSH5)	874	722	21	865	717	21
Sorghum (local)	533	456	17	460	400	16
Ragi	646	499	30	470	355	32
Bajra	465	441	5	462	364	27
Setaria	472	411	15	422	356	19
Groundnut	822	625	32	521	458	14
Sunflower	326	286	14	257	234	10

Table 5 Impact of resource conservation through watershed management in drought proofing in rainfed areas (Sorghum grain equivalent, kg ha^{-1}).

Particulars	GR Halli watershed*	Chinnatekur watershed**	Joladarasi watershed**
Pre-project	384	367	690
Drought years	1135	584	689
Normal years	1434	770	861
Post-project	953	623	783

Note: The data pertains to 1988-89 to 1994-95; *2 drought years and 5 normal years; **3 drought years and 4 normal years.

Tillage Practices

Cultivation of soil helps to increase pore space and also keeps the soil loose so that high rate of infiltration is maintained towards the end of runoff. Musgrave and Free (1936) found that cultivation of the surface greatly enhanced water intake of soil particularly in the beginning of storms. In the absence of cultivation, the highly crusting red soils produce as much or even more runoff than the low permeability Vertisols under similar rainfall situations. Larson (1962) stated that pulling a tillage implement through soil results in the temporary increase of total porosity and thickness of the tilled area. Surface roughness and micro depressions play greater roles in higher retention of water (Unger and Stewart, 1983).

Off season tillage or early tillage after the harvest of standing crop keeps the land in rugged condition and helps to avoid the runoff apart from having other benefits such as reduction in pests and weeds, burial of previous season's crop residues and timely seeding. The beneficial effects of off season tillage are much pronounced during the low rainfall/drought year (43% increase in yield) as compared to mild drought year (31% increase in yield) and near to the normal rainfall year (24% increase in yield) (Sanghi and Korwar, 1987) (Table 6).

Shallow tillage soon after rain is beneficial for retaining water in the soil profile particularly in the fine textured soils. At Bijapur, on medium to deep black soils, deep tillage increased the soil water content in the profile and infiltration rate and decreased the bulk density and consequently increased grain yield of sorghum (1877 kg ha^{-1}) by 22% and 45% over medium and shallow tillage, respectively (Patil, 1998). On coarse textured soils, deep tillage could be more desirable.

Table 6 Effect of off-season tillage on sorghum grain yield in red soils of Hyderabad.

System	Grain yield (kg ha^{-1})			
	1977	1978	1979	Mean
No off season tillage	1950	934	1052	1312
Off season tillage	2430	1336	1965	1910
Percent increase due to off season tillage	24	43	31	46
Rainfall in growing season (mm)	595	391	508	

Soil and Water Conservation Measures at Inter-Terrace Level

Vertical Mulch

In vertical mulching, sorghum stubbles of 60 cm length are placed in the trenches of 50 cm depth and 15 cm width across the slope at pre-determined spacing. Soil water is the main limiting factor for successful crop production in the rainfed agriculture with inadequate rainfall and/or poor distribution. The problems become much more severe when soils are also problematic. The crop productivity in vertisols can be increased with increased intake rates as nearly 25% of rainfall during crop growth period goes as runoff. Adoption of vertical mulch in black soils conserved soil water and increased the winter sorghum yields to the greater extent in the dry/drought years as compared to wet/normal or above normal rainfall years (Rama Mohan Rao et al., 1978 and Ranga Rao et al., 1978). Compared with low yields in control plots (grain: 20 kg ha^{-1}; straw: 0.95 t ha^{-1}), mulches spaced at 2, 4 and 8 m produced on an average 390 kg ha^{-1} of grain and 1.90 t ha^{-1} of straw in extremely dry conditions of 1972-1973 (Table 7). However, the increase in grain and straw yields in wet conditions in 1973-1974 was 47% and 15%, respectively. Averaged over dry and wet years, vertical mulch resulted in 45% and 38% higher grain and straw yields. Higher sorghum yields were attributed to higher soil water content near the mulch and the favorable effects of mulch extended to 1.5 m on either side of the mulch row.

Table 7 Sorghum grain (kg ha^{-1}) and straw yields (t ha^{-1}) as affected by spacing of vertical mulch in vertisols of Bellary.

Treatments	1972–73		1973–74		1974–75		1975–76		Mean	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
2 m	523	2.19	1641	3.03	1495	2.94	1027	3.68	1172 (40)	2.96 (37)
4 m	412	2.02	1692	3.25	1775	3.02	1246	3.85	1381 (53)	3.04 (41)
8 m	236	1.48	1614	2.86	1770	3.73	1122	3.64	1186 (42)	2.93 (36)
Cracks filled with straw	198	1.46	1310	2.70	1240	2.08	982	3.51	929 (11)	2.44 (13)
Control	017	0.95	1120	2.65	1123	1.89	1085	3.15	836 (–)	2.16 (–)
CD (0.05)	-	-	459	0.39	N.S.	0.99	N.S.	N.S.	–	–
Rainfall situations	Drought year		Normal year		Drought year		Normal year		Mean over years	

Surface Mulch (Organic and Soil Mulch)

Deep black soils are kept fallow in *kharif* and hence they remain bare by the time intense rains occur in September/October. Beating action of the rain causes structural deterioration which reduces the intake rate. Besides, the high evaporation losses in the absence of crop canopy in the initial stages of crop growth, the greater runoff and soil loss results in formation of cracks in the soil by mid November to early December and this further accentuates evaporation losses. If these are not controlled, soil water stored in the profile gets lost early and crops dry prematurely. Studies (1965 to 1969) with organic mulches have not brought out any yield increase and were attributed to the late application and incorporation of organic mulches. In contrast to these results, application of surface mulch at sowing was found to have a positive effect on grain and straw yields (Table 8) (Rama Mohan Rao et al., 1985).

Table 8 Winter sorghum yields as influenced by moisture conservation practices in vertisols of Bellary.

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Control	1052	1400
Control + Surface mulch	1375	1914
Vertical mulch (4 M)	1719	2405
Vertical mulch (4 M) + Surface mulch	2138	2953

As the availability of organic materials is scarce, the effects of soil mulch through tillage during crop growth are evaluated on sorghum yields (Table 9). Creating dust mulch up to a depth of 10 cm resulted in 8% more grain yield (1833 kg ha^{-1}) over organic mulch. Mulches (organic and soil) increased the sorghum grain and straw yields by 63 and 20% over control by proving their applicability especially during drought situations in the black soil region during post rainy season for the crops cultivated on residual soil water (Rama Mohan Rao et al., 1985).

Table 9 Winter sorghum yields as influenced by dust and surface mulches in vertisols at Bellary.

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Control	934	2.43
Organic mulch	1760	2.95
Intercultivation up to 5 cm depth	1243	2.95
Intercultivation up to 10 cm depth	1833	2.95
Intercultivation up to 15 cm depth	1510	2.78

Sand Mulching

Sand mulching has been practiced by farmers in some pockets of Northern Karnataka. Experiments conducted at Dryland Centre, Bijapur, and Main Research Station, Dharwad (Karnataka), indicated distinct advantages with sand mulching (Anon, 2000 and Sudha, 1999). The benefits were directly proportional to the quantity of sand applied or mulch thickness (Table 10). Benefits of sand mulching were attributed to the reduced runoff and increased wetting front. The improved crop yields in sand mulching compared to non-mulched soil was a result of increased soil temperature, conservation of rainwater *in situ*, reduced evaporation and controlled wind and water erosion which in turn increased water content at different stages of crop growth. In the Koppal, Gadag and Bagalkot Districts of Karnataka, sand mulching increased the cropping intensity to 200% especially in the years of drought in this low rainfall region (around 600 mm rainfall) with bi-modal distribution. In this region, in the medium to deep black soils, farmers with sand mulching cultivated a short duration greengram compared to non mulched areas. In addition, winter sorghum yields in the post rainy season increased by 60 to 70% with sand mulching as compared to non-mulched areas. The utility of sand mulch therefore needs intensive long term study in comparison with non-mulched soil.

Table 10 Effect of sand mulch on soil water (cm) and pod yield of groundnut in vertisols of Dharwad, Karnataka.

	Soil depth (cm)	30 DAS*	90 DAS*	Pod yield (kg ha^{-1})
No mulch	0-15	3.56	4.99	960
	16-30	3.60	5.14	
	31-60	7.56	11.29	
Sand mulch (5.0 cm)	0-15	4.87	5.66	1376
	16-30	5.38	5.80	
	31-60	11.13	12.74	
Sand mulch (7.5 cm)	0-15	4.95	5.67	1276
	16-30	5.42	5.86	
	31-60	11.72	12.83	
CD 0.05	0-15	0.87	0.29	219
	16-30	1.48	0.62	
	31-60	2.75	NS	

*DAS: Days after sowing.

Contour Cultivation

Carrying out all the field operations and sowing the crops across the slope (contour cultivation) provides a series of miniature barriers to water and also reduces runoff and soil loss and increases soil water and nutrient content in the soil profile. The conservation of rainwater is more beneficial during drought years especially at the reproductive stages of the crop growth. The effectiveness of this practice was compared with up and down cultivation in the farmers' fields over a period of 4 years (Table 11). Contour cultivation resulted in 35% and 22% increase in grain yields in sorghum and setaria, respectively, in black soils and 66% increase in sorghum grain yields in red soils over up and down cultivation (Rama Mohan Rao et al., 1985).

In a field study (0.324 ha plots of each treatment) conducted in the black soils at Bellary from 1991 to 1997 indicated that the runoff and soil loss increased, whereas the grain yield of winter sorghum decreased with increase in the slope from 0.5 to 1.5%. It was observed during the study period, 1991–92 and 1995–96 were drought years and 1992–93 and 1996–97 were the normal years. The magnitude of increase in winter sorghum grain yield was higher during drought years as compared to normal years with adoption of different *in situ* moisture conservation practices over up and down cultivation (Farmers practice) in all the three land slopes. This is a clear indication that the *in situ* moisture conservation practices are more beneficial during the years of water scarcity (drought years) than the water availability (normal years) to the crop at different stages of crop growth. The simple technology of contour cultivation was more beneficial (92% increase in yield) over up and down cultivation (farmers practice) during drought year (Table 12). Conservation of rainwater through vegetative barrier (*cymbopogan martinii*) at 60 m across the slope was beneficial and its effect was of a greater magnitude during drought years (62% increase in yield) over normal years (41% increase in yield). Vertical mulch along with surface mulch conserved greater quantity of rainwater especially during drought years and doubled the sorghum yields i.e., 127% increase over farmers practice as compared to normal years i.e., only 18% increase in grain yield of winter sorghum.

Table 11 Contour cultivation vs up and down cultivation (1957-61) in vertisols of Bellary.

Crops		Mean yield (kg ha^{-1})		
		Contour cultivation	Up and down cultivation	% increase
Black soils				
Rabi sorghum	Grain	285	211	+35
	Straw	1607	1209	+33
Setaria (H-2)	Grain	195	159	+22
	Straw	430	390	+10
Red soils				
Kharif sorghum (K-340)	Grain	812	189	+66
	Straw	6097	3824	+59

The yield decrease was to a greater magnitude with increase in slope from 0.5% to 1.5% in the up and down cultivation (farmers practice) i.e. 40 to 44% as compared to the adoption of moisture conservation practices i.e. 31 to 25% in the drought years and the decrease in yield was lower in the normal years both in farmers practice i.e. 8 to 21% and across moisture conservation practices i.e. 15 to 19% (Table 12). These results clearly indicate that adoption of *in situ* moisture conservation practices are more beneficial in conserving rainwater especially during drought years over normal rainfall years and further it is advised to level the land in between two bunds to increase the yields especially during the drought years as the yield reduces with increase in slope from 0.5 to 1.5% especially during the years of water scarcity (drought years) in different stages of crop growth (Rama Mohan Rao et al., 2000b).

Compartmental Bunding, Ridges and Furrows

Compartmental bunding In compartmental bunding, the entire field is laid out into small bunded compartments with bund farm varying in size from 6×6 m and 10×10 m in medium to deep black soils depending up on the land slope (1-2%). The compartmental bunding is helpful in conserving the runoff up to 30-40%.

Ridges and furrows Ridges and furrows are prepared across the land slope during off season/rainy season on all types of soils for conserving the rainwater in situ and reducing the soil loss. This practice is helpful in conserving runoff up to 50-60%.

Table 12 Effect of moisture conservation practices on winter sorghum grain yield (kg ha^{-1}) during drought (1991-92 and 1995-96) and normal years (1992-93 and 1996-97) in the vertisols at Bellary.

Treatments	Drought years				Normal years			
	Slope				Slope			
	0.5	1.0	1.5	Average	0.5	1.0	1.5	Average
Up and down cultivation (control)	662	400 (– 40)	370 (– 44)	477 (—)	1191	1096 (– 8)	939 (– 21)	1075 (—)
Moisture conservation practices								
Vegetative barrier	1014 (53)	642 (61)	656 (77)	771 (62)	1673 (40)	1543 (41)	1316 (40)	1511 (41)
Contour cultivation	1213 (83)	670 (68)	864 (135)	916 (92)	1291 (8)	897 (–22)	987 (5)	1058 (– 2)
Vertical mulch + surface mulch	1115 (68)	992 (148)	1000 (170)	1036 (117)	1333 (12)	1204 (10)	1157 (23)	1231 (15)
Mean	1114 (68)	768 (92)	840 (127)	908 (90)	1432 (20)	1215 (11)	1153 (23)	1267 (18)
Per cent yield decrease over 0.5%	—	(– 31%)	(– 25%)	—	—	(– 15%)	(– 19%)	—

Note: Figures in parenthesis indicate % increase.

In a field study on vertisols at Bellary from year 2000 to 2003 indicated that the moisture conservation through *in situ* moisture conservation practices i.e. compartmental bunding and ridges and furrows increased the soil water in the profile and grain and straw yield of winter sorghum (Patil, 2005a). The magnitude of increase in grain yield of 28% in compartmental bunding, and 36% in ridges and furrow during 2000-01 was attributed to efficient utilization of water, especially conserved water to produce grain yield even though it was a moderate drought year (Table 13). During severe drought year (2002-03), the relative increase in grain yield was comparatively lower in compartmental bunding (16%) and ridges and furrows (20%) as compared to 2000-01 and was attributed to occurrence of water stress at reproductive stages of crop growth. During 2001-02 (with crop season rainfall of 248.5 mm) resulted in higher water availability to the crop at different stages of growth and hence, the water conserved through compartmental bunding and ridges and furrows increased the grain yield only by 13% and 16%, respectively. The mean grain yield (average of 3 years) increased by 17% (2122 kg ha^{-1}) and 22% (2206 kg ha^{-1}) in the plots laid-out with compartmental bunding and ridges and furrows, respectively over flat bed (1815 kg ha^{-1}). The mean straw yield increased by 20% (3.56 t ha^{-1}) with compartmental bunding and 21% (3.60 t ha^{-1}) with ridges and furrows over flat bed (2.97 t ha^{-1}). Water use efficiency (WUE) was higher during 2000-01 (drought year) as compared to 2001-02 (above normal rainfall year) and 2002-03 (severe drought year) indicating that every unit of water was more efficiently utilized to produce grain yield (Table 14). Even though grain yield was higher during 2001-02, the WUE was lower and attributed to higher crop season rainfall 248.5 mm resulted in higher consumptive use. The results of three years mean indicated that the WUE increased by 13% (8.26 kg ha^{-1} mm^{-1}) and 16% (8.48 kg ha^{-1} mm^{-1}) over flat bed (7.34 kg ha^{-1} mm^{-1}) (Patil, 2003).

Table 13 Grain yield of winter sorghum as influenced by *in situ* moisture conservation practices in vertisols of Bellary.

Treatments	Grain yield ($kg\ ha^{-1}$) 2000–2001		2001–2002		2002–2003		Pooled		Straw yield ($t\ ha^{-1}$) Pooled	
In situ moisture conservation practices										
Flat bed	1290	—	2816	—	1339	—	1815	—	2.97	—
Compartmental *bunding*	1648	(28)	3169	(13)	1548	(16)	2122	(17)	3.56	(20)
Ridges and furrows	1756	(36)	3256	(16)	1605	(20)	2206	(22)	3.60	(21)
S.Em.±	83.2		54.7		45.9		—			
C.D. at 5%	326.8		214.6		180.2		—			
Antecedent rainfall (mm)	142.7 (7–14 October 2000)		189.0 (17–26 September 2001)		125.7 (8–7 October 2002)					

Note: Figures in parenthesis indicate % increase.

Table 14 Water use efficiency of winter sorghum as influenced by moisture conservation practices in vertisols of Bellary.

Treatments	Water use efficiency ($kg\ ha^{-1}mm^{-1}$) 2000–2001		2001–2002		2002–2003		Pooled	
In situ moisture conservation practices								
Flat bed	8.57	—	7.24	—	6.20	—	7.34	—
Compartmental *bunding*	9.86	(15)	8.20	(13)	6.71	(8)	8.26	(13)
Ridges and furrows	10.77	(26)	7.86	(9)	6.82	(10)	8.48	(16)
S.Em.± C.D. at 5%	0.54 NS		0.14 0.53		0.20 NS			

Note: Figures in parenthesis indicates % increase.

The above results indicate that conservation of rainwater through moisture conservation practices are beneficial in both red and black soils in the semi-arid tropics of South India.

Agronomic Practices

Selection of Suitable Crops and Varieties

Crops grown in a specific area are determined by number of factors. Even with adequate precipitation and sunlight, optimum temperature and fertile soils, it is quite possible that the other factors such as economic concerns (commodity prices, transport costs, marketing facility etc.) or even Government policies (marketing boards, price controls, price stability) determine the crop choices that the farmers cultivate. In the past, selection of crops and varieties was governed by the needs of a farm family rather than the crops suitability for a given environment. The choice of crops should be dictated by the land use capability that in turn is mainly decided by soil water availability. In case of rainy season crops, the rainfall pattern and length of the effective growing season should decide the choice of crops and varieties. The cultivation and the choice of post-rainy season crops and their cultivars mainly depend on the conserved soil water that is available in the profile at sowing in rabi cropped vertisols region (Tables 15 and 16) (Patil and Basappa 2004a; Patil and Basappa, 2004b; and Singh, 1987).

The crops and their genotypes differ in their yield potential and water use efficiency, some being more efficient than the others in the same environment. For example, in the shallow to medium deep vertisols of Solapur safflower proved more efficient in water use than groundnut and pigenopea crops (Umrani et al., 1981). At the same centre, in the post rainy season, the WUE of sorghum, chickpea and safflower was practically the same, but chickpea and safflower may be advocated to farmers due to higher net returns. In deep black soils, safflower was more efficient and remunerative than the traditional cotton.

Table 15 Suggested cropping strategy for conserved soil moisture storage in different rainfall situations at Bellary.

Soil/ Location	Rainfall (mm)	Crops	Varieties	Hybrids
Vetisols (Bellary)	> 500	Sorghum	Phule Yashoda, SPV–86, SPV–1413, M35–1	CSH–13K&R, SPH–1010, SPH–1077, SPH–1079
		Safflower	A–1, A–300	
		Chickpea	A–1, ICCV–2	
	375-500	Sorghum	M 35–1, Phulae Moulee	CSH–19R, CSH–15R and SPH–1230
		Safflower	A–2	
		Chickpea	ICCV–2 (Swetha) and ICCC–37	
	250-375	Sorghum	M35–1 for fodder with 60,000 plants ha^{-1}	
		Safflower	A–2	
		Chickpea	ICCV–2 (Swetha) and ICCC–37	
	<250	Sorghum	M35–1 for fodder	
		Chickpea	ICCC–37 with 2/3rd recommended population	

Table 16 Relative yields of traditional and efficient crops in vertisols.

Place	Soils	Traditional crop	Yield (t ha^{-1})	Efficient crop	Yield (t ha^{-1})
Bellary	Vertisols	Cotton	0.20	Sorghum	2.67
Bijapur	Vertisols	Wheat	0.94	Safflower	1.85
Indore	Vertisols	Greengram (k)	1.18	Soybean	3.33
		Wheat (R)	1.12	Safflower	2.42
Rewa	Vertisols	Kalitur	0.40	Soybean (yellow)	1.20

Use of Microorganisms

Inoculation of Azospirillum in Winter Sorghum

Results of a field study in vertisols at Bellary on seed treatment of *Azospirillum* in winter sorghum clearly indicated that the response of *Azospirillum* depends upon the sowing time, antecedent rainfall, crop season and total rainfall and the soil water availability during crop season (Patil and Manjunath, 2003; and Patil, 2005b). The grain yield increased by 7% (2234 to 2395 kg ha^{-1}) during normal year, 13% (1020 to 1152 kg ha^{-1}), 23% (1176 to 1449 kg ha^{-1}) and nearly 138% (176 to 419 kg ha^{-1}) during drought years of different intensities (Table 17). The straw yield and water use efficiency also increased from 5% to 20% and 2% to 25% in drought years, respectively. These results indicate that, the simple low cost technology of seed treatment with *Azospirillum* is more beneficial during drought years as compared to normal and above normal rainfall years. The mean (average of 3 years) grain and straw yields increased by 13% and water use efficiency by 11% over control. In general, WUE was higher during 2000-01 (drought year) as compared to 2001-2002 (above normal year of rainfall) and 2002-03 (severe drought year). The results show that every unit of water was efficiently utilized to produce higher grain yield during 2000-01 as compared to 2002-03 as moisture stress occurred at physiological maturity. Higher consumptive use and higher water availability in the profile throughout the cropping season resulted in lower WUE during 2001-02 even though grain yields were higher.

Higher winter sorghum yields with *Azospirillum* inoculation is probably attributed to the biosynthesis and secretion of bacterial indole-3-acetic acid (IAA) (El-Khawas et al., 1996; and Beyeler et al., 1997). Bacterial IAA stimulates plant root production, especially lateral roots and greater root hair development (Sompong Meunchang et al., 2004). Okon and Kapulnik (1986) also pointed out that colonization of the plant root by *Azospirillum* may enhance the permeability of N, P, and K ions into the roots. Thus this plant-growth-promoting-rhizobacterium (PGPR) enhances the uptake of soil nutrients by host plant (Beyeler et al., 1997; and Salamone et al., 1997).

Table 17 Grain yield of winter sorghum as influenced by *Azospirillum* seed treatment in winter sorghum in vertisols at Bellary.

Treatments	2000–01	2001–02	2002–03	Mean	% increase
		Grain yield (kg ha^{-1})			
Control	1020	2234	1176	1477	—
Azospirillum seed treatment	1152 (13)	2395 (7)	1449 (23)	1665	13
		Straw yield (t ha^{-1})			
Control	1.62	4.15	2.52	2.76	—
Azospirillum seed treatment	1.70 (5)	4.67 (13)	3.02 (20)	3.13	13
		Water use efficiency (kg ha^{-1} mm^{-1})			
Control	6.94	5.81	5.54	6.09	—
Azospirillum seed treatment	7.11 (2)	6.23 (7)	6.95 (25)	6.76	11
Crop season rainfall (mm)	45.6	248.5	9.8	—	—
Rainy days	3	14	1	—	—
Antecedent rainfall (mm)	144.1 (6-12 Oct.)	189.0 (15-25 Sept.)	125.7 (8-17 Oct.)	—	—
Total rainfall (mm)	550.9	566.6	432.6		

Seed treatment with *Azospirillum* in winter sorghum in the fields at the PC Pyapili watershed in the Anantapur District of Andhra Pradesh increased the native microorganism population and crop yields in all the three varieties i.e., SPV-1359, SPV-1413 and M35-1. The increase in sorghum yield varied from 5% (SPV-1359) to 6% in SPV-1359 (Phule Yashoda) with *Azospirillum* seed treatment (Table 18).

Table 18 Effect of seed treatment (*Azospirillum*) and improved cultivars of rabi sorghum during 1999-2000 in PC Pypili watershed in Anantpur District of Andhra Pradesh.

Varieties	Grain yield (kg ha^{-1})		
	No seed treatment	Seed treatment	% Increase
SPV–1359	1350 (23)	1430 (24)	6
SPV–1413	1100	1150	5
M35–1	1150	1210	5

Note: Figures in parentheses indicate the percentage increase in yield over SPV-1413.

Plant Population Corrections

Plant populations in winter sorghum and safflower exhibited significant interaction with seasons in Vertisols of Bellary. The magnitude of response to plant density depended on the residual soil water status in the profile with the response being very low under limiting soil water conditions. Indeterminate crops like safflower possessed greater plasticity to plant density unlike determinate types. The grain yield of winter sorghum depends upon the kharif rains, antecedent and crop season rainfall in addition to sowing time. In the extremely drought year (1973-74), a plant population of 0.45 lakhs per ha produced greater yields (760 kg ha^{-1}) as compared to 100 kg ha^{-1} with the optimum plant population of 1.35 lakhs per ha (Table 19). During the normal year (1974-75), a plant population of 0.75 to 1.0 lakh per hectare proved beneficial for optimum yields. Yields reduced either with excess of plant population (more than a lakh per ha) or less than 0.75 lakhs population per ha. Hence, during normal year it was advised to remove weak seedlings or seedling infested with shoot fly (Ranga Rao et al., 1978). During above normal year, it was advised to sow winter sorghum with 1.30 lakh population per hectare to get optimum sorghum yields and reduction in plant population reduces the yields.

Table 19 Effect of plant population corrections on the performance of winter sorghum and safflower in vertisols at Bellary.

Treatments	Plant populations '000 per ha		Winter sorghum Grain yield (kg ha^{-1})		Plant populations '000 per ha	Safflower Grain yield (kg ha^{-1})		
	I	II	N	AN	I	D*	N*	AN*
Original plant population	150	130	1550	2420	30	470	1280(33)	1230(33)
Alternate plant removed	75	65	2150	-	36	430	1130(37)	1170(37)
Alternate row removed	75	65	2070	1450	43	290	980(41)	1370(45)
Alternate row + Alternate plant removed	37	32.5	1500	1370	52	250	900(54)	1490(50)
Third row removed	100	86.7	2110	2020	60	–	910(64)	1570(60)
Third plant removed	100	86.7	2160	2190	76	240	950(80)	1660(75)
Third plant + third row removed	67	–	1530	–	92	150	–	–
CD (0.05)	–	–	180	250		**	110	**

*D: Drought year; N: Normal year; AN: Above normal year.

In the Chinnatekur watershed in Andhra Pradesh, population corrections considering soil water availability in the profile have increased the winter sorghum yield from 29% to 41%, whereas, in the Joladarasi watershed yields increased from 22% to 27% during normal and drought years respectively, bringing stability to productivity apart from averting crop failure (Rama Mohan Rao et al., 2000a) (Table 20).

Table 20 Impact of drought management techniques on grain yields of winter sorghum (kg ha^{-1}) in Chinnatekur and Joladarasi watersheds.

Technique	Crop	Chinnatekur watershed			Joladarasi watershed		
		Without	With	% increase	Without	With	% increase
Population Corrections (removal of alternate rows)							
Normal year	Sorghum	1020	1330	29	1130	1380	22
Drought year	Sorghum	760	1070	41	960	1220	27

WATER HARVESTING AND REUSE

In the semi-arid tropics of South India, nearly 10% to 40% of rainfall goes as run off from the farmers' fields depending upon the land slope. Of this runoff, nearly 10% can be harvested and recycled as protective irrigation especially during subnormal rainfall/drought years. Probability of occurrence of runoff in Bellary region for hydrological design purpose is illustrated in Fig. 2. Maximum runoff is observed in September (highest probability) followed by October, June, November and May indicates the feasibility of farm pond technology in black soils in this semi-arid Bellary region (Table 21). The optimum size of farm pond is worked out to be 250 m^3. It is evident that water in dug out ponds is available for more than 90 days providing opportunity for recycling during periods of moisture stress. Supplemental irrigation from the farm ponds was useful for yield stabilization especially during drought years. The increase in yields was higher in drought years (85% to 180%). In normal years the yield increase due to supplemental irrigation was from 24% to 114%. This improves stability in yields under rainfed conditions. The runoff when received in the months of May and June is utilized for a short duration greengram by providing supplemental irrigation from harvested water (Table 22) (Adhikari et al., 2000).

Table 21 Effect of supplemental irrigation on rabi sorghum grain yield (kg ha^{-1}) in vertisols at Bellary.

Years		Graded bund		Percent increase
		With irrigation from farm pond	Without irrigation	
Normal years	1981-82	1945	1572	24
	1982-83	1904	888	114
Drought years	1987-88	400	169	137
	1988-89	1680	908	85
	1989-90	1320	472	180
	1990-91	1584	768	106

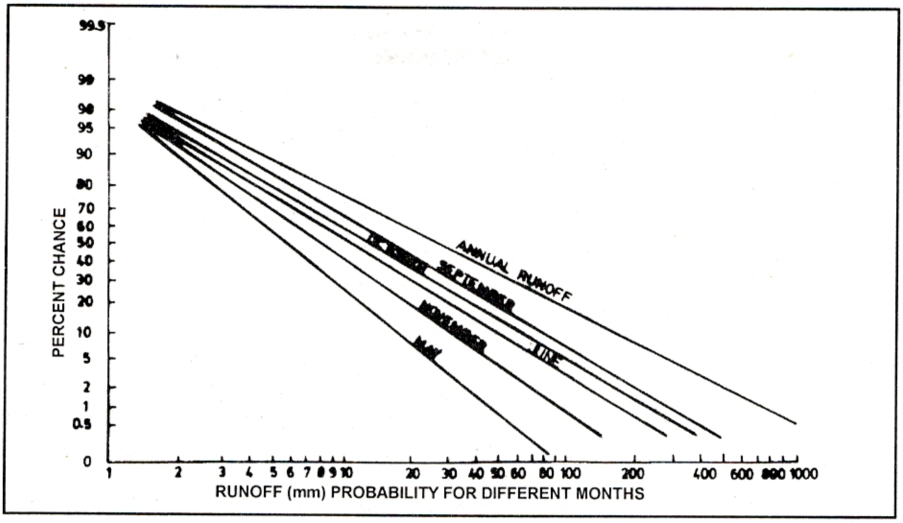

Fig. 2 Monthly and annual runoff probabilites at Bellary Research Farm.

Table 22 Effect of supplemental irrigation to greengram in kharif season from area with graded bund.

	Years	Area covered (ha)	Depth of irrigation (cm)	Seasonal rainfall (mm)	Grain yield (kg ha^{-1})
Drought years	1986	0.16	17.7	60.7	231
	1988	0.25	9.2	65.2	500
	1989	0.25	—	106.8	200
	1991	0.25	6.0	59.2	320
	Average	—	—	71.4	324

Note: Low yields are due to uncertain and meager rainfall during kharif period.

In this vertisol region, irrigation to the winter sorghum is advocated either at boot leaf stage or with the first appearance of crack as the indication of moisture stress. In the drought year (1971-72) application of 11.8 cm of irrigation increased the winter sorghum yields by 157% (530 to 1360 kg ha^{-1}) as compared to 219% increase in sorghum yields (430 to 1370 kg ha^{-1}) in severe drought year with 6.5 cm irrigation at knee height stage (Table 23). The response to irrigation was only 12% (2190 to 2450 kg ha^{-1}) with 5 cm irrigation at grain filling stage during normal rainfall situation.

Table 23 Winter sorghum (M35-1) response to supplemental irrigation in vertisols at Bellary.

Crop stages	Irrigation depth (cm)	Grain yield (kg ha^{-1})		
		1971–72	1972–73	1974–75
Boot leaf	11.8 cm	1360	—	—
Knee high	6.5 cm	—	1370	—
Grain filling	5.0 cm	—	—	2450
	Control	530	430	2190
		Drought year	Drought year	Normal year

The watershed development programme having continuous interaction with technical personnel have established evasion technologies on firm footing in the watershed area, which is not observed in the areas without watershed programmes. The supplemental irrigation during water stress brought about 49% to 86% increases in yields in groundnut and sorghum in Chinnatekur watershed, whereas, in winter sorghum yield increased by 34% at Joladarasi watershed in black soils (Rama Mohan Rao et al., 2000a) (Table 24).

Table 24 Impact of drought management techniques on grain yields of crops (kg ha^{-1}).

Technique	Crops	Chinnatekur			Joladarasi		
		Without	With	% increase	Without	With	% increase
Supplemental irrigation							
	Sorghum	570	1060	86	1460	1950	34
	Groundnut	610	910	49	—	—	—

Effect on Groundwater Source

Water balance studies have revealed that conservation measures increased ground water recharge varying from 13.7% to 14.2% of annual rainfall in different watersheds depending upon the location and rainfall (Table 2). Monitoring of water levels in the wells has already established a rise of 1.0 to 1.5 m in water table in the areas falling inside the watershed as compared to areas outside the watershed, over the years. As a result of increased groundwater recharge, the area under irrigation has increased from 91% (GR Halli watershed) to 178% (Chinnatekur watershed) irrespective of drought years (Table 25).

Table 25 Impact of conservation measures on groundwater use for irrigation.

Watersheds	Area irrigated (ha)		% increase over pre-project
	Pre-project	Post project	
GR Halli	16.95	32.41	91
Chinnatekur	89.00	246.94	178
Joladarasi	2.12	5.26	149

CONCLUSIONS

Drought can not be defined only by simple departure of rainfall by -20% from normal. Even in normal rainfall years, drought occurs and crop fails. On the research front, specific studies should be undertaken to define drought by considering the meteorological, hydrological and agricultural droughts together for arriving at site specific prescriptions for combating drought. Stress should be given on long term preventive measures for building the resources on a sustainable basis. Particularly in rabi-cultivated deep black soils areas (cultivation on conserved moisture) receiving North-East rainfall, the antecedent rainfall and soil moisture condition should be considered for defining drought. Droughts of different intensities (year to year and within the season) can be well managed through the rainfall analysis and its forecasting. This has not been perfected at micro level upto the aspiration of the farming community. In developing countries the available information on weather forecasting is not reaching the end users at appropriate time for efficient crop planning. The preventive measures either before the onset of South-West or North-East monsoon or even during the rainy and post rainy cropping seasons can be planned with forecasting techniques. In addition, droughts of different intensities can be mitigated through resource conservation i.e. reduction in runoff and soil loss and conservation of rainwater either at terrace level through bio-engineering measures and at inter-terrace level through *in situ* moisture conservation practices. In addition, proper tillage practices also ameliorate the drought effects and improve the water use efficiency of crops.

Selection of suitable crops and cropping systems with mid-seasonal correction plays a major role in stabilizing the crop yields in the red and black soils of the low rainfall semi-arid region of South India. It is also interesting to observe that to some extent drought is mitigated through the seed treatment i.e. *Azospirillum* to cereals and oilseeds. Dust or organic mulching plays a major role in combating late season drought and increasing crop yields and water use efficiency. Sand mulch is found effective in conserving rainwater *in situ* for improving the crop yields in this low rainfall region. The runoff harvesting and recycling proved highly beneficial in improving and stabilizing the yields particularly in drought years. A comprehensive management plan needs to be developed by integrating drought assessment and risk transfer with a strong capacity building programme.

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