SOIL AND WATER MANAGEMENT STRATEGIES FOR DRYLANDS

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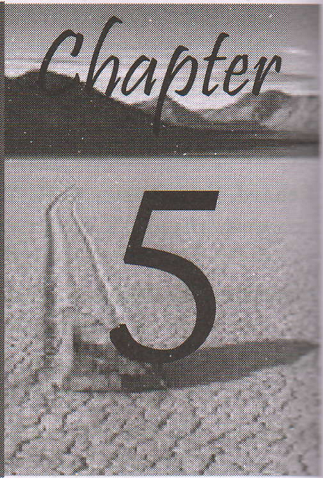

Soil Erosion and Runoff Control in Farm Lands of Dry Areas

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ABSTRACT

In the recent past, with changing rainfall scenario, land degradation as well as scarcity of water has become a common phenomenon in the dry areas. Runoff management is an important area to be considered while managing the limited resources of soil and water in dry areas. Some important and basic techniques have been described in this chapter to manage agriculture land in such areas. These techniques are especially in relation to rainfall, soil, local cropping practices and mechanism for management of excess runoff. The principles of runoff management are to minimize the concentrations of runoff volume and slowing the runoff velocity. The choice of appropriate measures depends on soil, topography, climatic and socio-economic considerations. It is difficult to generalize about applicability of these measures. The soil conservation becomes a critical task for sustainable development for combating further land degradation and investing in future conservation. The improvement in soil quality along with sequestration of soil organic carbon has tremendous potential for increasing productivity and conserving natural resources. The most appropriate strategy for combating soil erosion and runoff management in dry regions depends upon identifying the influencing key factors and their adoptability in the area.

1 INTRODUCTION

There is a need to focus on rainfed production as most of the world's agricultural production is contributed by rainfed farming and the coverage of cropland under rainfed conditions is quite high in the developing countries like India. Crop production is generally affected, where availability of irrigation water is limited. It can happen even in humid and sub-humid regions where there is a theoretical need to dispose of excess water. Dry periods with water deficit frequently occur in the arid regions and positive responses to moisture conservation techniques are commonly obtained. Aridity is an ecological situation in which water income is less than potential water expenditure (runoff, evapotranspiration, etc.) (Kassas, 1977). Abrol and Sangar (2006) opined that, the mission of increasing food grains production somehow stands achieved, however, it is accompanied by series of problems related to the environment and natural resources. Conservation agriculture can be seen as a new way forward for conserving resources and enhancing productivity to achieve the goals of sustainable agriculture, which demands a strong knowledge base and a combination of institutional and technological innovations. Kumar *et al.* (2011) showed that conservation agriculture in its broader context not only improves soil health but also gives higher net returns per unit of land to the farmers. However, the conservation agriculture practices need to be adopted selectively in different rainfall, soils and agro-ecological situations and its advantage can be availed in rainfed agro-ecology, if practised appropriately over long-term basis. Management of rain water is the key to success in dryland agriculture as most of the cultivated areas in India as well as in the entire world depends on rainfed farming (Kanwar, 1982). In dry areas, the socio-economic status of the community is more dependent on the availability of water throughout the year and it has direct relationship with poverty reduction. In these areas runoff farming plays a vital role for proper utilization of rainwater. In case of the typical farm or small catchment with 2–10% slope of the landscape to runoff storage and mitigation features, the properties of the runoff regime can be radically altered (Quinn *et al.*, 2007). However, after a few years these features can fill with sediment, reducing their water retention capacity (Verstraeten and Poesen, 1999). Therefore the management of these features is an important issue (Wilkinson *et al.*, 2010). Mall *et al.* (2006) discussed that monsoons being likely to be even less reliable and run-off even more excessive, thereby reducing groundwater recharge potentials. The current lack of governance, management, and investment priorities given to upgrading rainfed agriculture in developing countries often is justified by the major water scarcity in dryland areas. However, water constraints are not always related to absolute water shortage, but rather to the variability of supply (Rockstrom *et al.*, 2010).

The dry arid climate mainly comprised of north-western Gujarat, western Rajasthan and south-western parts of Punjab and Haryana (Fig. 5.1). The semi-arid dry regions is mostly falling in the Gujarat, Rajasthan, Punjab, Haryana, Delhi, Madhya Pradesh, Uttar Pradesh, Tamil Nadu, Karnataka, Andhra Pradesh and Maharashtra states (Fig. 5.1). Monsoon rainfall in the dry regions usually includes short-duration storms of high intensity which give high rates and amounts of run-off. This is partly because the high rainfall intensity can temporarily exceed the infiltration rate, and also because the infiltration may be reduced by the formation of surface crusts, impermeable layer at shallow depths, and the high surface temperatures. One more thing that separates the dry areas from others in reference to soil erosion that during the first rainfall (mostly high intensity), the less coverage of vegetation accelerates the erosion process and more runoff. This situation tends to give more emphasis on providing additional measures for controlling soil erosion and safe disposal of excess runoff from dry areas.

The consequences of runoff and erosion are the impairment of the quality and productivity of the land. Erosion results in the decline of soil fertility as a result of loss of topsoil and nutrients. Loss of organic matter and clay facilitates the movement of nutrients and water from the soil. Runoff results in washing away of crops and fertilizer inputs, loss of soil moisture and consequently there is frequent stress in crop production. The region is losing soil 30 to 40 times faster than the natural replenishment rate. We should also keep in mind that it takes over ten thousand years to form a cm thick layer of fertile soil. It is estimated that if these soil losses are prevented, the productivity of agricultural land can rise by 30-40% through safe disposal of excess runoff.

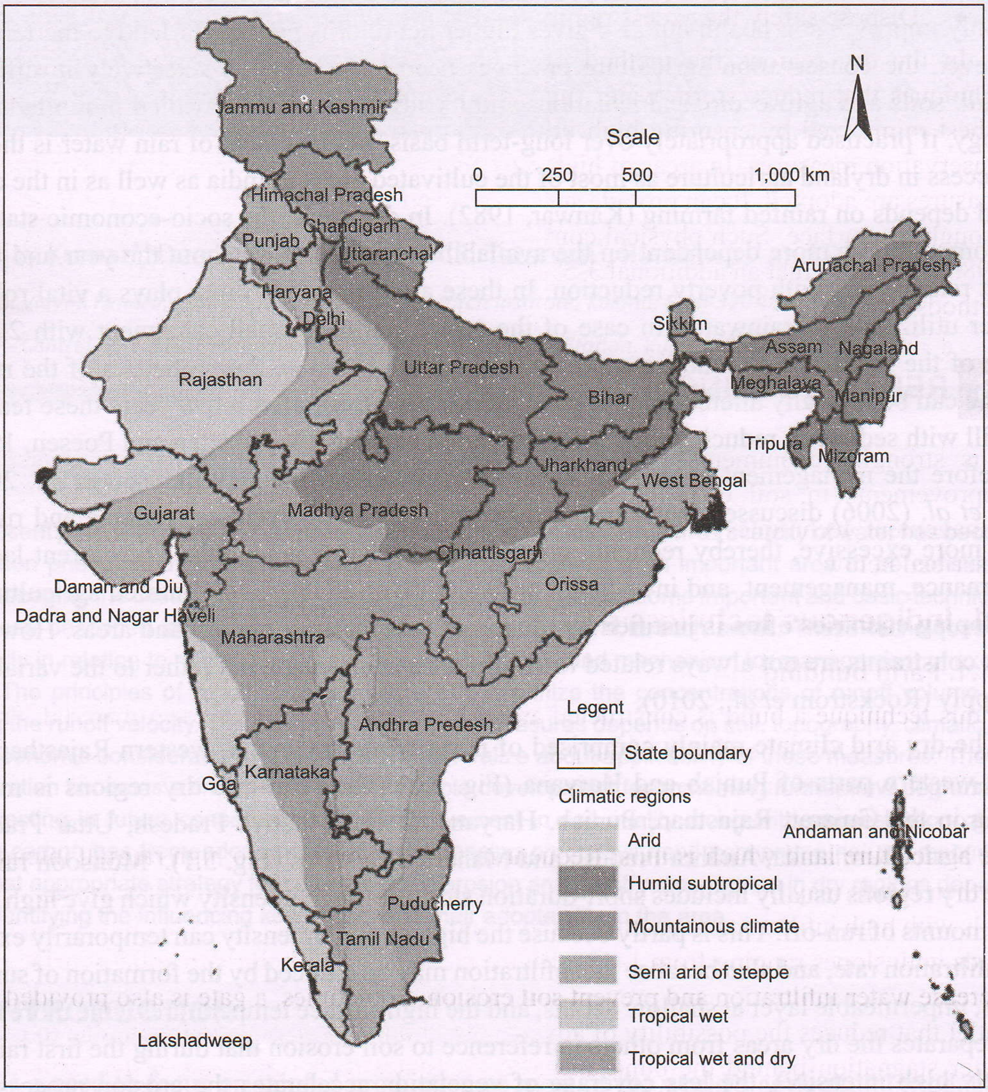

Fig. 5.1. Climatic regions of India (after www.mapsofindia.com)

2 PRINCIPLES OF RUNOFF MANAGEMENT

It is strongly recommended to provide mechanism for safe disposal of excess runoff. Improvements in soil conditions and soil-water regime to optimise crop production can be accomplished by runoff management techniques. It varies with the situation depending on existing conservation problems of soils in the dry areas. Various types of runoff management may be classified as those which:

- Increase water intake and storage and so reduce runoff,
- Control water movement over the soil surface,
- Dispose safely the excess rainfall as runoff or concentrate inadequate rainfall runoff.

In the dry regions the method of management is based to retain most of water by techniques that reduce storm-water runoff and improving soil infiltration. In general, runoff is best minimized by ensuring high infiltration of rainwater into the soil through biological conservation measures. In areas of high intensity storms and poor crop cover, physical control measures are adopted. It can provide surface protection by holding water to give it time to soak through the surface. Such physical conservation measures involve land shaping. Bruins *et al.* (1986) estimated that an additional 3-5% of arid areas could be cultivated using runoff farming methods.

3 REDUCING RUNOFF THROUGH FIELD MANAGEMENT PRACTICES

It is strongly recommended to provide mechanism for safe disposal of excess runoff. Improvements in soil conditions and soil-water regime can be accomplished by runoff management techniques. Various field management techniques suitable for dry areas are described below.

3.1. Indigenous techniques

3.1.1. Farm bunding

In this technique a bund is constructed around the field using local earth material. Primarily, this bund acts like a boundary of the particular field and it can also help to store some quantity of runoff water of small storms. It is frequently breached (Shown in Fig. 5.2) during rainy season and farmers need to repair it every year. This situation causes heavy soil loss from the agriculture land which is most frequent in the dry areas due to high rainfall intensity. The earthen bunds may be suitable for some extent for nearly level fields in continuous patches of soils with high infiltration capacity. The bunding-small earthen barriers are built on agricultural lands with slopes ranging from 1–6%. Bunds are used in agriculture to collect surface run-off, increase water infiltration and prevent soil erosion. Sometimes, a gate is also provided with an outlet that reduces the possibility of adverse effect on crop growth and yield due to prolonged water stagnation behind the bund and also facilitates to optimize the water infiltration into the soil (Pathak *et al.*, 1989). If the bunds are constructed on contours, it is named as contour bunds. The contour bunds are mostly suitable for low rainfall areas. A study conducted at Doon valleys in the northwest hills region indicted that contour bunds decreased runoff by 25%–30% compared to field bunds (CSWCRTI, 2011).

Fig. 5.2. Heavy soil erosion due to breach of earthen field bund

3.1.2. Stone bunding

Locally available stones are used in place of earth material for bunding in the field. It checks soil erosion more than that of earthen bunds as it can allow water to drain out from the field after temporary ponding. It is recommended to construct the stone bund in case of availability of local material or at the reasonable distances from where it can be transported economically. The size of stone for constructing the bund may vary from 5 to 30 cm in diameter. Round shaped stones from 5 to 10 cm can be used in the middle section of the bund and size is increased gradually up to the edge of the bund from the middle section. Edged stones of bigger size are placed at outer edges of the bund as shown in Fig. 5.3. It provides better stability to the bund and works well to dispose concentrated runoff from the field safely.

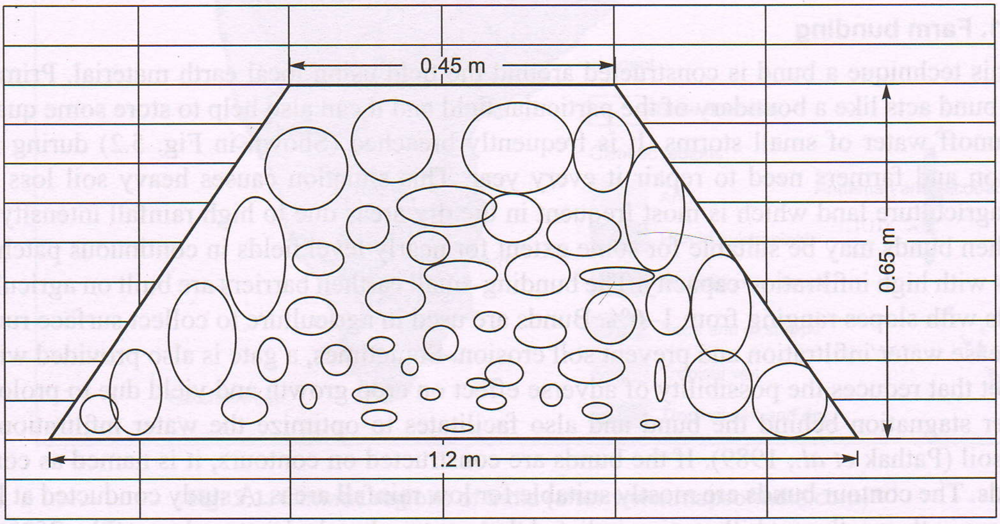

Fig. 5.3. Cross-section of a typical stone bund

3.1.3. Vegetative barrier

A barrier of vegetative cover with the locally available plants like grasses, *Aloe vera* and Cactus etc. may be planted to check the velocity of runoff. Such type of barriers works well after one or two rainfall events as it grow after getting water. This may not be able to check soil erosion due to first heavy rainfall event. The placement of vegetative barriers may be of a group of lines (2-3 lines) of recommended species or a strip of the same. It works well when planted on following the contours. Dividers of the same vegetation may also be planted perpendicular of the barrier (Shown in Fig. 5.4) to divide the concentrated runoff from the same piece of land.

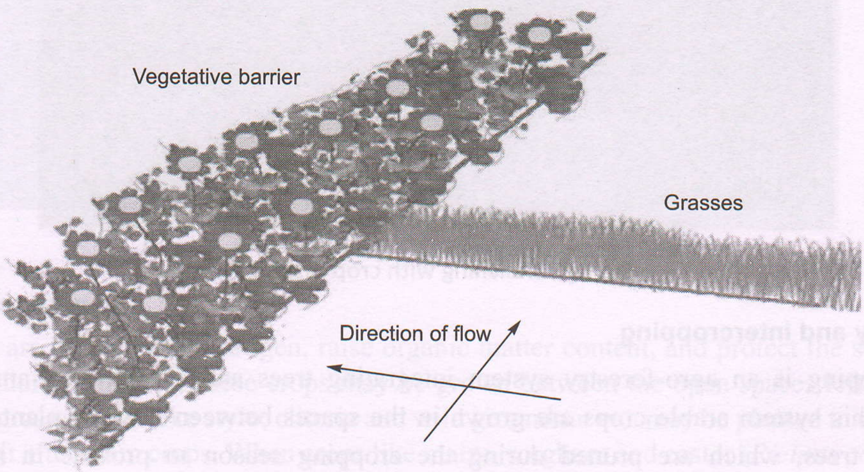

Fig. 5.4. Vegetative barrier for controlling soil erosion

3.2. Agronomic practices

3.2.1. Mulching

Mulching is a protective cover of vegetative residues on the soil surface at all times. The method is suitable where a satisfactory plant cover cannot be established when erosion risk is greatest. The beneficial effects of mulching include protection of the soil surface against raindrop impact. It also decreases flow velocity by imparting roughness and improved infiltration. The process also enhances burrowing activity of some species of earthworms. Mulching improves transmission of water through the soil profile. It also reduces surface crusting and improves soil moisture storage in the root zone. The organic materials such as crop residues, farm yard manure and bye-product of timber industry are used as per the availability. Mulching can be done in fruits (mango, pomegranate and papaya etc.), vegetables and some cash crops (cotton and castor etc.) in the dry regions. Mulching material should be selected as per the local availability otherwise the cost will increase. The crop residue of castor, cotton, cluster bean and sunflower can be used for mulching purposes as per their availability. Based on the age of the plant 0.5 to 5 kg per plant of mulching material can be applied for mulching purpose. It can be placed continuously over the field (shown in Fig. 5.5) or in discrete manner depending upon the placement of the plants.

Fig. 5.5. Mulching with crop residues

3.2.2. Alley and intercropping

Alley cropping is an agro-forestry system integrating trees and shrubs with annual food crops. In this system arable crops are grown in the spaces between rows of planted woody shrubs or trees, which are pruned during the cropping season to provide in situ green manure and to prevent shading of crops. The beneficial effects of the system in reducing erosion, surface runoff and soil moisture loss depend on the proper choice of the protective species.

Intercropping is to grow more than two crops at a time. Some leguminous grass species (clitoria, stylo, wild groundnut etc.) may be planted between the fruit crops (pomegranate, mango etc.) in the dry areas for improving soil health and checking soil erosion. Intercropping between ber plants is shown in Fig. 5.6. After some time regular crops may be taken between the fruit crops. The selection of crop may be based on the soil binding properties and plant cover over the soil surface. Leguminous crops (green gram and cluster bean) along with cereal crops (sorghum and pearl millet) during *kharif* season. Growing soybean (*Glycine max*)/groundnut (*Arachis hypogoea*)/cowpea (*Vigna radiata*) with maize (*Zea mays*)/jowar (*Sorghum bicolor*)/bajra (*Pennisetum glaucum*) is a common example of intercropping in the drylands (Srinivasa Rao *et al.*, 2014). Intercropping cowpea with maize (2 rows of cowpea with 1 row of maize) decreased runoff by 10% and soil loss by 28% compared to pure maize. Minimum runoff (36% of rainfall) was recorded under barnyard millet (*Echinochloa frumentacea* L.) followed by black soybean (*Glycine max* L.) and maize which was 37% and 42%, respectively. Black soybean and maize alone had maximum soil loss of 7.1 and 6.7 ton ha^{-1}, respectively, followed by barnyard millet (4.8 ton ha^{-1}) (Bhattacharyya *et al.*, 2015).

Fig. 5.6. Inter-cropping with vegetable crops in Ber

3.2.3. Cover crops

Some crops are useful to fix nitrogen, raise organic matter content, and protect the soil, such as green manure or mulch. These crops may be grown between the open spaces left in main crop. Some grass species like stylo, clitoria and wild groundnut etc. may be planted to cover the open area left after main crops. When crops like maize, sorghum and castor (*Ricinus communis* L.) are cultivated along with legumes such as groundnut, green gram (*Vigna radiata* L.), black gram (*Vigna mungo* L.), soybean and cowpea in inter-row spaces, sufficient cover on the ground is ensured and erosion hazards are decreased (Rao and Khan, 2003).

3.2.4. Strip cropping

Strip cropping is a combination of contouring and crop rotation in which alternate strips of row crops and soil conserving crops are grown on the same slope, perpendicular to the wind or water flow in drylands and hilly regions, respectively. Strip cropping provides effective erosion control against runoff on well-drained erodible soils on 6 to 15% slopes. In this, inter-tilled row crops and close-growing crops (cover crop or grass) are aligned at right angles to the direction of natural flow of runoff. The close-growing strip slows down runoff and filters out soil washed from the land in the inter-tilled crop. Usually, the close-growing and inter-tilled crops are planted in rotation. The width of the strips is varied with the erodibility of the soil and slope steepness.

3.2.5. Contour farming

Contour farming involves aligning plant rows and tillage lines at right angles to normal flow of runoff. It creates detention storage in the soil surface horizon and slows down the runoff thus giving the water time to infiltrate into the soil. The effectiveness of contour farming in water and soil conservation depends not only on the design of the system but also on soil, climate, slope aspect and land use. The beneficial effect is least marked on compact or slowly permeable soils. These become saturated quickly compared to highly permeable soil. Contour bunds are another important physical measure. Contour ploughing reduces soil erosion by 30 times and surface runoff by 13 times in comparison to ploughing along the slope.

3.3. Soil treatment methods

3.3.1. Ploughing

Plough operations help to keep the upper soil layers porous to allow root development and infiltration in compact soils. Ploughing also helps to minimise runoff by assisting infiltration capacity of the soil. It helps to check the initial process of soil erosion *i.e.* rill and inter rill erosion to some extent. Inter rill is the advanced stage of rill erosion where rills are started to connect each other to form concentrated runoff in the field. Initial stage of inter rill erosion can be controlled by this operation.

3.3.2. Minimum tillage

The most effective way to alter and improve soil physical condition is to till it. Once good tilth is obtained it should be kept that way as long as possible. The concept of minimum tillage includes the minimum disturbance to the soil surface by using no- or minimum-tillage; keeping the soil surface covered all the time through practices such as retention of crop residues, mulching, or growing cover crops; adopting crop sequences or rotations that include agroforestry in spatial and temporal scales; and controlled traffic (FAO, 2010). This can be done by using heavy machineries to a minimum to avoid compaction. Restrict wetting the soil surface with a heavy irrigation and not allow the soil to dry out for avoiding the crust formation. Surface runoff by this operation is reduced by about 35% and soil erosion by about 40%.

3.3.3. Strip tillage

In this type of cultivation, narrow strips of approximately 0.2 m width and 0.1 m depth are generally laid out following the contour. The land between the strips is left uncultivated. This practice is suitable for sloppy lands where soils are more prone to erosion due to less depth and less binding capacity like sandy and gravelly soils.

3.3.4. Special tillage

A wide range of special tillage operations are in use such as inversion, chiselling, subsoiling or deep tillage (an impeding layer within rooting depth). It should be done at least once in every three years. These have been found to be beneficial in improving surface detention, storage, infiltration, root development and by minimizing soil hardening. It may also help for controlling soil borne diseases in the area. It is not recommended for the less soil depth and sloppy lands (more than 5-8% slope). A study with three tillage treatments consisting of conventional tillage (CT), CT + subsoiling in alternate years, and CT + subsoiling in every year showed that the basic infiltration rate and soil water storage in the 90 cm profile were greater in CT + subsoiling every year than in CT (Rao *et al.*, 1998).

3.3.5. Application of organic manure

Organic manure may be added by use of animal manures, compost, peat moss, sawdust, biogas slurry or similar materials. The green manuring is also an effective method for increasing the organic matter in the soil. It regulates the availability of organic carbon in the soil. It increases the water holding capacity of the soils, which is very low in most of dry soils in India.

3.4. Engineering or structural technologies

3.4.1. Micro-catchment runoff farming

Micro-catchment runoff farming is a method of collecting surface runoff from a contributing area over a flow distance of less than 100 m and storing it for consumptive use in the root zone of an adjacent infiltration basin (Boers and Asher, 1982).The catchment area and the infiltration basin are the two basic elements of a micro-catchment. In the infiltration basin there may be a single tree (Evenari *et al*., 1971), bush (Fink and Ehrler, 1979), or a row crop (Gardner, 1975). This infiltration area may be planted with annual crops, or with a single tree or bush. Micro catchments Negarin & Flood types (Shown in Fig. 5.7) are suitable for planting trees and field crops for the lands with 5 to 20% slopes. The success of runoff farming depends very much on rainfall and soil type. Runoff irrigation is carried out mainly where the annual precipitation ranges between 300 and 500 mm. It is possible however, to employ this method for areas where the rainfall is as low as 100 mm per annum and even if the rainfall is very erratic (Prinz *et al*., 1994).

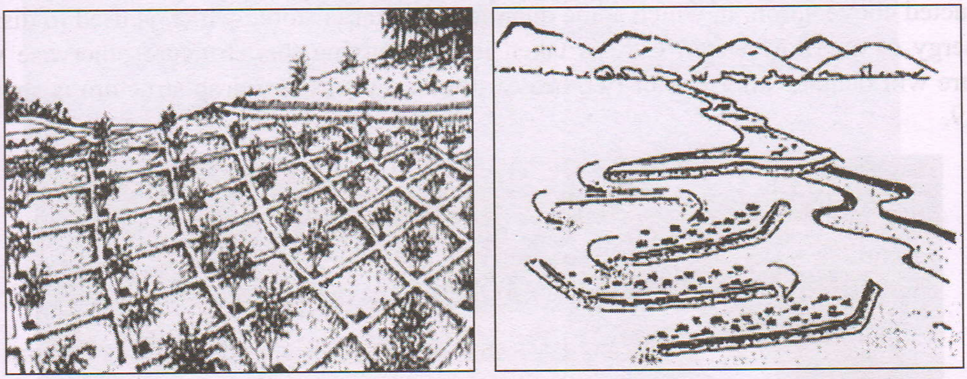

Fig. 5.7. Micro-Catchments: Negarin and flood type for controlling concentrated runoff (***Source:*** FAO, 1999)

3.4.2. Practices to restrict and disposing of undesirable runoff

Where land use management alone is insufficient to prevent runoff, the excess water has to be removed without causing erosion. Undesirable runoff can be intercepted or diverted from an area above cultivated land and led away safely. Physical measures including interception terraces, diversion ditches (Fig. 5.8) or storm water drains, waterways and terrace channels are adopted. Here protection is required to intercept runoff on the hillside and channelled across slope at a non-erosive velocity (less than 0.6 m^{-1} sec). The side slope of a trapezoidal diversion drain should not be more than 1:1. Diversion terraces are recommended on slopes up to 12%. Waterways are smooth channels usually lined with sods for the safe removal of runoff water.

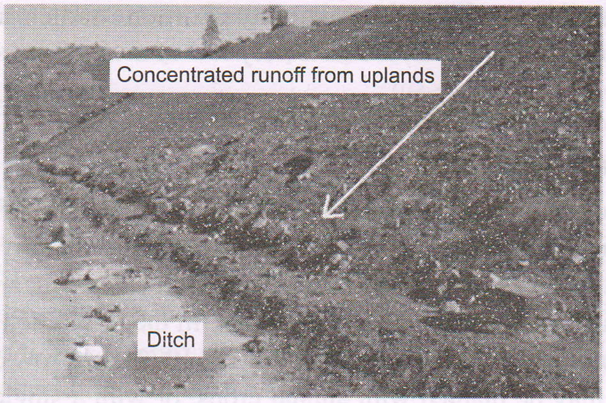

Fig. 5.8 Diversion ditch to control excess runoff from the uplands

3.4.3. Drop spillway

Such type of structure is mostly suitable where the collecting drain is quite below the outlet of agriculture lands. It can be constructed up to the drop of outlet up to 2 m. It is an overflow structure with difference in levels of upstream and downstream called drop. Some extra measures are also taken to drop the concentrated water during high peak floods. A conduit is constructed above apron, in which some quantity of water is stored which is used to dissipate the energy of overflow water. Care is taken in constructing this structure otherwise whole structure will damage after one or two heavy storms. A masonry drop structure is shown in Fig. 5.9.

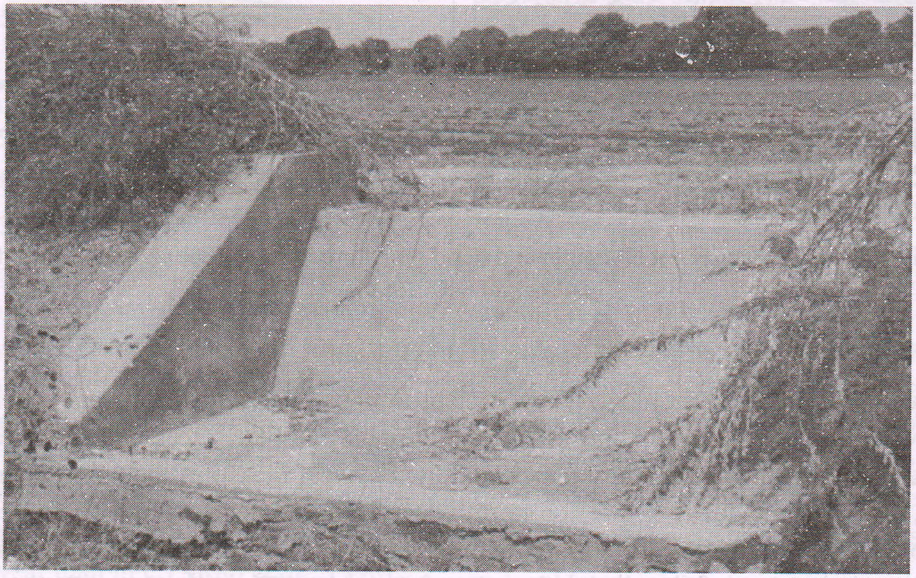

Fig. 5.9. Masonry drop spillway constructed at farmland

3.4.4. Farm waste weir

It is constructed to store excess runoff temporarily in the agriculture field. It also permits for surplus flood water to pass from the field safely at an advance stage of erosion. The waste weir is the outlet of the field designed to do this. The dimensions of the waste weir dependent on the intensity of rainfall and the area of farm land. The cost of waste weir varies with the material used for its construction. For small area (less than 0.5 ha) loose boulder stone waste may be suitable. The cost is greatly increased if waste weirs have to be built of concrete or similar materials. Major factor in site selection is looking for sites where the overflow can be safely discharged over grass-covered spillways or locally available material. For area more than 1 ha gabions and masonry structures are planned. Gabions (Fig. 5.10) are compartmented, rectangular containers made of galvanized steel hexagonal wire mesh and filled with stone. They are designed to solve the problems of soil erosion and safe disposal of high runoff water. It reduces the cost of construction from 30 to 40% in comparison to stone masonry structure of same size.

Fig. 5.10. Low cost gabion waste weir for safe disposal of excess runoff in dry areas

The most appropriate strategy for runoff management in arid regions depends upon identifying the key factors influencing runoff. The appropriate techniques will be based on acquired knowledge and adoptability.

4 CONCLUSIONS

There is too little research undertaken in the arid areas on runoff management. The work done is inadequate for safe disposal of excess runoff from agriculture lands in dry areas. Some important and basic techniques have described here to manage agricultural land. These are especially in relation to rainfall, soil and local cropping practices. Runoff management is based on the principles of minimising the concentrations of runoff volume and slowing the runoff velocity. It diminishes the capacity of runoff to cause scour erosion. It aims to enhance surface detention storage. The agronomical practices like intercropping, strip cropping, cover crops and mulching etc. also play vital role for utilising the maximum rainwater in the dry areas. Therefore, it allows the water more time to soak into the soil by making runoff non-erosive. A wide range of runoff management techniques are in use. The choice of appropriate measures depends on soil, topography, climatic and socio-economic considerations. It is difficult to generalize about applicability of these measures. Combating further land degradation and investing in soil conservation is a major task involving promotion of sustainable development and nature conservation. An integrated watershed approach should be given maximum attention to combat land degradation and environmental problems particularly in the dry areas. Innovative farming practices with sustainable agricultural intensification have tremendous potential of increasing productivity and conserving natural resources, particularly by sequestering soil organic carbon and improving soil quality. The technologies like micro-irrigation, fertigation management, and improvement of problematic soils using specific and necessary technologies may hold great promise to increase productivity of crops and fruits and reverse soil degradation in the dry areas.

The most appropriate strategy for runoff management in arid regions depends upon identifying the key factors influencing runoff. The appropriate techniques will be based on acquired knowledge and adoptability.

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