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Land use planning for sustainable agriculture in arid agro-ecosystem: Issues and strategies

D.C. JOSHI

7-A-66, Nandan Van, Chopasani Road, Jodhpur-342 008, India

Abstract: In arid agro-ecosystem during recent past with the increase of human and animal population, development of infra structure like ground water and IGNP irrigation and inflow of technology *viz.* mechanization of cultivation, improved seed and fertilizer *etc*., agriculture has taken momentum but without consideration of climatic and edaphic constraints. The marginal and unsuitable areas have come under plough resulting in wide spread land degradation. To rationalize the extensive and intensive spread of agricultural land use two approaches *viz*. (1) environment based, by consideration of agro-climatic zones, land capability, watershed and agro-forestry and, (2) soil quality/ constraints based *viz*. sandy, hardpan at shallow depth and salinity of soil and ground water, agricultural land use for sustainable crop production have been suggested. Besides biophysical potential/ limitations socio-economic parameters need consideration for achieving benefit of sustainable agricultural land use.

Key words: *Arid agro-eco system, land use planning, bi-physical constraints, soil quality*

Introduction

Land use pattern is a reflection of human activities within the boundaries of climatic and edaphic factors. Land use has spatial and temporal dimensions. The spatial dimensions are governed by the population flux where as temporal dimensions are the result of interactions of land resources with climatic factors, technological advances and market forces. High magnitude of land use changes are perceptible in resource rich regions, well connected by transport and communication net work. But in resource poor arid region land use changes are of low magnitude because of climatic and edaphic constraints.

In hot arid region, during recent past, with the development of infra structures like roads and electricity, availability of ground water in pockets and import of water through Indira Gandhi canal agriculture has taken momentum and as the result even non-arable lands have also been brought under plow to meet needs of growing population which has resulted in soil and environmental degradation. There is a need to rationalize the extensive and intensive spread of agriculture in the region. In this article issues relating present scenario of agricultural land use and strategies for planning sustainable agriculture in arid agro-ecosystem are presented.

North western hot arid region: Climatic and edaphic variability

The arid region of India is spread in 38.7 million ha, out of which 31.7 million ha is under hot and 7

million ha under cold arid zone. Major part of hot arid region (90%) covering 28.57 million ha, lies in north western India and the rest 3.13 million ha in pockets in southern India. The north western (N W) hot arid region of India extends between 22°30" to 32°05" N latitude and 68°05" to 75°45" E longitude covering western part of Rajasthan (19.6 million ha, 69 %), north-west Gujarat (6.22 million ha, 21 %) and south-western parts of Haryana (1.28 million ha, 4.49%) and Punjab (1.45 m ha 5.08%) (Fig. 1). The region has common characteristics of aridity and high temperature, but within the region there are large spatial variations in rainfall pattern, physiography, soils, surface and ground water and vegetation. Accordingly, the NW hot arid region has been classified in 4 sub region, 11zones and 34 sub zones (Faroda et al., 1999). These variations have been reflected in land use pattern (Table 1).

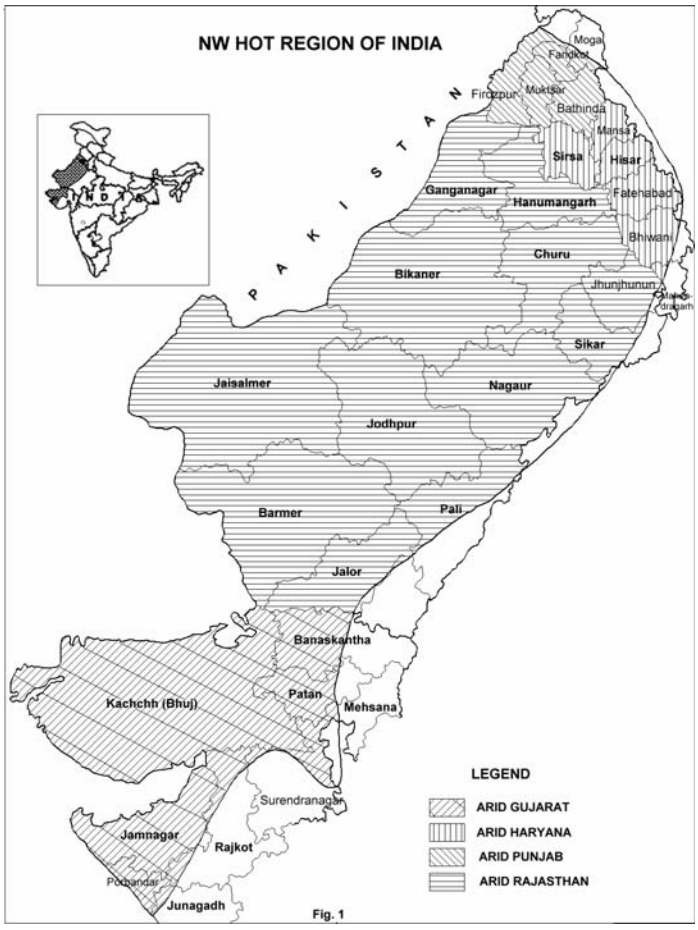

Fig.1 North western humid arid region of India

Table 1. **Agro-ecological zones of north western hot arid region of India**

Agro-ecological zones	Area (m ha)	Rainfall (mm)	Soils	Land use	Districts
			Sub region: Western sandy plain		
1. Hyperarid zone	0.86 (3.0)	<100	Torripsamments (D)	Sandy waste	Jaisalmer
2. Dune complex with scrub and grasses	2.32 (8.1)	100-150	Torripsamments (D)	Open grazing land	Jaisalmer, Biknaer, Barmer
3. Hard pan zone	1.57 (5.5)	150-250	Petrocalcids, Lithic Cambids, Lithic Calcids	Limited rainfed cropping, open grazing	Jaisalmer, Biknaer, Barmer, Jodhpur
4. Sandy plain with scattered sand dunes	7.96 (27.9)	250-450	Torripsamments (P & D), Haplocambids, Haplocalcids	*Kharif:* Pearl millet, moth, guar, moong, til *Rabi*: Wheat, mustard	Bikaner, Churu, Sikar, Jhunjhunu, Jalor, Barmer, Jodhpur, Nagaur, Ganganagar, Bhiwani, Bhatinda, Faridkot, Hisar, Sirsa.
			Sub region: Central Alluvial plain		
5. Luni Banas basin	5.45 (19.0)	300-450	Haplocambids, Haplocalcids, Haplosalids Torripsamments (P), Torrifluvents, Lithic Cambids, Lithic Calcids, Ustipsamments (P)	*Kharif:* Pearl millet, guar, moong, til, Jowar Cotton, maize, Pulses, *Rabi:* wheat, cumin mustard, isabgol, spices	Nagur, Pali, Jodhpur, Jalor, Barmer, Sikar, jhunjhunu, Bansakantha, Mehsana
			Sub region: Northern canal irrigated		
6. Canal irrigated sandy plain	2.79 (9.7)	150-300	Torripsamments (P &D), Petrocalcids, Petrogypsids, Haplogypsids, Haplosalids, Torrifluvents	*Sand dunes*: Silvipasture. *Kharif*: Pearl millet, guar, cotton, ground nut, *Rabi*: Wheat, mustard	Jaisalmer, Biknaer, Ganganagar, Hanumangarh, Sirsa, Faridkot, Firozpur
7. Canal irrigated alluvial plain	1.42 (5.0)	400-500	Ustipsamments (P)Haplocambids, Haplosalids, Ustorthents, Ustochrepts,	*Kharif*: Pearl millet, gram, maiz, urd, jowar *Rabi:* wheat, paddy, mustard, sugarcane, cotton	Faridkot, Firozpur, Bhatinda, Hisar, Sangrur, Jind, Bhiwani,
			Sub region: Southern coastal and basalt		
8. Coastal saline/ rocky upland	3.32 11.7)	150-300	Salids, Torrifluvents, Udifluvents	Saline waste, salt pan, Mangroves, open grazing limited rainfed cropping of groundnut pearl millet, pulses, castor, cowpea, jowar	Kachchh, Jamnagar, Junagarh
9. Kachchh alluvial plain	1.06 (3.7)	250-450	Haplocambids, Haplocalcids, Ustipsamments, Lithic Calcids	Limited rainfed/ irrigated cropping of groundnut, cotton, jowar, pulses, horticulture	Kachchh,
10. Santhalpur plain with saline soils	0.71 (2.5)	250-350	Haplocambids, Haplosalids, Torripsamments (P)	Limited rainfed/ irrigated cropping of groundnut, til, castor, jowar, Pearl millet, wheat	Bansakantha, Mehsana,, Kachchh, Jalor
11. Basaltic piedmont plain	1.11 (3.8)	250-500	Lithic Ustorthents, Vertic Ustochrepts, Typic Haplusterts	Rainfed/ irrigated ground nut, cotton, sugarcane, spices, rabi: wheat, mustard	Jamnagar, Junagarh, Rajkot

D: sand dune, P: sandy plain; data in parenthesis indicate % of total area.

The Agro-ecological zones 1, 2, 3 (4.75 m ha) and zone 8 (3.32 m ha) with a total area of 28.3% , receives 100-150 mm rainfall and covered with sand dunes/ coastal saline rocky waste which is mostly under animal grazing and wasteland. The zones 4, 5, 9, 10, 11 (16.22 m ha, 56.9%) receive 250-450 mm rainfall, is endowed with better soils are largely under rainfed cropping, however in pockets where tube wells have been sank irrigated rabi crops are grown. The zone 6 and 7 (4.21 m ha, 14.7%) receive canal water and high yields of irrigated crops are realized.

Constraints and Potentials for agricultural land use

Climatic constraints

High air and soil temperature: The region is characterized by high summer (April to June) air temperature which varies between 31.2° C and 42° C with peak values as high as 50°C in May month. During winter (December to February) air temperature varies between 4.1°C and 14.3° C. Soil temperature follows the diurnal and annual cycles of air temperatures and shoots up to 62°C during May and June.

Low and erratic rainfall: Low and erratic rainfall with high spatial, seasonal and annual variability is the characteristic of the region. Mean annual rainfall at extreme western part in Jaisalmer and Barmer districts varies from <100 to 250 mm, which gradually increases and at Nagaur and Jodhpur districts 300 to 350 mm and at eastern fringe along Aravalli hill ranges the rainfall is over 400 mm (Table 2). Arid region of Gujarat receives < 400 to 600 mm of mean annual rainfall. In Kachchh and Hisar districts the rain fall varies from 350 to 450 mm. Rainy days vary from 8 at Jaisalmer to 22 in Nagaur district.

Table 2. **Rainfall and potential evapo-transpiration (PET)**

Station/ State	Mean annual Rainfall (mm)	Rainy days	PET (mm)
Jaisalmer, Rajasthan	189	8	2063
Barmer, Rajasthan	260	13	1857
Nagaur, Rajasthan	332	22	1641
Jodhpur, Rajasthan	368	18	1843
Kutch, Gujarat	348	14	1897
Hisar, Haryana	446	18	1616

Annual potential evapo-transpiration (PET) is very high (1600-2063 mm) resulting in severe aridity. Because of moisture stress choice of crop is limited, crop yields are low and crops often fail. This has direct effect on land use pattern.

Frequent droughts: In arid Rajasthan drought is a recurring feature, varying in magnitude from year to year. According to Sastri et al. (1982) probability of severe droughts is more in low rainfall zone (<200 mm) while mild droughts are common in 300- 400 mm rainfall zone (Table 3).

Table 3. Probability of occurrence of agricultural droughts in western Rajasthan

District	Mean annual rainfall (mm)	Percent probability of agricultural drought			
		nil	mild	moderate	severe
Jaisalmer	189	1	11	9	79
Barmer	260	7	46	7	40
Nagaur	332	7	43	11	39
Jodhpur	368	16	28	16	40
Sikar	468	31	44	3	22

Narain and Singh (2002) reported that during last 100 years Jaisalmer and Barmer, districts experienced more severe droughts than Bikaner and Jodhpur districts (Table 4).

Table 4. Frequency of droughts in the arid Rajasthan (1901- 2001)

District	Moderate droughts	Severe droughts	Total droughts
Jaisalmer	25	43	68
Barmer	18	30	48
Bikaner	23	23	46
Jodhpur	26	17	43

Short length of crop growing period (LGP): Length of crop growing period (LGP) expressed in days, the period during which rainfall exceeds half PET plus the period for which stored moisture meets the crop water requirement after cessation of the rainy season. LGP depends on rainfall distribution, soil type, soil depth and its water holding capacity and PET. Data presented in Table 5 indicate that in Jaisalmer and western part of Bikaner district having lowest rainfall and highest PET, the LGP is <45 days. With increase in rainfall and reduced PET the LGP has increased to 75-90 days (Jain *et al*. 2000). In arid part of Gujarat Length of crop growing period varies between 60-90 days. Thus LGP is one of the important factors which decide the agricultural land use.

Table 5. Length of crop growing period (LGP) in different districts of arid Rajasthan

Districts	Rainfall (mm)	PET (mm)	LGP (days)
Jaisalmer, western part of Bikaner	<100- 200	1900 - 2000	<45
Ganganagar, Hanumangarh, eastern part of Bikaner and western part of Churu, Jodhpur and Barmer districts.	200-300	1600- 1900	45-60
Eastern part of Churu and Nagaur; Sikar Jhunjhunu.	400-500	1600- 1700	60-75
Eastern part of Jodhpur and Barmer, Nagaur, Jalor and Pali	300- 500	1600-1700	75-90

Edaphic constraints

Soils of arid region are associated with following constraints and potentials which determine their agricultural land use.

Soils highly prone to wind erosion: Sandy soils associated with dunes are dominant formations in ~25% area of western Rajasthan. These are highly prone to wind erosion during summer season.

Low moisture retention capacity and fertility: Moisture retention capacity of sandy soils is low. These soils are marginal to low in major and micronutrients.

Hard pan at shallow depth/ salinity: Petro-calcids are characterized by the presence of hard pan formed due to lime and Petrogypsids hard pan due to gypsum. The hard pan occurs at 40 to 50 cm depth is impervious to roots and water. Other shallow miscellaneous soils included *Torriorthents* and *Lithic Cambids* occur scattered in the region. Natural salt affected soils are common feature in arid region. Due to high salinity these soils restrict plant and occur as bare land in highly degraded state.

Potential agricultural soils: Sandy plain soils with scattered sand dune classified as ***Torripsamments*** are fine sandy, deep, low moisture and nutrient retention, prone to wind erosion, surface covered with low sand dunes sand hummocks and sand sheet. These soils are under rainfed cropping. Sandy plain soils without sand dunes are loamy sand to sandy loam, 60-70 cm deep, having calcic, cambic horizons are mostly under rainfed cropping but occasionally small pockets are irrigated wherever ground water is struck. The medium and fine textured soils of alluvial origin with little or no edaphic constraints are well suited for agriculture. Recent alluvium, which occurs along the bank of ephemeral rivers and streams are medium to fine texture associated with good quality ground water are productive soils. Soils of northern part of Kachchh region are moderately deep, loamy *Typic Natrargids*/ Salids. Soils in Banaskantha and Mahesana districts are deep loamy/ sandy/ *Typic Cambids* and *Torripsamments. Typic Chromusterts and Vertic Ustochrepts.* These soils are generally under rainfed cropping with occasional irrigation if ground water is struck.

Water constraints

Scarce surface water resources: In arid Rajasthan surface water potential is very low in the central, western and southern part covering 52% area. There are ephem-

Fig.2. Traditional agro-forestry with khejari

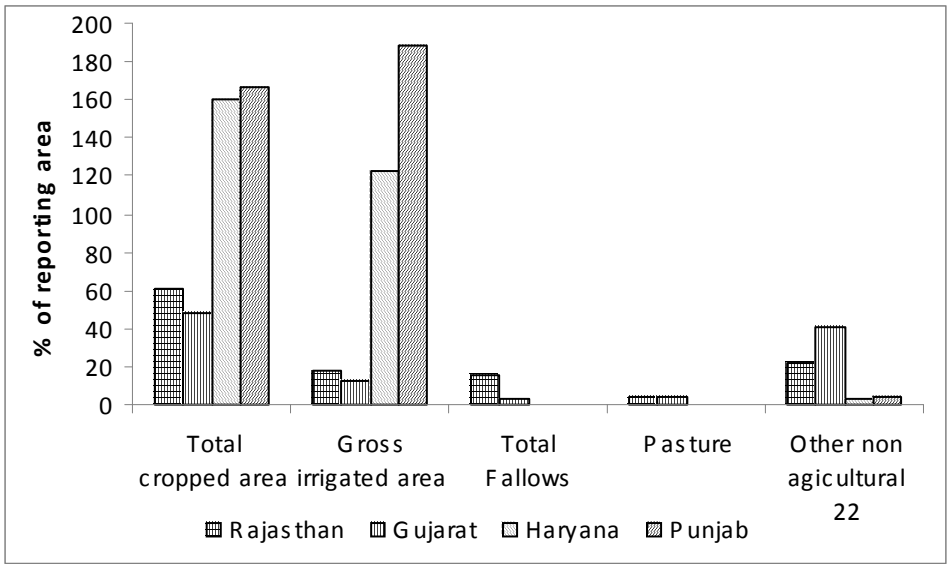

Fig 3. Major land uses in arid region of Rajasthan, Gujarat, Haryana and Punjab

eral streams which flow only during torrential rains and runoff water lost in sandy terrain. Luni river and its tributaries flow in the eastern part of arid Rajasthan. In the Luni basin along integrated stream net work medium and minor water reservoirs have been constructed which support irrigation in limited area. The northern part of the arid region including Punjab, Haryana and Rajasthan receives canal water for irrigation.

Poor quality ground water: Throughout the region, ground water is meager and even not sufficient to meet the drinking water requirement. Quality wise it is moderate to highly saline/sodic over large part. The state of ground water development has exceeded due to over exploitation for irrigation. In arid Rajasthan water level is declining @ 0.5 m per year in 9 out of 12 districts.

Unique dimensions of traditional land use

Successful crop production in arid region is always at risk because of the climatic and edaphic constraints. Livestock of the region viz. cattle, goat sheep and camel, and trees are drought hardy. Desert dwellers, through generations' of experience, have learnt to live with the vagaries of nature by adopting following traditional land use practices.

Mixed farming: Because of low, erratic and untimely rainfall, crop yields are low and uncertain. Therefore, the arid zone farmers have integrated crop husbandry with livestock rearing. Even if crops fail the livestock component supports their livelihood through income from sale of milk, wool and goat for mutton provide good support during drought years. Cattle have been preferred species but large population of goat and sheep are also maintained. Livestock can sustained on crop residues, top feed species, and shrubs growing on farm land. Jodha and Vyas (1969) reported that during drought the animal productivity is less affected than the crop production.

Agroforestry: In arid region integration of arable cropland with perennial vegetation helps in many ways (Raina 2003). Tree species *viz*. *Prosopis cineraria, Tecomella undalata* and *Acacia nilotica* and shrubs *Zizyphus nummularia* are drought tolerant, multipurpose and nutritious fodder. Realizing the beneficial effect of tree farmers have suitably blended the crop-tree-livestock relation in the system to fight vagaries of the nature. As the result, *Prosopis cineraria* (Khejri) is a dominant tree species on crop lands (Fig. 2). In eastern part of arid Rajasthan receiving 450-500 mm rainfall khejri stand is 50-70 trees per ha which decreases to 20-30 trees per ha in western part receiving 250-300 mm rainfall zone and 5- 10 trees per ha in 200 mm rainfall zone.

Fallow land: Under this system nearly half of total cultivated area available with the farmer is not cropped but kept fallow for 2 to 4 years. This fallowing helps in build up of soil fertility through regeneration of natural vegetation and droppings from livestock during grazing.

Oran land: The oran is the uncultivated land dedicated to local hero or deity where grazing is allowed but cutting of tree or bush is prohibited. There are large areas of oran land scattered in the region. The wisdom for maintaining oran land is for protection of soils from wind erosion and conservation of plant/ animal biodiversity.

Gochar land: In each village sizable area is allocated for livestock for open grazing. These lands are a big relief for mixed farmers and pastoralist. Mixed farmers graze their cattle on these lands where as pastoralists who maintain goats and sheep take animals to long distance for grazing.

Khadin system: The Khadin is a system of cropping evolved in 100- 200 mm rainfall area. The khadins have large size natural catchment with moderate slope from where the rainwater is collected in the adjoining basin area. The basin is provided with an earthen embankment to store runoff water from catchment and sluice to drain out excess water after rainy season. After rainy season as the stored water recedes or drained through sluice, winter crops *viz*. wheat, mustard are grown on conserved moisture.

Present land use

Land use data of arid region of Rajasthan, Gujarat, Punjab and Haryana for the year 2005-06 (Table 6, Fig. 3) reveals that agriculture is the dominant land

use which constitute 62.85 per cent area of the region. This includes net sown area (52.1%), current fallow (5.%) and other fallow lands (5.09%). Total cropped and double cropped area comes to 67.9 and 15.8 per cent respectively. Punjab and Haryana have more than 75 per cent area under double cropping while Rajasthan has around 10.0 per cent and Gujarat around6 per cent only. The rainfed croplands (Net sown- net irrigated) constitute about 11.1 million ha or 33 per cent of the total area of the region. With the decreasing rainfall, the intensity of cultivation decreases from east to west.

Table 6. Present land use in arid region (2005-06, area in million ha)

States	Rajasthan		Gujarat		Haryana		Punjab		Total	
Districts	12		6		5		6		29	
Reporting area (mha)	20.8		9.4		1.7		1.7		33.6	
Land use	mha	%	mha	%	mha	%	mha	%	mha	% of reporting area
Agricultural land use										
Total cropped area	12.7	61.1	4.5	47.9	2.8	159.8	2.8	165.9	22.8	67.9
Net sown	10.7	51.2	3.9	41.6	1.5	83.9	1.5	88.2	17.5	52.1
Area sown more than once	2.1	9.9	0.6	6.3	1.3	75.9	1.3	77.7	5.32	15.8
Net irrigated	2.7	12.9	1.1	11.2	1.2	67.1	1.6	88.1	6.4	19.1
Gross irrigated	3.8	18.1	1.2	13.2	2.2	123.3	2.8	165.9	10.0	29.8
Current fallows	1.5	7.3	0.2	2.6	0.1	5.6	0.02	1.3	1.9	5.6
Other fallow	1.7	8.2	0.005	0.05	0	0	0	0	1.7	5.1
Non Agricultural Land use										
Culturable waste	3.7	17.7	1.8	18.9	0.003	0.2	0.005	0.3	5.5	16.2
Permanent Pasture	0.8	3.9	0.4	4.0	0	0	0	0	1.2	3.5
Forest	0.5	2.2	0.6	6.4	0.006	0.3	0.03	1.7	1.1	3.2
Barren and uncultivable land	1.1	4.8	2.1	22.6	0.04	2.5	0.07	4.1	3.2	9.6

Source: Anonymous (2008 a, b, c, d).

In arid Rajasthan out of 61.1 per cent total cropped area only 18.1 per cent area is gross irrigated. Similarly in arid Gujarat out of 47.9 per cent gross cropped area gross irrigated area is 13.2 per cent. In arid Haryana out of 159.8 per cent total cropped area 123.3 per cent is gross irrigated. In arid Punjab entire 165.98 per cent total cropped area receives irrigation.

Other non agricultural land use categories included are forest (3.2%), barren and uncultivable lands (9.6%), and permanent pastures (3.5%). Pasture lands and culturable waste lands are concentrated in Rajasthan and Gujarat states only. Similarly other fallow lands occur only in Rajasthan because of sandy desertic terrain. In arid part of Haryana and Punjab, adverse effect of aridity on agricultural land use has been minimized because of irrigation available from canals.

During the period from 1982-83 to 2005-06 in arid region the net seeded area increased by 13.1 per cent and that of double cropped area by 71.5 per cent. Major land use changes have occurred in the arid region of Rajasthan and Gujarat where net seeded area has increased in the sandy plain and inter-dune plain. Area under culturable waste land has declined by 18.1 per cent. This was compensated by an increase of 16.7 per cent under other fallow lands.

Land use changes in arid Rajasthan

Due to extreme climate, difficult dune terrain for long remained un-habitated. Gradually people from the adjoining areas entered the desert, they adopted animal rearing with limited agriculture. With increasing human and livestock population, land use underwent changes. The human population which in 1901 was 3.567 million increased to 5.87 million in 1951, 22.511 million in 2001 and 27.31 million in 2011. Similarly total livestock population which was 13.3 million in 1956 rose to 22.43 million in 1983 and 28.51 million in 2007. Development of infra structures like roads and availability of electricity paved way for agricultural development. Introduction of tractors for agricultural operations and expansion of irrigated area through tube wells and Indira Gandhi canal gave momentum to agricultural productivity.

After formation of Rajasthan State in 1950, land records in terms of ownership, land use and crops grown became available from revenue year 1956-57. The data available from 1956-57 and onwards (Table 7, Fig. 4) have been used for interpretation of land use changes.

In the year 1957-58, total cropped area was 36.1 per cent, net sown was 35.5 per cent and double cropped area was 0.7 per cent. Total irrigated area was only 2.6 per cent.

Table 7. Land use change in arid Rajasthan during 1957-58 to 2010-11(% of reporting area)

Land use	1957-1958	1997-1998	2001-2002	2005- 2006
Reporting area (m ha)	20.8	20.8	20.8	20.8
Agricultural land use (% of reporting area)				
Total cropped area	36.1	64.5	61.0	61.1
Area sown more than once	0.7	12.2	8.6	9.9
Net sown	35.5	52.3	52.4	51.2
Current Fallow	9.1	5.9	6.3	7.4
Fallow other than current Fallow	14.2	7.1	7.9	8.2
Total irrigated area	2.6	11.3	11.2	18.1
Non- Agricultural land use (% of reporting area)				
Culturable waste	24.2	19.3	18.5	17.7
Forest	0.7	2.0	2.1	2.1
Permanent pasture and oran	2.3	3.9	3.9	3.9
Barren and uncultivated	11.2	4.9	4.8	4.8

Source: Ram (2003, 2006, 2009).

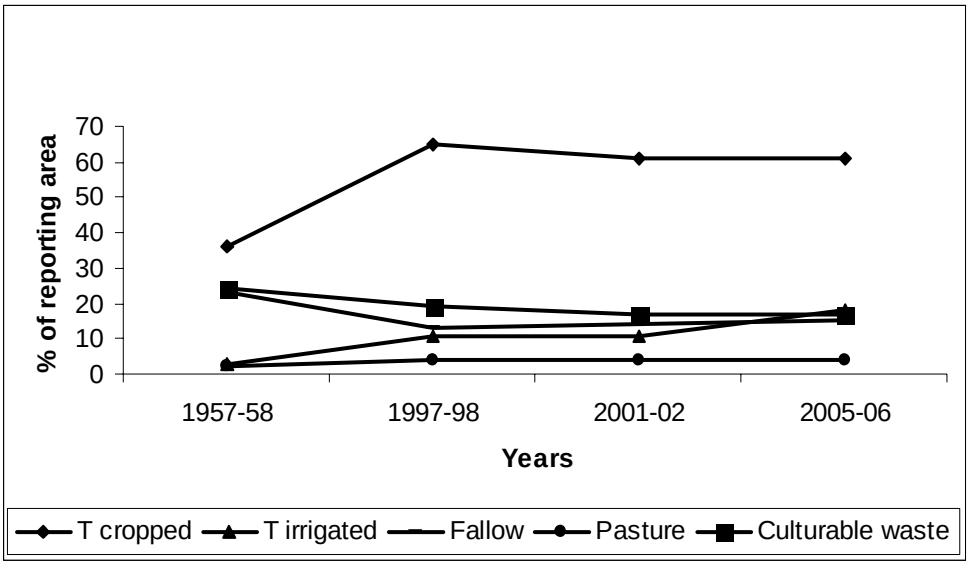

Fig. 4. Land use changes in arid Rajasthan

Fallows and pasture + oran accounted for 23.3 and 2.3 per cent area respectively. During 1957-58 to 1997-98 period increase in total cropped area was from 36.1 to 64.5 per cent, under sown more than once area increased from 0.7 to12.2 per cent and net sown area from 35.5 to 52.3 per cent. Under current fallows and other fallows area decreased respectively from 9.1 to 6.0 per cent and 14.2 to 7.9 per cent. During this period total irrigated area increased from 2. 6 to 11.3 per cent. Similar changes in land use but with less magnitude have been observed during 1997-98 to 2005-06 except in irrigated area which increased to 18.1 per cent. This increase in irrigated area was possible due to sinking of tube wells, Indira Gandhi Nahar Project and construction of medium and minor irrigation projects,.

Crops and cropping pattern:

N W arid region: Pearl millet and cluster bean are major kharif crops and wheat and mustard major rabi crops and during the year 2005-06 constitute 20.8, 10.8, 13.9, 8.9 per cent of the gross cropped area. Other crops grown are gram (4.4%), mung bean (3.2%), moth bean (5.5%), groundnut (4.6%), castor (1.3%), sesame (2.2%), cumin (1.2%), and isabgol (0.4%). Punjab and Haryana are major producers of rice, wheat, and cotton. Gujarat contribute in groundnut, castor, sesame, and cumin crops while Rajasthan leads in pearl millet, mung bean, moth bean, mustard, cluster bean, and isabgol production. Out of the total agricultural production of this region, Punjab contributes highest (34.6%) followed by Gujarat (23.3%), Haryana (21.4%) and Rajasthan (20.7%). Thus, in spite of the large area, the production in Rajasthan is comparatively less due to the large area of rainfed crops, with high risk and uncertain production (Anonymous 2008 a, b, c, d).

Arid Gujarat: Based on soil and climatic data and LGP Jain et al. (2003) reported that Banaskantha district is moderately suitable for pearl millet, sorghum and maize. The Kachchh district is only marginally suitable for crops due to very high salinity. Arid areas of Jamnagar, Rajkot and Surendranagar districts are suitable for groundnut and moderate to marginally suitable for pearl millet, sorghum and castor. Costal belt of Jamnagar district is marginally suitable for cropping. The crop suitability under rainfed condition of arid Gujarat is in the order: pearl millet> sorghum > maize > ground nut > tobacco > castor and cotton. Under irrigated condition the crop suitability is in the order: ground nut > maize > sorghum >castor >tobacco and cotton.

Arid Rajasthan: During kharif pearl millet, clusterbean, moongbean, moth bean and sesame are grown under rainfed condition. Pearl millet and moong bean are grown as mixed crop in central and eastern districts of arid Rajasthan, whereas pearl millet with moth bean are wide spread in western drier part. In the year 2008-09 pearl millet was grown on largest area (39.46%), followed by cluster bean (28.4%), moth bean (12.6%) and moong bean (6.6%). Even if rains fail residues of pearl millet and pulses is used as fodder for livestock. In rabi under irrigation wheat, mustard, are major crops followed by cumin and isabgol. Gram is grown under conserved moisture. In Canal command area rice and cotton are major crops grown on large scale.

Variation in intensity of cultivation: In arid region of Rajasthan area under rainfed cropping varies from year to year depending on amount and distribution of rainfall. Intensity of cultivation decreases from east to west. Ram and Lal (1997) based on field surveys and remote sensing data (Table 8) reported that area with high intensity (80-100% and 60-80 %) of cultivation under rainfed mono cropped land is very low (5-6%) in Jaisalmer, Barmer and Churu districts followed by Jodhpur (15%) and Bikaner (23%) districts. In Pali, Sikar Ganganagar and Nagaur districts high intensity of rainfed mono crop was observed in 35 to 51 per cent area.

Table 8. Area under rainfed mono-crop land and irrigation in some arid districts

District	Total geographical area (sq. km)	Intensity of cultivation (%) of rainfed mono-crop					Irrigated
		80-100	80-60	30-60	<30	Total	
		Per cent of total geographical area					
Jaisalmer	38401	3.7	2.2	1.7	1.0	8.7	0.01
Barmer	28287	1.5	13.5	31.0	30.9	77.7	0.87
Churu	16830	4.3	19.4	40.1	24.0	89.9	2.13
Jodhpur	22850	13.7	21.0	22.9	18.4	77.1	1.06
Bikaner	27244	20.9	3.9	4.5	17.3	48.3	1.48
Pali	12387		14.3	4.4	3.1	64.7	5.73
Sikar	7732	38.2	16.4	5.8	2.2	79.4	16.74
Nagaur	17718	44.9	22.4	12.4	4.6	87.5	3.15
Ganganagar + Hanumangarh	20634	33.7	21.7	7.3	6.8	85.4	15.8

Land degradation

Land degradation refers to human induced or natural processes which reduce its productivity on temporary or permanent basis. Land degradation leads to reduction of crop yield, biomass production in pastures and forestlands. Land degradation is mainly due to human activities Land degradation process in arid, semi arid and dry sub humid area is termed desertification.

Causes of land degradation: With the increasing human and livestock population marginal lands have been brought under cultivation without consideration of land capability. Upon cultivation on marginally suitable and unsuitable land, the risk of soil damage increases and productivity decreases. Results of Integrated resources survey carried out by CAZRI for seven districts of arid Rajasthan (Table 9) reveal that in none of the districts

land qualified for class I and II. In Jaisalmer, Barmer and Bikaner districts class III and IV area (Suitable/ marginally suitable for growing crops) together accounted respectively for 7, 27 and 49 per cent of total area of respective district. In another four districts the situation is better with nearly 70% area suitable/marginally suitable for cropping. As per revenue record actual area under cropping is much higher than the area indicated under class III + IV. Cultivation on such unsuitable land has resulted in land degradation. Other important causes of land degradation are irrigation with brackish ground water, increased use of tractors and other farm machinery and excessive irrigation in command area.

Table 9. Area suitable for arable cropping as per land capability classification

District	Mean annual rainfall (mm)	Area (km^2)			
		Total	Class III for suitable cropping	Class IV marginally suitable for cropping	(III & IV)
Jaisalmer	164	38401	280	2492	2772 (7)
Barmer	275	28287	1673	5844	7517 (27)
Bikaner	250	27244	6287	7107	13394 (49)
Jodhpur	360	22850	7689	9626	17315 (75)
Nagaur	390	17718	9563	3422	12985 (74)
Jalor	421	10640	5376	2623	7999 (75)
Sikar	440	7732	3261	2258	5519 (72)

Data in parenthesis indicate (%) of total area of respective district

Land degradation processes

Wind erosion/deposition: Wind erosion is the dominant land degradation process in arid region. During May –June the winds acquire speeds of 20 to 40 kmph, for few hours to days together resulting in wind erosion. Slight land degradation results in sand sheeting along fence line and field proper, moderate degradation in thick sand sheeting associated with sand hummocks in fields, along transport net work and habitation and severe in the formation of mobile sand dunes It has been observed that sandy soils cultivated with heavy machinery are highly vulnerable to sand drift where as well managed grasslands are least affected. Deposition of wind blown sand in fields reduces productivity of land.

Water erosion: Land degradation due to water erosion is apparent by stripping off of surface soils and presence of rills and gullies. In the eastern and central part of arid Rajasthan receiving 300-400 mm rainfall water erosion is very active at the foot hill zone and on the uplands. Slight degradation is manifested as surface runoff, moderate degradation as sheet erosion with rills and severe degradation results in extensive rills and gullies.

Secondary salinisation/sodification: Ground water in arid region is generally saline-sodic containing high soluble salts and residual sodium carbonate (RSC). In arid Rajasthan irrigation with water of RSC 10-12 mmol L^{-1} for 5 to 8 years resulted in build up saline-sodic soils. Similarly in arid part of Gujarat and Haryana states substantial area has turned sodic due to such poor quality water irrigation.

Water logging: In the Indira Gandhi Nahar command area, water table is rising at the rate of 0.43 to 0.83 meter per year. Both, seepage from canal and excessive irrigation are contributing to rising water table resulting in land degradation in canal command area of arid Haryana and Punjab.

Extent of land degradation

Various attempts have been made to map the extent of land degradation/ desertification in the arid region (Raina *et al*. 1991&1992; Singh *et al*. 1992). Based on country wide land degradation mapping project Kar *et al*. (2009) have reported (Table 10) that in arid Rajasthan, on cropland, wind erosion is dominant process which caused slight to moderate degradation under rainfed condition on 29.9 per cent and on irrigated lands 13.3 per cent and severe degradation on crop land on 6 per cent and on irrigated lands to the extent of 0.18 per cent. Water erosion on cropland has degraded only <1 per cent area. In arid Gujarat water erosion is the most dominant process affecting ~12.9 per cent rainfed and 17.5 per cent irrigated area.

Table 10. Desertification of agricultural land arid Rajasthan and arid Gujarat (based on visual interpretation of 1:500,000 scale AWIFS satellite imagery (2003-04)

Land use	Type of degradation	Area (km2)	% of total area mapped	Area (km^2)	% of total area mapped
		Arid Rajasthan		Arid Gujarat	
Crop land (Rainfed)	Wind erosion (slight-moderate)	62868	29.9	1875	2.5
	Wind erosion (severe)	12584	5.9	-	-
	Water erosion (slight-moderate)	1143	0.54	9693	12.9
	Water erosion (severe)	39	0.02	373	0.5
	Salinity (slight-moderate)	1928	0.92	3066	4.1
	Saliniry (severe)	118	0.06	278	0.4
Crop land (Irrigated)	Wind erosion (slight-moderate)	27906	13.3	2072	2.8
	Wind erosion (severe)	380	0.18	-	-
	Water erosion (slight-moderate)	1350	0.64	13128	17.5
	Water erosion (severe)	-	-	1618	2.2
	Salinity (slight-moderate)	527	0.25	47	0.1
	Saliniry (severe)	6	0.00	-	-
	Water logging (slight-moderate)	177	0.08	-	-
	Water logging	6	0.00	-	-
	Total	**109028**	**51.81**	**31150**	**42.9**

Acquisition of agricultural lands for non agricultural purposes

Agricultural lands with good productive soils, is an assett for those who reside in villages and carry out agriculture and related economic activities for their livelihood. Such good land is being acquired for construction of township, setting up special economic zone (SEZ), IT parks, business installation, industries, mining, establishment of atomic reactor, aerodrome, high ways etc. There is severe opposition from the land owners. The agitation has taken a violent struggle in many States including West Bengal, Odisha, Uttar Pradesh, Karnataka and Maharastra. There are 170 million ha of wastelands spread in every city and village which can be used for such non-agricultural purposes. We can't become economic power with empty stomach.

Land use for sustainable agriculture

Optimum utilization of soil resources for enhancing agricultural productivity is only through sustainable land use. The concept of sustainable land use includes environmentally sound, culturally sensitive and

economically viable approach (FAO 1989) has defined sustainable agricultural as one which involves successful management of resources to satisfy changing human needs, while maintaining or enhancing the quality of environment and conserving natural resources. Many of the technologies adopted for increasing crop/biomass production are lopsided, short lived and incompatible with host environment resulting in deterioration in soil quality and decrease in crop/biomass production. Land use for sustainable agricultural productivity should be based on two approaches *viz*. 1) environment based, and (2) soil constraints/quality within ecosystem boundaries.

Environment based Land use for enhancing agricultural productivity

Environment based land use approach follows broad climatic and edaphic considerations and includes agro-ecological zones, land capability classification, watershed management and agro-forestry. These are described below.

Agro-ecological zone based production system: The agro-ecological zone is uniform with respect to soil, water and other natural resources which have similar production potentials for food, fibre and fodder crops and pasture grasses under a set of management practices. Based on the zones identified for the arid agro ecosystem (Faroda *et al*. 1999) land use planning can be under taken. Within the zone variability exist in the land capability. The land suitable for arable farming (Land capability class I to IV) may be put under the adapted crops of the region. Cultivation on non-arable and marginal land (Land capability class V to VIII) increases soil degradation, therefore these may be kept under grasses, tree and shrub plantation.

Watershed approach: Watershed is a geographical entity where surface water drains through a common single outlet. Watershed approach helps is *in situ* rainwater conservation for raising crops and perennial component, collect excess runoff water for supplemental irrigation, prevent land degradation, improve land productivity and maintain ecological balance amongst land, water vegetation and animals. The package of practices for watershed development has to be site specific.

Agro-forestry: Agro-forestry is an integrated land use system involving agricultural crops, trees and livestock on the same piece of land. Tree is central to the agro-forestry system because these benefit both the agricultural crops and the livestock. Trees help crop by controlling wind erosion, enriching soil fertility, improving moisture availability and micro-environment (Joshi 1997). Tree leaves are nutritious fodder for livestock. Additionally trees provide timber, fruits and fuel. Agro-forestry is a viable approach to soil management in arid ecosystem. A suitable mix of drought tolerant multipurpose trees *Prosopis cineraria*, *Tecomella undalata* and *Acacia nilotica* and *Zizyphus nummularia* shrubs provide conservation and production functions in rain fed crop land (Joshi and Raina 2005; Joshi 2011).

Soil quality/constraints based land use for sustainable crop production

Arid soils distinguish themselves from rest of the semi arid and sub humid soils by their low clay, silt and organic matter, and high soluble salt and CaCO3 contents. The soils are characterized by aridic moisture regime (Dry for more than 90 consecutive days) and hyperthermic temperature regimes (Mean annual soil temperature is >22^{o} C and difference between mean summer and mean winter temperature >5^{o} C at 50 cm depth). Physiographic micro-relief variations and arid climate have contributed to minimum mineral weathering and weak pedogenic manifestations. Pedogenic processes *viz*. weak illuviation of silicate minerals, segregation followed by accumulation of lime in concretionary and powdery forms and translocation/ accumulation of salt in the profile have resulted the formation of ochric epipedon and the Calcic, Petro-calcic, Cambic, Gypsic, Petro-gypsic and Salic diagnostic horizons. Soils of arid Rajasthan classified in orders Aridisols and Entisols extend respectively in 41 and 52 per cent area. Extent of different soil groups in arid Rajasthan are presented in Table 15. These arid soils are associated with constraints like low available

water capacity, low nutrient retention and availability, vulnerable to wind erosion, shallow soil depth, salinity, sodicity and physical constraints like surface crust and high infiltration. Kind and magnitude of constraint may vary with the soil group. Sustainable land use for higher productivity should be based on consideration of these constraints (Joshi 1996 & 2000).

Table 11. Extent of different soil great groups in arid Rajasthan

Soil group	Classification	Area, km^2	%
Dune and interdune	Typic Toripsamments	48553	25.1
Sandy plain with scattered sand dunes	Typic Toripsamments	54647	28.3
Sandy plain (Coarse loamy)	Haplocambids	43795	22.7
	Haplocalcids	12535	6.5
	Calcigypsids	702	0.4
Alluvial plain (Fine loamy)	Haplocambids	5107	2.6
	Haplocalcids	1441	0.7
	Torrifluvents	4340	2.2
	Aquicambids	1157	0.6
Hard pan soils	Petrocalcids	2580	1.3
	Petrogypsids	565	0.29
Salt affected	Haplosalids	1640	0.9
Shallow Miscellaneous	Lithictorriorthents	7870	4.1
	Lithic Cambids	8719	4.5

Source: Soil Resource Atlas of Rajasthan, SRSAC, Jodhpur, (2010)

***Sustainable land use for crop production on sandy plain soils*:** Sandy plain soils with scattered sand dune classified as Typic Torripsamments occur in 54647 km^2 (28%). Surfaces of these soils are covered by sand sheets and hummocks of variable thickness, moderate to severe wind erosion is major soil degradation process.

Sandy plain soils with no sand dune in general have loamy fine sand/ sandy loam texture and 70-90 cm deep with with calcic/ cambic/gypsic horizon. These soils have less than 18 per cent clay + silt classified as coarse loamy Haplocambids (43795km^2, 22.7%)/ Haplocalcids (12535 km^2 , 6.5%), calcigypsids (702 km^2 0.4%). These have moderate AWC (90-120 mm m^{-1}). Sandy plain soils are generally low in org. carbon (<0.2%) and nitrogen, medium in available phosphorus (10-15 kg ha^{-1}) and medium to high in potassium (140 to 200 kg ha^{-1}). These soils are mostly under rainfed agriculture in kharif and bajra, moong, moth, guar and til are cultivated.

Management approach: For enhancing productivity of these soils, wind erosion control, conservation of rain water and nutrient management are most important. Following approaches enhance the productivity of these soils.

Improved technology for rainfed cropping: Improved varieties of pearl millet HHB-67, Moong S-8, cluster bean, moth bean RMO 40, top dressing of fertilizer @20-40 kg N per ha after one month of sowing when the crop has been established. *In situ* rain water harvesting, contour bunding , field bunding are to be practiced. For *in situ* moisture conservation, organic mulch using crop residue may be adopted.

Improved technology for irrigated cropping: Under irrigation for rabi, improved varieties of wheat, cumin and mustard with the recommended fertilizer dose and plant protection measures be adopted. Sprikler system of irrigation be adopted. Micro-sprinkler and drip system are adopted for vegetables and fruit crops.

Trees on farm boundaries as shelterbelt and in fields: shelter belts are planted across wind direction and on the margin of agricultural fields consisting of a row of tall tree viz. *Acacia tortilis, Tamarix articulata or Azadirachta indica* flanked by two rows of small trees like *Acacia senegal, Parkinsonia aculata* with two rows of shrubs like Aerva tomentosa, Calligonum polygonoides. Such shelterbelts are effective up to a distance of 15 to 20 times the tree height help in control of wind erosion and improve micro environment. Agri-horticulture : Agri-horticulture involves growing fruit plants and agricultural crops on the same piece of land and the components of the system are complementary to each other. The Gola and Seb varieties of jujube once established proved very successful. Jalor seedless and Ganesh varieties of Pomegranate and Aonla perform well under saline water irrigation.

Sustainable crop production on alluvial plain soils

The south eastern part of western Rajasthan, covering the southern part of Nagaur, south eastern part of Jodhpur and entire Pali district the soils have developed from the sediments deposited by the streams flowing in the area.

Soil qualities: The soils are medium to fine textured having cambic/ calcic / gypsic horizon and classified as fine-loamy *Haplocambids* (5107 km^2 , 2.6%) and fine-loamy *Haplocalcids* (1441 km2 , 0.7 %). Recent alluvium classified as *Torrifluvents* (4340 km^2, 2.2%) and *Aquicambids* (1157 km^2 0.6%). These are dark brown to greyish brown, sandy loam to loam, sub-angular blocky, surface and greyish brown to very dark greyish brown, clay loam to silt clay loam with 15 to 22% clay and 10 to 15% silt, well developed sub-angular blocky subsoil. The soil depth ranges from 60 to 120 cm. These soils are characterized by high resource potential and high available water capacity (150-200 mm m^{-1}). Moderate water erosion, crusting , high available water capacity, and fertility indicate good resource potential.

Management approach: These soils have high resource potential in terms of water holding and nutrient retention capacity. These respond to fertilizer and irrigation with good quality water and cultivated for cash crops like cotton, mustard, ground nut and wheat. Sizeable area of these crops is under orchards. These are the best soils of the region often associated with ground water of good to moderate quality. Improved varieties, with recommended fertilizer, plant protection measures high yields of cash crops can be realized.Sprinklers and drips should be used as per crop requirement.

Sustainable crop production under brackish water irrigation

Soil qualities: In arid region ground water available for irrigation is generally saline or contains high residual sodium carbonate (RSC) water. Irrigation with such water results in development of sodicity, reduction in soil porosity, water infiltration and unusual hardness. Nutrients like phosphorus, zinc and calcium are rendered unavailable.

Management approach: Gypsum @ 100% soil requirement is applied in field before rains, incorporated with soils, and field provided with bunds to conserve rainwater. This helps in decrease of soil pH, sodium absorption ratio (SAR) and improvement in soil physical properties resulting an increase in grain yield (Joshi and Dhir 1991, 1994). Once the soils have been ameliorated, further small application of gypsum are needed every year to avoid sodification.

Sustainable management of sand dune soils

In western Rajasthan 48553 km^2 (25%) area is under sand dunes. There are six types of sand dunes viz. Parabolic, longitudinal, transverse, coalesced parabolic, obstacle and barchan. All the dunes except barchans are stable. However because of biotic interference surfaces of most of the sand dunes are activated and during summer moderate to severe soil erosion takes place.

Soil qualities: Dune soils, classified as *Typic Torripsamments* have characteristic undulating topography, complex slope, very low clay (2 -5%) and silt (2-3%), and 90-95 per cent soil mass is made up of fine and very fine sand fraction. and. The soils are very deep, low in organic carbon (0.05-0.15%), available P (10-16 kg ha^{-1}) and available K (116-392 kg ha^{-1}). Available water capacity is low (80- 90 mm per metre depth). Infiltration rate is high but the capillary movement of moisture is very low resulting in absence of upward movement of moisture.

Management approach: Sand dune stabilization by adopting (i) *Protection from biotic interference* by angle iron posts with lining of barbed wires. (2) *Erection of micro wind breaks*: by using locally available dried brushes, like twigs of *Ziziphus nummularia, Calotropis procera, Crotolaria burhia, Aerva tomentosa* and *Leptadenia pyrotecnica* and (3) *Planting* suitable species *viz*. *Calligonum polygonoides, Colophospermum mopane, Acacia tortilis, Acacia nubica*. In between the tree species root slips of grasses *Lasiurus sindicus, Panicum turgidum, Cenchrus biflorus, Cenchrus setigerus Citrullus colosynthis and Saccharum munja* are planted depending on rainfall. Within 4 -5 years trees and shrubs make good growth and sand dunes are stabilized.

Sustainable management of hard pan/ shallow soils

Hardpan soils widely occur in Jaisalmer and Bikaner districts and to lesser extent in Barmer and Jodhpur districts. These classified as *Petrocalcids* (2580 km^2 1.3%) and Petrogypsids (565 km^2 , 0.3%). Rocky/ gravelly areas classified as *Torriorthents* (7870 km^2 4.1%) and *Lithic Cambids* (8719 km^2 4.5%) occur scattered in all districts.

Soil qualities: Soil are gravelly loamy sand/sandy loam, depth varies from 10-40 cm and water retention is low (20-25 mm 50 cm^{-1} depth). Water erosion is the major land degradation process. This category may have three type of situation 1) Petrocalcic/ Petrogypsic horizon at shallow depth, 2) surface covered with gravels/ stones, and 3) Undulating topography with 3-4% complex slope and exposed rocks. Their present uses are limited to grazing land, in pockets rainfed cropping and mining for gypsum and lime.

Management approach: Productivity of these soils can be enhanced by adopting silvi-pastoral, horti-pastoral and horti-silvi-pastoral systems. For establishment of trees and grasses, protection from other biotic interference an optimum combination of land shaping, rainwater harvesting/limited irrigation, profile modification, planting techniques, and appropriate plant species: *Acacia tortilis, Colophospermum mopane, Hardvickia binata trees* and *Capparis decidua, Z. rotundifolia* shrubs in 5 m wide rows.

Sustainable management of salt affected soils

In arid Rajasthan natural salt affected soils widely occur in all the districts and occupy total 1640 km^2 (0.9%) area. In arid region of Gujarat in the Jamnagar and Kachch districts the salt affected soils occupy vast area.

Soil qualities: These are grayish brown to very dark grayish brown, loam to clay loam, angular blocky soils with high soluble salts, high pH and extremely low permeability which restrict their use for agriculture.

Management approach: Silvi-pasture approach is followed for enhancing productivity of such lands. Tree growth exerts ameliorative effects by improving physical, chemical and biological properties of salt affected soils. Through their roots, trees open the compact subsoil and improve water and air permeability and thus facilitate salt leaching. Leaf fall from trees and shrubs, help in improving soil fertility and microbial activity.

Resource Management Domain (RMD) - Approach for Sustainable Agricultural Development

Agricultural development planning is based on the biophysical potential/ limitations of land resources. Inspite of best efforts the dream of the potential benefits of natural resources management is not realized because the socio-economic factors are not considered. Ram and Joshi (2010) for the arid region formulated 15 RMD units

by integrating biophysical attributes viz. land forms, soil, and land use, mean annual rainfall range, source of irrigation (well/canal) and socio-economic indicators *viz*., population density per km2, % literacy, livelihood base (livestock, labour), socio economic status (Low/ high), % net area sown, % net area irrigated. Each RMD is uniform with respect to the natural resource base and socio-economic indicators, thus, these have similar potential/ constraints and social status and may help in development planning.

Conclusion

Sustainable crop production in arid region is always at risk because of climatic and edaphic constrains. Desert dwellers through generations have evolved traditional land use practices *viz*. oran and gochar, mixed farming and agro-forestry by suitably combining crop - live stock –trees to overcome the impact of low, erratic and uncertain rainfall and drought. Present land use data (2005-06) revealed that total cropped and gross irrigated area (% of reporting area) was much less in Rajasthan (61%, 18%) and Gujarat (48%, 13%) than in Haryana (160%, 123%) and Punjab (166%, 166%). In arid Rajasthan, during last ~50 years (1957-58 to 2005-06) increase in total cropped area from 36 to 61% and irrigated area from 2.6 to 18.1 % and decrease in fallows from 23.3 to 15.6 % indicated that cultivation on marginal and unsuitable land have resulted in land degradation. In arid Rajasthan wind erosion has degraded 36% rain fed and 13%irrigated land. In Gujarat water erosion has degraded ~13% rainfed and 17.5% irrigated area.

For rationalization of agriculture land use for sustainable crop production two approaches *viz*. (1) environment based by consideration of agro-climatic zones, land capability, watershed and agro-forestry, and (2) soil quality/ constraints based like prone to wind erosion, low moisture and nutrient retention capacity, hardpan at shallow depth and salinity of soil and ground water have been discussed. Besides biophysical potential/limitations socio-economic parameters need consideration for achieving benefit of sustainable agricultural land use.

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