MANAGEMENT OF NATURAL RESOURCES FOR SUSTAINABLE DRYLAND AGRICULTURE

SEMINAR WRITE UP

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ABSTRACT

There is a wide spread consensus that the sustainability of dryland area is endangered due to over exploitation of natural resources beyond their carrying capacity (Katyal and Das, 1992). Rainwater and soil, being the key natural resources of dryland agriculture, this seminar emphasizes on management practices that can maximize the usefulness of limited rainwater by imposing relevant conservation measures and land uses matching with the water availability period. The key issue thus, is the conservation of water and soil resources against erosive forces of rainwater and wind in dryland areas.

First step for improving the dryland crop yields is the conservation of rainwater, which can not be separated from soil conservation (Prihar, 1994). Soil and water conservation practices such as land levelling and grading, furrow diking, contour tillage and terracing can be used to increase surface storage, reduce slope gradient and conduct water from field at non-erosive velocities (Joshi and Singh, 1994). However, impact of these conservation measures varies with the soil type and agro-climatic location and their effectiveness can not be generalized (Vittal *et al*., 2002). Studies at Central Arid Zone Research Institute have shown that in situ rainwater harvesting makes the efficient use of limited rainfall in dryland areas (Narain and Goyal, 2005).

Intercropping is one of the important cropping systems recommended to mitigate the aberrant climatic conditions. Climatologically efficient and economically valuable cereal-legume, legume-cereal and cereal - cereal intercropping systems have been developed in recent years, which enhance productivity and profitability overtime and space in dryland areas by better use of production resources (Singh, 2002; Shukla *et al.,*2002).

Not all drylands as recognized as suitable for crop production. Some land may be suitable for pasture management while other for tree farming, ley farming and dryland horticulture or agroforestry systems including alley cropping. All these systems that are alternative to crop production are less risky, more stable and remunerative on marginal lands and are referred to as alternate land use system.

Livestock are other resources in dryland areas. Nearly two-third of the total 450 million heads of livestock in India thrive in rainfed regions. Rainfed farming mixed with livestock farming provides a dependable source of income to dryland farmers (Singh, 2001).

Implementation of all these practices on farm situation is, however, constrained by several factors such as poor enterprising ability of the rainfed farmer, lack of knowledge, lack of training of farmers and extension workers on overall dryland practices etc. Therefore, treatment of dryland areas on a watershed basis has been adopted as a comprehensive approach to manage natural resources through effective techniques (Singh, 2001).

Mineral resources like limestone, gypsum, sand stone, dolomite, calcite, silica sand, marble, etc. and fossil fuels such as crude oil, oil shale, sand tar, coal and natural gas are other natural resources in dryland areas. Systematic and planned mining operations, suitable site selection for waste disposal, proper exploration and utilization of these resources would help in socio-economic development of the dryland areas.

MANAGEMENT OF NATURAL RESOURCES FOR SUSTAINABLE DRYLAND AGRICULTURE

"**Dryland agriculture**" means raising crops with rainwater is spread in four continents covering almost 48 countries. Worldwide, 6510 million hectares (mha) of land is under rainfed agriculture of which approximately 60 percent are in the developing countries. **India ranks first among the dryland agricultural countries in terms of both extent and value of produce.** Out of every three hectares of cultivated land in India, nearly two hectares are under the influence of rainfed agriculture. Out of a total 142.1 million hectares of cultivated area in India, dryland accounts for 91.0 million hectares and in the foreseeable future also nearly 60% of our population will still continue to depend on dryland agriculture (Singh, 2001).

Characteristics of Dryland Agriculture

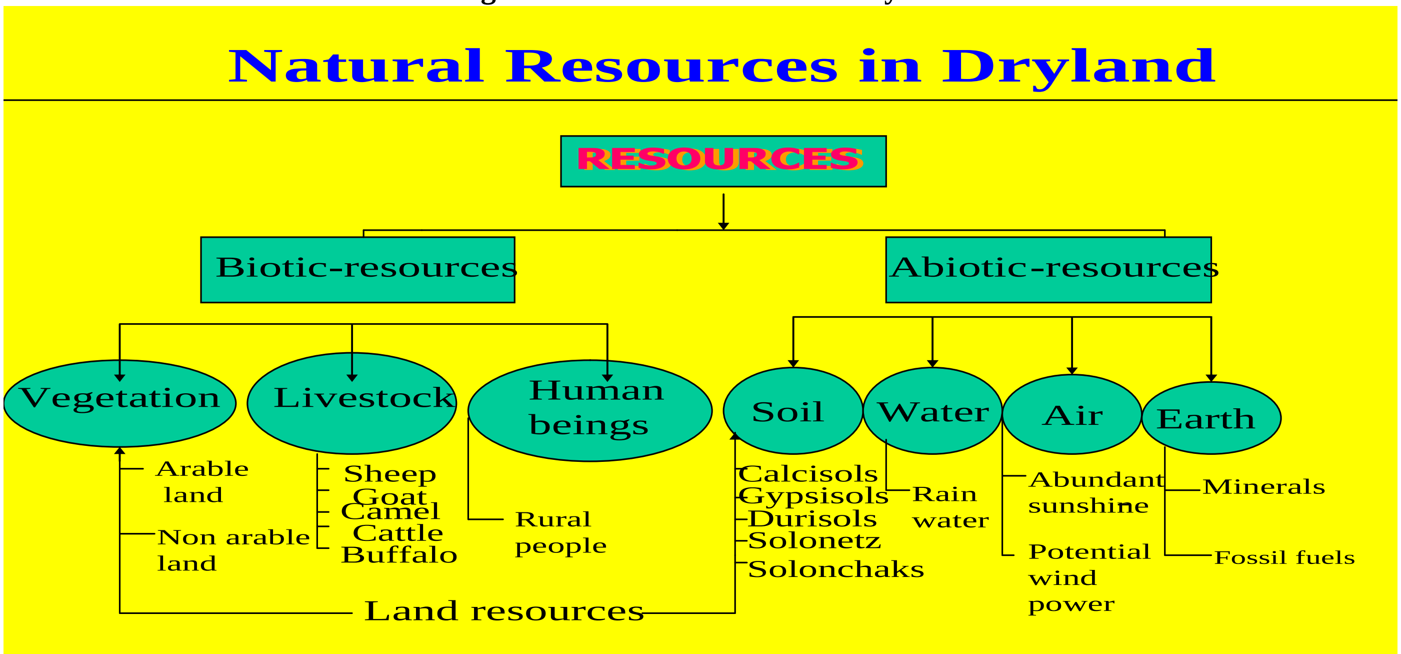
In the present context, dryland/rainfed agriculture has been broadly classified on the basis of proportion of cropped area irrigated. Based on the **National Sample Survey Organization (NSSO) regions, areas with less than 25 percent of irrigation were classified as dryland areas** while those with more than 25 percent irrigation were considered as irrigated regions. Considering this classification, all the 58 regions, covering major states in India, for which information about important indicators was available, half of the regions were identified as dryland.

Constraints to Dryland Agriculture

Rainfed/dryland areas are harsh environment and suffer from a number of constraints such as low and uncertain rainfall, limited irrigation, low moisture, poor and degraded resource base, declining soil fertility, low income and low saving capacity, lack of infrastructure, lack of adequate and timely credit, low capital formation, dominance of low value crops, low productivity, and inadequate attention paid by policy makers and scientists, etc. However, the basic problem of dryland areas is one of a vicious cycle that starts with degradation of the natural resource base through poor management leading to low productivity, low income, low surplus, and low investment. This, in turn, leads to over-exploitation of the existing natural resources and further degradation.

The sustainability of dryland area is endangered due to over exploitation of natural resources beyond their carrying capacity (Katyal and Das, 1992). Rainwater and soil, being the key natural resources of dryland agriculture, this seminar emphasizes on management practices that can maximize the usefulness of limited rainwater by imposing relevant conservation measures and land uses matching with the water availability period. The key issue thus, is the conservation of water and soil resources against erosive forces of rainwater and wind in dryland areas.

Figure 1. Natural resources in dryland



Management strategy of natural resources

1. **Comprehensive field survey of natural resources-** Filed survey will enable to know the kind and amount of available natural resources. For this purpose the use of GIS, GPS and remote sensing could be done for précised information.
2. **Conservation and efficient use of natural resources-** The available resources should be conserved and utilized efficiently.
3. **Economically feasible and environmental appropriate technology (farm ponds, sprinkler, drip & land shaping equipments)-** The technologies used for conservation and utilization of the natural resources should be eco-friendly, environmentally sound and economically viable.
4. **Conjunctive use of surface and ground level resources-** There should be integrated use of surface and ground level natural resources.
5. **Optimum use of scarce natural resources-**Unscientific and reckless use of natural resources should be avoided.
6. **Fixing priority in soil and water use-**According to capability of soil, arable lands should be used for crop cultivation and other soils should be used for building houses or industrial purposes. Likewise surface water should be used for current purposes and ground water should be stored for long-term uses.
7. **Reuse of water and alternate use of land-**Water used for household and sewage purposes could be reused for kitchen gardening and vegetable growing. The marginal lands and the land not suitable for food grain crops can be used for agro-forestry and other purposes.
8. **Rainwater harvesting for replenishing ground water and renovation of the traditional source of storage of rainwater-**India is rich in using traditional knowledge of soil and water conservation. These traditional sources of rainwater storage should be popularized providing scientific importance.
9. **Priority for completion of on going projects-**Before starting a new project for better management of natural resources in dry land, one should see whether on going project is completed successfully.

Management of natural resources in dryland can be done under following heads-

1. **Sustainable water management**
    (a) In-situ moisture conservation
    (b) Water harvesting
2. **Sustainable soil management**
    (a) Erosion control
    (b) Desertification control
    (c) Soil health maintenances
    (d) Alternate uses of different lands
3. **Sustainable crop management**
    (a) Cropping system
    (b) Nutrient management
    (c) Irrigation management
    (d) Weed management
4. **Integrated watershed management**
5. **Sustainable use of dryland bio-diversity**
6. **Livestock management and**
7. **Management of dryland mineral resources**

1. Sustainable water management

First step for improving the dryland crop yields is the conservation of rainwater, which can not be separated from soil conservation (Prihar, 1994). Soil and water conservation practices such as land levelling and grading, furrow diking, contour tillage and terracing can be used to increase surface storage, reduce slope gradient and conduct water from field at non-erosive velocities (Joshi and Singh, 1994). However, impact of these conservation measures varies with the soil type and agro-climatic location and their effectiveness can not be generalized (**Table 1**) (Vittal *et al*., 2002). Studies at Central Arid Zone Research Institute have shown that in situ rainwater harvesting makes the efficient use of limited rainfall in dryland areas (Narain and Goyal, 2005).

Table 1. Influence of soil and water conservation measures on crops at different locations

Crop (No of Years)	Location	Soil	Treatment	Yield (kg/ha)	SI
Pearl millet (3)	Agra Arid	Inceptisols	**Nutritious cereals**		
			I. Raised bunds (20 cm high) with rectangular belts (6 X 2.7 m) across slope	2193	0.67
			II. Compartment bunding (3 X 4.5 m)	2153	0.66
			Farmers' method (control)	1845	0.46
Peal millet (3)	Dantiwala Semi arid	Aridisols	I. Compartment bunding (3 X 4.5 m)	1132	0.67
			II. Flat sowing and ridges at 3 m distance	986	0.57
			Farmers' method (control)	819	0.46
Caster (3)	Dantiwala Semiarid	Aridisols	**Oilseeds**		
			I. Ridges and furrows	1668	0.40
			II. Flat bed	1598	0.38
			Trench (control)	1412	0.30
Vegetables (3)	Agra Arid	Inceptisols	**Horticulture**		
			I. Ridges and furrows	6652	0.77
			Flat sowing (control)	5008	0.55
Gooseberry (4)	Rajkot Semi arid	Vertisols	**Agroforestry**		
			I. Soil mulch	5 m height	0.92
				53 cm dia	0.92
			II. Straw mulch	5 m height	0.90
				48 cm dia	0.83
			Farmer's method (no mulch)	5 m height	0.92
			(control)	48 cm dia	0.79

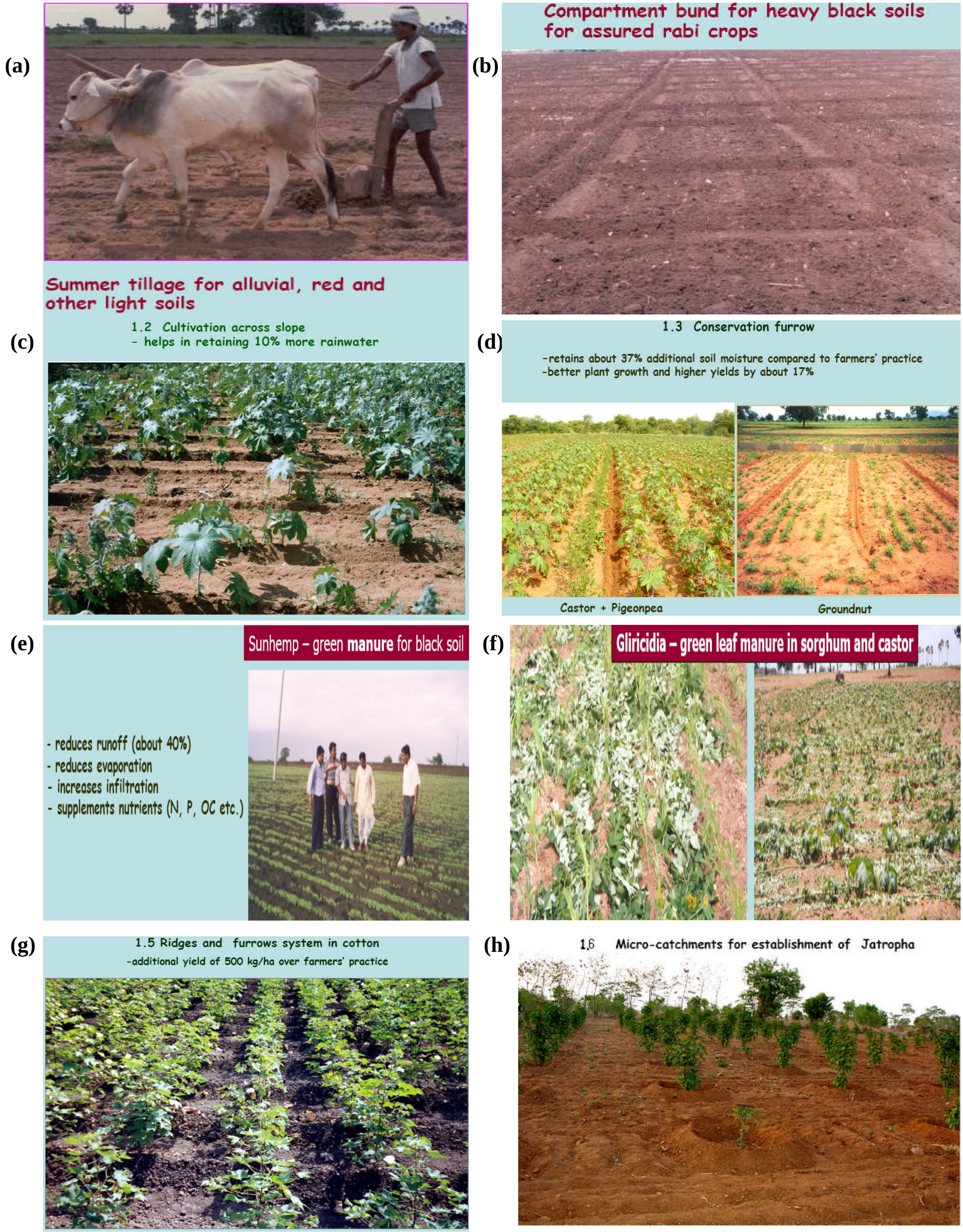
1. I and II are the top first and second rated treatments
2. Height and diameter of tree was measured in the absence of yield — Vittal, *et al.*, (2002)

1.1 In situ moisture conservation

Various in situ conservation measures like –

An off-season land treatment such as summer tillage (figure 2 (a)) for alluvial, red and other light soil not only conserves soil moisture but also reduces weed growth for next crop. Compartmental bunding (figure 2 (b)) in heavy black soils conserves sufficient moisture for assured rabi crops. Cultivation across the slope (figure 2 (c)) helps in retaining 10% more rain water in soil itself. Conservation furrow (figure 2 (d)) retains about 37% additional soil moisture compared to farmers practice resulting in better plant growth and higher yield. Mulch cum manure technique (figure 2 (e & f)) helps in reducing runoff and evaporation and increases the infiltration rate of the soil. Besides this it also supplements nutrients like N, P, and organic carbon. Ridge and furrow method (figure 2 (g)) is tested method in terms of moisture conservation for widely spaced crops like cotton. Micro-catchments (figure 2 (h)) around the root surface of the plant retains most of the soil water in root zone itself, thus providing maximum supply to the plant.

Figure 2. In situ moisture conservation methods



1.2 Rainwater harvesting

Rainwater runoff varies from 10-40% of the total precipitation depending upon the rainfall intensity and distribution, soil characteristics (slope, water intake rate and water holding capacity) and vegetative cover. It offers good potential for rainwater harvesting. Average summer and winter rainfall in dryland areas ranges from 250 mm to 600 mm and 50 mm to 200 mm respectively (Oswal, 1994). It is projected that 24-mha m (**Table 2**) of surface water is potentially available for harvesting, of which, 1/4th can be harvested in ponds and percolation tanks in rainfall zone up to 1000 Macro Management Scheme. Harvested water used for supplementary irrigation of 5-7 cm during the period of moisture stress at a critical growth stages for increasing yields gain in number of dryland crops.

Table 2. Estimated potential volume of rainwater storage for small-scale water harvesting structures (Katyal, 1997)

Rainfall zone (mm)	Geographical area (million ha)	Rainwater availability (million ha)	Harvestable runoff (million ha m)
<500	52.07	15.6	0.78
500-750	40.26	25.2	1.51
750-1000	65.86	57.6	4.03
1000-2500	137.24	205.9	14.61
>2500	32.57	95.7	3.26
Total	**328.0**	**400.0**	**24.19**

Dohare and Singh, (2003)

Traditional knowledge and practices have their own importance as they have stood the test of time and have proved to be efficacious to the local people. India has a rich history of use of traditional systems of water harvesting in almost all the states (**Table 3**). Ponds and tanks represent an important component both on-farn and on-station in identification of measures of rainwater management.

Table 3. Indigenous rainwater harvesting technologies in semi-arid regions of India (ICAR, 1999)

System	Technology	Region
Kunta	Small size community pond for providing supplemental irrigation to paddy, chillies and tobacco during long breaks in rainfall	Prakasam, Guntur and Nizamabad (Andra Pradesh)
Percolation tank	Used for recharging the groundwater to bring stability to rainfed agriculture	Andra Pradesh, Karnataka and Maharashtra
Haveli	Storing rainwater by raising field bunds used in Kharif fallow	Madhya Pradesh Mahakaushal Area
Risers	Stone pitching of bench terrace risers to conserve rainwater	Hilly regions
Stone pitched barriers	Stone pitching along with stubbles of pigeon pea/sorghum/cotton across the slope for rainwater conservation	Vidarbha region of Maharashtra
	Field bunds with waste weirs, stone checks and stone/boulder boundaries to conserve rainwater	Andhra Pradesh, Gujarat and Karnataka

Dohare and Singh, (2003)

2. Sustainable soil management

2.1 Erosion control

Wind erosion is a land surface process that takes place mainly in dryland areas. Wind erosion is a major threat for the sustainable use of land resources in hot arid region and may result in considerable losses of soil and nutrients and damage the crops through sand blasting and seedling burial. Wind erosion control measures are generally classified into three categories: tillage operations, residue management practices and vegetative barriers. Vegetative barriers include plant or tree residue barrier (locally called as kunabandh), shelterbelts and windbreaks. The practice of keeping plant residues in narrow strips on the land surface against the normal wind direction is called kunabandh. This traps soil particles and reduce soil erosion by reducing the wind velocity. During rainy season, these barriers are incorporated in the soil thereby improving soil fertility status (Singh and Poonia, 2003). Vegetative barrier kunabandh of tree sticks (KBTS) was found to be more efficient in soil and water conservation and crop production due to its compact structure as compared to lose structured kunabandh of plant residues (KBPR) (**Table 4**)

Table 4. Effect of wind erosion control measure on soil and water conservation, soil fertility, growth and yield of dewbean and culsterbean on marginal lands eroded by wind

Wind erosion control measure	Plant height (cm)	Grain yield (kg/ha)	Soil loss/conservation (cm)	OC (%)	Soil moisture at harvest (%)
Dewbean (2000)					
Ridge & Furrow	27.0	310	-0.82	0.38	1.98
KBTS*	31.2	410	-7.55	0.43	2.92
KBPR**	28.1	360	-5.38	1.23	2.66
Control	21.0	245	-5.6	0.13	1.23
CD (P=0.05)	3.8	45	-	0.66	-
Culsterbean (2001)					
Ridge & Furrow	101.8	285	-0.92	0.40	2.36
KBTS*	111.9	348.5	-6.52	0.44	3.24
KBPR**	105.4	275	-5.75	0.26	2.73
Control	77.3	208.5	-6.34	0.14	1.64
CD (P=0.05)	14.8	37.3	-	0.05	-

*KBTS-Kanabandh of tree sticks — Poonia and Singh, (2005)

**KBPR- Kanabandh of plant residues

Contour vegetative barriers (CVB) of locally adapted, drought resistant plant species were evaluated for their effectiveness in reducing runoff and soil loss in the farmers' fileds. Amongst all the fields, the highest seed yield of clusterbean was obtained in the field having CVB of *Cympopogon jwarancusa* and *Cenchrus ciliaris* followed by *Barleria prionitis* and *Cymbopogon jwarancusai* (**Table 5**). The seed yield increased between 37 and 51 % over control.

Table 5. Yield of clusterbean under different contour vegetative barriers

Contour	Seed yield (kg/ha)			
	1992	1993	1994	Mean
Cenchrus	543	390	1283	739
Barleria + Symbopogon	469	333	1459	754
Cenchrus + Symbopogon	1122	375	989	829
Ubhorbia	408	626	1252	762
Control	499	378	772	549

Sharma *et al*, (1997)

2.2. Desertification control

Desertification is a major problem in the drylands of India, affecting the way of life for its inhabitants. Two major activities to control desertification are sand dune stabilization and shelterbelt plantation. Cultivation of dune slopes is a major form of land use in the more than 150 mm average annual rainfall zone. The locally adapted species, which can provide some economic return to the local population, are preferred by the villagers and, hence, they are not averse to protecting and managing such planted species, provided such plantation does not interfere with crop cultivation. The tree, shrub and grass species, suitable for stabilization programme, are described in **Table 6**.

Table 6. Plant species suitable for sand dune stabilization in Thar Desert (after Venkateswarlu, 1993)

Annual rainfall zone (mm)	Trees	Shrubs	Grasses
150-300	*Prosopis juliflora, Acacia tortilis, A. senegal*	*Calligonum polygonoides, Ziziphus nummularia, Citrullus colosynthis*	*Lasiurus sindicus*
300-400	*A. tortilis, A. senegal, P. juliflora, P. cineraria, Tecomella undulata, Parkinsonia aculeata, Acacia nubica, Dichrostachys glomerata, Colophospermum mopane, Cordia rothii*	*Ziziphus mauritiana, Z. nummularia, C. polygonoides, Citrullus colosynthis*	*Cenchrus ciliaris, C. setigerus, L. sindicus, Saccharum munja*
400-550	*A.tortilis, P. cineraria, P. juliflora, A.senegal, Dalbargia sisoo, Ailanthus excelsa, Albizzia lebbek, P. aculeata, T. undulata, D. glomerata, C. mopane*	*Z. mauritiana, Cassia auriculata*	*C. ciliaris, C. setigerus, S. munja, Panicum antidotale*

2.3. Soil health maintenances

Soil health is the most important element in soil management. Good soil contains all the stuff a root could ever need—water, oxygen, minerals, and organic material. Like a desert soils have no organic content. Sandy soil has oxygen, but if it lacks organic materials, can't hold on to water long enough to benefit the plants. Our heavy clay soils hold water at the expense of oxygen—the cure? Organic matter. Our soils also suffer from high pH and calcium—attributes that tie up the multitude of minerals in our soils. Only organic matter can unlock those minerals—nutrients in the raw, making them available to plants. The most important element in balancing soil is organic content—add water, oxygen, fertilizer, or raw minerals without organic material and the soil will become lifeless. The only magic potion you can buy for your soil is organic material.

Various studies have shown the utility of chemical fertilizers in improving crop yield under dryland conditions, but with unreliable rainfall, good grain yields and response to fertilizers is never certain. Therefore, dependency on chemical fertilizers alone may not provide a viable economic option and to maintain soil productivity on a sustainable basis an integrated nutrient management approach, using both organic and inorganic sources of nutrients should be adopted. The use of manures must be given prime importance and fertilizer use should be limited to balance the nutrient requirement of the crops. Continuous cultivation for seven years without addition of FYM marginally decreased the status of organic carbon, available N and P in soil (**Table 7**).

Table 7. Effect of continuous cropping of pearl millet and addition of FYM (t/ha/year) on fertility status of soil

Properties	Initial values (1983)	Final value (1989)	
		0	10
pH (1:2)	8.1	8.1	8.1
Organic carbon (%)	0.27	0.25	0.33
Nitrogen (%)	0.03	0.03	0.04
Available phosphorus (ppm)	6.31	5.68	8.00
Available manganese (ppm)	2.54	5.60	5.86
Available iron (ppm)	2.00	2.09	2.18
Available copper (ppm)	0.16	0.16	0.19
Available zinc (ppm)	0.31	0.37	0.45
Available nitrogen N (kg/ha)	140.0	138.6	144.3

Aggarwal and Praveen-Kumar, (1996)

2.4. Alternate uses of different lands

Not all drylands as recognized as suitable for crop production. Some land may be suitable for pasture management while other for tree farming, ley farming and dryland horticulture or agroforestry systems including alley cropping. All these systems that are alternative to crop production are less risky, more stable and remunerative on marginal lands and are referred to as alternate land use system. Following are the some important alternate land use system for drylands.

ALTERNATIVE LAND USE SYSTEMS

(1.) Alternate land use systems for arable lands

(i) Alley cropping ex.-*Leucaena leucocephala* for forage and green manuring

(ii) Agro-horticultural system ex.- mango. sapota, tamarind, cashew, ber, jack fruit with annual crops.

(iii) Horticulture-pastoral system ex.- *Cenchrus ciliaris* and *Stylosanthus hamata* with ber and guava etc.

(iv) Silvi-Horticulture system ex.-sapota, pomegranate, ber, custard apple, fig and phalsa with tree species of wider distances

(v) Agro-forestry system ex.- Annual crops like finger millet, groundnut, red gram, pearl millet and pulses with *Casurina*, *Dalbergia* and *subabul*

(vi) Agro-silvi-horticulture system ex.- Horticulturasl crops + quick growing trees like *Casurina, Subabul,* Neem and *Dulbergia* + annual crops

(vii) Bamboo cultivation

(viii) Intercropping of nitrogen fixing tree species (NFTS) ex.- *Subabul. Acacia albida, Albizia lebek, Prasopis cineraria*

(ix) Lay Farming ex. *Stylosanthus hamata*

(2.) Alternate land use systems for cultivable waste and marginal land

(i) Tree farming ex.- *Acacia nilotica, Acacia albida, Acacia catechu,* Neem, *Acacia, subabul Dalburgia etc.*

(ii) Silvi-pastoral system ex.- trees + forages (*Sehima nervosum, Dicanthium annuliatum, Cenchrus ciliaria* and *Cenchrus setigerus*)

(iii) Timber and Fibre (TIM-FIB) system ex.- Trees which yield timber and shrubs which yield fibre.

However, sustainability of these alternate land use systems varies with the plant species, soil type and agro-climatic location and their effectiveness can not be generalized (**Table 8**) (Vittal *et al*., 2002).

Table 8. Performance of different tree species and crops for alternate land use at Arjia (semi arid vertisols)

System (no of years)	Treatment	Yield (kg/ha)	SI
Silvi-pasture(5)	**Agroforestry** I. *Prosopis cineraria + Cenchrus setigerus* II. *Jetropha + green gram*	 3483 63	 0.61 0.57
Silvi-pasture(5)	I. *Cenchrus setigerus* (100%) II. *Cenchrus setigerus* (50%)	2670 1813	0.58 0.55
Silvi-pasture(3)	I. *Acacia tortilis* (bunding and chiseling) II. *Parkinsonia aculeata*	1716 1545	0.94 0.82

I and II are the top first and second rated treatments Vittal *et al*., (2002)

3. Sustainable crop management

Sustainable crop management is another aspect of good natural resource management.

3.1. Cropping system

One of the most important aspects of formulating a cropping system for a dryland situation (whether impaled or rain-fed) is the selection of crops and varieties that are suited - with reference to their yield and quality - to the region. Intercropping is one of the important cropping systems recommended to mitigate the aberrant climatic conditions. Climatologically efficient and economically valuable cereal-legume, legume-cereal and cereal - cereal intercropping systems have been developed in recent years, which enhance productivity and profitability overtime and space in dryland areas by better use of production resources (Singh, 2002; Shukla *et al.*,2002). Some of important cropping systems suitable for dryland agriculture are given in **Table 9.**

Table 9. Efficient cropping systems for different situations (Singh, 1995)

Soil and region	Water availability Period (days)	Double cropping system	Intercropping system
Vertisols and related soil zones			
Malvapleteau (M.P.)	210-230	Maize-safflower-chickpea	Maize + Soybean
	191-210	Sorghum-safflower/chickpea	Soybean + Pigeonpea
Bundelkhand (U.P.)	190-220	Sorghum-chickpea, Blackgram-mustard/safflower	Pearl millet+fodder legume Sorghum + Pigeonpea

Continued----			
Vidharbha (Maharastra)	190-210	Groundnut-Safflower Sorghum-safflower	Sorghum + Pigeonpea Cotton + Pigeonpea
	170-190	Greengram-Sorghum/Safflower	Pearlmillet +Greengarm Sorghum + Greengarm
Southern Maharastra	160-180	Greengram-Sorghum/Safflower	Pearlmillet + Pigeonpea Sunflower + Pigeonpea Groundnut + Sunflower
Southern Rajasthan	160-180	Greengram-Safflower	Miaze + Pigeonpea Groundnut + Pigeonpea Chickpea + Mustard
Northen and central Karnataka	130-150	Cowpea-Sorghum Greengram-Safflower	Pearlmillet + Pigeonpea Groundut + Pigeonpea Sunflower + Pigeonpea
	100-120	-	Sorghum + Coriander Safflower + Coriander
Saurastra (Gujarat)	130-140	-	Groundut + Pigeonpea Pearlmillet + Pigeonpea
Southern Tamil Nadu	120-130	-	Sorghum + Blackgarm Cotton + Blackgarm
Alfisols and related soil zones			
Southern Karnataka	190-220	Cowpea-Fingermillet Soybean-Fingermillet	Fingermillet + Pigeonpea Groundnut + Pigeonpea Fingermillet + Soybean
Telangana (Andra Pradesh)	140-160	-	Sorghum + Pigeonpea Castor + Clusterbean Groundnut + Pigeonpea
Rayalaseem (Andra Pradesh)	110-130	-	Groundnut + Pigeonpea Groundnut + Pearlmillet
Arid soil zone			
North western Gujarat	100-120	-	Pearlmillet + Greengarm Pearlmillet + Clusterbean Clusterbean + Greengarm
	75-90	-	Pearlmillet + Blackgarm Pearlmillet + Clusterbean Clusterbean + Blackgram Pigeonpea + Blackgram

Production potential of cropping system for rainfed situations can be seen in terms of crop yields in the cropping systems, sustainability in production (SYI), land use efficiency (LUE) etc. The SYI helps in identifying the treatment that gives the maximum sustainable yield over long term. The SYI of pearl millet – isabgol system was more as compared to pearl millet – mustard, but pearl millet – mustard system produced higher pearlmillet equivalent yield (**Table 10**). The highest land use efficiency was recorded in case of pearlmillet –mustard and pearl millet – isabgol because these double cropping systems occupied land for the longest duration (205-210 days). It was least in pearl millet-fallow-fallow-fallow.

Table 10. Land use efficiency, sustainable yield index and soil organic carbon content of different cropping systems (mean of four years)

System	LUE (%)	SYI	SOC (%)
Mono-cropping systems			
PM-Fallow-Fallow-Fallow	13.7	-	0.140
PM-Fallow-PM-Fallow	24.7	0.09	0.153
PM-Fallow-CB-Fallow	24.7	0.30	0.167
PM-Fallow-GG-Fallow	21.2	0.22	0.165
PM + Senna	-	0.81	0.143
Double cropping systems			
PM-Mustard- PM-Mustard	57.5	0.35	0.183
PM-Isabgol- PM-Isabgol	56.2	0.41	0.152

SOC= Soil Organic Carbon; Saxena *et al.* (2005)
LUE= Land Use Efficiency

3.2. Integrated nutrient management (INM)

Concern has also grown in recent years that the use of fertilizers, particularly inorganic fertilizers, can lead to serious environmental consequences and lead to degradation of natural resource base. Environmental contamination of this type, however, is largely a problem in the developed world and a few regions of the developing world. As fertilizers make up a small share of the total production costs in many developed countries, farmers often apply fertilizer in excess of recommended levels in order to ensure high yields. Overapplication of inorganic and organic fertilizers is estimated to have boosted nutrient capacity in the soil by about 2,000 kilograms of nitrogen, 700 kilograms of phosphorus, and 1,000 kilograms of potassium per hectare of arable land in Europe and North America during the past 30 years (World Bank 1996). Such oversupply of nutrients can lead to environmental contamination, which often has negative consequences for humans and animals. Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased output and incomes, especially for low-income groups, without depleting the natural resource base. In this context, INM maintains soils as storehouses of plant nutrients that are essential for vegetative growth. INM's goal is to integrate the use of all natural and man-made sources of plant nutrients, so that crop productivity increases in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations. Therefore, application of targeted, sufficient, and balanced quantities of inorganic fertilizers will be necessary to make nutrients available for high yields without polluting the environment (**Table 11**). INM relies on a number of factors, including, crop, location, soil type, appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers.

Table 11. Integrated nutrient management of crops under permanent manure trial

Crop (No. of years)	Location	Soil	Treatment	Yield (Kg/ha)	SI
Pearl millet (5)	Agra (Arid)	Incept-isols	I. 50% N urea + 50% FYM II.RDF + ZnSO4 @25kg/ha Control	2255 2210 1136	**0.73** 0.72 0.32
Pearl millet (5)	Kovil patti (Semi-arid)	Incept-isols	I. 100% N urea + 20 P + ZnSO4 @25kg/ha II.50% N FYM + 50% N urea + 10 P Control	1234 1173 714	**0.13** 0.10 -0.09
Maize (5)	Rakh Dhiansar (Sub humid)	Incept-isols	I. 100% RDF, NPK + ZnSO4 @20kg/ha II. 100% RDF, NPK (60-40-20) Control	3633 3511 1544	**0.76** 0.74 0.31
Sorghum-Safflower (3)	Bijapur Semi-arid	Verti-sols	I. RDF + ZnSO4 @15kg/ha II.50% N, FYM + 50% RDF Control	954 871 245	**0.39** 0.33 -0.13

I and II are the top first and second rated treatments Vittal *et al.*, (2002)

3.3. Irrigation management

Productive use of water in dryland crop production- In dryland agriculture, water is the most limiting factor in crop production. Every drop of water must be carefully conserved and used. The conserved/harvested water could be of real use only when it improves the crop production. For productive use of the precious water, selection of short duration, low water requiring crops and their varieties, cropping systems and critical crop stage and quantum and right method of application of harvested water and improved agronomic measures for cultivation of crops including the balanced doses of plant nutrients, are to be determined. The water requirement for optimum production of various commonly grown dryland crops is given in **Table 12.** The crop should be selected on the basis of water requirement of the crop and expected rainfall during the growing season i.e. water availability period.

Table 12.Water requirement of some dryland crops

Summer crops	Water requirement	Winter crops	Water requirement
Black gram, cowpea, mung bean	250 mm	Rocket plant	150 mm
Clusterbean, pearl millet, finger millet	300 mm	Mustard	200 mm
Sesame	350 mm	Barley, pea, safflower	300 mm
Castor, red gram, sorghum	400 mm	Sunflower, wheat	350 mm
Groundnut, maize, soybean	350 mm		
Sunflower, tobacco	500 mm		

Oswal, (1994)

Critical irrigation with a small quantity of water harvested in a pond is of immense value to improve and stabilize the dryland crop production and to build up confidence of farmers in dry farming. Such irrigation when applied as life saving irrigation or as pre sowing irrigation can increase crop yield many fold **(Table 13).** Even a small quantity of water (2.5 to 3.0 cm) available for irrigation is quite useful to harness the carried over sub soil moisture for crop production, after the harvest of a short duration summer crop, or after the summer fallowing. When such an irrigation is applied it charges the otherwise dry top soil with water, which on joining the subsoil moisture makes an ideal profile for crop growth.

Table 13. Effect of critical irrigation on performance of dryland crops

Location	Crop	Yield (t/ha)	
		Without irrigation	With critical irrigation
Agra	Wheat	2.19	2.74 (5 cm)
Anand	Tobacco	1.21	1.81
Bellary	Safflower	0.13	0.29
Hisar	Pearl Millet	1.32	2.24 (7 cm)
	Mung bean	0.83	1.30
	Chickpea	0.58	1.90
	Mustard	0.75	1.44 (5 cm)
Hyderabad	Chickpea	0.82	3.57
Ludhiana	Sorghum	2.57	3.57
	Wheat	1.92	4.1 (7 cm)
Soolapur	Chickpea	0.80	1.04 (5 cm)
	Safflower	0.77	1.03

Oswal, (1994)

3.4. Weed management

Most of dryland crops are sown at the onset of the rainy season and becomes infested with several grassy and broad-leaved weeds. These weeds deplete considerable amount of nutrients, thereby resulting in poor growth and yield of the crops. Therefore, weed removal at optimum time to minimize nutrients losses by weeds and to increase the yield is necessary. Singh and Yadav, 1994 conducted a field experiment **(Table 14)** on pear millet and found that the uptake of N and P by different weeds increased progressively with an increase in the time of weed removal and was maximum at 60 DAS. Nutrients uptake then decreased because of lower environmental temperatures, competition among weed species and between the weeds and the crop and lastly weed maturity. Removals of weeds at 20 to 50 DAS led to significantly low N and P uptake by the weeds at crop harvest compared to unweeded and weed removal at 10 DAS.

Table 14. Effect of time of weed removal on nutrient uptake (kg/ha) by crop at harvest and seed yield

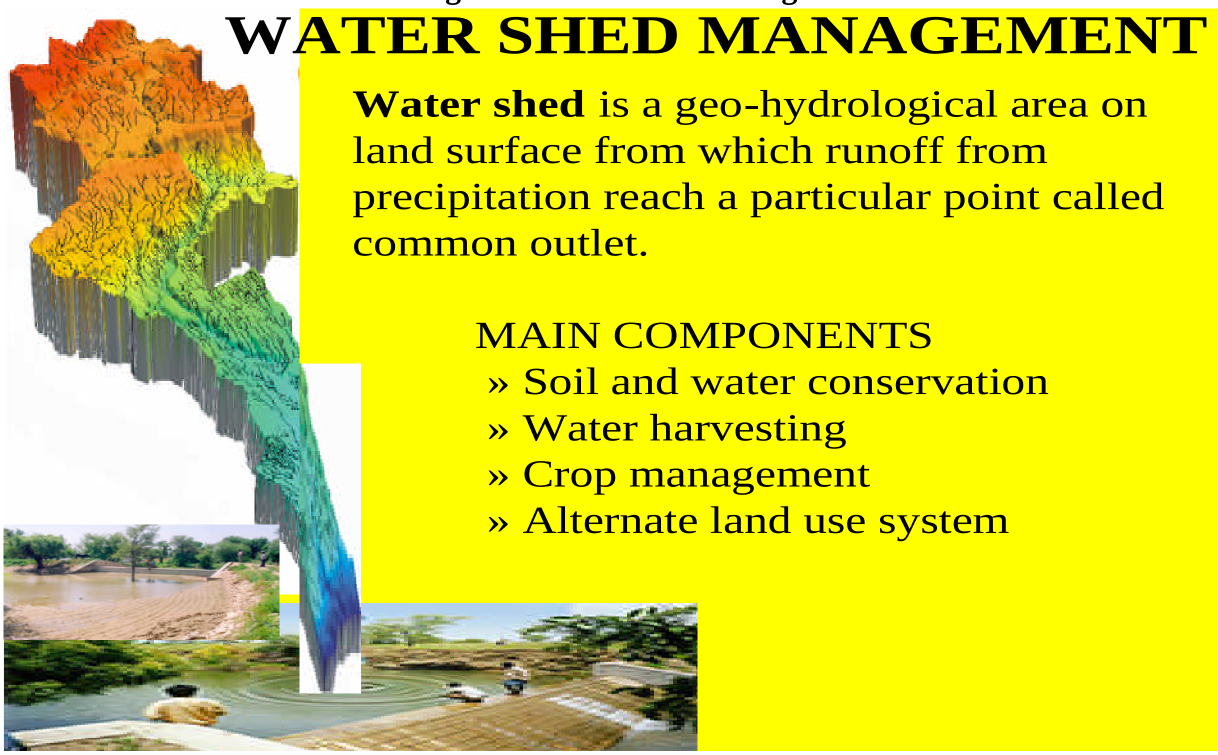
Treatment	Nutrient uptake (kg/ha)				Grain yield (t/ha)	Stover yield (t/ha)
	Grain		Stover			
	N	P	N	P		
Unweeded	24.6	4.78	31.1	1.64	1.45	4.14
Clean weeded	52.2	11.84	53.5	3.50	2.82	6.00
Weed removal						
10 DAS	32.3	6.80	36.7	2.30	1.89	4.74
20 DAS	42.8	9.44	44.4	2.90	2.42	5.37
30 DAS	38.4	8.18	41.3	2.66	2.21	5.24
40 DAS	33.8	6.90	36.7	2.22	1.98	4.90
50 DAS	27.2	5.44	34.9	1.97	1.60	4.41
60 DAS	26.5	5.15	31.7	1.68	1.56	4.21
CD (5%)	3.2	0.76	4.4	0.30	0.12	0.33

Singh and Yadav, (1994)

4. Integrated watershed management

Implementation of all the above mentioned practices for natural resource management in dryland agriculture at on-farm situation is, however, constrained by several factors such as poor enterprising ability of the rainfed farmer, lack of knowledge, lack of training of farmers and extension workers on overall dryland practices etc. Therefore, treatment of dryland areas on a watershed basis has been adopted as a comprehensive approach to manage natural resources through effective techniques (Singh, 2001) (Figure 3).

Figure 3. Watershed management



Watershed Management is a 'Holistic Approach' for natural resource management. The following points justify the sentence-

- The sum of collective efforts is greater than the parts.
- Working at the watershed scale opens up opportunities to plan and implement different strategies that complement and increase the benefits of in-field practices.
- The efforts are effectively targeted and coordinated.
- The most compelling advantage of working at the watershed scale is the ability to "focus for effect" to direct conservation efforts at the most vulnerable parts of the landscape and during the most vulnerable times of the year.

Various interventions introduced and various mechanical and biological measures including water resource development implemented in the watersheds reduced runoff by 9 to 24% due to better interception of in situ rainwater and soil loss was brought within permissible limits in the range of 0.042 to 10 t/ha/yr. In case of Bunga, soil loss reduced from 768 to 435 whereas in case of Kokiguda and Badakhera, watersheds soil loss reduced by 75 to 82% from initial of 38 to 40 t/ha/yr (**Table15**).

Table 15. Impact of interventions of surface runoff and soil loss in the watersheds

Watersheds	Surface runoff (%)		Soil loss (t /ha/yr)	
	Pre-project	Post-project	Pre-project	Post-project
Bazar-Ganiyar (Haryana)	7.3	3.5	NA	8.5
Behdala (H.P.)	30	10	12	7
Bunga (Haryana)	30	21.6	768	435
Chhajawa (Rajasthan)	50	18.5	NA	10.6
GR Halli (Karnataka)	1.4	1	1.4	1
Joladarasi (Karnataka)	NA	6.7	12	2.3
Siha (Haryana)	NA	1.5	NA	9.7
Aganpur-Bhagwashi (Punjab)	48.5	24	12.6	2.8
Antisar (Gujrat)	33	16	0.405	0.042
Badakhera (Rajasthan)	30	10	40	10
Bajni (M.P.)	25.4	16.3	12.1	8.3
Kokeiguda (Orrisa)	36.8	12.4	38.2	6.6
Salaiyur (Tamil Nadu)	4.5 to 7.2	1.3	1.7 to 8.9	0.5 to 1.5

NA- Not available Singh, (2006)

5. Sustainable use of dryland bio-diversity

Drylands have an immense scientific, economic and social value. They are the habitat and source of livelihood for about one quarter of the earth's population. It is estimated that these ecosystems cover one third of the earth total land surface and about half of this area is in economically productive use as range- or agricultural land (CCD Secretariat, 1997). Dryland ecosystems contain a variety of native animal, plant and microbial species that have developed special strategies to cope with the low and sporadic rainfall, and extreme variability in temperatures that prevail in these ecosystems. Such adaptive traits have global importance, especially in the context of predicted climate change.

Dryland pastoralists and farmers have developed efficient pastoral and mixed cropping systems adapted to the difficult conditions of drylands. These systems have sustained the livelihoods of generations of dryland people. Furthermore, dryland pastoralists and farmers have successfully created and maintained high levels of agrobiodiversity of crops and livestock breeds. Yet, global awareness about the great value of drylands remains frustratingly low. Compared to tropical rain forests, for example, the wealth of dryland biodiversity and indigenous knowledge is less well documented, and has received much less support and advocacy in conservation media.

5.1 Grassland Improvements and Management

Grasses are ideally suited for the dryland ecosystem. Important grasses are *Cenchrus ciliaris* (Anjan), *Lasiurus sindicus* (Sewan), *Cenchrus setigerus* (Dhaman), *Dichanthium annulatum* and *Panicum antidotale* and *Sehima nervosum etc.* These grasses should be grown with scientific cultivation methods to improve the dryland biodiversity.

5.2 Dryland trees and management

Azadirachta indica, Eucalyptus camaldulensis, E. terminalis, Acacia albida, A. tortilis, A. bivenosa, A. ampliceps, A.eriopoda, Colophospermum mopane, Dichrostychus nutans, Prosopis spp. (Peruvian), *P. alba, P.chilensis, Hardwickia binata,* and *Pongamia pinnata* have shown promises in Indian dryland. Plus trees of *Prosopis cineraria, Tecomella undulata, Acacia albida, A. senegal, A.nilotica* subsp *cupressiformis* and *A. tortilis* subsp *raddiana* have been identified for immense value in dryland ecosystem. These trees can be used for different agroforesty and alternate land use systems.

5.3 Plants of medicinal and industrial values

Balanites aegyptica, Commiphora wightii, Euphorbia antisyphilitica, Haloxylon, Cassia angustifolia, etc. are the some examples of potential plants of medicinal and industrial values in dryland ecosystem. Conservation and scientific utilization of this type of plants would help in sustaining the natural resource base in drylands.

6. Livestock management

Livestock is an essential component of dryland ecosystems. Yet there are practically no support systems available for livestock rearing for most of the dryland regions/farmers. The entire livestock support systems are Â‘milkÂ’ centric. It is time we think about the role of livestock beyond milk. The main problem with livestock management is to feed in drought conditions in dyland areas. The areas of fodder, grazing lands and grazing are essential. Integral to this the cropping patterns should be adopted. Some option for feeding livestock in drylands are-

Multi-nutrient feed block

- Using low-cost ingredients like animal-grade jaggary, urea, common salt, mineral mixture and wheat bran are the local prepared multi-nutrient feed blocks for animals.

Non-conventional silage

- *P. cineraria* leaves have been made more digestible by removing tannin from it through heating with 0.5 N aqueous solution of sodium bicarbonate.
- Tumba (*Citrullus colocynthis*) seed cake, a by-product of oil industry that contains 16-22% protein, has been found to be a healthy non-conventional feed for heifer.

Tumba (*Citrullus colocynthis*) is indigenous to western India and belongs to the family cucurbitaceae. After oil is extracted from its seeds, the residues, known as tumba cake, may be used as a cheap source of protein to replace expensive conventional cakes. Tumba cake contained appreciable amount of crude protein comparable to commonly available conventional cakes, viz., cotton seed cake, etc. Besides the nutrient composition, digestibility could be done an important index in assessing the nutritional worth of the feed. The results of conventional digestion trials, as depicted in **Table 16** clearly support the usefulness of tumba cake. The DCP and TDN amount of tumba cake is in proximity as in other non-conventional cakes like, Mahua cake, Kokam cake etc.

Table 16. Nutritive value of basal feed and tumba cake

	Ingredient	DM	CP	CF	EE	NFE	TDN	NR	SE
Mean digestibility	Wheat straw	50.30	56.42	56.50	48.80	50.3	-	-	-
Coefficients	Tumba cake	43.96	54.60	55.14	65.87	60.99	-	-	-
Digestible	Wheat straw	-	0.87	22.60	0.21	22.96	46.93	1:52.60	46.22
Nutrients	Tumba cake	-	10.35	30.22	4.15	5.62	5.50	1:4.36	53.90

Sharma *et al*, (1996)

7. Management of dryland mineral resources

Mineral resources like limestone, gypsum, sand stone, dolomite, calcite, silica sand, marble, etc. and fossil fuels such as crude oil, oil shale, sand tar, coal and natural gas are other natural resources in dryland areas. Systematic and planned mining operations, suitable site selection for waste disposal, proper exploration and utilization of these resources would help in socio-economic development of the dryland areas.

Conclusion and general recommendations

1. **Dryland regions are harsh environment and need concerted efforts to improve productivity based on regional specificities: -** Dryland regions are harsh environment and vary to a large extent in terms of extent of irrigation, soil type, rainfall distribution and cropping pattern. Moisture is the most limiting factors in these regions and in the absence of reliable rainfall and assured irrigation water farmers grow mainly low value subsistence crops. Most of the farmers face severe risk of crop failure mainly due to climatic variability. The other risks such, as price risk is not that important in these regions. Crop productivity in dryland region is very low and needs concerted efforts to improve productivity based on regional specificities
2. **Incorporate refined traditional/indigenous knowledge of land and water management techniques for wider acceptability: -** There are many traditional technologies available in dryland regions, which have been tested over time under stress conditions. These technologies can be improved and incorporated in the package of technologies offered to the farmers. Also, a number of crops that used to be grown in dryland areas, which were able to withstand climatic risk have disappeared over time. There is a need to improve these crops and incorporate them in the cropping system of dryland farmers. They may have wider acceptability and adaptability in these regions.
3. **Management of water alone is impossible without proper land management and vice versa: -**Due to close linkage between soil and water there is need to adopt a comprehensive approach to conserve soil moisture through effective land and water management technique.
4. **Complimentarity between crop-centered and natural resource-centered technologies cannot be ignored: -** Efforts should be made to concentrate on those elements of protective technology, which do not require group action. This would mean emphasis on crop improvement technology involving development of low-cost HYVs and associated practices of crops suited to the unstable weather. If the full potential of crop improvement technology is to be achieved, the complimentarity between crop-centered and natural resource-centered technologies cannot be ignored.
5. **Agricultural diversification and linking arable farming with animal husbandry is necessary for good management of natural resources: -** Rainfed farming mixed with livestock farming, provides a dependable source of income to dryland farmers. Adopt farming system approach with close linkage between arable and animal farming. Besides, diversify land uses for fodder production and plantation of fruit trees and integrate species of crop/tree interblend with local relevance, need and interest of all segments of society. Developing models offering combination of plant cover management, both perennial and annual; through agro forestry models would be more appropriate.
6. **Implementation of watershed development programme as a holistic approach needs to be encouraged in all the regions: -**Develop a holistic policy to examine relationship between status of watershed and yield of water reservoir for hydrological interventions and afforestation (plant cover management).
7. **Management of natural resources by both public and government becomes crucial. (Limitation is the mother of good management.): -** There are number of factors affecting a good management of any project. Thus it calls for a need of people's participation with full support of government and policy makers. Improve partnership between NGOs and private sector in agricultural research, to reduce not only the overall cost but also reduce the dependence on public sector research. Promote participatory varietal selections and participatory varietal breeding. This is different from the demonstration trials, which essentially duplicate in farmers' field what researchers have done under the ideal conditions of an experiment station.

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