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Strategies for mitigation of drought effects through resources management practices including indigenous rural technologies with special reference to Madhya Pradesh: A review

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Abstract
Climatic conditions in India are knowns to cause about 20% variability in productivity due to intra-and inter-seasonal fluctuations. Management of drought by employing various practices may help minimizing these variations in crops' productivity to a greater extent. Apart from many reasons, the poor resource baseness of farmers deter them to adopt improved technology particularly land and water conservation related activities. Rrainfall aberrations and frequent occurrence of drought spells of different degrees are the main reasons for low productivity. Drought management strategy consists of the two main approaches; (i) drought evading practices, and drought alleviating practices. This paper presents in very brief an overview of such practices which tend to alleviate the drought effects. Some examples from success stories have been given which are based on experiments done on research stations and also on-farm research experiences with specials reference to black clay soils of Madhya Pradesh.
Further, a lot of modern technologies and practices have been tried during recent past to conserve rain water and soil for enhancing the productivity on sustainable basis, traditional wisdom on 'Indigenous Rural Technologies' must also be linked and tried in a big way with suitable modifications, if any. This will not only help in maximizing agricultural production per unit of area but also trigger the people's participation in the process and therefore mitigating drought effects.

Keywords: Vertisols, drought mitigation, mulching, water harvesting, water recycling

Introduction

The fate of Indian agriculture depends upon Rainfed farming as it is practiced over 63% of the arable land and contributing about 45% of the total agricultural production. Very low average crop productivity of about 1 t/ha from these areas is really a matter of serious concern. Even an increase of 0.5 tones/ha of productivity from these areas will added around 50 million tones of additional food grains every year. Small and marginal farmers, having less than 2 hectares land dominate the farming community as they constitute 78.2% of total farm families and posses 53.7 million ha of arable land, practice rainfed farming. Apart from many reasons, their poor resource baseness deter them to adopt improved technology particularly land and water conservation related activities, rainfall aberrations and frequent occurrence of drought spells of different degrees are the main reasons for low productivity.

Climatic conditions in India are said to cause about 20% variability in productivity due to intra-and inter-seasonal fluctuations (Yadav and Singh, 2000) [42]. Management of drought by employing various practices may help minimizing these variations in crops' productivity to a greater extent. Further, a large area of 57.45 % in the bifurcated state of M. P. is reported to be degraded mainly due to water erosion. The rainfed farming is practiced on 69% of the cultivated area. Despite potentially productive soils and fairly good annual precipitation received (600 to 1600 mm) in different regions of the state, productivity of rainfed crops is very poor (About < 1 t/ha) for obvious constraints. Studies conducted over a period of about 3 decades revealed runoff losses in the range of 20% to 50% on medium and 5% to 25% on deep soils accompanied with tremendous amount of soil and nutrient losses (10- 34 Kg N/ha & 3-26 Kg S/ha). Frequent occurrence of droughts of different degrees coupled with Poor land and Water Management practices further aggravate the situation. There may arise either one or combination of the four kind of aberrant conditions leading to drought spells of varying duration. These may be; (1) Normal onset and withdrawal of monsoon having normal total precipitation in terms of amount but drought spells of 8 - 20 days duration in the middle of the rainy season, (2) Late onset of monsoon i.e. early season drought, (3) Late onset of monsoon and early withdrawal, and (4) Normal onset of monsoon but early withdrawal of monsoon.

What is a drought?

The American Heritage Dictionary (1976) defined Drought as a long period with no rain especially during planting season. The Random House Dictionary (1969) defined it as an extended period of dry weather, especially one injurious to crops. Drought may occur in high as well as low rainfall areas. Drought is indeed a many faceted natural disaster that leads to serious adverse socio-economic impacts, which have long-term implications on any country's economy. Farmers' term drought as deficient rainfall, lack of moisture or a dry spell resulting in low crop yields including crop failure. They realize that seasonal variations in precipitation and temperature are much more important in farming than annual averages.

Agricultural drought is usually defined as a period when insufficient water is available to support the normal activities of a crop over a fairly long period of time. Drought is distinguished from aridity and it may be expected that both very wet and very dry regions experience drought. From an agricultural standpoint, a Drought Index should record crop management on the phonological drought sensitivity. Weather technology should be collimated. Thus, the partition between weather effect on yields and technology should be diffused. Emphasis should be placed on identifying periods within a given growing season when drought related weather conditions have greatest effect like yield altering impacts and crops. An operational definition would be one that compares daily precipitation values to evapo-transpiration rates to determine the rate of soil moisture depletion and express these relationships in terms of drought effects on plant behaviour at various stages of crop development. Intensity of drought is a ratio of actual evapo-transpiration to potential evapo-transpiration (AET/PET) – during the growing seasons at various phenophases of crop growth (Table 1).

Broadly droughts have been classified into three categories, *viz*. Meteorological, Hydrological and Agricultural droughts. Meteorological drought is known as a situation when there is significant decrease (> 25%) of normal rainfall over an area. Prolonged meteorological drought which lead to marked depletion of surface and ground water levels are known as hydrological droughts while Agricultural drought means when both rainfall and soil moisture are inadequate during crop growing season to support a healthy crop. The probabilities of occurrence of droughts in different meteorological sub-divisions are given in Table 2. The severe drought years that occurred in 19th and 20th century in the country (Kulshreshta, 1997) [14] are shown in Table 3.

Table 1: Classification of drought intensity and severity.

Intensity of Drought	Severity of Drought
0.00 – 0.24	Severe
0.25 – 0.49	Moderate
0.50 – 0.74	Mild
0.75 – 0.99	Low
1.00	Nil

Table 2: Probability of occurrence of droughts in different meteorological sub divisions (Source: Apparao *et al* (1981) [4].

Meteorological sub-divisions	Frequency of deficient rainfall (75% of normal or less)
Assam	Very rare, once in 15 years
West Bengal, Madhya Pradesh, Konkan, Bihar and Orissa	Once in 5 years
South Interior Karnataka, eastern Uttar Pradesh and Vidarbha	Once in 4 years
Gujarat, east Rajasthan, western Uttar Pradesh, Tamil Nadu, Jammu & Kashmir and Telangana	Once in 3 years
West Rajasthan	Once in 2.5 years

Table 3: All India droughts during past 200 years.

Period	Drought years	Number of years
1801-25	1801, 04, 06, 12, 19, 25	6
1826-50	1832, 33, 37	3
1851-75	1853, 60, 62, 66, 68, 73	6
1876-1900	1877*+, 91, 99*+	3
1901-25	1901*, 04, 05*, 07, 11, 13, 15, 18*+, 20, 25	10
1926-50	1939, 41*	2
1951-75	1951, 65*, 66, 68, 72*+, 74	6
1976-96	1979*, 82, 85, 87*+	4

*Severe drought years = 10 (>39.5% area affected) +Phenomenal drought years = 5 (> 47.7% area)

Drought Management Approaches

A lot of experience has been gathered from long term experimentation for combating above referred situations and techniques have been evolved to alleviate the agricultural drought effects on crop productivity. Strategy consists of the following two main approaches; (1) Drought evading practices, and (2) Drought alleviating practices.

Individual farmers are used to reduce consumption, postpone social arrangements such as marriages and other functions etc, migrate to better areas with live stock or sell live stock, take consumption loans and sell assets like gold ornaments to cope up with the drought (Venkateswarlu, 1987) [41]. Only very few of the farmers are able to store food grains and fodder to tide over the crisis during the years of drought.

Strategies to alleviate drought effects include avoiding Kharif fallowing practice which still persist in many parts of the country, use of short duration, fast growing and high yielding varieties of crops in different cropping systems, inter-cropping systems, practices of soil profile stored moisture conservation through inter-culture, residue mulching, enhancing moisture retentivity through incorporation of FYM and crop residues, keeping weed free soil surface and rain water management i.e. runoff harvesting and its recycling during drought spells etc. Some of the important mid season corrections during severe drought spells e.g. reducing plant population pressure on land and defoliation practices have also been found useful. Adoption of certain agronomic practices *viz*; timely planting and inter-culture operations are also helpful in alleviating drought effects on crops.

The management options for mitigating early season and mid season droughts include raising a community nursery for cereal crops and transplanting the seedlings with the commencement of the rains, sowing of alternate crops / varieties depending upon the time of occurrence of sowing rains and if there is poor germination and poor plant stand, it is better to re-sow the crop. In western parts of the state of Madhya Pradesh if monsoon is delayed or there is failure of timely sown crops due to intermittent droughts then for delayed sowing of improved crops and their varieties may be chosen for planting (Table 4). If the dry spell after sowing is of short duration then gap filling is also recommended. Defoliation and uprooting of plants for reducing plant population pressure may also be the options but this has been the subject of controversy. However, defoliated and uprooted bio-mass are used as fodder and this practice tend to reduce depletion of soil moisture. Reduction in plant population and defoliation actually decrease yield potential after the revival of rains in the season. Instead, it is better to increase the total soil water available to the crop either through short term measures like weed control and mulching or through long term measures like land configurations.

Table 4: Contingent crop plan to tackle drought situations

S.N.	Period	Crops and their varieties recommended for planting
1.	(A) Up to July, 15	Soybean: JS-93-05, Samrat, Monetta, NRC-7.
		Maize: Sathi (Local), JM-8, JM-12, Navjot, IVM-421(Indore Vikas Maize, white, 100days duration, good for Rabi also)..
		Moong or Greengram: (On Shallow soils): JM-721, Khargone-2, Kopergaon, Pusa Baishakhi.
		Urid or Blackgram: (On shallow soils): JU-8-6, T-9.
		Cowpea: Gomati, PusaKomal & local varieties.
2.	(B) 15th to 31st July	Maize: Sathi (Local), JM-8, JM-12, Navjot, IVM-421(Indore Vikas Maize, white, 100days duration, good for Rabi also).
		Pigeonpea: (under deep soils preferred varieties ICPL-151 (Jagrati), T- 21, Kh-2, ICPL-87 (Pragati), ICPL 88039, ICPL87119(Asha).
		Sunflower: Morden, Surya, Manjira and other hybrids
		Sesame (Til): JT-21, JT-22, JT-55 & JTS-8 & Bhadeli (Local) etc.
		Cowpea: Gomati, Pusa Komal and Pusa DoPhasali.
		Castor: Gauch, Varuna and other hybrids.
		Niger (Ramtil): JNC-1
		Fodder crops:– Sorghumsudanensis, Maize- African tall, Dinanath grass and Bajra etc.
		Merigold (Flower): African tall, Pusa Narangi,Pusa Basanti & Sathi(local).
		Chillies- Pusa jawla & Agni.
		Leafy vegetables (for green leaves)-Coriander, Spinach, Amaranths & Fenugreek.
3.	(C) 1st to 15th August	Sunflower – Morden, Surya, Manjira and other hybrids.
		Sesame (Til) – JT-21, JT-22, JT-55 & JTS-8 & Bhadeli (Local) etc.
		Cowpea - Pusa Komal and Pusa DoPhasali.
		Amaranthus (Rajgira)-Co-1 and Co-2.
		Castor- Gauch,Varuna and other hybrids.
		Fodder crops: Sorghum Sudanensis, Maize-African tall, Dinanath grass & Bajra etc
4.	(D) 15th to 31st August	Safflower: JSF-1, JSF- 7 (spineless), JSF-73, Sharda
		Sunflower: Morden, Surya and Manjira other hybrids
		Sesame (Til): JT-21, JT-22, JT-55 & JTS-8 & Bhadeli (Local) etc
		Amaranthus (Rajgira): Co-1 and Co-2
		Castor: Gauch, Varuna other hybrids
		Fodder crops: Barley, Oats, Safflower and sunflower.

1. Soil and Rain Water conservation Measures

Various conservation practices *viz*; bunding, land form treatments, mulching are some of the options for in-situ soil and water conservation in arable areas. Of late mulching-cum-manuring has been recommended as an INM practice. Although graded bunds coupled with vegetative bunds have been found effective bunds majority of farmers are observed to be little reluctant to adopt these as they prefer field boundry bunds for bvious reasons (Table 5).

Table 5: Seasonal runoff, soil loss and nitrogen loss from black clay soil as influenced by vegetative barriers on 2% land slope at Indore (Ranade *et. al.* 1995) [19].

Treatments	Runoff (mm)	Soil loss (Kg/ha)	N loss (Kg/ha)
Check	115.7	986	23.85
Vetiver Grass	94.9	662	17.40
Graded bund	91.9	633	19.04
Bund + Cymbopogon	94.6	567	17.18

2. Runoff Harvesting and Its Recycling

There is always tremendous scope of harvesting and recycling runoff (Anonymous, 1981- 87) [2]. Runoff potential in western parts of the state of Madhya Pradesh varies from about 21 to 54% of annual precipitation depending upon soil type and intensity of rains. Runoff water may be collected during rainy season when it is in surplus and be utilised during drought spells. If there are no drought spells during the rainy season then it may be utilised for ensuring double cropping under rainfed situations. Experimental results presented in Tables 6 and 7 reveal the above cited fact. It is obvious from the data presented in Table 6 that only one irrigation of runoff collected water not only enhanced the productivity of rainy season soybean and maize by 14.2% and 17.0% respectively but an average production of chickpea (552 to 979 kg/ha) and of safflower (1290 and 1859 kg/ha) could be realised which otherwise was not possible.

Table 6: Influence of runoff recycling to kharif crops on yield of kharif and Rabi crops on black clay soils at Indore, M.P. (Sharma, 1990).

Cropping system	Yield of Kharif crops(kg /ha)		Yield of Rabi crops (kg/ha)	
	Control	Recycling of 8 cm runoff	Control	Recycling of 8 cm runoff
Soybean (Brag) – safflower (JSF 1)	1795	2050 (+14%)	Crop failed to emerge	1290
Soybean – chickpea	1795	2050	-do-	552
Maize (Ganga-5) – safflower	2945	3450 (+17%)	-do-	1859
Maize – chickpea	2945	3450 (+17%)	-do-	979

3. Use of suitable crops and varieties

Input-responsive, fast growing, short duration (i.e. duration matching with water availability period for a particular location) plant types bestowed with stress resistance should be preferred particularly where occurrence of drought spells is a common feature. Information on these aspects is now available for different agro-ecological zones. Growing crops and cropping systems according to soil types is the key factor for successful crop production even under adverse situations. Soil moisture storage capacity of shallow, medium and deep black clay soils is estimated to be 75, 150, and 300 mm respectively which corresponds to moisture availability period of about 90, 150 and 220 days under normal rainfall amount and distribution in the rainy season. Thus the priority of crops and their varieties should be such that their duration matches with the water availability period. The improved cropping systems have been evaluated for different soil categories occurring in Malwa region as have been given in Table 7.

Table 7: Different suitable cropping systems for different land conditions.

Soil category	Cropping system
Shallow black soils (depth <40cm)	Only kharif crops of short duration.
Medium black soils (depth 40-90 cm)	Single cropping in rainy season, soybean based inter- cropping systems e.g. soybean + pigeonpea /maize, sorghum, cotton.
Deep black soils (soil depth > 90 cm)	Inter-cropping system as above, soybean based sequential cropping i.e. short duration soybean followed by chickpea, linseed, wheat and safflower.

4. Inter-cropping Minimises Risk

Adoption of inter-cropping systems using appropriate crop components pays dividends as compared to sole cropping systems due to increased and water use efficiency (Table 8). In areas receiving 625 to 850 mm of rainfall and having medium and deep black clay soils, inter-cropping systems would lead to higher returns by way of diffusing the adverse effects of drought to a greater extent. The potential inter-cropping systems for western parts of the state of Madhya Pradesh are Soybean + pigeonpea, Soybean + Sorghum, Soybean + maize, cotton + blackgram etc.

Table 8: Productivity of soybean and pigeonpea in monocropping and intercropping systems in farmers' fields **(***LER = land equivalent ratio)

At Ringnodia micro-watershed, Indore, M. P, India	Yield (kg ha^{-1}) at different locations			Mean	LER*	Gross returns (Rs ha^{-1})
	1	2	3			
Pure soybean	960	780	765	835	1.0	6680
Intercropping of Soybean/Pigeonpea	782 + 940	636 + 826	652 + 786	690 + 851	1.7	18285
Pure Pigeonpea	1330	1140	-	1239	1.0	18585

5. Organic manures and crop residues alleviate drought effects

Organic manures, green manuring, compost, FYM and incorporation of crop residues are very well known to improve hydrophysical, chemical and biological properties of soils and thus alleviate the drought effects on growing crops for obvious reasons. Some experimental results of AICRPDA, Indore, summarised in Table 9 through 11, witness this fact. In these experiments, FYM in prescribed treatments was applied only once in the rainy season i.e. prior to planting of soybean every year; Crop residues in prescribed treatments was applied to both the crops as surface mulch inbetween crops rows followed by its incorporation in the soil in subsequent seasons every season; "RDF" refers to recommended dose of fertiliser N and P to each crop at the rate of 40 and 26 kg /ha respectively.

Table 9: Seed yield and sustainable yield index (SYI) of soybean –safflower due to different treatments (Mean for 7 consecutive years of 1992 - 1998-99 on rainfed vertisols).

Treatments	Crops in sequence		Seed yield (kg/ha)		Sustainability yield Index (SYI)	
			Soybean	Safflower	Soybean	Safflower
½ RDF	Soybean	Safflower	1614	892	0.31	0.16
RDF	Soybean	Safflower	1926	1405	0.44	0.40
½ RDF + FYM 6 t	Soybean	Safflower	2062	1645	0.51	0.53
½ RDF + Residues 5 t	Soybean	Safflower	1702	1341	0.37	0.43
FYM 6 t -	Soybean	Safflower	1856	1480	0.42	0.51
Resides 5 t	Soybean	Safflower	1589	1075	0.33	0.27
C.D. 5%	soybean	Safflower	147.4	243.9	-	-

Table 10: Seed yield of unirrigated safflower grown after soybean as influenced by residual effect of FYM (Mean of 1983 – 84 to 1987 - 88) (Sharma and Gupta, 1993) [36].

Treatments	Mean seed yield (kg/ha)		Water use efficiency (Kg/ha. mm)	
	Soybean	Safflower	Soybean	Safflower
N0 P0	1131	695	2.38	3.71
N20-40	1628 (+ 43.9%)	1132 (+ 62.9%)	3.32	5.79
N10-20	1517 (+ 34.1%)	955 (+ 37.4%)	3.08	5.03
6t/ha FYM alone in rainy season	1808 (+ 59.9%)	1539 (+ 121.4%)	3.66	7.19
6t/ha FYM + N10-20	1913 (+ 69.1%)	1692 (+ 143.5%)	3.86	8.70

Table 11: Water holding capacity and soil organic matter content changes due to application of farmyard manure (Average of 3 seasons.) (Sharma and Gupta, 1993) [36].

Treatments	Organic Carbon (%)	Max. Water holding Capacity (%)	Estimated volume of water in top 15cm soil (Lac lit./ha)	Soil Swelling (%)
Control	0.26	70.00	14.000	15.57
N20-40	0.30	72.16	14.432 (+ 0.432)	16.25
FYM 6t/ha	0.70	81.62	16.324 (+ 2.324)	17.44
6t/ha FYM + N10-20	0.66	82.12	16.424 (+2.424)	17.33

Note: One lac litres of water /ha = One irrigation of One cm water per hectare

6. Soil, straw and green biomass mulching

During post-rainy season period, excessive rates of water loss by evaporation should be minimized to increase water availability and water use efficiency of crops. Black clay soils form deep and wide shrinkage cracks during dry spellsleading to crop yields. Mulching with crop residues, green biomass, by way of influencing hydro-thermal regimes of soil not only enhance shoot and root growth, minimize weed population, increase water use efficiency of crops, but also in long run build up soil fertility and maintain soil health after their decomposition in subsequent seasons. Organic mulches have been found to be useful in improving crop yields during post-rainy season (Randhawa and Venkateswarlu, 1979) [17]. Various kinds of mulches cut down evaporative losses of soil profile stored moisture and enhance crop water use leading to enhanced water use efficiency and productivity of crops. Incorporation of these materials which are initially applied as surface mulch and later on incorporated in soil build up soil fertility in long run. Some of the research results have been summarised in the Tables 14 to 16. Soil and straw mulches have been known to minimize such losses and increase water use efficiency of crops (Sharma *et al* 1985) [31]. Sharma *et al*. (1982) [30] reported that rainfed wheat and safflower produced an additional grain yield of 161 and 153 kg/ha and witnessed significant increase in water use efficiency by 20% and 29.2% respectively due to soil mulching (Table 14).

Table 12: Influence of soil and straw mulching on yield and water use efficiency (WUE) of rainfed crops at Indore, Madhya Pradesh, India (Sharma *et al*, 1985) [31].

Parameters	Crops	No mulch	Soil mulch	Sorghum cob husk mulch (6 t/ha)
Yield (kg/ha)	Chickpea	1430	1750 (+22.4%)	1800 (+25.9%)
	Linseed	905	968 (+ 6.9%)	1043 (+15.2%)
	Wheat	1730	1837 (+6.2%)	1835 (+ 6.1%)
	Safflower	1755	1942 (+10.6%)	1822 (+ 3.8%)
WUE (kg/ha.mm)	Chickpea	6.5	8.1 (+24.6%)	9.4 (+44.6%)
	Linseed	3.9	4.3 (+10.3%)	4.6 (+17.9%)
	Wheat	6.6	8.2 (+24.2%)	7.5 (+13.6%)
	Safflower	6.8	8.1 (+19.1%)	7.6 (+13.8%)

Note: Figures in parentheses indicate increase in yield and WUE due to mulching.

Table 13: Effect of different mulches on mean yield of soybean and safflower grown in Sequence at Indore, M. P. (Anonymous, 1989-96) [2].

Treatments	Crops treated	Seed yield (kg /ha)		Yield increase (%)	
		Soybean	Safflower	Soybean	Safflower
Control	Both	1954	562	-	-
Soil mulch (I.C.)	Both	2188	881	10	58
Green weed biomass 6t/ha	Soybean	2450	778	23	38
Soybean stover mulch 4t /ha	Soybean	2315	791	17	41
Safflower tresh mulch 4t /ha	Soybean	2379	787	20	40

Note: I.C. refers to shallow interculture operation for creating soil mulch.

Table 14: Influence of soil mulching or shallow tillage in between crop rows on productivity and water use efficiency of rainfed crops (Sharma *et al*., 1982) [30].

Parameters	Crops	Treatments	
		No mulch	Soil mulch
Grain yield (kg /ha)	Wheat	1392	1553
	Safflower	685	838
ET from 90 cm soil (mm)	Wheat	165.4	154.5
	Safflower	165.7	156.7
WUE (kg/ha.mm)	Wheat	8.5	10.2
	Safflower	4.1	5.3

Table 15: Low till farming strategy for enhancing productivity and resource use efficiency. (Anonymous, 1999- 2003) [3].

Treatments	Seed yield (Kg/ha)				Water use efficiency (Kg/ha/mm)		
	1999	2000	2001	2002	2000	2001	2002
CT+RDF-OFFSEASON TILLAGE+HW	1521	1302	2054	1019	3.66	4.15	1.74
CT+RDF+OFFSEASON TILLAGE+HW	1577	1405	2130	1413	3.85	4.30	2.38
LOW TILLAGE+ 4t/ha STRAW+HW	1359	989	2064	1382	2.80	5.22	2.30

LOW TILLAGE+ 4t/ha STRAW+Hb	1200	926	2060	711	2.64	5.24	1.19
LOW TILLAGE+ 4t/ha COMPOST+HW	1457	1108	2058	1353	3.15	5.18	2.25
LOW TILLAGE+ 4t/ha COMPOST+Hb	1420	1038	2012	776	2.74	5.04	1.29
LOW TILLAGE+ 2t/ha GLIRICIDIA GREEN LEAVES+HW	1389	996	2064	466	2.80	5.21	0.80
LOW TILLAGE+ 2t/ha GLIRICIDIA GREEN LEAVES+Hb	1425	1055	1977	1388	3.07	4.96	2.31
CD5%	111.7	1047	NS	244.7	-	-	

Where CT =Conventional Tillage (summer cultivation fallowed by one cross cultivation before sowing),
LT= Low Tillage (plough plant), OT=Off Season Tillage (summer tillage), Hb= Herbicide use, HW = Hand Weeding.

Table 16: Rainfall, runoff, and other water balance components, water use and water use efficiency of Soybean due to different land treatments (Mean of 1988 –1997).

Treatments	Rainfall (mm)	Runoff (mm)	Soil loss (kg/ha)	Yield (kg/ha)	Deep Percolation (mm)	Water Flux to root zone (mm)	W.U. by Soybean (mm)	W.U.E. of Soybean (kg/ha.mm)
FLAT	831	111	1597 (Tr.– 4674)	1218 (262–1790)	190	77	572	3.05
BBF	831	96	1117 (Tr.– 2983)	1469 (929 – 2095)	148	51	595	3.29
BBTF	852	116	954 (Tr.– 2902)	1435 (952– 2100)	161	45	650	3.07
RSB	831	66	471 (Tr.– 1414)	1433 (852– 2014)	252	69	571	3.46

WU=Water use, & WUE= Water use efficiency, Tr= traces, Values in parentheses are range during study period

Table 17: Effect of conjoint use of tillage and organics on the yield and water use efficiency of soybean grown in rainfed Vertisols.

Treatment	Seed yield (Kg/ha)			Straw yield (Kg/ha)			Water use efficiency (Kg/ha/.mm)	
	1999	2000	2001	1999	2000	2001	2000	2001
T1- CT+RT+(-OT) + HW	1521	1302	2054	2877	3386	2179	3.66	4.15
T2- CT+RT+(+OT)+ HW	1577	1405	2130	2897	3470	2566	3.85	4.30
T3-LT+4t/ha straw +HW.	1359	989	2064	2510	2583	2202	2.80	5.22
T4- LT+ 4t/ha straw +Hb	1200	926	2060	2421	2536	2569	2.64	5.24
T5-LT+ 4t/ha compost +HW	1457	1108	2058	2860	2828	2571	3.15	5.18
T6- LT+ 4t/ha compost + Hb	1420	1038	2012	2862	2717	2717	2.74	5.04
T7- LT+ 2t/ha gliricidia green leaves + Hb	1389	996	2064	2629	2593	2466	2.80	5.21
T8- LT+ 2t/ha gliricidia green leaves + HW.	1425	1055	1977	2708	2698	2355	3.07	4.96
CD5%	111.7	104.7	NS	151.9	269.5	NS	-	-

7. Tillage, land configuerations and land treatments

Low tillage or minimum tillage practices, certain cost effective land configurations and land treatments alone and coupled with residue applications have been reported to be useful in minimizing the drought effects by way of conserving rain water, soil moisture and enhancing the water use efficiency of rainfed crops (Gupta and Sharma, 1990). The experimental results presented in Tables 15 through17 substantiate this fact.

8. Contingent crop plan to tackle drought situations

If monsoon is delayed or there is failure of timely sown crops due to intermittent droughts then for delayed sowing improved crops and their varieties may be chosen for planting. If the crops encounter moisture stress late in the rainy season or reproductive stage due to early cessation of rainy season, there may be rise in temperature hastening the process of crop maturity (forced maturity). The crop yields are highly correlated with the water availability conditions during reproductive stage of growing period (Ramana Rao *et al*, 1983; Rao *et al*, 1984) [16, 18]. Short duration, high yielding varieties may are known to escape late season droughts. In situations where there is availability of water even in limited quantity then it is recommended to irrigated the crops using water saving irrigation methods like alternated furrow method, drip or sprinkling etc. Increased water use efficiency of crops can be achieved by using improved irrigation methods. For example; alternate furrow irrigation, sprinkling, drip methods are known to be most effective and economic as they apply water without much loss and can irrigate 1.5 to 3.0 times area compared to flooding for the same amount of water. These methods are specially suitable for slowly permeable soils, undulating topography etc and are more profitable in high value vegetable and horticultural crops.

There are some other measures which tend to conserve soil profile stored moisture and in-situ rain water conservation. These are; (1) Soil and straw mulching, (2) Agricultural operations across the land slope, (3) Agronomic measures for rain water conservation e.g. Ridge and furrow planting, BBF, NBF, Graded furrows after each 6 – 10 m interval across the slope etc., (4) Weed control measures and (5) Life saving irrigation through sprinklers etc.

Land and water management practices

Vast areas of arable land have become degraded because of fast disappearance of vegetal cover from earth's surface. The major constraints that limit the productivity of rainfed crops in black clay soil regions are soil related, climatological, biological, technological and socio-economic. We, therefore, are left with no choice but to regenerate the environment and utilize the nature in a planned manner following a holistic approach aimed at optimizing the use of available natural resources (Land, water and vegetation) in an area so as to prevent soil erosion, improve water availability, alleviate drought, moderate floods and increase food, fuel, fibre and fodder production on a sustainable basis.

Land management should aim at providing the safe drainage, in situ conservation of soil and rain water, maintenance of soil health and ultimately enhanced productivity of crops. Rain water management, water harvesting, recycling and runoff control are the central issues in the NRM while ground water recharging is considered a larger issue in the tube well/ wells irrigated area. Further, for enhancing the productivity of various crops, some cost effective indigenous technologies related to balanced nutrition of crops, crop diversification, improved farming systems' components (sequence cropping, intercropping systems, agro-horti systems, silvi-pastoral systems, agro-forestry systems, livestocks, poultry, goatery, fish culture, piggery) also deserve to be linked with the conventional conservation activities.

Cost effective conservation measures for land and water which have been found effective in rejuvenating the productivity of crops and live-stocks include improved land, water and crop management practices depending on the land capability and rainfall situations. For high rainfall areas (1200 mm or more annual precipitation) raised-sunken bed system, broad bed and furrows and broad bed and tied furrows have shown promise in conserving rain water, nutrient and soil resources and making their efficient utilisation by arable crops (Gupta and Sharma, 1994) [11]. For relatively low but dependable rainfall situations (700 - 1000 mm annual rainfall), land management practices *viz*, land shaping, construction of low cost earthen mechanical structures such as water diversion bunds, small cross section graded bunds, graded furrows (Gupta and Sharma, 1990, Sharma and Ranade, 2004), grassing of waterways, stabilisation of gullies, reclamation of washes, and drop structures have been found effective in long run over traditional system of contour bunding or field bunding in black soil regions. Vegetative barriers alone or in combination with earthen graded bunds have been found useful and effective means of conserving land and water resources. Agronomical practices for efficient utilization of these resources have also proved beneficial on large scale. These include planting of crops on different land configurations, integrated nutrient supply system, conjunctive use of organics and chemical fertilisers, conservation of soil profile stored moisture through the use of mulches and increasing water use efficiency of crops.

Watershed development approach

In order to achieve these goals, we choose a piece of geographical area starting from the highest point and draining into a single outlet. The area thus delineated is called a "watershed". The technology for the watershed development should consists of land and water management practices, and crop husbandry practices.

Land and water management practices

Land and water management practices would depend upon whether the erosion or water logging/ water stagnation or both are the problems. Practices of controlling soil erosion aim at slowing down the velocity of runoff water, allowing most of it to soak into the soil or to drain off slowly to the natural streams. Various activities are; (1) stabilization of slopes > 6% with shallow soil by vegetative cover, (2) bench terracing on land with slope > 6% and with deep soil, (3) water diversion bunds, (4) grassed waterways, (5) mechanical structures for stabilization of waterways, (6) graded bunds / planting appropriate vegetation on a grade, (7) waste-weirs, (8) gully reclamation works, and (9) water harvesting works.

Practices that control water logging and water stagnation are; water diversion bunds, grassed waterways, graded drainage channels, and stabilization works for waterways and drainage channels. The basic principle is to use land according to its capability, taking into consideration the type of land, its slope, and the depth of soil. Also, to achieve maximum moisture use efficiency; the land is to be cropped during the period in which most of the rain received. Various activities are; (1) Afforestation of bare hillocks, (2) Planting grass on sloppy lands with shallow soil, (3) Short duration crops/varieties on moderately or less sloppy land with shallow soil, (4) Intercropping on medium deep soil, (5) Sequential cropping on deep soil after providing crop drainage in rainy season, and (6) Growing more remunerative crops / varieties. Some low cost conservation practices which have been found useful are; (1)Sowing crop against the slope on sloppy land, (2) Planting on grade rather than on graded broad ridges, and (3) Providing surface drains / graded furrows on flat land (between crop rows).

Improved Package of Practices

Benefits of the conservation technologies can not be realized unless crops are grown with improved package of practices for different crops and cropping systems. These include; (1) Appropriate land management and seedbed preparation, (2) Selection of crop/varieties, (3) Seed grading /treatment, (4) Early but safe planting, (5) Judicious use of fertilizers, (6) Control of weeds, (7) Control of pests and diseases, (8) Harvest at physiological maturity, and (9) Post-harvest technology and value addition etc.

Indigenous Rural Technologies

Although a lot of modern technologies and practices have been tried during recent past to conserve rain water and soil for enhancing the productivity on sustainable basis, traditional wisdom on 'Indigenous Rural Technologies' must also be linked and tried in a big way with suitable modifications, if any. This will not only help in maximizing agricultural production per unit of area but also trigger the people's participation in the process. There is a lot of indigenous technological knowledge (ITK) which are being practiced in rural areas for the conservation of natural resources particularly rain water, soil and efficiently utilizing them for enhancing the productivity of crops. Some of these have beeen summarized here.

1) **Bunding/Bandhan Making/ Pal making:** This is an age-old practice and has been evolved from experience of controlling floods. This practice consists of earthen bunds which are constructed manually to check runoff and impound runoff water in kharif fallow lands. The bunds are covered with grasses like *Dicanthium annulatum*, *Chrysopogen fulvus*, *Sehima nervosum* etc. These grasses are regenerated naturally. This costs about Rs. 500/-ha and occasional maintenance is required. It is cost effective, technically feasible apart from socially acceptable. This can be adopted in a big way. Advantages of this ITK are making field boundaries, use of surface area of the bund for production of grasses to account for the loss of land area due to bunding.
2) **Deep ploughing in summer:** This practice has been evolved from experience and ploughing in cotton growing areas since ancient time. About 1-2% of the farmers are practicing this in villages. In this practice farmers are ploughing the land upto depth of 20-30 cm by M.B. plough during summer season, it controls perennial weeds like Saccharum, Ziziphus and others. This practice is very common in Malwa plateau. The cost of adoption is Rs. 2500/-ha with bullock drawn implement and Rs. 1500/-ha for tractor drawn implement. It is technically suitable apart from providing comparative yield advantage of 12 to 15%.

This practice is socially acceptable. This can be done in 3 years. This can be adoptable in big way.

3) **Crop stubbles/Residue Management:** This practice is most common and prevalent practice in wheat growing tracts. After harvest of wheat crop residue are put to firing or burning in fields itself. But some farmers practice incorporation of crop residue on individual basis. This has been evolved from the experience in preparation of seedbed by cultivators and is being practiced since ancient time. The incorporation of residue is done after harvest of crops by plough/bakher. The cost of adoption in Rs. 350-400/ha. This practice helps to increase moisture holding capacity along with improving organic matter content in the soil. This practice can be simplified by using implements like rotavator. This practice is socially acceptable and technically feasible. This practice should be adopted in a big way. This ITK mproves organic matter content and water holding capacity in soil.
4) **Application of tank silt:** This ITK is adopted by medium and big farmers on individual basis. This is an age-old practice. In this practice, during summer season tanks and ponds are desilted and silt is transported and spread on cultivated fields. This is done by bullock carts, dumpers, trollevs and even manually. This is to be maintained periodically. This practice should be adopted in a big way. This helps improved water storage capacity of tank and improvement in soil health.
5) **Interculture operation:** This ITK practice is followed by all categories of farmers on individual basis since ancient time. A mini blade harrow namely 'Dora' is adopted by 100 % farmers in all the villages in Malwa and Nimar regions of M. P. In this practice, after 10 to 30 DAS of kharif crops 'Dora' is operated in between the rows by one bullock pair and 2 to 4 labourers. Two or three Dora operations within a month time after sowing are most common in soybean and more so in widely spaced crops like maize, cotton etc. The cost of adoption is Rs.350/ per hectare. This practice can be improved by tractor drawn interculture Dora to cover large area per unit time. This costs Rs. 350-400/ha and comparative yield advantage is 15-20%. This practice is cost effective and technically suitable apart from socially acceptable. This practice is adoptable in a big way. It controls weeds, helps in aeration of root system, and makes soil friable for better interception of rainfall, It breaks capillarity to reduce evaporation and helps in earthing up of crops.
6) **Strip Cropping:** This ITK is adopted in erodible and sloppy areas. In this practice, sowing of soybean and maize is done with 10:10 row ratio in broad strips. Rows of soybean act like erosion resisting crop. This improves the soil and moisture conservation in the fields and is cost effective and technically feasible. It is known to reduce runoff and soil erosion.
7) **Inter row Cropping:** This ITK is practiced by small and medium farmers on individual basis. This is practiced for the last 25 years. Less than 5% of the problematic area is under this practice. This practice is soybean based with maize/pigeonpea/sorghum in Kharif season in 4:2 ratio and wheat based with chickpea/linseed in rabi is sown as intercrop by *Dufan/ Tifan* (bullock drawn) implement. The Cost of adoption is Rs. 400/ha for one pair of bullock and 3 labourers. This helps in mitigating the aberrant weather conditions, better moisture conservation and soil fertility improvement.
8) **Green capping:** This ITK is adopted by all categories of farmers on individual basis. This practice is evolved from growing of vegetation on the hillocks to reduce the runoff and is in practice since ancient time. This practice covers a considerable area in the villages. In this practice, planting of grasses like *Dichanthium, Cenchrus, Chrysopogan fulvus* etc. shrubs on the hillocks, trees on slopes. There is restricted grazing on permanent pastures and grass lands. No recurring cost is involved in this practice. The pasture is regenerated automatically. This is cost effective, technically feasible apart from socially acceptable. This practice helps in reducing soil loss, water loss and nutrient loss. Sowing across the slope will help in increasing the time of concentration. It reduces the soil, water and nutrient losses and Increase in biomass.
9) **Green manuring:** This ITK is adopted by big category farmers since ancient times. Very few farmers are practicing this. In this practice, growing of green manure crops like sunhemp, sesbania and cowpea and turning at maximum vegetative growth after 1 to 1 ½ months of sowing. Turning ensures proper incorporation of green manure and adequate rainwater conservation in the field. This practice is, technically suitable apart form getting 10-15% more yield. Advantages of this practice are improvement in organic matter content soil, About 25-30 % N requirement of crop is met through N-fixation by green manure crops and also increased organic matter enhances the release of fixed nutrients form soil pool, and improvement in water holding capacity.
10) **Talab/ Pond:** This ITK is practiced by all categories of farmers on individual basis. This is an age-old practice. About 3 % of the cultivated area is covered under this practice. In this practice, pond is constructed by hiring machinery and labour on community basis to store runoff water. They can be made by putting along obstruction across the flow of water or by making dug outs. This has to be maintained every year. Due to electric power supply problem, the well water is pumped in to the tank at night and pond water is used during day time for irrigating the near by crops by gravity. Water is used by gravity or by pumping. This practice can be adopted in a big way on community basis. This practice helps meet out domestic needs, improves water level in nearby wells, avoids water-logging of lower reaches of the fields.
11) **Earthen bunds supported by vegetation:** This ITK is adopted by all categories of farmers on an individual basis. About 2 to 5% of the farmers are practicing in the problematic areas. In this method, farmers grow pigeonpea on bunds of sloppy lands. Some farmers raise bamboo on the bunds. Few farmers grow vetiver grass for stabilizing the bunds. The cost of adoption of this practice is Rs. 1000 to 3000/ha. It is cost effective and technically feasible and accepted by the farmers. This practice can be adopted in a big way. This practice helps in erosion control, stabilization of bunds, stabilization of banks of rivers, and waterways etc.
12) **Dug Wells:** This is practiced by all categories of farmers on individual basis. It is an age-old practice. In this system 2- 6 m diameter well is dug manually. The depth of the well varies from 5-12 m depending on the availability of groundwater in the shallow aquifer. The wall of the well is pitched by setting foundation stones upto a height of 1 m above the ground level. The water lifting system is installed in the well. The cost involved in this practice is Rs. 20,000 to 50,000 depending on the size of the well.

This practice requires improvement as the adoptability is very good and the users take water from the wells wither manually, mechanically or electric pumps or motors for domestic use and irrigation. This is socially acceptable. Dug well water is used for drinking, domestic and irrigation purpose. Dug wells ensure the use of shallow aquifers.

13) **Haveli/Bharel system:** This practice is most common in central M.P. as 15-20% of the farmers of the villages follow this. In this practice, the haveli field is surrounded by earthen bunds all around and the rain water is collected in the Haveli up to the month of September. Thus is adopted on slope up to 3%. The bund height is about 1-2 m and width 1-3. The size of the bund is increases with the increase in land slope. In may havelies, summer ploughing (MB plough once in 3 years) is done before the onset of monsoon. Harrowing is done after first showers to kill weeds. The average size of haveli is 2-6 ha. Then the water is drained off in October when the field preparation condition is achieved; sowing of Wheat, Chickpea, lentil, pulses, coriander, mustard, peas etc. is done in the receding moisture. The cost involved for making the surrounding bunds is Rs. 20000 per ha. Besides, the bunds have to be maintained manually every year. This practice is the best device for reducing soil loss. water loss and loss of nutrients, besides controlling weeds in Kharif season. Haveli system is an age-old practice. This practice controls weeds and increases yield of crops through rainwater conservation.
14) **Bandh system of cultivation:** This ITK is practiced by big and medium farmers on individual/community basis. This covers about 20-30% of cultivated area having low lying areas. This is an age old practice. The construction of vandh is usually done by manual labourers. The cost of construction of bandh ranges from Rs. 50, 000 to 2,50,000 (1 ha to 5 ha). The cost depends on size of bandh. This structure requires maintenance needs of Rs. 3000 to 5000/- in alternative years. This bandh area may be utilized to kharif crops by way of making water harvesting pond in 10% pond in 10% of area. This practice is cost effective and technically feasible apart from 10% higher yield in kharif crop by providing life saving irrigation during kharif. Besides, rabi crops are also assured. This practice is socially acceptable for adoption.
15) **Tank (Talab):** This Practice is adopted by large category farmers on individual and community basis. This is an age old practice. About 1 to 3% of farmers make talab. In this practice, 2 to 3 m deep low lying field is excavated using bulldozer or excavators. Then the whole tank is surrounded by excavated earth. The cost of construction is 1 lakh to 5 lakh rupees depending on size of the tank. This tank is to be desilted and cleaning of vegetation, garbage are to be done once in 3 to 4 years. Water lifting devices for irrigation system, fish growing, singhara (water nut) cultivation and green capping surrounding bund may be improved for greater adoption of this practice. The tank needs bund strengthening and repairing once in 3-4 years. Advantage of the ITK are availability of water for use through out the year, Fish and waternut cultivation possible, recharge of water table, water is available for irrigation, livestock and recreation purposes.
16) **Earthen check dams:** In this practice, farmer make earthen bund for creating water reservoir after recession of rains to collect lean season flow. A dam waterway is used to irrigate the fields, which are situated near the bank of waterway. Any type of water lifting device can be used for water supply. The cost of construction in Rs. 2,000- 5,000 per bund/ check dam. This structure collapses every year. This structure can be made stronger using stones and RCC. Pucca check dam is suggested at minimum cross-section of the waterway. Such check dams may be built-in series after every 100 to 200 meter length of water-way, this costs Rs. 10,000 to 35,000 per dam. This helps to supply the water to both sides of the fields. Water may be stored for a longer period, fields located on either side of the waterway get at two irrigation.

Water conservation measures experimented

The measures for conserving rain water *in-situ* and its safe disposal on cost effective basis include ridge and furrow system, graded furrows, raised and sunken beds system, broad bed and furrows, broad bed and tied furrows, etc.

i) **Ridge and Furrows:** Ridge and furrow system envisages planting of upland rainy season crops on ridges laid out on such soils having slope less than 1%. Furrows serve an effective means of surface drainage and carry excess water into cut off drains dug across the slope. Spacing of cropped rows and rainfall would be deciding factors for specification of ridges. The system has proved highly effective in medium to high rainfall areas (rainfall ranging from 700 to 1200 mm).

ii) **Graded furrows:** In areas receiving moderate rainfall (less than 1000 mm), productivity of upland rainy season crops can be substantially increased simply by providing graded furrows of 0.2 to 0.3% slope which can conveniently carry runoff water to drainage channel. Spacing between such furrows may vary from 8 to 10 m depending upon slope and rainfall characteristics.

iii) **Broad bed and furrows (BBF):** This system consists of a series of broad beds and furrows (Kanwar *et al*, 1982) [12] accommodated in 90 - 150 cm wide parallel running strips. These are developed with the help of two furrow openers and a bed former attached to a bullock drawn or tractor drawn tropiculture (Sharma and Gupta, 1990-96) [25]. In this system beds and furrows are created on a grade of 0.5%. Furrows drain into grassed waterways. This system permits collection of runoff water in a tank provided down the slope. The system permits safe disposal of runoff, tends to conserve soil and water *in-situ*, reduces soil and nutrient losses and enhances crop productivity and sustainability (Tables 16 and 17).

iv) **Broad bed and tied furrows (BBTF):** This system is similar to BBF except that furrows are tied with small cross section earthen bunds at a regular interval of 10 m in mid August month to retain runoff, if any, towards the end of rainy season for the benefit of rainy season crops during reproductive growth phase. In a long term study conducted by authors (Tables 18) average reduction in the loss of soil due to sheet erosion, N, P, K and S was 40.3%, 3.5%, 13.5%, 16.9%, and 1.1% respectively while enhancement in soybean seed yield, water use by crop and water use efficiency was 17.8%, 13.6% and 0.7% respectively due to broad bed and tied furrows system over conventional system.

v) **Raised and sunken bed system (RSB):** In black clay soil regions with assured and high rainfall, the upland rainy season crops suffer because of poor drainage during periods of continuous and intense rainfall. On sloppy lands, runoff causes severe soil and nutrient losses. RSB system allows sustainable production of *Kharif* crops. This system is of semi-permanent nature and consists of an array of raised and sunken beds of 6-8 m and 3- 4 m widths respectively, with elevation difference of 15 - 30 cm. The system is created by mechanically shifting soil from demarcated 3- 4 m wide strips, designated as sunken beds to adjoining 6 - 8 m wide strips called raised beds. Sunken beds are tied with small cross section earthen bunds of about 10 cm height at 20 m distance interval to ensure uniformity in runoff retention. Raised and sunken bed system ensures surface drainage, encourages *in-situ* rain water conservation and retards soil erosion and nutrient losses to a considerable extent. The runoff from raised beds, planted to any upland crop, is arrested in the adjacent sunken beds supporting a relatively water tolerant crop such as upland rice. The dimensions of beds would depend on many factors *viz*; rainfall amount and intensity, runoff potential and water intake rate of soil under consideration. For example, in central parts of the state of Madhya Pradesh, India, water intake rate of soil is poor (4 - 6 mm/hour) and annual rainfall is high (> 1200 mm), 3 to 6 m wide raised beds with elevation difference of 20 to 30 cm have been observed to work successfully (Gupta *et al,* 1978) while for western regions of the state, where water intake rate of soil is relatively high (10 - 12 mm / hour) and rainfall is moderate (less than 1000 mm), 8 m wide raised beds alternated by 4 m wide sunken beds with elevation difference of 15 to 20 cm have been found suitable (Gupta and Sharma, 1990a, Gupta and Sharma, 1990b, Sharma and Gupta, 1990, Gupta and Sharma, 1994) [9, 11] for conserving rain water, soil and plant nutrients *insitu* and significantly high soybean yields particularly in heavy rainfall seasons.

Table 18: Yield of soybean, loss of soil and plant nutrients due to different land Treatments (Mean of 1991 – 1997).

Treatments	Yield (kg/ha)	Soil loss (kg/ha)	Nutrient loss (kg/ha)			
			N	P	K	S
FLAT	1218 (262– 1790)	1597 (Tr. – 4674)	17.91 (Tr.– 34.9)	0.37 (Tr. – 0.8)	0.77 (Tr. – 0.8)	8.52 (Tr.–14.6)
BBF	1469 (929– 2095)	1117 (Tr. – 2983)	15.03 (Tr.–21.35)	0.32 (Tr. – 0.75)	0.84 (Tr.– 1.12)	9.11 (Tr.–13.5)
BBTF	1435 (952– 2100)	954 (Tr. – 2902)	17.28 (Tr.–27.89)	0.32 (Tr. – 0.73)	0.64 (Tr.- 0.66)	8.43 (Tr.–13.20)
RSB	1433 (852– 2014)	471 (Tr. – 1414)	9.26 (Tr.–15.99)	0.28 (Tr.– 0.64)	0.38 (Tr. – 0.44)	5.48 (Tr.–11.46)

Tr.= traces, Values in parentheses are range during the study period.

Erosion control measures

Erosion control measures include various mechanical, biological and agronomic practices as discussed below:

a) Mechanical measures

Some of the cost effective and promising erosion control measures are discussed below:

- **i) Gabion structures:** "Gabion" structures have been successfully used on large scale in black clay soils (Verma and Raje, 1981) [40] for reclaiming gullies. A "*gabion*" is a flexible structure of loose boulders packed into prefabricated galvanized iron wire netting. Drop structures of various sizes and shapes can be made by placing a number of such boxes (gabions) together at the top of one another as per requirement. Gabions have been found more effective than masonry structures of the same design as they are porous, flexible and allow the runoff water to pass through while retaining the silt upstream. Because they are flexible in nature, gabions are highly suited to black soils which exhibit structural changes during wetting and drying.
- **ii) Graded bunds:** Mechanical bunds of 0.3 m^3 cross section are laid along a grade of0.3%. They have been reported to minimize soil erosion from lands up to 6% slope (Verma, 1981) [39]. The optimum vertical interval for graded bunds for land slope up to 1.5%, 2%, 3%, 4%, 5%, and 6% has been reported as 1.3 m, 1.5 m, 1.7 m, 1.8 m, 2.0 m, and 2.2 m respectively (Gadkary, 1966) [7].
- **iii) Conservation ditches:** In vertisols, conservation ditches can also be adopted, which serve the dual purpose of terrace and small water storage structures (Patnaik *et al*, 1982) [15].
- **iv) Water diversion bunds:** Diversion of runoff water coming off a hillock or upper land reaches into cropped fields saves the land from inundation, erosion and degradation. This can be achieved by constructing a bund with a shaped drainage channel along it on a grade of 0.2 to 0.3 per cent. The cross section of the bund will depend upon the rate of runoff and catchment area contributing runoff to be diverted. The base width of 1.0 m, 1.5 m, 2.3 m, and 3.5 m for 20 ha, 30 ha, 40 ha and 50 ha catchments area, respectively has been suggested by Gadkary (1966) [7]. The optimum side slope of a bund is considered to be 1.5 to 2.0: 1.0. If the catchment area includes a bare hillock, the base width has to be increased by about 50% and pitching with boulders at the bunds may also be required. Appropriately located diversion bunds lead the water safely into a natural drain or into a grassed waterway either constructed or available for this purpose.
- **v) Bench terracing:** Bench terracing coupled with plantation of trees and grasses on lands having more than 6% slope is an effective measure of erosion control.
- **vi) Grassed waterways:** Grassed waterways are required to be constructed at suitable sites to lead water diverted by storm drains or water diversion bunds and graded bunds to natural stream. The cross section of a waterway would depend upon the rate of runoff, catchment area and of permissible velocity of flowing water. The permissible velocity of flowing water for a bare sandy soil, bare clay soil, grassed soil, and weathered basalt (*Murrum)* or hard rock are 0.5, 1.0, 1.4 and 1.7 m/ second, respectively (Verma, 1981) [39]. If the bed of waterway is too deep, it gets eroded when the velocity of water exceeds these limits and in such cases the bed of waterway should be stabilized by constructing suitably designed *gabion* structures at appropriate sites.
- **vii) Stabilisation of washes:** Washes formed in the cultivated fields may develop into gullies if not controlled in initial stages. Stabilization of washes can be achieved by leaving that strip of land uncultivated over which water flows so

that grasses may be planted initially and some may develop naturally. If a wash is in advanced stage of erosion and getting deeper and wider every rainy season, it is essential to provide drop structures. For a shallow wash (depth up to 50 cm), a rectangular weir type drop structure of loose boulders at appropriate site with reverse filter (consisting of pebbles, gravels and sand layers) upstream from the structures will be sufficient. For deeper washes (depth more than 50 cm), appropriate *gabion* structures are necessary.

viii) **Provision of drainage between waterways:** Safe disposal of runoff water from areas between waterways is essential. For this, construction of open drainage channels on a grade at suitable intervals from ridge to grassed waterway has been found effective. The cross section of drainage channels will depend upon the rate of runoff and the area of its catchment. Depending upon the difference in the bed level of the grassed waterway and those of fields to be drained, drains or suitable fall structures have to be provided.

ix) **Gully Control:** Stabilization and reclamation of gullies is very essential as otherwise gullies go on widening and deepening with time due to falling of banks and bed erosion. The menace continues forever as side gullies start developing from secondary and tertiary washes resulting into the formation of a net work of small shallow-narrow and big wide and deep gullies. In this way in long run a lot of cultivable and fertile land turns into waste and unproductive lands. Construction of drop structures in the gully at appropriate points would help in controlling them. Planting or seeding of suitable grass species at the bed and on the sides of gullies help in stabilizing them. Fast growing locally available grass species may be useful for this purpose. Repeated seeding / planting of grass species in the beginning, middle and end of rainy season is essential to ensure good vegetative cover.

b) Biological Measures

Biological measures are generally used as preventive measures. These include appropriate plant cover, straw mulching, vertical mulching with stalks of maize or sorghum or any other crop residues and vegetative barriers.

i) **Planting of a Cover Crop:** A rainy season crop which tends to develop a thick canopy, intercepts rainfall and dissipates energy of falling rain drops is helpful in reducing soil erosion**.** Soybean, maize and sorghum crops are quite effective in this regard as they develop canopy at fast rate.

ii) **Mulching with Crop Residues:** Plant residues application are effective in enhancing the infiltration and reducing runoff. The immediate advantage of incorporation of crop residues in soil is to enhance infiltration and retard runoff losses. Later on, upon decomposition, it adds nutrients for the benefit of crops and enhances water use efficiency. Usually they can be applied at the rate of 5 to 8 t/ha. After emergence and establishment of crops, straw or crop residues may be spread in between crop rows. Straw mulching besides reducing erosion and enhancing infiltration, increases water use efficiency of crops to a considerable extent (Sharma *et al* 1985a, Sharma *et al* 1985b; Tables 12, 13, 14) [22].

iii) **Vegetative Barriers/Hedges:** Vegetative barriers/ hedges have been found useful in reducing the rain water runoff water and conserving soil and plant nutrients. These are also helpful in stabilizing the earthen bunds, particularly in black soil regions where masonry structures have limited utility due to swell shrink nature of these soils. For this purposes a number of grass species have been identified. Grasses such as vetiver, *Cymbopogon martinii* have proved to be useful (Table 5). Vegetative hedges are established at 0.5 to 0.75 m vertical interval. Two rows planted 30 cm apart make a good hedge which should be regularly cut to maintain 30 cm height.

c) Agronomic measures

Land use system should be based on land capability classes as far as possible so as to ensure efficient use of land and profile stored water. Agronomic practices which encourage conservation of soil, rain water and plant nutrients and enhance use efficiency of these resources are soil mulching Table 12), plastic mulching, contour farming, strip cropping, integrated nutrient management practices and minimum tillage practices etc.

i) **Soil mulching / shallow interculture / shallow tillage:** Soil mulch created in-situ tends to reduce evaporation as it minimizes and delays development of shrinkage cracks and besides providing a diffusion barrier (Sharma and Gupta, 1984, Gupta and Sharma,, 1990b, and Sharma and Gupta, 1990). Soil mulch may be created with the help of a suitable implement (hand-hoe, blade harrow etc.) in between crop rows as and when required. Animal drawn small blade harrow (blade width of 15 to 30 cm) can be conveniently operated in between crop rows to create soil mulch in-situ during early growth period of rainy season crops like soybean, maize, sorghum, cotton and pigeon pea etc. It can create 2 to 3 cm loose soil and removes growing weeds. During post-rainy season period, soil mulch delays the appearance of shrinkage cracks. Effectiveness of soil mulching varies with the crop type. On an average 6 to 25 per cent increase in water use efficiency of post rainy season crops can be realized due to soil mulching. (Tables 12, 13 and 14).

ii) **Deep tillage practice:** Deep tillage prior to onset of rainy season is practiced mainly with a view to increase infiltration and thereby reduce runoff, soil erosion and weed population. Off season deep tillage, particularly in subnormal rainfall years, has been found useful in conserving the soil and water resources and enhancing the crop yields substantially.

iii) **Plastic Mulching:** Plastic mulches although conserve soil profile stored moisture leading to sustainable increase in water use efficiency and crop yields but they are not cost effective for large scale adoption (Sharma, 1976) [20]. They can be of immense use for soil solarization (meant for minimizing the incidence of weeds and soil borne diseases), or for growing cash crops.

iv) **Contour Farming:** In contour farming, tillage operations are done along the contour lines as far as possible. It creates numerous ridges and furrows which retain a good volume of rain water after each wet spell. This water eventually infiltrates into soil. There is corresponding reduction in runoff volumes and therefore in erosion of soil and plant nutrients. Experiments conducted at Octacamond (India) have shown that by adopting contour farming for potato, cultivated on 25% slope, runoff was reduced from 52 to 29 mm and soil loss from 39 to 15 t/ha when rainfall received was moderate.

v) **Strip Cropping:** Strip cropping is the method of growing strips of cover crops in the same field along contours for controlling water erosion. Broad leaf pulses and grasses usually provide effective strips for reducing runoff and erosion.

vi) Run off farming: Harvesting of runoff at micro level, its storage and recycling for life saving irrigation during long dry spells improve productivity of a rainy season crop. The water thus stored can also be used for establishment of a post rainy season crop. This practice if adopted on large scale is potentially capable of addressing twin problems of water stagnation during *Kharif* and moisture stress during *Rabi*. An appropriate land management system combined with water harvest and recycling system seem to offer vast prospects of improving productivity of Indian vertisols even under rainfed conditions.

vii) Minimum tillage: Minimum possible disturbance of soil surface can save soil from erosion to some extent. For erosion control in gently sloping areas, mixed cropping or intercropping may be practiced in order to cover the maximum surface for a longer period. Minimum tillage during post rainy period reduces evaporation from soil, improves establishment of post rainy season crop (Sharma, 1990a) [23].

viii) Integrated nutrient management: Integrated fertility management envisages the conjunctive use of organics such as FYM, compost, green manures, crop residues, and bio-fertilizers. Long term studies conducted on black soils of high rainfall region (Sharma, 1990b, Sharma, 1992, Sharma and Gupta, 1993) [26, 34, 36] amply reveal that conjunctive use of FYM and chemical fertilizers lead to; (a) improvement in organic pool of soil and nutrient status of soil, (b) mitigation of drought effect on crop, (c) enhanced sustainable yield index, (d) significantly higher biomass production per unit land than that obtained through use of chemicals alone.

ix) Land use according to its capability: After employing appropriate conservation measures, it is essential to make efficient use of land resource for its protection and preservation and prevent further degradation. Land use should be planned based on its capability classes as any abuse of land at any point of time would be the beginning of land deterioration at a very faster rate.

d) Alternate land use systems

Increased use efficiency of marginal lands can be ensured by planting them to suitable systems. A number of options of alternate land use systems have been identified for different locations (Singh, 1988) [28]. Different high value crops like medicinal plant, spices etc, trees, Pastures and Livestock have got their own importance to find place for making alternate land uses under rainfed situations. The biodiversity of native vegetation in drylands has been comprehensively reviewed by Suresh Kumar (1999) [29]. Trees, shrubs and native pastures are the most important natural vegetation sources. Several multipurpose tree species yielding timber, fodder and fuel wood grow in SAT region on field bunds and scattered in the fields (park land system). This is a traditional agro-forestry system. Recent research has focused upon systematic integration of trees, crops and grasses through agrisilviculture, horticulture and silvi-pasture. Nitrogen fixing trees (NFTs) have a special role in rainfed farming systems from the point of view of nutrient cycling.

e) Agri-horticulture

In medium soil areas receiving annual rainfall of more than 750 mm, agri- horticultural systems consisting of a fruit trees intercropped with annual arable crop is recommended. *Ber, Custard apple, Aonla,* and pomegranate are some of the species suitable for drylands for both for pure plantations and mixed with crops. Cluster bean, cowpea, horse gram, and other grain legume have been found useful in this context in the dry tracts. Results of a long term experiment conducted at AICRPDA, Indore, as an example of the advantages of this system have been presented in Table 19. Results revealed tremendous scope of alternate land use of combining fruit trees and prevalent crops of Soybean, Pigeon pea and their intercrop combination. Lower yield of cowpea was due to heavy rains during reproductive phase.

Table 19: Agri-horti System, AICRPDA, Indore (1999 to 2003).

Treatments		Mean Yield of crops (kg/ha)	Yield Range of crops (kg/ha)	Mean gross return (Rs./ha)	Soybean Equivalent Yield (kg/ha)	Yield range (kg/ha)
T1 -Aonla – Sole Soybean		1290	940 -2177	13372	1539	1054 -2321
T2-Aonla - Sole Pigeon pea		1130	384 -1765	18728	2255	534 - 4069
T3-	Aonla –Soybean	747	521-1088	7756	1978	1015 -2965
	+ Pigeon pea (4:2)	539	264 -908	8879	-	-
T4- Aonla – Sole Cowpea		179	139 -303	2574	330	240 -475
T5 - Drumstick – Sole Soybean		1243	955 -1973	13098	1488	1084 -2109
T6- Drum stick-Sole Pigeonpea		1195	472 -2025	19859	2388	639 -4656
T7	Drumstick –Soybean	718	492 -952	7559	1916	1152 -2869
	+ Pigeon pea (4:2)	534	324 -885	8846	-	-
T8- Drum stick – Sole Cow pea		206	168 -371	182	381	290-582
T9- Ber – Sole Soybean		1119	838 -1837	11599	1332	933 -1962
T10- Ber – Sole Pigeon pea		1118	378 -1834	18579	2214	665 -4255
T11	Ber – Soybean	665	434 -884	6918	1749	1014 -2731
	+ Pigeon pea (4:2)	483	301 -810	8029	-	-
T12- Ber- Sole Cowpea		187	124 -336	2723	342	215 -519

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