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Resource management for sustainable crop production in arid zone – A review

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ABSTRACT

The arid region in India is spread over 3,17,090 sq km, of which 70,300 sq km is classified as cold arid and the remaining is hot arid region. Western Rajasthan alone carries the onus of nearly 61% of hot arid lands in India. In this region, biotic pressure is high and resource base both in terms of soil and rainfall is poor. The mean annual rainfall varies from <150 to 400 mm and longest crop growth period available is <6 to 12 weeks only. Under such circumstances, realizing sustainable crop production is a daunting task. Efforts have been made in this paper to discuss the management of resources in the arid zone and technologies developed for obtaining sustainable crop production. On-farm rainwater management has been advocated through inter-plot and intra-plot water harvesting system. *Khadin* as a water-harvesting system is unique in the region for farming. Crop, water and nutrient management strategies as well as alternate land use systems relevant to local needs have been discussed in detail. Possible measures to mellow the effects of factors that lead to resource degradation and consequent influence on production have been discussed. Suggestions on future research needs on issues such as moisture conservation, soil conservation, nutrient management, crop establishment, cropping systems and alternate land-use, decision criteria etc. have been given.

Key words : Alternate land use systems, Cropping systems, Nutrient management, Resource management, Water management

In India, nearly 3,17,090 sq km area falls under arid region, of which 70,300 sq km is classified as cold arid and the remaining is hot arid region. About 61% of total hot arid area lies in the Rajasthan, 20% in Gujarat, 9% in Punjab and Haryana, and 10% in Karnataka and Andhra Pradesh. The arid region is characterized by low and erratic rainfall, high temperature, high wind velocity, high potential evapo-transpiration and scanty vegetation. Water scarcity is experienced frequently in the region, which leads to frequent droughts. The shortage of water adversely influences the food and fodder availability, which causes migration of human and livestock. Besides aberrant climatic condition, the Indian arid ecosystem is one of the most densely populated regions of the world. The high biotic pressure on the arid lands aggravates the desertification process and reduces the productivity of crops, which results in over-exploitation of resources of the region (Gupta and Narain, 2003). The per capita availability of land is consequently decreasing; while food and fodder demand is increasing. Sustainable crop production is thus a major concern to meet the food and fodder requirement under such circumstances. Apart from this, the concept of low input - low risk - low yield needs to be revolutionized using the technologies developed by the research institutes working in the arid region.

THE SCENARIO

Crop failure is a common feature either due to inadequacy of rainfall or due to shortage of soil moisture to meet the crop water requirements during different phenophases. Besides this, the arid region has several biotic and abiotic limitations that are responsible for low productivity.

Rainfall and water availability

Rainfall is the chief source of water replenishment in the arid region, but it is low and highly erratic. Coefficient of variation of annual rainfall varies from 37 to >50% (Rao and Singh, 1998). Much of the rainfall (78 to 96%) is received during July to September by south-west monsoon, while the remaining is received during winter (December - February) through north-east disturbances. The whole monsoon rain is received in 8-10 days. The mean annual rainfall of the region varies from <150 to 400 mm. The arid region annually receives about 62,623 million cubic meters (MCM) water, of which 89% is through rainfall (Khan, 1996). The total surface water potential of arid

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zone is 1,361 MCM. Underground water reserves in this region are estimated to be 4,545 MCM with 3,355 MCM being utilizable for irrigation with an annual recharge of 2,957 MCM (Sharma and Dubey 1993). The electrical conductivity (EC) of most of the ground waters is very high (up to 15 dS/m). Land irrigated with such waters develops salinity. Some of the waters contain high relative sodium carbonate (RSC) (10-35 and moderate salinity 3.5-4.5 dS/m) in the region predominantly of Na, Mg, Ca with Cl results in soil alkalinity/sodicity.

Due to excess irrigation in canal command areas, waterlogging has become major problem. The water table is rising at a rate of 0.88 m/yr. Major area of the hot arid region in Rajasthan is irrigated with the canal system (56.4%). The tube-well and wells cater to 40.7% area, while only 2.9% area is irrigated through tanks. The total area under irrigation is about 10.8% of total arid region, but due to over-exploitation, the groundwater table is going down very sharply.

Temperature

The region is subjected to extreme variations of diurnal and annual temperatures. The temperature varies between 5.7 and 50°C. The high temperature results in high evaporative demand of the vegetation. The annual estimated potential evapo-transpiration values range from 1,600 mm in eastern parts to > 1,800 mm in the western arid region. Besides air temperature, soil temperature reaches beyond 62°C during May and June. The diurnal range of surface soil temperatures in dune areas vary between 25 and 40°C during monsoon period (Ramakrishna *et al.,* 1990).

Wind velocity

The arid region is characterized by hot and high velocity winds with peak in the months of May and June (14.6-18.5 km/h). Dust storms are frequent due to lack of vegetation. The dust storm causes severe soil erosion, besides increasing the evaporative demand of the crop.

Soils

The soils of arid region are generally coarse-textured with sand content varying from 90% in dunes to 60% in comparatively heavy textured soils. These soils are deficient in organic matter as well as N content (Joshi, 1993). Mean organic C content in the arid soil ranges from 0.05% to 0.2% in coarse, 0.2-0.37% in medium and 0.3-0.4% in fine-textured soils. Low clay content, hot climate and low rainfall are mainly responsible for low organic C in the arid soils (Kumar *et al.,* 1998). The sandy soils generally have low productivity because of the sandy nature (clay 1.5-4.5%, silt 1.2-5.5% and sand 90-97%) coupled with poor moisture retention and storage capacity (50 to 80 mm water/m soil depth). These soils contain total N in the range of 0.002 to 0.005% and available P varies from 5.4 to 8.5 kg/ha (Aggarwal and Lahiri, 1981). Major soil type in arid regions is light brown sandy soil (64.6%), whereas brown loams, grey brown loam soil with hard pan, sierozems, alluvial soil with dunes and other soil types occur in pockets and occupy 1.7, 13.6, 5.9, 1.6 and 6.8% of the area, respectively. Besides accelerating runoff, these soils are prone to crusting after rains, which impede seedling emergence. Thus, soils of arid region are degraded due to many processes like wind erosion/deposition, water erosion and salinisation.

Biotic problem

The human and livestock population in the region is increasing by leaps and bounds. The human population of arid zone of Rajasthan has increased from 5.87 million in 1951 to 22.50 million in 2001. Similarly, the livestock increased from 13.80 million in 1956 to 27.55 million in 2003. The increase in human population led to decrease in land holding size (from 6.1 ha per person in 1907 to 1.0 ha in 2001) and over-exploitation of the natural resources.

Besides biotic and abiotic problems, many traditional and socio-economical problems are also prevailing in the region. Under such circumstances, realizing sustainable crop production is a major task. Efforts have been made to discuss the technologies developed for obtaining sustainable crop production in the arid zone of India.

RESOURCE MANAGEMENT

Rainwater management

Water is the most precious input for arid agriculture. The availability of surface water resources is very limited due to hostile climatic conditions and poor water production efficiency of the sandy terrain in the region (Khan, 1996). The underground water is very deep, limited and mostly brackish in nature. Irrigation with saline water restricts the choice of the crops and varieties. The only major source of good quality water in arid region is rainfall. Therefore, its proper conservation, distribution and use need special consideration for realizing sustainable crop production in the region.

Efficient rainwater management acts as an insurance for the crop during the rainfall deficit periods. Management techniques that increase infiltration and soil water storage, and decrease water losses by runoff, evaporation and evapo-transpiration by weeds would lead to increase the amount of water retained in the soil for subsequent use by crops. Joshi (1987) reported occurrence of rainfall with intensity of 56-65 mm/h for 18-20 minutes in arid zone. Such high intensities produce significant runoff. The excess rainwater is lost as runoff causing soil erosion. Low moisture retention capacity of sandy soils further deteriorates the situation. Therefore, rainwater harvesting will not only conserve the soil, its fertility and vegetation; but also could be utilized as supplementary irrigation that will be advantageous in enhancing total water supply available to crop plants during low rainfall period (Singh, 1985).

Inter-row and Inter-plot water harvesting

Under inter-row system (ridge furrow configuration), furrows of about 30-40 cm width (15 cm deep) are made. Distance of 60-90 cm is kept between two ridges. The ridges are prepared at right angle to the field slope. This reduces runoff and at the same time, water is concentrated in furrows causing better water availability. This system is particularly suitable for medium to heavy-textured and deep to moderately-deep soils. In light soils, the crops are sown in furrows, whereas in heavy soils, planting may be done on ridges to eliminate the water logging hazards. Laying out of ridge-furrow configuration against the prevailing wind direction of south-west to north-west was found effective for increasing moisture availability in the arid region (Singh and Bhati, 1988).

In inter-plot water harvesting, micro-catchment is prepared in one or both sides of cropped area. In this system 2/3rd area of the field is to be used for cropping and leaving 1/3rd as catchment. Cultivated strips are alternated by benches with a slope of 5% towards the cultivated area, which increase soil moisture and yield of crops (Singh, 1988). In this system, 1.5 m or 0.75 m area is used as catchment on one or both sides, respectively.

Water harvesting at surface

The runoff water is harvested in several surface bodies like *khadin*, ponds, tanks, etc. The harvested water can be used for supplementary irrigation at critical stages of the crop growth during moisture stress periods.

Khadin: In larger catchments, runoff is carried to distant places in small streams and collects wherever it meets a depression or a natural topographic barrier, which limits its further movement. Runoff water is harvested from shallow, gravely and rocky upland catchments in the low-lying valley plains that are converted into the bunded farm land structure (*khadin*) where either *kharif* or *rabi* crops are raised, depending upon the amount of rainfall and consequent runoff received during the monsoon. The *khadins* of Jaisalmer and Barmer in Rajasthan are the best example of this phenomenon. The soils in these areas are generally heavier in texture with high moisture storage capacity due to deposition of fine sediments for a long time from catchment. *Khadin* system makes the use of shallow, gravely and rocky uplands (normally used for grazing) as the catchments for efficient harvesting of the runoff water. Any excess water in *khadin* is passed out through a spillway provided in the bund. The crop is grown in the *khadin* during *kharif* and *rabi* seasons, depending upon the availability of water. Soils in the *khadins* are extremely fertile because of the frequent deposition of fine sediment, while the water that seeps away removes salts (Kolarkar *et al.*, 1983). The *khadin* is therefore, a land use system, which prevents soil deterioration and provides, assured returns during post-rainy cropping season, even if rainfall is below average or erratic during rainy season. Crops like wheat, mustard, *taramira* (*Eruca sativa*) and chickpea are successfully grown during post-rainy season on receding moisture.

Average pearlmillet yield ranges from 300 to 500 kg/ha during poor rainfall (60-70 mm) year. Similarly, during better and high intensity rainfall season, wheat yield ranges from 1200 to 2000 kg/ha and chickpea from 1000 to 1500 kg/ha (Kolarkar and Singh, 1984). Khan and Singh (2005) recorded seed yield of 1803 kg/ha of chickpea (cv. 'RSG-44') grown under *khadin* system, besides improving the physico-chemical properties of the soil.

Farm ponds: Runoff water is collected from a treated or untreated catchment and stored in reservoir or farm pond. The stored water is utilized for supplemental irrigation during long dry spells at critical stages of plant growth. Farm ponds are the bodies of water made either by constructing an embankment across a water course or by excavating a pit. Farm ponds hold a great promise as a life-saving device for rainfed crops in low and erratic rainfall areas. Experience has shown that a supplemental irrigation of 5 to 7 cm given to rainfed pearlmillet or legumes at reproductive stage can make all the differences between success and failure of the crop.

Irrigation water management

Irrigated area in arid region is very less (about 10.8%). Indira Gandhi *Nahar Pariyojna* (IGNP) has created a boom to agricultural production and has remarkably improved the socio-economic conditions of local population. However, injudicious use of water from source to fields has resulted in the ill effects of waterlogging and soil salinisation; and therefore, need urgent attention. Emphasis should be on extensive irrigation rather than on intensive irrigation. Drip and sprinkler irrigation systems would be of help in preventing or delaying the process of rise in groundwater table in vulnerable areas.

Over-exploitation of ground water and inefficient irrigation methods further aggravated the situation. It is estimated that as much as 70% of water is lost in conveyance, application and distribution (Sharma, 1992). Thus, efforts should be made to reduce the water losses and consequently increasing the irrigation efficiency. Water plays a paramount role when it is applied at the right time and in proper amount. Adopting sprinkler and drip systems of irrigation, which also increase crop yield, can save sufficient amount of water. Kushal and Pathak (1977) obtained 38, 18 and 33 cm saving of water in wheat, groundnut and cotton, respectively and the highest water use efficiency as well. At Jodhpur, yield of cucumber under drip system was 1 to 1.5 times higher over furrow irrigation (Singh and Singh, 1978). The grain yield of wheat was 33 and 37% higher with sprinkler irrigation over check basin and border strip irrigation, respectively in arid region (CAZRI, 1979). However, this method has limitations under high wind velocity and saline water.

Saline water can however, be used with drip irrigation system. Besides higher production, 30-50% water in most of the high-value vegetable crops can be saved with drip irrigation system (Singh *et al.,* 1978). Results of a study conducted at Jodhpur revealed that potato and tomato crops were successfully raised with 3 to 10 dS/m saline waters using drip irrigation method. Detrimental effects of salinity were minimized because it maintained higher moisture content due to daily drip irrigation, thereby salts were drained beyond active root zone (Gupta and Singh, 1983). Water use efficiency increased further by adequately fertilizing the crops through drip irrigation. Drip system provided gainful use of nutrient management with water and provided maximum yield of tomatoes and chillies in arid condition (Singh *et al.*, 1989). Thus, adoption of efficient irrigation methods like sprinkler and drip can be effective for increasing water use efficiency in arid zone. Yield of pearlmillet increased when a supplementary irrigation of 14.5 cm was applied and it provided the highest water use efficiency (Singh, 1977). About 16-28% of total seasonal rainfall could be harvested in ponds and can be utilised as supplemental irrigation to pearlmillet increasing the yield several-folds (Singh, 1982).

Soil moisture conservation

Crop production in arid region is very much influenced by high evapo-transpiration requirements. The seasonal evapo-transpiration of unstressed pearlmillet, clusterbean, mothbean and mustard were 618, 654, 295, and 530 mm, respectively (Rao and Singh, 1998). Moisture stress takes place whenever evapo-transpiration exceeds the moisture availability. The moisture stress severely affects the physiological activities, growth and development of plant and yield. The losses of soil moisture can be minimized through moisture conservation practices like mulching, crop cover, use of anti-transpirants, weed control etc. In a study, Rao and Venkateshwarlu (1987) found that nodule number and fresh weight of legume crops gradually declined with increasing stress. The threshold limits for nitrogenase activity were found to be 2.4, 2.2 and 1.8 Mpa in clusterbean, greengram and mothbean, respectively in arid zone. The application of grass mulch (6 t/ha) decreased the maximum soil temperature by 1 to 9^{0}C, reduced evaporation loss and increased emergence of pearlmillet during June (Gupta and Gupta, 1983). Mulching increased the yield of greengram, mothbean and clusterbean by 178, 90 and 71% over control, respectively. Chickpea seed yield increased by 12.6 and 18.1% due to grass and polyethylene mulch, respectively. Bhaskar (1985) recorded significantly higher grain and straw yields of sorghum with straw mulch + anti-transpirant (kaolin).

Tillage and residue management

Proper soil tillage is a prerequisite for good crop stand, growth and yield. Excessive tillage, particularly in light textured soils, disintegrates clods and exposes soil to wind and water erosion. Reduced tillage implies economy in time, labour and energy besides reduced soil moisture losses, maintenance of soil structure and increased cropping intensity. Gupta (1987), however, reported reduction in crop yield due to no tillage. Sandy soils are vulnerable to erosion due to excessive tillage, whereas reduced tillage results in compaction due to low organic matter content of sandy soils, which seriously affects crop growth and yield. Deep tillage improved the soil moisture storage, water use efficiency and grain yield of pearlmillet (Saxena *et al.*, 1997).

Crop residues are important source of nutrients and also improve the physical and biological properties of soils (Venkateshwarlu and Hedge, 1992). Gaur (1992) estimated that about 236 million-tonnes straw is produced in India from five major cereal crops. Even if 50% of these residues are used as animal feed, well over 100 million tonnes can be recycled through soil, providing 1 to 2 million tonnes N input to these soils. Decomposition rate and release of N from residues depends on soil, climatic conditions and the C : N ratio of plant residues (Prasad and Power, 1991). Crop residues decomposition rate is slow in arid climates because of limited water availability. Consequently, the entire N requirement of a crop can seldom be met from decomposition of crop residues during the growing season. Therefore, an integrated nutrient supply from inorganic and organic N sources may be a more compatible approach under arid conditions.

Crop management

In arid areas, the productivity of crops is low not only because of climatic, biotic and abiotic stresses, but also owing to traditional methods of cultivation. Therefore, to obtain the sustainable crop yield, it is often necessary to tailor suitable package of practices, besides management of biotic and abiotic stresses. Notwithstanding the importance of continuous endeavour for development of newer agro-techniques for augmenting crop production, a vast array of methods and package of practices are already available today for stabilizing and improving the yield of crops cultivated in the arid zone.

In sandy soils, farmers practice deep tillage after every 3-4 years. It reduces the clod percentage in the surface soil but may encourage wind erosion. Tillage can also cause hardpan development below the depth of tillage and crusting due to loss of soil structure (Papendic and Parr, 1997). Reduced tillage is therefore, recommended for such areas and summer ploughing is discouraged.

Selection of suitable crops

The suitability of the crop in the region depends on many factors like soil type, rainfall pattern and socio-economic conditions. As the arid zone has been endowed with variety of soils (Dhir, 1977), the choice of crops should be based on nutrient and moisture requirement *vis-à-vis* soil type. The soil fertility is quite low for crop production considering the nutrient status of the soil and nutrient requirement of the crops. Cropping systems practised in the region are given in Table 1.

Table 1. Cropping systems practiced in relation to various soil textural units

Textural unit	Cropping system
Light to medium	Pearlmillet
Dune sand	Pearlmillet + mothbean
Medium	Pearlmillet followed by sorghum and sesame
Heavy	Fallow in monsoon, wheat/barley as *rabi* season crop
Light with hard pan salt affected	Clusterbean and wheat with saline ground water use

Source: Kolarkar and Dhir (1981)

The crop-growing period in western Rajasthan varies from less than 6 weeks to 12 weeks (Table 2). Legumes fit very well in this situation (Rao and Singh, 2004) as they have very low consumptive use (CU). The CU of mothbean, greengram, cowpea and clusterbean was only 218, 226, 280 and 332 mm, respectively. *Kharif* pulses were found to be more drought-prone than pearlmillet (Sastri *et al.,* 1984). For obtaining stable productivity in the arid region, longer duration crops like pearlmillet and sorghum in 45% area, pulses in 23% area and grasses in 32% area should be considered. Venkateshwarlu (1992) gave allocation of cropping patterns depending on the rainfall distribution.

Table 2. Crop growing period in arid zone

Rainfall range (mm)	Growing season (weeks)	Cropping pattern
<150	<6	Only trees and shrubs
150-250	6-8	Grasses
250-300	8-10	Short duration pulses
300-400	10-12	Pearlmillet and short duration pulses

Source: Rao *et al.* (1994)

Varieties

Choice of a suitable variety plays paramount role for obtaining efficient and successful crop production in arid zone. Peak rainfall is received during July and August and generally recedes by first fortnight of September. Thus, the rainy season in the region remains only for 50-60 days (Rao and Singh, 1998) showing the limitation of cropping period. Hence, it is pre-requisite that variety should mature within this limited period of moisture availability. As the rainfall is very low and erratic, the high inter-annual variability of rainfall is a major single factor influencing crop yield in arid region (Rao and Singh, 1998). Some short-duration varieties that suit to this condition are 'HHB 67', 'CZP 9803' (pearlmillet), 'RMO 40', 'CAZRI moth 3' (mothbean), 'RMG 62' (greengram) and 'RGC 936' (clusterbean).

Sowing time

Timely sowing of crops plays a vital role in maintaining adequate plant stand, growth and development of the crop. In arid regions, sowing time considerably influences the thermal time requirement of the crop as it modifies the photoperiod, temperature and radiation regimes besides, photo-climate of the crop (Rao and Singh, 1998). However, sowing time in rainfed conditions depends on onset of monsoon. The normal onset time of monsoon in arid zone of Rajasthan is last week of June to first week of July. Average yield of pearlmillet under normal sowing (leading to moderate drought stress) was good, while foxtail and proso-millet produced 62 to 66% less grain yield than pearlmillet. In late sowing where all the crops encountered prolonged drought, pearlmillet yielded much better than other millet crops, indicating drought tolerance due to well-developed root system (Joshi, 1988). Delayed sowing reduces the seed yield of greengram (Singh and Faroda, 1982), mothbean (Bhati, 1989), cowpea and clusterbean (Sharma *et al.,* 1984). Therefore, sowing time is an important variable that significantly influences the yield of the crops.

Seed rate and spacing

Seed rate plays a vital role in maintaining the adequate plant population, which is a pre-requisite for obtaining better yields. Seed rate depends on several factors, viz. method of sowing, soil moisture, seed size and purpose for which crop is grown. Use of seed in adequate amount would be helpful in maintaining the optimum plant stand and yield.

Row spacing of 45 cm in pearlmillet (Garg *et al.*, 1993), 30 cm in late-sown and 45 cm in early-sown clusterbean (Yadav *et al.*, 1989a & 1989b; Rana *et al.*, 1991), 30-40 cm in cowpea (Mali and Mali, 1991; Anitha *et al.*, 2004), and 45 cm in mothbean (Yadav and Beniwal, 2006) gave the highest seed yields. The row spacing of 30 cm for unbranched and 45 cm for branched genotypes of clusterbean (Taneja *et al.*, 1982) under normal season and 40 cm row spacing in drought year gave the highest seed yield (Garg *et al.*, 2003), whereas Patel *et al.* (2004) found 45 cm row spacing as optimum.

Cropping systems

To sustain the arid agriculture, efficient cropping system can contribute to a great extent. An effective crop rotation not only helps to increase the crop productivity and soil fertility, but also improve the water use efficiency by reducing weeds, providing conducive micro-climate for plant growth and development, reduction in soil thermal regime and improving physical properties of the soil. Weed infestation was least in pearlmillet - mustard rotation as mustard residue on decomposition release S containing volatile compounds, which were effective in controlling weeds (Saxena and Lodha, 2003). Pearlmillet - mustard system gave the highest pearlmillet equivalent yield as well as net returns (Saxena *et al.*, 2003a). Similarly, a study carried out by Singh (2006) indicated that greengram - mustard cropping sequence resulted in 18.2% higher weed control efficiency as compared to fallow-mustard sequence under western Rajasthan conditions. Pearlmillet - clusterbean rotation gave 11% higher pearlmillet yield compared to continuous pearlmillet cultivation (Singh *et al.*, 1985). Saxena *et al.*, (1997) reported 23.6% higher grain yield of pearlmillet when it was grown after clusterbean compared to continuous pearlmillet (Table 3).

Table 3. Grain and total dry matter yield of pearlmillet in different cropping systems

Cropping systems	Grain yield (kg/ha)		Total dry matter (kg/ha)	
	Year I	Year II	Year I	Year II
Continuous pearlmillet	772	2247	2698	6904
Pearlmillet – clusterbean rotation	1375*	2700	2878	7805

*Pearlmillet equivalent yield of clusterbean

Kumar *et al*, (1998) found that maximum improvements in the organic C, available P, NO_3-N, Fe, Zn, Cu and Mn in clusterbean – clusterbean – clusterbean - pearlmillet - pearlmillet five-year mono-cropping rotation in arid zone. For sole cropping of pearlmillet, a triplet planting system was developed by skipping every fourth row in normal planting. Triplet planting system, without any population adjustment (125 x 10^3 plants/ha), produced as good yield as uniform planting (Joshi, 1999) in normal rainfall and in moderate drought years (Table 4), with significantly higher yield in severe drought year (152 mm). This indicated that yield losses, which would have occurred owing to 25% less sown area in triplet system, were compensated by higher yields of border rows.

Table 4. Influence of planting systems on pearlmillet yield (kg/ha)

System	Plant population ($\times 10^3$/ha)	Rainfall (mm) 409	260	193	152
Uniform	166	2781	2058	646	503
Triplet	125	2680	1958	822	551
Triplet	166	2836	2217	883	634

Source: Joshi (1999)

Intercropping

Since the rainfall is quite low and erratic, farmers of the region hesitate to invest money in agriculture due to risk of crop failure. For minimizing the risk of climatic vagaries, farmers traditionally practice mixed cropping. Though mixed cropping has many demerits and limitations, yet it is practised in the region as it provides higher equivalent yields and benefit : cost ratio than sole cropping (Singh, 1995). Growing of two or more crops simultaneously in rows instead of mixing the seed of all crops can give better yield without affecting the goal of mixed cropping. Intercropping improves soil fertility and has yield advantage in comparison of cereal crops, besides providing insurance against complete crop failure and high sustainable yield compared to the sole cropping (Joshi, 1999a). Intercropping provides higher moisture use efficiency and grain yield under moisture stress conditions as it minimizes the water losses at early vegetative stage over mixed cropping (Singh and Joshi, 1994 and 1997). Intercropping of mothbean with pearlmillet in 3:1 row ratio gave higher seed yield of mothbean than 2:1 and 2:2 row ratios without much affecting pearlmillet grain yield. This combination also provided highest monetary returns. Double rows of dew gram, clusterbean and greengram planted in the inter-spaces of paired rows of pearlmillet (30/70 cm) yielded 381, 381 and 458 kg/ha, additional seed yield respectively without affecting yield of pearlmillet (Singh and Joshi, 1980).

Growing of greengram with pearlmillet was more beneficial than sole greengram (Singh *et al.,* 1978a). Singh and Singh (1977) found that greengram and cowpea as intercrops with sunflower showed no significant difference between the yield obtained due to application of 30 and 60 kg N/ha. Study carried out by Yadav (1994) at Bikaner revealed that intercropping of pearlmillet + clusterbean (1:1) and (2:2) gave yield advantage of 137 and 126%, respectively over sole cropping.

Alternate land use systems

Due to uncertainity and erratic rainfall, trees and grasses are more reliable for achieving sustainability in the region. However, cultivation of annual crops like greengram, clusterbean, mothbean, sesame and pearlmillet in strips along with grasses, forest and fruit trees can be environmentally-protective and economically-viable system even during drought years (Faroda, 1998). Cultivation of crops along with trees not only shows the stability, but also improves the soil fertility, moisture use efficiency and physical properties of the soil. Nitrogen-use efficiency of pearlmillet increased from 27 to 40% when grown with *Prosopis cineraria* (Aggarwal and Kumar, 1990). Similarly, Singh and Khan (2003) found 6.4% increase in the seed yield of clusterbean grown with *Prosopis cineraria* as compared to sole clusterbean. But the selection of suitable tree species is very important for obtaining good yields from the crops. Jindal *et al.* (1990) reported that clusterbean, cowpea and mothbean crops failed when grown with *Acacia tortilis*, while these crops performed better in association with *Prosopis cineraria* and *Tecomella undulata.* Strip cropping of crops and grass or shrub with fodder value, has been found to be useful for control of wind and water erosion. Plants for the strips are chosen so that they do not compete for moisture, nutrients etc. The width of strips depends on the type of soil and crop. On the sandy loam soil in arid areas, the strips may vary from 6 to 30 m. Strips of *Lasiurus sindicus* (*Sewan* grass) and *Ricinus communis* (castor) between two rows of *kharif* crops help to reduce wind erosion and increase crop production. The perennial grass strips of *L. sindicus, Cenchrus biflorus* and *Pennisetum turgidum* not only reduce wind erosion, but also help to form surface crusting which binds the soil particles.

Studies on the cultivation of arable crops with fruit trees under agri-horti system revealed that an additional yield (782 kg/ha) of clusterbean was recorded when it was grown with jujube (*Symmondsia chinensis*) planted at spacing of 5 × 8 m (Prasad and Vashishtha, 1998). Under integrated farming system growing of greengram, mothbean and clusterbean gave higher net returns and benefit : cost ratio as compared to sole cropping of these crops. Similarly, better seed yields of mothbean and clusterbean were recorded (CAZRI, 2005) when grown in association of *bael* (*Aegle marmelos*) as compared to citrus and *goonda* (*Cordia myxa*). Growing of greengram with jujube as intercrop even with very low rainfall condition (270 mm), gave higher net profit as compared to sole cropping of greengram.

Weed management

The productivity of crop is often limited due to severe competition by weeds for essential nutrients and space in general, and soil moisture in particular for arid zone. The losses caused by heavy weed infestation are higher than other pests. In spite of inhospitable conditions in the arid zone, weeds have become adapted through a variety of ecological and physiological characters. These include prolific reproduction, variability in colour, size, shape, weight, viability of seeds, various types of dormancy and germination. Seeds of many weeds can remain buried in the soil for several years and germinate when conditions become favourable. Dormancy of seeds especially that of arid zone weeds is significant in delaying the germination until the environment has become congenial for the development and establishment of seedlings. Weeds begin the competition from the emergence of the crops. Yield losses due to weeds varied between 50 and 75% in most of the field crops. Severe weed competition with crop resulted in yield reduction up to 60% in pearlmillet (Mali *et al.*, 1980). 80% in greengram (Mali *et al.*, 2000), 54% in clusterbean (Saxena *et al.*, 2004), 50-62% in cowpea (Anitha *et al.*, 2004), 65% in sesame (Punia *et al.*, 2001), and 75% in mothbean (Saxena *et al.*, 2003b). Thus, weeds if not controlled at critical period of competition, can cause enormous reduction in the yield. However, effective weed management results in obtaining high yield of crops.

The critical period of weed removal in clusterbean is 15 to 30 days after sowing (DAS) (Kumar *et al.*, 1996). 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 in pearlmillet (Singh and Yadav, 1994). The moisture retained in pearlmillet field in weeded plots was significantly higher as compared to unweeded plots in arid zone (Mishra and Kumar, 1962).

Several practices have been developed to avoid the losses caused by weeds. Kaur and Singh (2006) reported that sowing of pearlmillet in paired row system reduced the weed infestation significantly and increased grain and stover yields of pearlmillet as compared to regular planting method. Further, mulch application at 4 t/ha decreased weed density significantly in pearlmillet. Integration of herbicides with hand weeding has been found beneficial in controlling weeds in pearlmillet (Sharma and Jain, 2003;

Deshveer and Deshveer 2005; Kaur and Singh, 2006), clusterbean (Kumar *et al.,* 1996; Yadav *et al.,* 1997), greengram (Mali *et al.,* 2000), mothbean (Singh and Singh 2005a and 2005b), cowpea (Yadav, 1992; Anitha *et al.,* 2004) and sesame (Dungarwal *et al.*, 2003; Sukhadia *et al.*, 2004).

Nutrient management

In arid areas, besides the climate being hostile, the physical and chemical properties of the soil are very poor. Nearly 70% of desert region is covered by wind worked sandy soils that are poor in organic matter and N. The phosphorus is low to medium. Soils of arid regions are generally adequate in K. Total K content varies from 0.54 to 1.57%. Thus, there is a need to improve productivity with adequate nutrient management practices. Most of the crops grown in the region respond very effectively to nutrient application. Though, it is generally agreed that response to applied nutrients by rainfed crops is not assured and sometimes may not be profitable unless proper soil moisture is assured. Nevertheless, nutrient management is of prime importance in the region. Kathju *et al.* (1987) reported that N use efficiency in pearlmillet and sesame was 7.5-18.0 kg/ha and 4-14.7 kg/ha, respectively, while P use efficiency in clusterbean, greengram, mothbean, pearlmillet and sesame was 4.2-5.3, 1.4-4.1, 0.1-0.9, 1.3-17.1 and 1-2.7 kg/ha, respectively. Thus, adequate nutrient management is pre-requisite for obtaining sustainable yield.

Nitrogen

Nitrogen plays an important role in improving the yield of cereals, but in legumes also it is required as a starter dose. Application of 80 kg N/ha was as good as 120 kg N/ha but proved superior to 40 kg N/ha and resulted in 72% increase in grain yield of pearlmillet (Parihar *et al.*, 1998). In another study, N application up to 80 kg/ha in pearlmillet increased yield in good rainfall years, but in drought years, non-significant effect was observed beyond 40 kg N/ha (Aggarwal and Kumar, 1996). Joshi and Singh (1985) reported significant impact of 40 kg N/ha in increasing the grain and stover production of pearlmillet.

Nitrogen application increased the sustainability of both sole and inter croping systems (Table 5). Nitrogen application not only improves the yield of cereal crops but also has marked influence on the performance of legumes in arid region. Several workers have reported the positive response of legumes to N application on different growth parameters and yield (Yadav *et al.*, 1990; Singh *et al.,* 1993). Besides cereals and legumes, N application also showed significant response on the performance of oilseed crops, viz. sesame (Daulay and Singh, 1982), sunflower (Daulay and Singh, 1980), and mustard (Patidar *et al.,* 2000).

Table 5. Sustainable yield index of cropping systems in arid zone

Cropping system	Sustainable yield index at N level (kg/ha) of			
	0	30	60	90
Intercrop (paired rows 30/70 cm)	0.23	0.24	0.27	0.31
Intercrop (alternate rows 1:1)	0.24	0.22	0.23	0.26
Sole crop (pearlmillet)	0.09	0.13	0.16	0.17

Source: Seeling and Joshi (1997)

Phosphorus

The arid zone soils are deficient in organic P, but total and inorganic P are irregularly distributed in their soil profiles. The amount of added P becomes less available to plants in arid soils (0.87-1.35 g P/100 g soil). Phosphorus plays an important role in stimulating seed setting, hastens maturity and extensive root system besides favourable condition for nodulation in legumes and enhances oil content in oilseed crops. Phosphorus application to improved the pearlmillet seed yield (Singh and Singh 2002) and nodulation and seed yield arid legumes (Mali and Mali, 1991).

In loamy sand soil of Haryana with medium P status, 13.2 kg P/ha was found as the economic dose (Dahiya *et al.*, 1986). Application of 18 kg P/ha was found superior to 9 kg with regard to increase in yield and yield attributes of clusterbean in loamy sand soil (Shivran *et al.*, 1996). Application of 25 kg P/ha resulted in 9.13% higher crude protein and gum contents besides significantly increasing seed yield over control and 13.2 kg P/ha (Joshi and Mali, 2004). Jain *et al.* (1988) reported that gum content increased with the application of 10 kg P/ha over control. Application of P also improved nutrient uptake in clusterbean. Yadav *et al.* (1991) found significantly higher update of N and P in both seed and straw yields of clusterbean due to the application of 18 kg P/ha.

Secondary and micronutrients

In recent years, the continuous cultivation and use of only N and P led to the deficiency of micronutrients in the arid soils. Deficiency of micronutrients has great detrimental effects on the performance of the crops and uptake of macronutrients. Zinc application increased the concentration and total N uptake in pearlmillet (Aggarwal and Singh, 1978). Increase in N : Zn ratio negatively affected the quality and production of grain. Application of Mo (0.2%) increased N content of grains over control, besides increasing nodules and dry weight of pods in clusterbean (Ghosinkar and Saxena, 1973). Zn application significantly increased the nitrogenase activity, carbohydrate and protein content in clusterbean (Nandwal *et al.*, 1990). Application of 10 ppm Fe increased yield of sorghum by 19% compared to control in 18 arid soils (Gupta and Potalia, 1987). Application of S, Fe and Mo significantly increased yield attributes and grain yield in mothbean (Jain, 1971).

Sulphur application markedly influences crop productivity in sandy soils of arid region, as this nutrient is becoming scarce in these soils. Shivaran *et al.* (1996) reported the increase in growth, yield attributes and yield of clusterbean up to a dose of 60 kg S/ha in loamy sand soil, while 20 kg S/ha resulted in significantly higher seed yield and gum content over control in clusterbean (Kumar *et al.*, 1999). Application of 15-60 kg S/ha increased protein content and its synthesis in mothbean (Jain and Raheja, 1980) and dry matter yield of cowpea (Aggarwal *et al.*, 1985). Soil pH also decreased with increasing level of elemental sulphur in arid zone.

Microbial inoculants

With the high cost of fertilizers and low fertilizer use efficiency, biofertilizers have become an alternate source of nutrient supply in arid agriculture. Biofertilizers contain micro-organisms that play vital role in soil and thus influence the availability of major nutrients like N, P, K and S. *Rhizobium* inoculation alone in greengram obviates the need for fertilizer N and P under natural conditions in arid ecosystem (Singh, 1977). Increase in seed yield of clusterbean and mothbean upon inoculation with efficient strains of *Rhizobium* varied from 8-15%, depending on the intensity and distribution of rainfall. These legumes fix about 20-40 kg N/ha and a residual effect equivalent to about 15-20 kg N/ha. Besides legumes, micro-organism inoculation affects the yield of cereals. Pearlmillet seed inoculated with *Azospirillum* gave significantly higher pearlmillet yield (Venkateswarlu and Rao, 1983; Joshi and Rao, 1989). Though the total P content in the desert soils is high (557-729 kg/ha), but only 2.4-3.9% is present in plant available form depending upon the land use pattern. Phosphate solubilising bacteria (PSB) are effective in utilization of native P in arid soils for pearlmillet (Tarafdar *et al.*, 1991), greengram and clusterbean (Tarafdar *et al.*, 1995). Singh *et al.* (2006) observed significant response of combining *Rhizobium* and PSB on the seed yield of clusterbean in arid region.

Integrated nutrient management

It is well established that adequate supply of nutrients plays an important role for obtaining the higher productivity. But the source of nutrient is of prime importance. Since the climate of arid zone is harsh and socio-economic condition of the farmers is very poor, use of chemical fertilizers may not be feasible under such conditions. Moreover, continuous and excess use of fertilizers deteriorates the soil health, encourages environmental pollution and degrades the quality of the produce. Thus, to maintain sustainable productivity and soils health, integrated nutrient management system has great promise. Integration of 10 kg N/ha from inorganic fertilizer along with 10 t FYM/ha was found beneficial for pearlmillet production even under below-normal rainfall conditions (Aggarwal and Venkateshwarlu, 1989). Grain yield of pearlmillet with 80 kg fertiliser N/ha was at par with the application of 40 kg N/ha + FYM (Aggarwal and Kumar, 1996). Application of crop residues along with 20 kg fertiliser N/ha provided pearlmillet grain yield equivalent to that of 40 kg fertilizer N with no residues (Aggarwal *et al.*, 1997). Combined application 10 kg N + 9 kg P + (*Rhizobium* + PSB) gave at par seed yield of clusterbean but higher net returns to that recorded with 20 kg N + 18 kg P/ha (Singh *et al.*, 2004).

FUTURE RESEARCH NEEDS

Considerable research efforts have been made to develop improved technologies during last several decades for obtaining sustainable crop production in the arid region. The impact of technologies can be seen through the enhancement in average yield of most crops. However, considering the ever-increasing food and fodder demand, these efforts are not enough. There is a need to develop further alternative approaches, which can be useful to further increase yields. Arid regions have potential to at least double the present productivity, but limitations should not be forgotten. Further research may be useful on issues such as moisture conservation, soil conservation, nutrient management, crop establishment, cropping systems, alternate land-use, decision criteria, etc.

- We need to understand more about the effectiveness of current utilization of rainfall and the potential for improving rainfall-use efficiency by manipulation of cultural and soil conservation practices. We should also lay greater emphasis on maximising the usefulness of limited ground and surface water resources, which consequently would realize high water use efficiency.
- Extensive studies are needed to work out improved land management technologies that would lead to efficient use of degraded lands and arresting the further degradation.
- The role that legumes play in fertility management in the arid region need to understood clearly in terms of the effects of various legumes on soil fertility. This information is a pre-requisite to improving ex-

isting nutrient strategies. There is also a need to examine the status of P in soils of this region and lay emphasis on use of PSB, *Rhizobium* and other microbes in INM. Intensive studies are also needed on precision farming in the context of nutrient management.

- There is scope for improving crop establishment. Possibilities include pre-soaking seeds, optimum seed rate, improving seed vigour by seed production under high-nutrition conditions, soil compaction, and improving stand by seed placement at proper planting depth and crust management.
- In the highly risky crop production environments of arid regions, it would be useful to examine the potential for alternate land use or area specific cereal/oilseed – legume system that place greater emphasis on enhancing and stabilizing farm income, and hence the sustainability of farm enterprises. Extensive studies are needed on crop diversification that would ultimately help achieving sustainable crop production in arid zone. In-depth studies for working out agronomy of new cultivars should also get priority from the point of view of efficient resource utilization.
- We also need to understand how farmers acquire and use information in making cropping decision, i.e., what indicators they monitor and rules of thumb or decision criteria they use to make management decisions? We need to develop indicators to improve farmers' predictive capability. Extensive work on simulation modelling and validation of such models for different crops and situations would be of great help in this direction.

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